

# Implementation of Lean Manufacturing Techniques for the Replenishment of Purchased Parts Used at a Tier One Automobile Supplier

by

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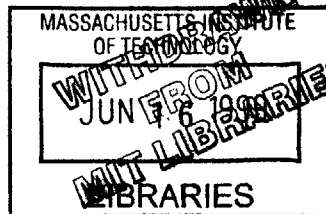
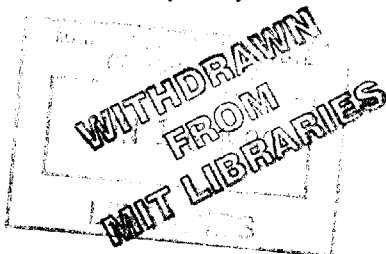
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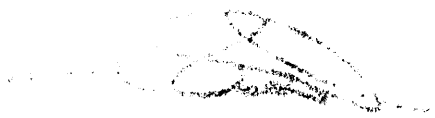
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# **Implementation of Lean Manufacturing Techniques for the Replenishment of Purchased Parts Used at a Tier One Automobile Supplier**

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## **Abstract**

Ford's management recognizes that in order to be competitive into the next century, Ford must continue to decrease costs by removing waste from its core processes - design, sales, and manufacturing. The primary tool that Ford intends to employ to remove waste from manufacturing is the Ford Production System. The Ford Production System (FPS) is Ford's version of the Toyota Production System which is generally referred to as "lean manufacturing".

This thesis presents the process that was followed in order to implement elements of lean manufacturing in one of Ford's traditional mass production assembly plants. Specifically, the process followed to design and implement a "pull system" as part of a pilot implementation of Synchronous Material Flow (an element of FPS) is presented in detail. The process description provides an integrated approach to implementation by supporting the specific tasks that were executed with the inventory management theory that underlies them.

This thesis also presents two approaches to process implementation - the "cookbook" approach and the "applied learning" approach. The cookbook approach is highly structured and is based on the execution of well defined tasks without much focus on the theory behind the tasks or the linkages between the tasks. The applied learning approach prescribes that people implementing a process possess theoretical, system level knowledge about how the process they are implementing works. This knowledge makes apparent the tasks that need to be executed in order to implement the process. Both approaches were followed to some extent during the development of the pull system. The research presented here identifies points where the implementation team encountered the limits and strengths of each of the two approaches.

The research presented in this thesis suggests that while not everyone that is involved in the development and implementation of the pull system needs to be an expert in lean manufacturing fundamentals, in order for implementation to be successful some key stakeholders must truly understand the theoretical underpinnings of the pull system. If this knowledge is lacking, strictly following the cookbook approach prescribed by Ford could lead to a failed implementation.

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# Table of Contents

|   |           |
|---|-----------|
| <b>CHAPTER1: INTRODUCTION.....</b>  | <b>11</b> |
| 1.1 STATEMENT OF PROBLEM:.....  | 12        |
| 1.2 GOAL OF RESEARCH PROJECT: .....   | 13        |
| 1.3 THESIS STRUCTURE: .....   | 13        |
| <b>CHAPTER 2: PROJECT BACKGROUND.....</b>   | <b>15</b> |
| 2.1 BACKGROUND OF THE CHESTERFIELD TRIM PLANTS: .....                                       | 15        |
| 2.2 OVERVIEW OF THE TOYOTA PRODUCTION SYSTEM (LEAN MANUFACTURING): .....                    | 15        |
| 2.3 OVERVIEW OF THE FORD PRODUCTION SYSTEM: .....   | 20        |
| 2.4 OVERVIEW OF THE MUSTANG SEAT ASSEMBLY SYSTEM: .....                                     | 28        |
| 2.5 SCOPE OF SMF IMPLEMENTATION IN MUSTANG: .....   | 29        |
| 2.6 COMPARISON OF PUSH AND PULL SYSTEMS: .....  | 30        |
| 2.7 OVERVIEW OF THE PURCHASED PARTS REPLENISHMENT PULL SYSTEM: .....                        | 32        |
| <b>CHAPTER 3: OVERVIEW OF PROCESS DEVELOPMENT AND IMPLEMENTATION<br/>PHILOSOPHY.....</b>    | <b>35</b> |
| 3.1 IMPLEMENTATION PHILOSOPHIES: .....  | 35        |
| 3.2 DESCRIPTION OF SMF IMPLEMENTATION MANUAL: .....   | 35        |
| 3.3 COOKBOOK APPROACH: .....  | 36        |
| 3.4 APPLIED LEARNING APPROACH:.....   | 36        |
| 3.5 APPLICATION OF THE COOKBOOK AND APPLIED LEARNING APPROACHES:.....                       | 37        |
| 3.6 PURCHASED PARTS REPLENISHMENT PULL SYSTEM IMPLEMENTATION PHILOSOPHY:.....               | 37        |
| <b>CHAPTER 4: STEP 1 – TEAM FORMATION .....</b>   | <b>39</b> |
| 4.1 TEAM FORMATION: .....   | 39        |
| 4.2 THE NEEDS MATRIX:.....  | 41        |
| <b>CHAPTER 5: STEP 2 – DETERMINATION OF LINESIDE DEMAND .....</b>                           | <b>43</b> |
| 5.1 NEEDS MATRIX FOR STEP 2:.....   | 43        |
| 5.2 HIGH LEVEL PROCESS INFORMATION: .....   | 43        |
| 5.3 BREAKING DOWN HIGH LEVEL DEMAND: .....  | 44        |
| 5.3.1 Average versus “Actual” Demand: .....   | 44        |
| 5.3.2 Product Mix:.....   | 47        |
| 5.3.3 Bill of Materials:.....   | 48        |
| 5.3.4 Component Level Demand: .....   | 48        |
| 5.3.5 Multiple Location Components: .....   | 50        |
| 5.3.6 Demand Runs: .....  | 51        |
| 5.3.7 100% Mix Strategy: .....  | 52        |
| 5.4 APPLICATION OF COMPONENT LEVEL DEMAND: .....  | 53        |
| 5.5 CHAPTER SUMMARY: .....  | 54        |
| <b>CHAPTER 6: STEP 3 – DETERMINATION OF PACKAGING AND SHIPPING<br/>SPECIFICATIONS .....</b> | <b>55</b> |
| 6.1 NEEDS MATRIX FOR STEP 3:.....   | 55        |
| 6.2 CARD VERSUS CALL PARTS .....  | 56        |
| 6.3 CARRY-OVER VERSUS NEW PARTS: .....  | 56        |
| 6.4 COLLECT PACKAGING SPECIFICATIONS FOR CARRY-OVER COMPONENTS: .....                       | 57        |
| 6.5 COLLECT SHIPPING SPECIFICATIONS FOR CARRY-OVER COMPONENTS: .....                        | 58        |
| 6.6 DETERMINE THE FREQUENCY OF DELIVERY OF COMPONENTS TO THE BUILD AREA: .....              | 59        |
| 6.7 THEORY UNDERLYING OPTIMAL PACKAGING AND SHIPPING SPECIFICATIONS: .....                  | 60        |
| 6.7.1 In-Plant Inventory Levels: .....  | 61        |
| 6.7.2 Packaging Impact on Inventory Levels: .....   | 62        |
| 6.8 OPTIMIZING PACKAGING SPECIFICATIONS:.....   | 63        |

|   |            |
|---|------------|
| 6.8.1 Hourly Demand and the Frequency of Delivery:  | 64         |
| 6.8.2 Safety Stock:   | 66         |
| 6.8.3 Packaging Costs:  | 67         |
| 6.8.4 Realities of Packaging Solutions:   | 67         |
| 6.8.5 Packaging Cost-Benefit Analysis:  | 68         |
| 6.9 OPTIMIZING SHIPPING SPECIFICATIONS AND SAFETY STOCK LEVELS:   | 71         |
| 6.10 CHAPTER SUMMARY:   | 72         |
| <b>CHAPTER 7: STEP 4 – DEVELOPMENT OF SMART CARD SYSTEM PARAMETERS AND DETERMINATION OF LINESIDE INVENTORY LEVELS</b> | <b>73</b>  |
| 7.1 NEEDS MATRIX FOR STEP 4:  | 74         |
| 7.2 REVIEW OF EQUATIONS PROVIDED TO DETERMINE LINESIDE INVENTORY LEVELS FOR CARD PARTS:                               | 75         |
| 7.2.1 Analysis of Inventory Level Equations:  | 76         |
| 7.3 REVIEW OF THE EQUATION PROVIDED TO DETERMINE THE ALLOCATION OF SMART CARDS:                                       | 77         |
| 7.4 APPLICATION OF SMF IMPLEMENTATION MANUAL EQUATIONS TO DEVELOP OPERATIONAL SPECIFICATIONS:                         | 79         |
| 7.5 OPERATION OF THE PULL SYSTEM:   | 80         |
| 7.6 FACTORS THAT CAUSE UNEXPECTED PULL SYSTEM PERFORMANCE:  | 82         |
| 7.6.1 Non-optimal Packaging:  | 82         |
| 7.6.1.1 Accumulation of Excess Stock:   | 83         |
| 7.6.1.2 The Critical Point of Accumulation of Excess Stock:   | 84         |
| 7.6.2 Over-Replenishment of Stock:  | 85         |
| 7.6.3 Variability:  | 87         |
| 7.6.3.1 Demand Variability:   | 87         |
| 7.6.3.2 Replenishment Cycle Variability:  | 89         |
| 7.7 SUMMARY OF PULL SYSTEM PERFORMANCE:   | 90         |
| 7.8 GAINING KNOWLEDGE AND APPLYING LEARNING:  | 90         |
| 7.8.1 The Learning Process:   | 91         |
| 7.8.1.1 Simulation Model Development:   | 92         |
| 7.8.1.2 Value of the Model:   | 93         |
| 7.9 MODIFICATION OF OPERATIONAL SPECIFICATIONS:   | 94         |
| 7.10 DETERMINATION OF OPERATIONAL SPECIFICATIONS FOR CALL PARTS:  | 96         |
| 7.11 CHAPTER SUMMARY:   | 97         |
| <b>CHAPTER 8: STEP 5 – DEVELOPMENT OF LINESIDE PART STORAGE AND PRESENTATION INFRASTRUCTURE</b>                       | <b>99</b>  |
| 8.1 NEEDS MATRIX FOR STEP 5:  | 99         |
| 8.2 BASIC INFRASTRUCTURE TYPES:   | 100        |
| 8.3 BASIC DESIGN RULES:   | 102        |
| 8.4 DESIGN PROCESS:   | 104        |
| 8.5 CHAPTER SUMMARY:  | 107        |
| <b>CHAPTER 9: STEP 6 – DEVELOPMENT OF CARD AND CALL PART MARKETPLACES AND MATERIAL REPLENISHMENT ROUTES</b>           | <b>109</b> |
| 9.1 NEEDS MATRIX FOR STEP 6:  | 109        |
| 9.2 OVERVIEW OF THE MARKETPLACES:   | 109        |
| 9.3 DETERMINE MARKETPLACE STORAGE REQUIREMENTS:   | 112        |
| 9.3.1 Determination of Maximum In-Plant Inventory Levels:   | 112        |
| 9.3.2 Conversion of Maximum Inventory into Storage Requirements:  | 114        |
| 9.4 DETERMINATION OF THE LOCATION AND CONFIGURATION OF THE MARKETPLACES:  | 117        |
| 9.4.1 Card Part Marketplace:  | 117        |
| 9.4.2 Call Part Marketplace:  | 119        |
| 9.5 CHAPTER SUMMARY:  | 121        |
| <b>CHAPTER 10: STEP 7 – TRAINING</b>  | <b>123</b> |
| 10.1 STAKEHOLDER GROUPS:  | 123        |



|   |            |
|---|------------|
| 10.2 TRAINING NEEDS:.....   | 123        |
| 10.3 EXECUTION OF TRAINING:.....  | 125        |
| 10.4 ISSUES WITH TRAINING: .....  | 126        |
| 10.5 CHAPTER SUMMARY: .....   | 126        |
| <b>CHAPTER 11: STEP 8 – IMPLEMENT.....</b>  | <b>129</b> |
| 11.1 PREPARATION FOR IMPLEMENTATION: .....  | 129        |
| 11.2 THE WALK THROUGH PROCEDURE: .....  | 129        |
| 11.3 LESSONS LEARNED:.....  | 132        |
| <b>CHAPTER 12: CONCLUSIONS .....</b>  | <b>135</b> |
| 12.1 THE CONSOLIDATED NEEDS MATRIX: .....   | 135        |
| 12.2 GENERAL CONCLUSIONS: .....   | 138        |
| <b>CHAPTER 13: TECHNICAL APPENDIX.....</b>  | <b>141</b> |
| TOPIC A) CALCULATION OF THE ACTUAL PRODUCTION RATE: .....                           | 141        |
| TOPIC B) ANALYSIS OF THE SMF IMPLEMENTATION MANUAL INVENTORY LEVEL EQUATIONS: ..... | 143        |
| TOPIC C) DETERMINATION OF THE NUMBER OF SMART CARDS: .....                          | 146        |
| TOPIC D) THE EFFECT OF EXCESS STOCK ON PULL SYSTEM OPERATION:.....                  | 150        |
| TOPIC E) CRITICAL POINT OF ACCUMULATION OF EXCESS STOCK: .....                      | 152        |
| TOPIC F) THE EFFECT OF OVER-REPLENISHMENT ON PULL SYSTEM OPERATION:.....            | 155        |
| <b>REFERENCES .....</b>   | <b>163</b> |



## Chapter1: Introduction

This thesis presents the process that was followed in order to implement elements of lean manufacturing in a traditional mass production assembly plant. Specifically, the process followed to design and implement a “pull system” for the replenishment of purchased parts is presented in detail. The process description provides an integrated approach to implementation by supporting the specific tasks that were executed with the inventory management theory that underlies them.

Effective implementation of lean manufacturing processes requires a balance between two approaches to implementation. At some points, task oriented prescription is needed in order to develop the lean process. This “cookbook” approach to implementation is valuable when structure is needed to kick-off and manage the development process and when tasks can easily be executed optimally without the need to understand the underlying theory. At other points, theory based understanding of the tasks that are being executed must be developed or applied in order to effectively implement the process. This “applied learning” approach to implementation is required when complex and inter-dependent elements of the lean process are being developed. The research presented here traces the implementation of a specific lean manufacturing process (a pull system) and identifies points where the implementation team encountered the limits and strengths of each of the two approaches to implementation.

The pull system that will be discussed was developed as part of a pilot implementation of Synchronous Material Flow (SMF). SMF is the element of Ford Production System (FPS) that is intended to provide a lean supply chain for the replenishment of parts used in the assembly process. Since SMF is a defined Ford process, a manual is provided to guide the development and implementation of SMF in the field. While the manual is well structured and is an excellent project management tool, it prescribes a high level, task oriented, “cookbook” approach to implementation which lacks the theoretical underpinnings of the activities that are being performed. The manual is not as much a teaching tool as it is a “doing” tool. Because of this, in some cases where knowledge of theory is needed (or needs to be developed) in order to optimally execute the tasks required to develop the pull system, the implementation manual fails to provide it. Therefore, one of the primary purposes of this thesis is to be a companion to the SMF implementation manual and supply some of the theory and teaching that the manual fails to provide.

Additionally, it is hoped that this thesis can shed some light on the potential dangers associated with strictly following a task oriented implementation manual when the implementation team does not possess significant knowledge about the process they are implementing. This will be done by highlighting instances during the development of the pull system where, if the implementation team had depended solely on the implementation manual for guidance, poor decisions would have been made resulting in, at best, a sub-optimal implementation.

Finally, it is important to note that while it is hoped that the process and lessons described in this thesis can be applied to a variety of lean process implementations, the research presented here is based on one specific case. The research served to generate a hypothesis about effective process implementation, not to test any preconceived belief. Therefore, the broad applicability of the findings presented in this thesis depends on additional research regarding implementation strategies in general and SMF implementations in particular.

### **1.1 Statement of Problem:**

*“Ford faces a challenge never faced in manufacturing history. The challenge is to transform 140 Ford plants, employing 280,000 people represented by more than 60 unions speaking more than 100 languages and dialects to a new system of production.”<sup>1</sup>*

Ford’s competitiveness has improved significantly since the early 1980’s when they, and the other two major automobile manufactures in the U.S., were reeling from the impact that high quality Japanese imports had on the auto industry. Although Ford has improved its quality and productivity dramatically in the last 15 years, management believes that to remain competitive in the next century Ford must continue to decrease costs and improve customer satisfaction by removing waste from its core processes.

Manufacturing is obviously one of Ford’s core processes. The primary tool that Ford intends to employ to remove waste from manufacturing is the Ford Production System. The Ford Production System (FPS) is Ford’s version of the Toyota Production System which is generally referred to as “lean manufacturing”. Ford is certainly committed to lean manufacturing having invested enormous resources to benchmark Toyota and develop the Ford Production System. However, the ultimate level of “success” achieved by FPS will not be based strictly on how closely its design mirrors that of the Toyota Production System. The determining factor that will control how effective the Ford Production System is at improving manufacturing operations and increasing profitability and productivity is the level of success achieved in implementation. Unfortunately, history has shown that lean manufacturing “is not easy for U.S. auto makers to implement”.<sup>1</sup>

One of the key resources that Ford will need to successfully implement the Ford Production System is people who truly understand lean manufacturing. Lean manufacturing is not simply a process, it is a philosophy, a system, a way of thinking which takes time to internalize. This fact presents a basic conflict involving the dynamics of change management. Generally, initial applications of the new process need to be successful in order for the change to truly be embraced and lasting. However, most of the early implementations at Ford will be performed by people with little experience in lean manufacturing and with little understanding of the principles on which it is based. This is certainly not a desirable scenario when initial implementations may be critical to the long-term success of FPS.

The question facing Ford then is whether initial implementations can be successful when being performed by teams who lack in-depth fundamental understanding of the system they are implementing. Shingo in his book A Study of the Toyota Production System From an Industrial Engineering Viewpoint claims that, “In addition to an appreciation of the techniques of the Toyota Production System, an understanding of the concepts that lie behind those techniques is crucial. If it is missing, errors in application are unavoidable”.<sup>2</sup> The validity of Shingo’s statement may indeed define Ford’s manufacturing operations for years to come.

### **1.2 Goal of Research Project:**

The specific goal of the research project was to develop and implement a “pull system” (a material management system based lean manufacturing principles) for the replenishment of purchased parts used in the assembly of Ford Mustang seat sets. The pull system was expected to improve plant operations by decreasing lineside and in-plant inventory levels, by improving the organization of and decreasing the storage space required for raw materials, by removing waste from the assembly process through improvements in ergonomics, and by improving the integrity of the records used by the procurement department.

The larger and more significant goal of the project was to provide a small, early success that the plant could use as a cornerstone in their transformation to lean manufacturing. The learning that occurs during successful small-scale implementations early on in the change process can help to build momentum and facilitate long-term, large-scale success. This thesis documents the process followed and the knowledge gained during the successful implementation of one element of the Ford Production System with the hope that others can use the experience to further the implementation process on the whole. In summary, the overarching goal of the research project was not to convert the plant to full-scale lean manufacturing but rather to set the stage for that process to occur in the future.

From a personal perspective, I hoped to learn about lean manufacturing implementation and share that knowledge with other stakeholders in the research project. These stakeholders include Ford, Polaroid Corporation (my sponsoring organization), the Leaders for Manufacturing program and its affiliates at MIT, and my classmates.

### **1.3 Thesis Structure:**

In total, this thesis presents the process that was followed to design and implement a pull system for the replenishment of purchased parts. Before the design and implementation process is discussed explicitly, Chapter 2 reviews the project background which is intended to create a common frame of reference to be used throughout the thesis. The background information includes a brief overview of the plant in which the research project was performed, an overview of the Toyota Production System (lean

manufacturing) and the Ford Production System, , and a high level description of the process that was implemented.

After the background has been set, Chapter 3 provides an overview of the process development and implementation philosophy that was employed by the team that implemented the pull system. The overview begins with a discussion of some alternate philosophies of process implementation. There is a description of the manual that was provided to the implementation team to guide it through the development and implementation process and a discussion of the “philosophy” espoused in the manual. Next, there is a description of a very different implementation philosophy and its merits. The chapter concludes and the approach that the implementation team chose to follow.

Next, in Chapters 4 through 11, the process that was followed to develop and implement the pull system is discussed in detail. The process is broken down into eight steps. The first seven steps focus on process development while the last step focuses on implementation. The description of each step includes the specific tasks performed, the inventory management theory underling the tasks, an assessment of the skill base of the team relative to the “ideal” skill base needed for the step, and documentation of any issues that arose either during the step or as a result of the step which were caused by a lack of theoretical understanding of lean manufacturing.

Chapter 12 presents the conclusions drawn from the research project while Chapter 13 serves as a technical appendix.

## **Chapter 2: Project Background**

This chapter reviews the project background which is intended to create a common frame of reference to be used throughout the thesis. The background information begins with a brief overview of the plant in which the research project was performed, an overview of the Toyota Production System (lean manufacturing) and the Ford Production System, and a high level description of the process that was implemented.

### ***2.1 Background of the Chesterfield Trim Plants:***

Chesterfield Trim Plant #1 was first opened in 1973. In 1976 the Chesterfield site was expanded with the opening of Chesterfield Trim Plant #2, the location where this research project took place. In the Fall of 1997 the Chesterfield site was reassigned to the Visteon Division within Ford from Ford's Automotive Components Division. Currently the Chesterfield Trim Plants produce seat sets for many Ford products including the Escort, Expedition, Lincoln Towncar, and Mustang – the focus of this thesis. In addition to performing the final assembly of seat sets, Chesterfield also manufactures seat covers and foam which they consume internally and supply to other seat manufacturers. As with most Ford plants, in the 1990's Chesterfield focused extensively on quality improvements. As a result of the focus on quality, in 1997 Chesterfield received 2 J.D. Powers Award's for quality including the award for "Best North American Seat Supplier". The site currently employs over 2000 people, almost 1800 of which are hourly workers who are members of the United Auto Workers of America Union.<sup>3</sup>

### ***2.2 Overview of the Toyota Production System (Lean Manufacturing):***

The overview that is presented here is intended to provide the reader with a general understanding of the Toyota Production System and to, in part, explain the motivation behind Ford's decision to transition to lean manufacturing. This will be done by discussing the major elements of the Toyota Production System that are being applied at Ford and the impact they have on manufacturing operations. Also, a brief review of lean manufacturing implementation in U.S. auto industry will be presented.

The basic tenet of the Toyota Production System is the total elimination of waste that exists throughout the manufacturing organization. The primary goal that the removal of waste accomplishes is improved profits through cost reduction and improvements in productivity.<sup>4</sup>

Several key elements of the Toyota Production System help to achieve the overarching goal of waste elimination. The major elements are: <sup>4</sup>

- Just-In-Time production
- Production smoothing
- Standardization of operations
- Team work and continuous improvement
- Minimization of defects
- Visual controls

### Just-In-Time Production

Just-In-Time production simply means to produce the necessary units in the necessary quantities at the necessary time. By producing only what is needed when it is needed, JIT acts to eliminate the waste of “overproduction”, “which is regarded as the worst type of waste at Toyota”.<sup>4</sup> Overproduction is defined as “to continue working when essential operations should be stopped”<sup>4</sup> and is regarded as a symptom of typical mass production manufacturing practices. In general terms, overproduction simply means to continue to produce in absence of (internal or external) customer demand. Overproduction manifests itself most recognizably as excessive raw materials, work-in-process, and finished goods inventory which result in increased material handling costs, increased overhead costs (carrying costs and depreciation), and the need for increased storage space.

Overproduction also conceals quality problems and hampers learning about the constraints in the system. Overproduction is generally the result of large batch production by “disconnected” manufacturing processes.

JIT production is facilitated by the kanban system. The kanban system controls production by sending a “production initiation” signal, usually in the form of a card, from one process to the process immediately upstream. Once the upstream process has fulfilled the order it has received, the process stops production until receipt of the next kanban signal - the upstream process only produces when directed to do so by the downstream process. In this way, the kanban system acts to control the level of inventory between the two processes and assures that the upstream process is producing only what its customer (the downstream process) needs. The term “pull system” is often associated with the kanban system because of the way in which production is “pulled” from upstream processes to downstream processes. A more detailed description of a pull system in operation and comparison of it to a traditional mass-production “push” system will be presented later.

The JIT philosophy is also extended to deliveries of raw materials from suppliers to the plant and from stores within the plant to the processes where the raw materials are consumed. Under the JIT system, deliveries to the plant are smaller and more frequent than would be the case in a traditional mass production environment. The smaller, more frequent deliveries reduce raw materials inventory levels saving floor space and inventory carrying costs. Similarly, delivery of raw materials to their point of use within



the plant on a JIT basis (generally through the application of a kanban system), saves lineside floor space and reduces work area congestion.

### Production Smoothing:

Production smoothing is a process by which production of specific products is distributed such that at any point in time an equal proportion of the demand for each product has been met. That is, each product is produced in accordance with the average demand rate for that product. For example, if 30 of X and 20 of Y are required each week, the average demand rate is 6 of X and 4 of Y per day. Smoothed production would require that each day 6 of X and 4 of Y are produced. The smoothed policy is in direct opposition to the traditional mass production philosophy of large batch production where all 30 units of X would be produced before changing over to the production of Y.

Production smoothing can yield significant reductions in finished goods inventory from the levels that result from large batch production. Continuation of the example above will help to clarify this point. If X and Y were produced in large batches and shipments of X and Y to the end customer occur at the end of each day, then significant finished goods inventory would need to be kept on hand to satisfy the daily demand for 6 X's and 4 Y's. Assuming that X is produced during the first 3 days of the week and Y during last 2, the plant would need to have 12 units of Y on hand at the beginning of the week in order to satisfy customer demand until production of Y begins on the fourth day of the week. Similarly, there would be 4 "extra" units of X produced each day during the first 3 days of the week (10 X are produced each day when only 6 are required). The excess inventory of X would be carried over to the following week where it would be used to satisfy customer demand. If production is smoothed and 6 X and 4 Y are produced each day, then all of what is produced each day is shipped at the end of that day essentially eliminating finished goods inventory.

The process of production smoothing has a cascading effect through the supply chain which helps to reduce raw materials inventory levels at suppliers and in the plant.

### Standardization of Operations:

Standardization of operations helps to remove variation from production and improve quality within the plant. Standardization is most commonly achieved through the implementation of standard operation sheets. A standard operation sheet specifies the time in which a process must be completed (the cycle time), the exact steps to be followed in order to complete the process, and the inputs needed to complete the process.<sup>4</sup> Standard operation sheets help to reduce variability and improve quality (consistency) by insuring that processes are executed consistently - taking the same time, following the same steps, and employing the same resources each time.

### Teamwork and Continuous Improvement:

The Toyota Production System organizes workers into teams. Each team's "members are cross-trained, perform direct and indirect work, rotate jobs, and adapt to continuous changes in cycle time and job content".<sup>5</sup> Most team members share the same job classification and are expected to be able to perform all of the tasks that the team has responsibility for which results in a flexible work force. This concept differs from the traditional mass production model where many job classifications exist and workers are often organized by functional specialization.

Each team has an appointed team leader who has duties that exceed those of the other team members. The team leader will help to train new workers, assist those who fall behind in their work, prepare job rotation schedules, redistribute the work force and fill in when absenteeism occurs, and perform many paperwork type administrative tasks such as updating standard operation sheets.<sup>5</sup>

Teams are given more ownership for their work content than is traditional in a mass production environment. The ownership that teams are given is intended to drive continuous improvement through kaizen – the continual process of searching out waste, eliminating it, then deploying the resources made available to a more productive task.<sup>5</sup> For example, teams regularly update the standard operation sheets for the processes in their area. The updated standard operation sheets usually results in less wasted motion, better balancing of the workload, a reduction of idle time, etc., all of which are reductions of waste. Every team member has the opportunity to take part in kaizen through participation in quality circles and other "suggestion" programs as well as through informal discussions with team leaders and other team members.<sup>5</sup>

### Minimization of Defects:

Defects prohibit full realization of JIT production. If high levels of defects exist, either in raw materials, work-in-process, or finished goods, then large buffer inventories will need to be kept on hand to ensure that customer demand can be met. Additionally, production of a defective unit is a waste of valuable resources, and as such, will result in additional resources (such as overtime or supplemental workers) needing to be employed in order to meet customer demand. This situation worsens as the time between defect creation and detection increases.

If a defect can be detected and corrected immediately, before additional value added steps are performed, the effect on the production process is less severe than if several additional value added steps are performed before the problem becomes apparent. Additionally, immediate defect detection often helps to identify the root cause of the defect so that permanent corrective action can be taken. The traditional mass production environment with its large batch production and end of line inspection does not lend itself to immediate defect detection and correction which sometimes makes it difficult to perform root cause analysis. Because of this, defects reoccur and proliferate through the

production process resulting in large quantities of scrap and rework which require significant additional resources to absorb.

The Toyota Production System seeks to eliminate the production and proliferation of defects through automation (which is also called “jidoka”). Automation, or in-station process control, “supports JIT by never allowing defective units from a preceding process to flow into and disrupt a subsequent process”.<sup>4</sup> This is done with the implementation of mistake proofing devices called poka-yokes. Poka-yokes are physical devices that either prevent a defect from occurring or immediately indicate the existence of a defect if one has occurred. Poka-yoke devices are located throughout the production process which prevents defects from being passed on to subsequent processes and pinpoints the location(s) where defects are being generated which assists in root cause analysis.

#### Visual Controls:

Visual controls are used to improve organization, reduce the time needed to locate materials, and facilitate waste reduction by making waste visible. Typical visual controls include signs hung from the ceiling that specify the location of a particular part, maximum inventory level indicators in raw materials storage warehouses, outlines on workstations that indicate the proper location of tools used in the production process, and pictures which show how to properly perform a task.

Each type of visual control listed above helps to reduce waste. For example, the maximum inventory level indicators in the raw materials storage warehouse help to indicate when excess inventory exists within the plant. If repeated violations of the maximum inventory level occur corrective actions can be taken (such as improving the procurement process, etc.) so that the excess inventory, which is waste, can be removed from the plant saving carrying costs and storage space. Without the maximum inventory level indicators, excess inventory may go unnoticed and therefore remain in the plant. The signs hung from the ceiling help material handlers to quickly find and store parts and limit the number of locations within the plant that a part can exist. This helps to control inventory and prevent misplacement of parts within the plant.

#### Lean Manufacturing Implementation in the U.S. Auto Industry:

*“Many books are available that tell us in great detail what the Toyota Production System is and how it works. These are all valuable. Obviously, we need to understand the system to implement it. But time after time at conferences for manufacturing managers, I have been struck by the heightened interest in the audience when someone talks about implementation.”<sup>1</sup>*

The Toyota Production System first appeared in the United States in the 1980’s as part of the New United Motor Manufacturing, Inc. (NUMMI) joint venture between Toyota and General Motors.<sup>1</sup> The phenomenal success that TPS had in turning one of G.M.’s lowest performing plants into G.M.’s benchmark for cost, quality, and delivery helped to

convince the “Big Three” U.S. auto makers that the Toyota Production System could work in the United States.<sup>1</sup> By 1997, “all of the Big Three (G.M., Chrysler, and Ford) declared unequivocally that they were transforming all of their manufacturing to their own versions of TPS”.<sup>1</sup>

It is one thing to claim that you want to implement lean manufacturing while it is quite another to actually do it. General Motors, for example, has been unable to duplicate the performance of the NUMMI plant.<sup>1</sup> So why is it so difficult for U.S. auto makers to implement lean? Liker, in his book Becoming Lean: Inside Stories of U.S. Auto Manufacturers, indicates that the difficulty lies in the fact that several elements of the Toyota Production System (small batch production, frequent conveyance, low inventory levels, etc.) “fly in the face of common mass-production thinking”.<sup>1</sup>

The idea is that “mass-production thinking” is ingrained in the U.S. auto industry because of the decades where mass-production was all that they did and all that that they knew. Until the U.S. auto industry truly understands and adopts the *philosophy* behind the Toyota Production System, they will not be able to successfully implement TPS. Workers will not understand why they are being placed in teams so they, and their Unions, will resist it. Line supervisors will not understand why they are being told to reduce inventories so they will continue to allow their workers to produce excess “just in case”. Managers will not understand the right metrics to use to measure operational performance so they will rely on their old mass production metrics and believe that the lean manufacturing system is a failure.

This should not be interpreted as death sentence for lean manufacturing in the U.S. auto industry. It is simply one explanation as to why lean manufacturing has not been assimilated as quickly as its proponents would like.

### **2.3 Overview of the Ford Production System:**

This section provides an overview of the Ford Production System. Specific attention is paid to the “material flow” element of FPS which embodies the pull system that is the focus of this thesis. Additionally, a brief summary of the status of FPS implementation within Ford is presented. At the end of most FPS element descriptions, a brief summary of where Chesterfield currently stands relative to the FPS element being discussed is provided.

The Ford Production System is Ford’s version of the Toyota Production System. Ford describes FPS as:

*“A lean flexible and disciplined common production system that is defined by a set of principles and processes that employs groups of capable and empowered people who are learning and working safely together to produce and deliver products that consistently exceed customers’ expectations in quality, cost, and time.”<sup>1</sup>*

As the description indicates, Ford plans on implementing FPS in all of their plants world wide.

The goal of the Ford Production System – “to exceed customers’ expectations in quality, cost, and time” – is enabled by the seven integrated processes of FPS.<sup>1</sup>

- In-station process control (ISPC)
- Ford total productive maintenance (FTPM)
- Engineering
- Quality operating system (QOS)
- Material flow
- Industrial materials
- Human resources policies, practices, and procedures

#### In-station process control (ISPC):

In-station process control is Ford’s version of the “minimization of defects” element of the Toyota Production System. ISPC is implemented though the same type of poka-yoke devices that were described during the discussion of TPS. The key to successful in-station process control is that defects must be detected immediately, the root cause of the defect discovered, and corrective action taken so that defects are not passed on to subsequent processes.

Chesterfield has begun to implement the physical elements of in-station process control; however, the change in mindset that must take place in order for in-station process control to be effective has yet to occur. Generally, the traditional view that defects will be detected and corrected at the “end of the line” inspection station is still held.

#### Ford total productive maintenance (FTPM):

*“Without reliable equipment, a pull system with minimal inventory will simply bring the entire production system to a screeching halt”.<sup>1</sup>*

As can be inferred from the statement above, unreliable machinery disrupts JIT production. FTPM is a strictly scheduled preventative maintenance program that helps to insure high levels of equipment reliability. FTPM was in place before the development of FPS but was not nearly as critical (and therefore not practiced nearly as much) in the high inventory environment that existed at Ford in the past.

Chesterfield has considerable experience with FTPM having initially implemented the process in 1994.<sup>3</sup> Like at other Ford plants, however, the importance of FTPM is increasing at Chesterfield due to FPS.

### Engineering:

The characteristics of products, processes, and equipment that are desirable in a lean manufacturing environment sometimes differ from what has traditionally been considered important. For example, in a lean manufacturing environment equipment that can support production of small batches and facilitate quick changeovers is extremely valuable; whereas, historically, equipment that supported large batch production was desired. In order for products, processes, and equipment to work well in and support a lean manufacturing environment, engineers must learn what “lean” factors they need to consider in their designs – they must develop new consideration sets. For example, process engineers must be aware that they need to consider the design and integration of poka-yokes (error proofing devices) when developing new processes.

To facilitate the development of new consideration sets, “design rules” have been developed for engineers. The “Lean Manufacturing Design Rules” manual (a Ford publication) highlights the important factors to consider when designing the elements of a lean manufacturing system. Plant wide layout design, work cell design, and equipment design that supports lean manufacturing are all covered in the manual. The manual also supplies some of the lean manufacturing theory behind the design factors that are highlighted.

Lean manufacturing design rules were strongly considered during the development of the manufacturing infrastructure for the Mustang seat build area. For example, fixtures were designed to easily accommodate multiple products without the need for time consuming change-overs.

### Quality Operating System (QOS):

Quality operating systems highlight the critical factors needed for the production of quality products. For example, quality operating systems include a list of the “critical dimensions” which need to be controlled in order to manufacture a high quality product. Quality operating systems also help to manage by “the facts” by basing decisions regarding process or product modification on collected data (such as statistical process control data).<sup>1</sup> Like FTPM, quality operating systems existed before the development of FPS. However, with the development of FPS, quality operating systems have become more integrated with other quality initiatives such as in-station process control.

Chesterfield uses “tick sheets” (statistical data collection forms) to monitor the critical dimensions and characteristics of the products that they produce.

### Material flow:

Material flow encompasses the entire supply chain from raw materials procurement to product delivery to the final customer. Material flow processes are driven by the overarching goal of producing exactly to customer demand (whether the customer is internal or external). This is achieved through continuous (or single piece) flow, small

batch sizes, more frequent deliveries (from suppliers and to customers), pull systems for production control, and flexible manufacturing processes. Most importantly, lean material flow practices are established through the development of a mind-set that overproduction is waste.<sup>1</sup>

Synchronous Material Flow (SMF) is the defined process which Ford uses to implement lean material flow practices. SMF is based on the philosophy of JIT production and employs many of the same tools (such as kanban systems and frequent conveyance) for operations management. The pull system that will be discussed at length in this thesis was developed as part of a pilot implementation of SMF. A detailed description of SMF is provided below.

#### Synchronous Material Flow (SMF):

Synchronous Material Flow is defined as “a process or system that produces continuous flow of material and products driven by a fixed, sequenced, and leveled vehicle schedule, utilizing flexibility and lean manufacturing techniques”.<sup>6</sup> In simpler terms, SMF is intended to improve profitability and increase manufacturing flexibility by reducing inventory levels / increasing inventory turns, removing production waste, improving material management, conveyance and display, and “streamlining” the supply chain through the application of lean manufacturing techniques. In a macro sense, SMF can be thought of as a process that provides a lean supply chain for the replenishment of components used in the assembly process.

The main components of the SMF process are internal logistics and external logistics. Internal logistics coordinates the movement of materials within the plant and is generally applied through the implementation of visual management techniques and an inventory management system based on traditional pull systems called a SMART (Synchronous Material Replenishment Trigger) system. External logistics focuses on the movement of materials from suppliers to the plant - improving the stability and reducing the total cost in the upstream portion of the value chain.

There are 4 sub-process of SMF: plan and implement logistics, schedule component production, manage internal logistics, manage external logistics.<sup>6</sup>

#### Plan and implement logistics:

Plan and implement logistics is the development and implementation of a “material flow plan” and the training that accompanies it. The material flow plan is the embodiment of the SMF process for a specific application. Ideally, the material flow plan is developed for a product / program 18 to 24 months before production begins in the plant; this ensures that workstations are facilitated sufficiently to support a pull system and parts are packaged in accordance with small, frequent deliveries to the lineside. The material flow plan has two major components, the internal logistics plan and the external logistics plan.

The internal logistics plan specifies all details of the storage, movement, and presentation of parts within the plant. Specific issues considered in the internal logistics plan are inventory levels, part packaging, part presentation to the operator, in-plant part storage, and material handling / replenishment procedures. In short, the internal logistics plan should include all the information necessary to implement an in-plant pull system for the replenishment of purchased parts.

Whereas the internal logistics plan considers the movement of parts once they have arrived at the plant, the external logistics plan focuses on the movement of parts from suppliers to the plant. Development of the external logistics plan is mostly coordinated by a Lead Logistics Provider – an external company to which Ford subcontracts management of its supply chain. During the development of the external logistics plan, the Lead Logistics Provider (LLP) seeks to optimize the external supply chain by better coordinating the activities of the plant's many suppliers. An inbound logistics network is designed which targets optimizing carrier / equipment utilization in conjunction with increasing ship frequency (reducing the ship quantity) for each part at a lower overall total cost. Smaller, more frequent deliveries enables the plant to reduce inventory levels. The design includes establishing "milk runs" (where a carrier will make scheduled pick-ups at many suppliers) and fixed pickup and delivery shipping windows at both the supplier and plant. The external logistics plan also considers the plant's receiving methods.

Once the internal and external logistics plans have been integrated into a material flow plan, the material flow plan is implemented. Given a well developed material flow plan (there is an approval process that is intended to assure the plan's worth), and well executed training for stakeholders of the resulting process, the technical aspect of implementation is straightforward and is mostly an exercise in executing the points of the plan.

#### *Schedule component production:*

Schedule component production is the process of coordinating production with customer demand from a "lean manufacturing" standpoint. The main focus of schedule component production is the development of a level production schedule supported by pull manufacturing systems.

#### *Manage internal logistics:*

Manage internal logistics is the day to day management and continuous improvement of the internal logistics processes. These processes include the storage and visual management of in-plant inventories, operation of the material replenishment pull system (the SMART system), and the training of employees. A major focus of manage internal logistics is to create adherence to the new processes and procedures that resulted from the implementation of the material flow plan.



### Manage external logistics:

Manage external logistics is the day to day management and continuous improvement of external logistics processes. Management of external logistics is coordinated by the LLP that helped to develop and implement the external logistics plan.

Historically, Chesterfield fit the mold of a traditional mass production assembly plant when it came to material flow. Deliveries from suppliers were infrequent for most components, large quantities of finished goods accumulated before being shipped to the customer, and material was pushed through the plant. Recently however, Chesterfield has put significant energy into improving material flow. Through the implementation of elements of Synchronous Material Flow (as discussed in this thesis) and other independent activities, Chesterfield has begun the transformation to lean material flow. However, not all stakeholders have embraced the concept that overproduction (in all its forms) is waste. Until that occurs, the transformation process will not be completed.

### Industrial materials:

Industrial materials include tools, cleaners, lubricants, and tape that are used to support production. Through FPS Ford wants to control the procurement, storage, and use of industrial materials in the same way they plan on controlling the components used in production (as described in the material flow section above). This will be accomplished by the implementation of visual controls, workplace organization, and pull systems to support replenishment of industrial materials.<sup>1</sup>

### Human resources policies, practices, and procedures:

Ford is working with the Union leadership to develop human resource policies that will help to promote teamwork and continuous improvement. The new policies are intended to be the model for team formation and empowerment and result in workers on the shop floor making decisions that in the past have been made by management.<sup>1</sup> Ford hopes to empower employee teams and instill in those teams a feeling of ownership of the processes under their control. The goal is to develop the same type of continuous improvement culture within Ford that currently exists within Toyota.

While some teams of hourly workers have been created in Chesterfield, they are not yet to the point where there is true empowerment, accountability, or drive for continuous improvement.

## Ford Production System Implementation Strategy:<sup>1</sup>

Ford has developed a five phase process for FPS implementation. The five phases are:

- Stability
- Continuous Flow
- Synchronized Production
- Pull System
- Level Production

Beginning with pilot implementations (called initial application areas), all Ford plants are expected to pass through the five phases listed above. Each implementation phase is described below.

### Stability:

The stability phase, as its name implies, is the phase in which the ground work for consistent, stable production is put into place in order to support later phases of FPS implementation. As discussed earlier, without predictable processes, pull system based production is nearly impossible. The activities in the stability phase help to assure that processes will produce consistently by improving equipment reliability, standardizing operations, and minimizing defects. Activities during the stability phase include: development of quality process sheets (Ford's version of standard operation sheets), organization of work areas, development of visual controls, affirmation of FTPM, error-proofing (development of poka-yoke devices), reductions in changeover times, and root cause defect analysis.

Another important aspect of the stability phase is employee involvement. While no official team structure exists, where possible, FPS implementation coordinators seek to form small teams of workers to assist in (and in some cases coordinate) the tasks performed during the stability phase. Significant training is provided to the workforce during the stability phase to familiarize them with the basics of FPS and to help them develop teamwork and problems solving skills. It is hoped that employee participation in the stability phase will help to develop the culture of teamwork, accountability, and continuous improvement that is required for full implementation of FPS.

### Continuous Flow:

The goal during the continuous flow phase is to minimize production lot sizes by moving from large batch production to single piece or continuous flow. This process helps to reduce between-process buffers (work-in-process inventory) and throughput time (which is generically defined as the time it takes a to convert a unit raw material into a finished good). Throughput time is reduced because smaller buffer sizes at each stage in the production process lead to materials having to wait less time to be processed.

In order to be able to reduce lot sizes, changeover times must be reduced as well. Small lot or single piece production requires frequent machine changeovers. If changeovers are difficult or time consuming, single piece production becomes infeasible. Finally, and most importantly, the production mindset needs to be changed during this phase from the mass production point of view that in-process inventory is good and provides protection, to the lean point of view that in-process inventory is waste.

#### Synchronous Production:

The goal of the synchronous production phase is to balance workloads across processes so that all processes produce in-step with one another. When production is synchronized, all processes produce at the same cycle time which is equal to the rate of customer demand (this is called the takt time will be discussed in a later section).

#### Pull System:

During the pull system phase Synchronous Material Flow will be fully implemented. SMF implementation will: establish pull systems which will initiate production and provide frequent replenishment of raw materials, develop centralized material storage areas within the plant, develop visual controls for inventory management, further reduce raw materials and work-in-process inventory levels, and remove waste from production processes by improving part presentation and worker ergonomics.

It is important to note that the pull system on which this thesis is based was implemented somewhat out of sequence. Generally, stability, continuous flow, and synchronous production will all be in place before SMF is introduced. Having the first three phases of FPS implemented before the introduction of SMF gives SMF the greatest chance to achieve the goals it is intended to achieve. The factors that cause pull systems to fail - wild swings in demand, poor quality, large batch sizes, proliferation of defects, etc. - will all be minimized if the first three phases are in place by the time SMF is applied.

In the case that is discussed in this thesis some, *but not all* of the elements of stability, continuous flow, and synchronous production were in place before SMF was implemented. The fallout from this was minimal with the only negative effect being the occasional build up of raw materials at the lineside because of fluctuations in the demand caused by poor quality or cycle time variability.

#### Level Production:

Level production is the ultimate goal of FPS. Level production means that all processes produce (in a coordinated manner) the exact quantity and mix of products that are desired by the customer. The products are manufactured at the rate of customer demand in the order demanded by the customer. In order to achieve level production, the final assembly process and the supply chain that supports it must be very flexible and able to change between products very quickly.

### Status of FPS Implementation within Ford:

As mentioned earlier, the total implementation of FPS is an enormous task. The information reviewed here is intended to provide a feeling as to how far along Ford and Visteon are in the process of implementation. In the data presented below, Ford in total (including Visteon) is referred to as "Total Company".<sup>7</sup>

- 100% of the plants in the Total Company have started FPS implementation (defined as having conducted a Launch Workshop and Current State Mapping Workshop for the pilot area).
- 65% of the Total Company and 82% of Visteon plants have passed the Stability phase in at least one area.
- 10% of the Total Company and 10% of Visteon plants have implemented SMF (including a pull system) in at least one area.
- Overall average on the five phase implementation scale = 1.3
  - the majority of plants have stabilized in one or two areas but few have fully expanded across the entire plant or made in-roads in Continuous Flow

### ***2.4 Overview of the Mustang Seat Assembly System:***

Chesterfield was chosen to supply complete seat sets for the Mustang beginning with the 1999 model. Having never produced complete Mustang seat sets before, Chesterfield needed to develop a new assembly system in order to fulfill the contract they had just won. Plant management decided to use this greenfield opportunity to incorporate lean manufacturing principles (based on the Ford Production System) into the design of the Mustang seat assembly system. To facilitate this, a "lean team" composed of management, engineering, and hourly employees was charged with designing and implementing a "lean" Mustang seat assembly system.

The lean team had specific goals, based on Ford Production System guidelines and metrics, which they wanted to achieve:

1. single piece flow through assembly
2. limited buffers and work-in-process inventory
3. limited finished goods inventory
4. leveled production building exactly to customer demand
5. optimized material flow

With the design of the Mustang seat build area (the physical infrastructure such as workstations, fixtures, conveyors, etc. that facilitate the conversion of raw materials into finished Mustang seat sets) and the implementation of In-Line Vehicle Sequencing (ILVS) the lean team was relatively successful at achieving goals one through four. However, they had not developed a system to address material flow. They had not considered how raw materials would be delivered to the seat build area, how these same materials would be presented to the builders (the hourly employees that assemble

Mustang seat sets) for use, or how materials would be replenished as they were used. The lean team had focused so much energy on the design of the seat build area that they had neglected the material flow system that would supply the seat build area with the parts needed to manufacture seat sets.

This is not to say that there was no method for material conveyance, display, and replenishment. The “traditional” material flow processes used within the plant could have been applied to the Mustang seat build area; however, this certainly would not have had the effect of “optimizing” material flow. In fact, the application of traditional material flow processes would have prevented the achievement of a lean assembly system - while the build area could have been considered lean, the material flow processes supporting it certainly would not have been. In order to have a truly lean assembly system, both if its major components, the seat build area and the material flow processes supporting the seat build area, must be lean. Recognizing this, plant and Union management supported the implementation of Synchronous Material Flow for the Mustang seat build area in order to address material flow issues.

### ***2.5 Scope of SMF Implementation in Mustang:***

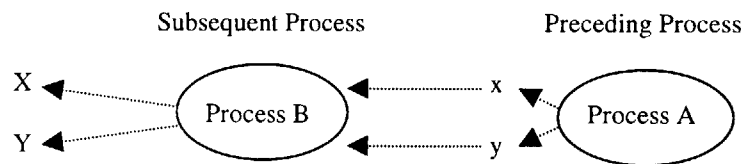
The Mustang seat build area was chosen as the initial application area, or pilot, for the implementation of SMF in Chesterfield. However, not all aspects of SMF were developed and implemented for the initial application area. Specifically, the external logistics piece was mostly ignored in large part because a Lead Logistics Provider had not been chosen for the plant. This is not to say that external logistics were not considered - in fact some improvements in external logistics were made by the core team developing the internal logistics plan. However, external logistics were not developed to the depth that the SMF process prescribes. Additionally, the schedule component production process of SMF was considered outside the scope of the pilot implementation. There were two main reasons for this. First, schedule component production is mostly an end-customer task which is then cascaded down through the supply chain. In Chesterfield’s case, schedule component production is addressed by their customer, Mustang vehicle assembly, through the generation of an In-Line Vehicle Sequence which is transmitted to Chesterfield. The ILVS schedule sets Chesterfield’s production schedule. Secondly, modifying the processes within Chesterfield that could have fallen under the schedule component production process, such as foam and seat cover production, was considered too large of a task to take on during the pilot. However, there were significant changes made to process of supplying foam to the seat build area.

The SMF implementation in support of the Mustang seat build area focused mainly on internal logistics. Specifically, the development and implementation of a pull system to manage the replenishment of purchased parts was the primary outcome of the pilot implementation. The “purchased parts replenishment pull system” will be the focus of this thesis.

## 2.6 Comparison of Push and Pull Systems:

This section, through a detailed example, will help to demonstrate the operation of a “pull” system and compare it with the operation of a traditional mass production “push” system. This example will also help to create a framework for later discussions involving the pull system that was developed as part of this research project.

Traditional mass production, batch and queue manufacturing systems are typically referred to as push systems whereas “lean” manufacturing systems such as the Toyota Production System are referred to as pull systems. A simple example concerning two adjacent processes will illustrate the fundamental differences between the push and pull systems. Suppose you have two processes, A and B. Process B, called the subsequent process, is the “customer” of process A, the preceding process. For simplicity sake, let’s also say the both process have the same cycle time, that is it takes each process the exact same amount of time to produce their respective parts. Let’s further say that B is the final process in the production process. Process B makes 2 types components, X and Y, each requiring a sub-component, x or y respectively, from process A. Finally, let’s say that the known end customer demand is 5 units of X and 5 units of Y. A representation of processes A and B, the products they manufacture, and the assembly flow direction is shown below.



**Figure 2.1: Two Adjacent Processes in an Assembly System**

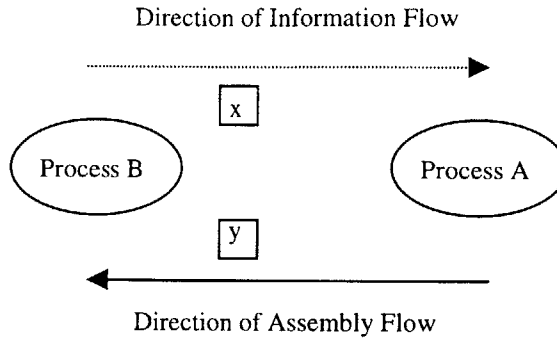
In a “push” system a schedule would be given to both processes showing the level of customer demand. Process A would produce its 10 components, most likely in batches such as 5 x’s and then 5 y’s. At the same time, process B would convert sub-components x and y into components X and Y as it received them from process A. Because process B received x and y in batches from process A, process B would produce X and Y in batches as well. Additionally, process B would receive x and y whenever they were completed by process A, even when process B was not ready for them. This is where a push system gets its name, process A “pushes” its completed parts to process B no matter the status of process B. The result of the push behavior is inventory build up between the 2 processes and batch production that may not necessarily match the pattern of customer demand resulting in increased finished goods inventory. The key characteristics of the push system are the lack of information exchange between the 2 processes, the existence of 2 “control points” (since each process has its own schedule), and the potential for variable amounts of work-in-process between the 2 processes. These characteristics lead to the likelihood of waste in the form of overproduction.

Overproduction is defined as performing value added tasks *before they are required and in the absence of customer demand*. Suppose process B was to “breakdown” due to a mechanical failure while process A continues to function. With the schedule as its only guide, process A would continue to build parts without any regard for the readiness of process B to accept these parts. Overproduction has occurred in this case as process A pushes parts to process B before they are required. Additionally, once the unnecessary value added work has been done, another type of waste has been created, excess inventory in the form of unneeded work-in-process in front of process B. Additionally, depending on the pattern of customer demand, the batch production process could result in less than satisfactory customer service.

In a “pull” system a schedule would be only given to process B. The schedule would be leveled meaning that although it would call for 5 X’s and 5 Y’s, it would call for them in batches of 1 leading to an alternating production sequence of X’s and Y’s. Additionally, there would be 2 spots, say taped squares on the floor, next to process B, 1 for component x and 1 for component y. When either of these spots are “open” it is an instruction to process A to produce a component to refill the spot. Process B would begin by instructing process A to produce 1 unit of x and then one unit of y to fill the spots. For the sake of explanation, we will have process B delay production until the spots for both x and y are filled. Once the spots are filled, process B would select x from its spot and in doing so send a signal to process A that it needs to produce another x. Just as process B is finishing producing X, process A will finish the production of x to replenish the part that was just used. Next, process B will select y from its spot sending a signal to process A that it needs to produce another y. This is where a pull system gets its name, process B “pulls” components to it as it needs them. The production will continue until 5 X’s and 5 Y’s are produced.

The key characteristics of the pull system are the information exchange between the 2 processes (which flows in the opposite direction of the production flow), the existence of only 1 control point (process B where the schedule is located), and the limits set on work-in-process inventory levels between the 2 processes (due to the 2 spots for x and y between the processes). With these characteristics, it is unlikely that operation of the pull system will result in the same level of overproduction as was possible when considering the push system described above. The existence of only 1 control point, a fixed amount of work-in-process inventory, and information flow between the 2 processes all result in process A only producing when process B (the customer) needs parts.

A representation of a pull system operating between processes A and B is shown below.



**Figure 2.2: Representation of a Pull System Operating Between 2 Adjacent Processes**

Historically, most assembly and material flow processes at Chesterfield were carried out by a push system. With the development of the Mustang seat build area and the implementation of elements of SMF, Chesterfield is beginning the shift to pull systems for production and materials control.

### ***2.7 Overview of the Purchased Parts Replenishment Pull System:***

The pull system that will be discussed in this thesis manages the replenishment of purchased parts used in the Mustang seat build area. Traditionally in Chesterfield replenishment of purchased parts was accomplished by means of a push system, with “pull” only occurring when stock out conditions arose. This resulted in unpredictable levels of lineside inventory and production stoppages due to part shortages. The “purchased parts replenishment pull system” which was developed as part of this research project is the first attempt at Chesterfield to move to a true pull system for the replenishment of components used in the assembly process.

Purchased parts are divided into two classifications - card parts and call parts – each having their own replenishment mechanism. Card parts are generally small and light with a full container weighing less than 40 pounds and are delivered to the build area during frequent replenishment routes. Call parts, on the other hand, are large, heavy parts that are moved to the build area with the use of a forklift. Call parts are delivered on a somewhat random schedule. The dedicated storage areas that house purchased parts are called marketplaces. Generally, card parts and call parts are stored in separate marketplaces. When purchased parts are delivered to the plant, they are immediately moved to their storage locations within the marketplaces. Each part has a unique storage location, referred to as a marketplace address, which it is assigned to. The purchased parts replenishment pull system operates between the Mustang seat build area and the marketplaces that house purchased parts.



In order to help visualize the operation of the purchased parts replenishment pull system let's relate it to the generic pull system described in section 2.6. Process B, the subsequent process, is the Mustang seat build area. It is also the *only* control point of the production process and is in possession of the production schedule. Process A, the preceding process, is the purchased parts marketplaces.

As with the generic pull system, there are a limited number of "spots" in the Mustang seat build area (process B) allocated to containers of purchased parts. For card parts the number of spots is equivalent to the maximum number of containers of that part that are allowed in the build area. Each container has a corresponding kanban card attached to it that is used for identification and as an order signal when replenishment is required. For call parts, there is generally only one spot allocated at the lineside for each part due to the large containers that call parts are packaged in. Limiting the number of spots has the effect of limiting purchased parts inventory at the lineside, just as it limited the work-in-process inventory in the generic example. Information flows from the build area to the marketplaces when purchased parts need replenishment and parts are only delivered to the lineside upon receiving replenishment signals.

Unlike the simplified example in section 2.6, the signal for replenishment of process B, the build area, is not visual. Instead, the signal can take one of two forms, either a physical signal in the form of a kanban card (referred to as a SMART card) for the replenishment of card parts or an auditory signal in the form of a call over a two way radio for call parts. Also, for card parts, replenishment is not based on a continuous review of the open spots.

In the generic example in section 2.6 it was implied that process A would *continuously review* the spots at process B and as soon as a spot opened, would begin producing a component to replace the part that had just been used. Although this type of continuous review policy is employed for the replenishment of call parts, a periodic review policy is followed for the replenishment of card parts. Employing a periodic review policy is analogous to process A only looking at process B periodically, every two hours for example, seeing how many spots are open, and then producing the correct number of components to fill the empty spots. The periodic review process is executed by material handlers called route drivers.

Route drives follow a fixed route through the build area every two hours. As they travel through the build area they check for open "spots" by collecting kanban cards that have been placed in "mailboxes" within the build area. Kanban cards are "generated" whenever a new container of card parts is opened in the build area - when a new container of parts is opened the kanban card is removed from the container and placed in a mailbox. After the route driver has collected the kanban cards, in effect collected his order, he travels back to the card part marketplace and fills the orders as instructed by the kanban cards.

Each kanban card represents one container of a specific part. The route driver attaches the kanban cards to the containers of purchased parts that match the descriptions on the

cards and heads back for the build area repeating the process every two hours. In this way only what was actually used in the build area gets replenished – the build area is pulling the parts that it needs from the marketplace to the lineside. Replenishment of call parts is slightly different. As mentioned above, replenishment of call parts is based on a continuous review process. In practice, when a container of call parts reaches a certain level equal to 20 minutes of usage, the operator using the parts places a call over a two way radio requesting a new container of parts. This order is received by a material handler which retrieves a new container of parts from the call part marketplace with the use of a forklift. The material handler then brings the parts to the line and replaces the used container with the full container.

## **Chapter 3: Overview of Process Development and Implementation Philosophy**

This chapter provides an overview of the process development and implementation philosophy that was employed by the team that implemented the purchased parts replenishment pull system. The overview begins with a discussion of some alternate philosophies of process implementation. This is followed by a description of the manual that was provided to the implementation team to guide it through the development and implementation process and a discussion of the “philosophy” espoused in the manual. Next, there is a description of a very different implementation philosophy and its merits. The chapter concludes with a discussion of the approach that the implementation team chose to follow.

### ***3.1 Implementation Philosophies:***

There are differing philosophies on how to implement lean manufacturing processes. Each of the philosophies have distinctive characteristics that are helpful to understand when examining implementation at the plant level. These include:<sup>8</sup>

- Pilot versus full-scale
- Top-down re-engineering versus bottom-up process improvement
- “Cookbook” versus “applied learning”

The implementation of the purchased parts replenishment pull system clearly falls into the category of a pilot implementation based on top-down re-engineering of existing processes. However, the implementation can not be characterized as following strictly either the cookbook approach or the applied learning approach (which are described later).

In general, there has been an increasing amount of attention paid to organizational learning and the importance of understanding learning dynamics in the context of implementation. Investigation of the cookbook and applied learning approaches helps to highlight the impact different approaches to implementation have on organizational learning.

### ***3.2 Description of SMF Implementation Manual:***

An SMF “implementation manual” (see reference 6) has been developed by the Ford Production System Institute. The manual provides background information and step by step tasks (referred to as single point lessons) to follow in order to implement the elements of SMF. For example, sections of the manual detail the tasks required to implement the purchased parts replenishment pull system. The manual is distributed as part of an in depth training course that is required for the SMF process owners (also

referred to as FPS material flow coordinators) within each plant. The manual covers all phases of SMF implementation from team formation to launch. In short, the SMF implementation manual is intended to guide an implementation team through the implementation process.

### ***3.3 Cookbook Approach:***

The SMF implementation manual is based on the “cookbook” approach to implementation. The manual provides very specific tasks to execute in order to implement SMF - it tells the implementation team exactly “what” to do. The structure of the manual helps to set the scope of the development process and provides a starting point from which to launch and manage the implementation of SMF. The cookbook approach espoused in the manual is also valuable in cases where tasks can easily be executed optimally without the need to understand the theory that underlies the task being completed. However, in some cases where theory is needed (especially in the more technical sections), the manual does not provide many explanations as to why the implementation team is performing the tasks it’s performing. The manual tells the team what to do without telling them why they are doing it. For example, the manual includes calculations that the team uses to determine the number of SMART cards required for each card part. However, there is little explanation as to why certain factors (such as route time, container size, etc.) appear in the calculations, the relationships between the factors, and what the results of the calculations actually represent.

The absence of the theory behind the tasks can result in a lack of understanding of the pull system elements that are being “created” by the tasks as well as a lack of knowledge of the linkages that exist between the elements. This lack of system level understanding is detrimental to the ability of the implementation team to make tradeoffs between system elements during the development phase and hinders continuous improvement activities once the replenishment system has been launched.

### ***3.4 Applied Learning Approach:***

The applied learning approach prescribes that people implementing a process have high, theoretical, system level knowledge about how the process they are implementing works. This knowledge provides insight into the interactions that occur between various elements of the process helping to make apparent the specific tasks required and specific tradeoffs to be made in order to successfully implement the process. The key principle is that change can’t be implemented just by following instructions - it involves independent judgements by the implementers at certain times in a given context.

In contrast to the cookbook approach, the applied learning model should facilitate better decision making during the development phase because of a greater understanding of the decision factors and enhance continuous improvement processes because of an increased understanding of how the elements of the system fit together. This is not a revolutionary

statement. Simply stated, a team that understands the fundamentals behind the process it is implementing is going to do a better job of implementation than a team that does not understand the fundamentals.

### ***3.5 Application of the Cookbook and Applied Learning Approaches:***

By definition, the applied learning model requires members of the implementation team to possess highly developed theoretical understanding of the process being implemented. Because of factors such as resource restrictions and learning curve effects, this “expert”, system level knowledge will not always be available - especially during pilot implementations. Therefore, claiming that an applied learning approach to implementation is preferred and actually being able to form a team that is capable of employing the applied learning method are two separate issues. This seems to indicate a somewhat interdependent and transitional relationship between the cookbook and applied learning approaches to implementation.

The cookbook can provide the initial framework and structure which allows an implementation team that is unable to follow the applied learning approach to begin process development regardless of their limited theoretical understanding of the process that they are implementing. The implementation team can continue to follow the cookbook until its limits are reached - at some point the cookbook will fail to provide the theoretical understanding that is needed to properly execute tasks and make tradeoffs between (or adjustments to) various elements of the process.

In some cases the implementation team may not be able to move beyond the limits of the cookbook resulting in a considerably sub-optimal or failed implementation. In other cases, if learning has occurred - through the execution of the tasks provided by the cookbook or through knowledge transfer from a team member or external source - the learning can be applied, allowing the team to move past the limits of the cookbook. As the overall level of knowledge on the implementation team grows, the team will become less reliant on the implementation manual (the cookbook) and more reliant on their own knowledge. Because of this, during a particular implementation as learning occurs the implementation process may transition from the cookbook approach to the applied learning approach. Additionally, subsequent implementations of the same process (by the same team) should follow more of an applied learning approach.

### ***3.6 Purchased Parts Replenishment Pull System Implementation Philosophy:***

The implementation of the purchased parts replenishment pull system in support of the Mustang seat build area was the first implementation of SMF at Chesterfield. Because of this, there was little theoretical, system level knowledge resident on the implementation team. The “expert” knowledge that did exist was possessed by “outsiders” (an outside consultant and an intern, the author) who had not yet built credibility with the

implementation team and by the SMF coach (an SMF expert that was only able to directly interact with the team once per week). Because of this, initially, the team employed the SMF implementation manual as its guide to implementation.

As the implementation progressed the team moved away from the implementation manual and began to use more of an applied learning approach. This occurred because of three main factors:

- acceptance of the outsiders as experts
- team learning occurred that could be applied to implementation tasks
- loss of confidence in the implementation manual because of the discovery of “errors”

In summary, the overall philosophy employed for the implementation of the purchased parts replenishment pull system was a mixture of the cookbook and applied learning approaches. It is important to note that even as the shift to the applied learning approach occurred, there were cases where a lack of theoretical understanding among team members and other stakeholders led to tasks being executed sub-optimally.

The next eight chapters detail the eight step process that was followed to develop and implement the purchased parts replenishment pull system. The steps are defined by the tasks which were executed by different combinations of stakeholders from distinct functional groups. Presentation and analysis of the steps provides insight into the technical and implementation philosophy related aspects of the development and implementation process. Where appropriate, deviations from the recommendations in the SMF implementation manual are discussed. The learning that occurred is also reviewed.

## **Chapter 4: Step 1 – Team Formation**

This is the first of eight chapters that describe the process that was followed in order to develop and implement the purchased parts replenishment pull system. The steps are presented chronologically in order to highlight the general precedence relationships that exist. There is significant interdependence between some steps, however, so where appropriate the interactions between the steps will also be explored. The description of each step includes the specific tasks performed, the inventory management theory underlying the tasks, an assessment of the skill base of the team relative to the “ideal” skill base needed for the step, and documentation of any issues that arose either during the step or as a result of the step which were caused by a lack of theoretical understanding of lean manufacturing. The first step in the process is team formation.

### ***4.1 Team Formation:***

Team formation is one of the most important steps in the implementation process. The right mixture of stakeholders representing as many of the areas effected by the new process as possible is critical to a successful implementation. It is important to have a balance of hourly and salary team members which have unique perspectives on their functional areas of expertise. The SMF implementation manual calls for three teams to work in concert to implement SMF: the Logistics Planning Team, the Lead Logistics Provider Team, and the In-Plant Replenishment Team.<sup>6</sup> The Logistics Planning team is a high level team that performs most of the early organizational communication and acts as a “governing body” over the SMF implementation process. The Logistics Planning Team approves the material flow plan, helps to resolve issues, and removes barriers. The Lead Logistics Provider Team develops and implements the external logistics plan. The In-Plant Replenishment Team develops and implements the internal logistics plan. The In-Plant Replenishment Team executed most of the tasks required for the development and implementation of the purchased parts replenishment pull system.

The SMF implementation manual provides a profile for the In-Plant Replenishment Team (referred to as the “implementation team” from this point forward) specifying what functional areas members should come from and what skills they should possess. Additionally, the manual divides the team into two segments a core team and a support team. Core team members are dedicated full time to the implementation of SMF. Support team members contribute at varying levels during different points of the development and implementation process. Support team members are resources to the core team and have other responsibilities outside of the SMF implementation. The implementation team for the purchased parts replenishment pull system differed somewhat from the team profile suggested by the SMF implementation manual.

The following matrix lists the team members, the stakeholder group they represent, and their team member status.

| <b>Title</b>                            | <b>Stakeholder Group</b>        | <b>Status</b> |
|---|---------------------------------|---------------|
| SMF Process Owner (Salary)              | Ford Production System          | Core          |
| SMF Process Owner (Hourly)              | Ford Production System          | Core          |
| Lean Manufacturing Consultant (Intern)  | Mustang Seat Build Area         | Core          |
| Ergonomics Representative               | Ergonomics                      | Support       |
| Material Replenishment Coordinator      | Ford Production System          | Support       |
| Division SMF Coach                      | Ford Production System          | Support       |
| Lean Manufacturing Expert (Consultant)  | Ford Production System          | Support       |
| Health and Safety Representative        | Health and Safety               | Support       |
| Material Handling Supervisor            | Material Handling               | Support       |
| Material Handler - route driver         | Material Handling               | Support       |
| Material Handler - forklift driver      | Material Handling               | Support       |
| Material Handling Engineer              | Material Handling               | Support       |
| Pre-production Analyst                  | Material Planning and Logistics | Support       |
| Production Supervisor                   | Mustang Seat Build Area         | Support       |
| Seat Builder                            | Mustang Seat Build Area         | Support       |
| Packaging Engineer                      | Packaging Engineering           | Support       |
| Procurement and Distribution Supervisor | Procurement                     | Support       |
| Plant Bargaining Representative         | Union Management                | Support       |

**Figure 4.1: SMF Implementation Team**

Not all team of the team members listed above were with the team through the entire process. For example, the material replenishment coordinator did not join the team until just before the pull system was launched. Additionally, post implementation interviews indicated that more representation from receiving could have improved the design of the purchased parts replenishment pull system.

The hourly and salary SMF process owners were technically the leaders of the implementation team. However, because of their lack of comfort and familiarity with the SMF process, they promoted a shared leadership environment. Specifically, leadership of most of the technical aspects of the project were delegated to the lean manufacturing consultant (the author).

While delegation of the technical tasks was certainly appropriate given the skill base of the team and the desire to get the implementation process moving quickly, there were some negative ramifications of delegation. First, by delegating the responsibility for the technical tasks, the process owners somewhat insulated themselves from the learning process and therefore did not initially get the direct exposure to SMF that would have made them more comfortable with the process. Second, there was some perception outside of the team that the consultant leading the technical tasks was in fact leading the SMF implementation. This was mainly due to the fact that the execution of technical tasks was highly visible while the project planning and team meetings that supported the implementation were far less visible. As the process owners learned about SMF and



became more confident in their knowledge of the process, they took more direct responsibility for technical tasks as demonstrated by their high level of involvement in task execution during the later steps of the implementation process.

In general, the members of the implementation team worked well together. There was a good deal of trust between team members so that, in most cases, once a task was completed or a decision was made, the team moved on without spending time second guessing what had been done. Hourly employees were strong contributors and were willing to share their opinions openly which provided great insight into how to reduce the waste that existed in the replenishment process. There was a feeling of accountability on the team with most team members completing their assigned tasks for each team meeting.

There were, of course, some points of friction between different stakeholders and different stakeholder groups during the implementation process. Most conflicts were brought to the surface quickly and discussed openly in both team meetings and in one-on-one sessions. While the open discussion of issues may have “hurt some feelings”, the “say what you feel” atmosphere promoted much faster resolution of issues than would have been the case had stakeholders let their concerns fester. In the end, open dialogue promoted mutual respect among stakeholders.

#### **4.2 The Needs Matrix:**

At various points in the development process, different team members and different stakeholder groups need to contribute at varying levels depending on how directly correlated the task at hand is to their functional expertise. To help clarify the resources required and the tasks that the resources must execute during various steps in the development process, most chapters will begin with a “needs matrix”.

In addition to resource and task descriptions, the needs matrix also provides an indication of where theoretical, system level knowledge needs to exist in order to optimally execute the tasks associated with a given step in the development process. The need for theoretical understanding is indicated by a checkmark in the “Theoretical Knowledge Required” column of the matrix. In some cases, the stakeholder or stakeholder group that is charged with the completion of a task that requires theoretical knowledge does not possess that knowledge. This is indicated in the needs matrix by the *absence* of a checkmark in the “Theoretical Knowledge Present” column (in a row where the “Theoretical Knowledge Required” column has been checked). Mismatches between the knowledge that is required and the knowledge that exists helps to identify where the cookbook approach may be at risk of resulting in sub-optimal process development and implementation and more of an applied learning approach is needed.

An example of a typical needs matrix is shown below.

| Title                         | Role in Step  | Theoretical Knowledge Required | Theoretical Knowledge Present |
|-------------------------------|---|--------------------------------|-------------------------------|
| SMF Process Owner (Salary)    | Coordinate execution of step                              | ✓                              |                               |
| SMF Process Owner (Hourly)    | Coordinate execution of step                              | ✓                              |                               |
| Lean Manufacturing Consultant | Execute tasks where needed                                | ✓                              | ✓                             |
| Division SMF Coach            | Oversee execution of step and provide consulting on tasks | ✓                              | ✓                             |
| Lean Manufacturing Expert     | Provide consulting on tasks                               | ✓                              | ✓                             |
| Pre-production Analyst        | Validate bills of material for all end items              |                                |                               |
| Production Supervisor         | Provide high level customer demand information            | ✓                              | ✓                             |

**Figure 4.2: Example of a Typical Needs Matrix**

Theoretical knowledge is not required for every task. In some cases, a stakeholder can easily and proficiently execute a task required for the development of the pull system without knowledge of the theory that underlies the task. For example, validation of the bill of materials (which is required to define the demand that the pull system will need to support) can easily be done without theoretical understanding of how the pull system operates or how demand is calculated based on the information in the bill of materials. In these cases only “what to do” knowledge is required in order to correctly execute the task. These type of tasks are indicated in the needs matrix by the *absence* of a checkmark in either of the columns. The absence of a checkmark helps to identify where the cookbook approach can lead to successful process development and implementation because generally, between the task descriptions included in the SMF implementation manual and the functional expertise that stakeholders possess, sufficient “what to do” knowledge exists.

## Chapter 5: Step 2 – Determination of Lineside Demand

*“One of the keys [to developing the pull system] is to understand the process you are going to be supporting.” - Salary SMF Process Owner<sup>9</sup>*

A cornerstone of any pull system is the determination lineside demand. The inventory kept at the line, the number of kanban cards circulating through the pull system, and the design of most other elements of the pull system are all based on lineside demand. This chapter summarizes the tasks that were performed in order to determine the levels of demand that the pull system would have to support at the lineside for each purchased part. The chapter begins with a summary of the high level demand information that was provided to the implementation team and proceeds through the steps taken to break the aggregated demand down into the measure of demand that drives the design of the pull system at the lineside - “component level demand”. Component level demand is the hourly demand for each component that is used in the assembly process. The specific factors used to break down the high level demand (such as product mix and the bills of materials) and their function in the disaggregation process are discussed in detail.

### 5.1 Needs Matrix for Step 2:

| Title                         | Role in Step  | Theoretical Knowledge Required | Theoretical Knowledge Present |
|-------------------------------|---|--------------------------------|-------------------------------|
| SMF Process Owner (Salary)    | Coordinate execution of step                              | ✓                              |                               |
| SMF Process Owner (Hourly)    | Coordinate execution of step                              | ✓                              |                               |
| Lean Manufacturing Consultant | Execute tasks where needed                                | ✓                              | ✓                             |
| Division SMF Coach            | Oversee execution of step and provide consulting on tasks | ✓                              | ✓                             |
| Lean Manufacturing Expert     | Provide consulting on tasks                               | ✓                              | ✓                             |
| Pre-production Analyst        | Validate bills of material for all end items              |                                |                               |
| Production Supervisor         | Provide high level customer demand information            | ✓                              | ✓                             |

**Figure 5.1: Needs Matrix for Determination of Lineside Demand**

### 5.2 High Level Process Information:

The first step in the determination of lineside demand is to collect information about the production process that the pull system will be supporting – the process that is the “customer” of the pull system. As the focus of this thesis is the development and implementation of a pull system for the replenishment of purchased parts used in the Mustang seat build area, the Mustang seat build process can be seen as the customer of the pull system. The Dearborn plant, the body and assembly plant where Mustang

vehicles are assembled, is in turn the customer of the seat build process. Therefore, although the immediate customer of the purchased parts replenishment pull system is the Mustang seat build area, the demand placed on it is directly derived from the requirements of the body and assembly plant.

Assessment of the seat assembly process was achieved through in depth conversations with the process engineer responsible for the implementation of the Mustang seat build area. He and the “lean team” had previously developed the operational specifications for the Mustang seat build area based on conversations with their customer, the Dearborn assembly plant. The process engineer responsible for implementing the Mustang seat build area provided the following operational information from which the implementation team determined the demand requirements that would be placed on purchased parts replenishment pull system at the lineside.

- Demand is seasonal but production volume would be adjusted by modifying the number of hours per day that the build area was run
- Production length = 16 or 20 hours per day (divided over two shifts) depending on demand
- Average production rate = 38 seat sets per hour
- Average planned uptime for build area = 54.5 minutes per hour
- Break time = 22 minutes every 4 hours
- Production sequence based on the In-Line Vehicle Sequencing (ILVS) broadcast from Dearborn vehicle assembly

A key point here is that the average production rate of 38 seat sets per hour is based on the production rate of Mustang vehicles at the Dearborn plant. Matching the production rate of Dearborn allows the Mustang seat build area to minimize finished goods inventory by not building seat sets faster than their customer consumes them.

### ***5.3 Breaking Down High Level Demand:***

The information above conveys the average aggregate demand. The aggregate demand is the summation of the demand for all the different end items where an end item is defined as a unique type of finished good (in our case a unique type of seat set). Knowing the aggregated demand is not sufficient information around which to design a pull system. The aggregate demand must be broken out into more specific elements of demand and combined with other information in order to calculate component level demand – the form of demand around which the pull system will be developed.

#### **5.3.1 Average versus “Actual” Demand:**

The first step in determining component level demand is to determine the “actual” rate of demand placed on the pull system at the lineside.

If the production volume during a shift is divided by the length of the shift then the quantity reported is the *average rate of production per scheduled hour*. For example, if 608 seat sets are manufactured during 16 hours of production, then the average rate of production per scheduled hour is 38 seat sets per hour. This is the standard form in which the average production rate of the Mustang seat build area is reported (and is the form in which the average production rate is presented in section 5.2). This is a handy number for plant personnel to know. If the area manager wants to know how many seat sets he can produce in a scheduled 20 hour day, all he has to do is multiply the number of scheduled hours by the average production rate per scheduled hour and the total production volume can be calculated. However, when it comes to the replenishment of lineside inventory, the average demand is not in fact the level of demand that the pull system must support.

*The “actual” level of demand that the pull system will need to support at the lineside is higher than the reported average - this is a subtle but critical distinction that is very easy to overlook.* The discrepancy arises from the fact that the average production rate is derived *without* consideration of scheduled downtime such as rest breaks. A simplified example will help to clarify this concept.

Let’s say a process produces 20 units of finished good Y per hour. The process is quite simply in that it converts raw material X - which is purchased from an outside supplier and stored in a marketplace - into finished good Y taking 3minutes to do so. If the process ran continually during an 8 hour shift it would produce 160 units of Y. However, after every 1.5 hours of production, a 30 minute rest break is given to the workers that run the process - the process is only operational for 1.5 of every 2 scheduled hours of production. This results in the process being idle for 2 hours of the scheduled 8 hour production shift. Therefore, in 8 hours the process only produces 120 units of Y (6 hours of production at 20 units of Y per hour). The average production rate *per scheduled hour* is 15 units per hour – the 120 units produced divided by the 8 hours over which production was scheduled. However, the actual production rate of the process when running, the “run rate”, is faster than the average production rate would indicate. This is an important factor when it comes to the replenishment of the input to the process, raw material X.

Let’s say that the material handler that delivers raw material X to the process takes his breaks at the same time the workers running the process take their breaks - when the process is idle, the material handler is idle (this is typical in the operation of most pull systems). Let’s also say that the material handler replenishes the process every 2 *working hours* which, when breaks are considered, translates into replenishment of the process every 2.5 scheduled hours. Since the material handler only replenishes the process every 2.5 scheduled hours, the process must have sufficient stock of raw material X to support the 2 hours of run time that elapse between deliveries from the material handler. In 2 hours of run time the process consumes 40 units of raw material X. Therefore, in order to not run out of raw material, the process must be initially stocked with 40 units of X and the material handler must deliver 40 units of X each time he replenishes the process.

*From this example it can be seen that the demand placed on the replenishment system at*

*the lineside is based on the actual production rate - the run rate - of the process, not the average production rate per scheduled hour.*

It is important to note that the argument just made hinges on the assumption that the material handler is idle when the production process is idle. This will generally be the case in a properly designed pull system - material handlers breaks will be scheduled to coincide with the breaks taken by the employees that are working in the area that the material handlers are replenishing. If the material handler never took breaks and replenished the process every 2 scheduled hours (as opposed to every 2 working hours), the above argument would be invalid. Under the “no break” scenario each time the material handler replenishes the process, only 1.5 hours of run time will have elapsed since he last performed his duties. Since 1.5 hours of run time consumes 30 units of raw material X, the usage that the material handler “sees” (and therefore must replenish) under the no break scenario is based on the average production rate per scheduled hour – not the run rate.

From the example above it is clear that in order to properly stock and replenish the lineside, the actual rate at which the build area is producing must be determined. In the case of the Mustang seat build process this is done by dividing the output of the process during a given time interval by the actual time it took to produce the output. The difference between the time interval and the actual time consumed to produce the output is the time allocated to rest breaks.

For example, the average production rate for the Mustang seat build area is stated as 38 seat sets per hour. Over an 8 hour shift the average production rate prescribes that the build area must produce 304 seat sets in order to satisfy customer demand. Since the length of a shift in the Mustang seat build area is inclusive of rest break time, the actual amount of time available for production during the 8 hour shift is less than the scheduled 8 hours. In fact, during an 8 hour shift the actual time available for production is only 7 hours and 16 minutes due to rest breaks. If the output of the build area is divided by the actual production time, as opposed to the scheduled production time, a true measure of the production rate can be made. Dividing the required output of 304 seat sets by the available time to produce those seats gives the actual production rate (the run rate) required to meet customer demand.

$$\text{Actual Production Rate} = \frac{\text{Units Required}}{\text{Time Available to Produce Units}} = \left( \frac{304 \text{ seat sets}}{7.27 \text{ hours}} \right) = 42 \frac{\text{seat sets}}{\text{hour}}$$

#### **Equation 5.1: Calculation of Actual Production Rate**

In other words, the actual rate of production of the Mustang seat build area, and hence the actual demand placed on the purchased parts replenishment pull system at the lineside, is 42 seat sets per hour. *A more detailed treatment of the calculation of the actual production rate is provided in the technical appendix, topic A.*

*At this point it is critical to point out that not all elements of the pull system are designed based on the actual production rate of the build area. In particular, the marketplaces that support the pull system are designed based on the average production rate per scheduled hour. Continuation of the example used earlier in this section will help to explain this discrepancy. As mentioned above, the material handler “sees” raw material X being consumed at a rate of 20 units per hour and replenishes stock based on that rate. The material handler replenishes the process 3 times during the 8 hour shift - after 2.5 hours of production, after 5 hours of production, and after 7.5 hours of production. In each case he delivers 40 units of raw material X to the process for a total of 120 units during the 8 hour shift. However, from the “perspective” of the marketplace from which raw material X is being withdrawn, the usage rate of raw material X is only 15 units per hour – the 120 units withdrawn divided by the 8 hours in the shift. Therefore, the usage rate that the marketplace must support is based on the average production rate per scheduled hour, not the actual production rate. In summary, at the lineside, the replenishment system must be designed to support demand based on the actual production rate; whereas, the marketplace is designed to support demand based on the average production rate per scheduled hour.*

### 5.3.2 Product Mix:

Once the actual demand rate has been calculated, the next step in determining component level demand is to determine the product mix. The product mix is defined as the percentage of total production that each end item represents. Understanding the product mix is critical to determining component level demand because different components are required to produce different end items. Because of this, some components may be used in less than 100% of the seat sets that are being produced each hour.

For Mustang, product mix was gauged by analysis of the “1999 Mustang Seat Mix”, a matrix that was generated by corporate planning. The seat mix matrix was a forecast of expected customer demand for each end item aggregated over the production year. The aggregation smoothed any seasonality that may occur such as high demand for convertible seat sets in the Summer. A simplified example of the seat mix matrix is shown below.

| Cover Material | Seat Type | Car Style |             |          |             |             |                |
|----------------|-----------|-----------|-------------|----------|-------------|-------------|----------------|
|                |           | V6 Coupe  | V6 Convert. | GT Coupe | GT Convert. | Cobra Coupe | Cobra Convert. |
| Cloth          | Manual    | 4.50%     | 1.70%       | 1.10%    | 0.16%       | NA          | NA             |
|                | Power     | 44.80%    | 12.30%      | 8.50%    | 1.33%       | 1.20%       | 0.30%          |
| Leather        | Manual    | 0.10%     | 0.10%       | 0.25%    | 0.20%       | NA          | NA             |
|                | Power     | 0.20%     | 0.10%       | 5.75%    | 9.60%       | 4.90%       | 2.90%          |

**Figure 5.2: Mustang Seat Product Mix Matrix**

As can be seen from the matrix, the seat mix is driven by 3 main factors: cover material, seat type, and car style. Each combination of cover material, seat type, and car style produces a unique end item. For example, a cloth, manual, V6 coupe seat set (italicized above), is a unique end item which represents 4.5% of the total production of Mustang seat sets.

An important element of product mix has been omitted from the matrix above. Specifically, there is no seat cover “color” information included in the matrix. Each unique end item is produced in variety of three or four colors. For example, there are three different colors of cloth, manual, V6 coupe seat sets that are produced – parchment, midnight black, and medium graphite. Therefore, each end item shown in the matrix above has a family of end items that exist below it. This causes a proliferation of the number of end items from the 20 that are shown in the matrix above to 62 when the seat cover color is considered.

A decision was made to exclude seat covers from the purchased parts replenishment pull system because of the significant changes that would have had to occur in the scheduling, packing, and delivery processes for seat cover manufacture in order to integrate it into the system – changes that were felt to be outside the scope of this project.

### **5.3.3 Bill of Materials:**

For each end item the Bill of Materials (BOM) spells out the type and quantity of components required for that particular end item to be produced. For example, the BOM for a power, V6 Coupe seat set lists all of the components used and the quantity of each component required for the production of a power V6 Coupe seat set.

Since the BOM is a key element in the determination of component level demand, it is critically important that it be validated for each end item. An inaccurate BOM can result in the procurement of the incorrect amount of a component, excess or insufficient stock at the lineside, and a misallocation of storage space. The best way to confirm the requirements stated in a BOM is to go to the build area and trace through the production process for each end item comparing what actually goes into each end item with what the BOM claims. Confirmation of the BOM will also help to identify where each component is used within the build area.

### **5.3.4 Component Level Demand:**

Component level demand can be determined by combining the BOM’s for all end items, the product mix, and the actual demand rate. As a simple example, let’s assume the build area produces 2 end items, 1 and 2, each representing 50% of the product mix. Additionally, each end item contains 4 components.



Combining the BOM's for the 2 end items results in the following table.

| End Item | % of Mix | Component | Usage per End Item |
|----------|----------|-----------|--------------------|
| 1        | 50       |           |                    |
|          |          | A         | 3                  |
|          |          | B         | 2                  |
|          |          | C         | 1                  |
|          |          | D         | 1                  |
| 2        | 50       |           |                    |
|          |          | A         | 3                  |
|          |          | B         | 2                  |
|          |          | C         | 1                  |
|          |          | E         | 1                  |

**Figure 5.3: Simplified Bill of Materials for 2 End Items**

Analysis of the table allows for the classification of components as either common or unique. A component is common if it is used in all end items or 100% of the product mix. Since components A, B, and C are used in both end items they are classified as common components. The demand for a common component is its usage per end item multiplied by the number of seat sets produced per hour. Given a production rate of 42 seat sets per hour, the demand for components A, B, and C is 126, 84, and 42 units per hour respectively.

A component is unique if it is used in only one or a few (but not all) end items. Accordingly, components D and E are classified as unique components. A general equation can be used to determine the demand for any unique component (and for common components as well by setting the % of product mix term equal to 100%).

**Hourly Demand** = component usage per end item × production rate × % of mix component is used in

**Equation 5.2: Calculation of Hourly Demand for Components**

Using the equation 5.2 (given the production rate of 42 units per hour and their usage in 50% of the product mix) the demand for components D and E is calculated to be 21 units per hour.

This process results in the creation of a consolidated bill of materials as shown below which details the demand for each component.

| Component | Usage per End Item | End Items | % of Mix | Hourly Demand |
|-----------|--------------------|-----------|----------|---------------|
| A         | 3                  | 1 & 2     | 100      | 126           |
| B         | 2                  | 1 & 2     | 100      | 84            |
| C         | 1                  | 1 & 2     | 100      | 42            |
| D         | 1                  | 1         | 50       | 21            |
| E         | 1                  | 2         | 50       | 21            |

**Figure 5.4: Consolidated Bill of Materials**

### 5.3.5 Multiple Location Components:

For the pull system to operate properly it is important to identify “multiple location” components - components that are used at more than one location within the build area. For example, the same component could be used in two different processes - one at the beginning of the line and one at the end of the line.

From a replenishment perspective, each locale of a multiple location component requires separate analysis. Most importantly, component level demand needs to be disaggregated over the number of locations at which the multiple location component is used in order to determine location specific inventory levels and identification information.

As an example, let’s assume component A in the example in section 5.3.4 is a bolt. Component A, which is classified as a card part and replenished based on SMART card generation, is used in 2 separate processes, process X and process Y. Process X is the first process in the assembly process and process Y the last. Additionally, the total component level demand for component A has been calculated as 126 units per hour. By tracing through the assembly process, how the demand for component A is divided between the 2 processes can be determined. Let’s say that analysis of the assembly process identifies that 84 units of component A are used per hour in process X and 42 units are used per hour in process Y. We now know that we need to supply 2 unique processes with differing amounts of the same component instead of simply supplying the assembly process to meet the aggregate demand for the bolt.

Next, the component needs to be identified differently for each process in which it is used in order to facilitate proper delivery of the correct amounts of stock. This is done through the application of unique lineside addresses and the eventual addition of “SMART numbers” (both of which appear on the SMART cards). The lineside address indicates the physical location of the point of use of the component. The lineside address is usually created by referencing the point of use to some fixed physical infrastructure within the build area such as a building support column. However, for the purchased

parts replenishment pull system, building columns were not used as a basis for lineside addresses. Instead, a component's point of use relative to the 5 major segments of the Mustang seat build area (which are the Front Back (FB), Rear Back, (RB), Front Cushion (FC), Rear Cushion (RC), and Head Rest (HR)) was used as its lineside address. At this point in the development of the purchased parts replenishment pull system, SMART numbers, which are simply identification numbers used in the management of the pull system, were not assigned. However, "mock" SMART numbers will be assigned in the following example to help clarify their role.

Given that component A is used in processes X and Y, it will have a different lineside address and SMART number assigned to it corresponding to the specific locations of processes X and Y within the build area. Because of this, when SMART cards are generated for the replenishment of component A there is no confusion as to whether the container of bolts is needed at process X or Y. The lineside address and the SMART number on the SMART card that has been generated uniquely define where the bolts are needed so that the route driver knows exactly where to deliver the component.

Identification of multiple location parts adds further refinement to the consolidated bill of materials that was created in section 5.3.4. The refined consolidated bill of materials is shown below (simplified SMART numbers have been used).

| Lineside Address | SMART Number | Component | Usage per End Item | End Items | % of Mix | Hourly Demand |
|------------------|--------------|-----------|--------------------|-----------|----------|---------------|
| RC 1             | 1            | A         | 2                  | 1 & 2     | 100      | 84            |
| RC 3             | 2            | A         | 1                  | 1 & 2     | 100      | 42            |
| FB 1             | 3            | B         | 2                  | 1 & 2     | 100      | 84            |
| FB 3             | 4            | C         | 1                  | 1 & 2     | 100      | 42            |
| RB 1             | 5            | D         | 1                  | 1         | 50       | 21            |
| RB 2             | 6            | E         | 1                  | 2         | 50       | 21            |

**Figure 5.5: Consolidated Bill of Materials Considering Multiple Location Components**

### 5.3.6 Demand Runs:

Up to this point when discussing demand we have assumed a completely level production schedule. For example, if we considered 4 end items, A, B, C, and D, each representing 25% of the product mix, we have assumed they will be produced in an alternating sequence such as A, B, C, D or C, B, A, D, etc. However, what if the same end item is produced consecutively, or in "runs"? For example, a production sequence of A, A, A, A, B, B, B, B, C, C, C, C, D, D, D, D would meet the product mix requirements of 25% per end item but would focus the demand for end item specific (unique) components at particular times. In-Line Vehicle Sequencing, which generates the production schedule for the Mustang seat build area, does not guarantee level production. Therefore, it is

highly likely that “demand runs” such as those shown above will occur where a particular end item will be in higher demand over a certain time interval (such as an hour or day) than it should be based on the percentage of the product mix it represents. An understanding of demand runs is important so that the proper adjustments can be made to the demand levels for unique components.

For example, suppose a process produces 4 end items, A, B, C, and D, with each unique end item requiring a unique component. Further, let’s say that each end item represents 25% of the product mix and that the production rate of the build area is 4 units per hour. If the production schedule was completely leveled - meaning that the required end items were produced at exactly the average rate - then the “demand run” for each end item would be 1 unit. The demand for unique components would also be 1 unit per hour, and the replenishment system would be designed to support that level of demand. However, if the production schedule was not level, the build area could have demand runs of up to 4 units of any particular end item in one hour - A, A, A, A for example. To protect against this type of demand run the replenishment system would have to be designed to support the maximum possible demand for any particular end item, in this case 4 units per hour. The possibility of a demand run has effectively changed the product mix from 25% (1 out of every 4 units) for each end item to 100% (4 consecutive units) for each end item. The result is that significant excess raw materials inventory will have to be kept at the lineside to protect against the maximum demand due to the uncertainty of the production schedule.

### **5.3.7 100% Mix Strategy:**

The SMF implementation manual does not explicitly outline any methods for dealing with demand runs. In fact, it seems as though the manual fails to consider the possibility of demand runs altogether. The division SMF coach suggested that a “100% mix” strategy could be employed to protect against demand runs on unique components. A 100% mix strategy suggests that you treat unique components as if they were common components which are used in 100% of the product mix.

For example, if a component is only used in the production of manual seat sets, which represent just over 8% of the product mix, the 100% mix strategy suggests that the lineside be stocked as if the part were used in all end items. If the 100% mix strategy were employed, there would be a 92% inflation in inventory over the actual, long run demand for the component. Further, if the component was expensive (such as \$100 per unit), protection against uncertain production schedules would be extremely costly. This case illustrates why the implementation team rejected the 100% mix strategy. The implementation team felt that there had to be some middle ground between the 100% mix strategy and stocking the lineside to the exact product mix which would most likely lead to stock outs. There are some very sophisticated ways to find this “middle ground”; however, these methods require data that was not available to the implementation team at the time of the problem. In the end, the team settled on a very simple method to

upwardly adjust the demand rate placed on unique components without going to a full 100% mix strategy.

The lean manufacturing consultant (the author) concluded that demand runs were most likely to effect unique components that were used in “popular” end items. This conclusion was based on discussions that the consultant had with the lean manufacturing expert (who had previous knowledge of ILVS - the production scheduling protocol that controls demand runs). Based on this conclusion, the implementation team agreed to apply the 100% mix strategy to the unique components used in the most “popular” end items.

Since the coupe was the most popular family of end items representing 70% of the product mix, it was decided that the 100% mix strategy would be applied to unique components used in “all coupes”. The 30% difference between the actual coupe demand of 70% and the demand forecast by application of the 100% mix strategy was then applied to all other unique components. For example demand for manual seat tracks, which represent 8 % of the product mix, was increased to 38%. While this solution is somewhat arbitrary, it is certainly not the “guess” that it may appear to be at first glance. The knowledge and experience of the lean manufacturing expert allowed the team to find a simple solution to a problem that could have been very costly had a comfortable middle ground not been found.

In summary, all unique components that were used in 70% or more of the product mix were increased to 100% and all others received a 30% uplift.

#### ***5.4 Application of Component Level Demand:***

The calculation of component level demand through the creation of the consolidated bill of materials and the determination of a “uplift” policy for unique components is an important step in the development of the “plan for every part”. The plan for every part, which will be developed throughout this thesis, is a document which captures a majority of the data required to implement a pull replenishment system. When fully developed, the plan for every part will include lineside and marketplace inventory level calculations, detailed descriptions of each component, the physical location of each component within the build area, and many other important elements.

At this point, the plan for every part is little more than the consolidated bill of materials. It identifies all of the components required for the production of the entire mix of products by description, part number, and vendor (via the bill of materials). The plan for every part also details the end item(s), and the adjusted percentage of the product mix (based on the 30% uplift strategy), in which components are used. It lists the point of use of each component (the lineside address) and highlights the existence of multiple location components if there are multiple entries for the same component. Finally, the plan for every part shows the usage of each component per seat set and the hourly demand for each.

An example of the plan for every part is shown below.

| Lineside Address | Description                       | Prefix | Base     | Suffix | Supplier       | Usage/seat set | End Item(s)       | % Mix | Hourly Demand |
|------------------|-----------------------------------|--------|----------|--------|----------------|----------------|-------------------|-------|---------------|
| HRLH             | Headrest Panel                    | E3DB   | 54611B54 | AA     | Reiter Auto    | 1              | All               | 100   | 42            |
| HRRH             | Headrest Panel                    | E3DB   | 54611B54 | AA     | Reiter Auto    | 1              | All               | 100   | 42            |
| RB2              | 17" Listing Wire for GT RSB Conv. | BS     | 7665447  | A      | Chelsea        | 4              | GT / Cobra Conv.  | 44.5  | 75            |
| FB2LH            | Lumbar Bag                        | F5ZB   | 6365500  | AB     | Bamal Fastners | 1              | GT/ Cobra Leather | 53.6  | 23            |

**Figure 5.6: The Beginnings of the Plan for Every Part**

### **5.5 Chapter Summary:**

The determination of lineside demand is an extremely important step in the development of the pull system. It is also a very complex step that requires the artful combination of many sources of data (the build area run rate, the product mix, the build area layout, bills of material, etc.). Additionally, in order to properly determine lineside demand, many subtle details (such as average versus actual demand) must be understood and taken into account.

In the case of the development of the purchased parts replenishment pull system, the process of determining lineside demand was fairly easily navigated due to the expertise that existed on the implementation team (specifically the lean manufacturing consultant and the lean manufacturing expert). However, since most of the tasks required to complete the step were executed by the team members who had pre-existing expertise in lean manufacturing principles, the “direct” learning that occurred was confined to those that already possessed significant understanding of SMF. The learning that took place was communicated to the other members of implementation team during team meetings. However, the “reporting out” that occurred did not result in the level of understanding that direct involvement in the tasks would have created.

Because of the complexity of the process, in cases where less expertise exists, it may be difficult for the implementation team to accurately calculate lineside demand.

## Chapter 6: Step 3 – Determination of Packaging and Shipping Specifications

In general, the importance of component packaging and shipping can not be overestimated. Packaging affects the levels of lineside and in-plant inventory, classification of parts (as either card or call), floor space utilization, ergonomics, and storage space requirements while shipping practices have a large impact on in-plant inventory levels and storage space needs.

This chapter steps through the process of determining “optimal” packaging and shipping specifications for the components replenished by the pull system. The chapter begins with the classification of components as either card or call, carry-over or new. Next, the tasks that need to be completed depending on the components classification are discussed. Some basic inventory management theory is then covered in order to set the framework for the actual packaging and shipping optimization process. Finally, examples of actual packaging proposals and the cost-benefit analysis performed on the proposals are reviewed.

### 6.1 Needs Matrix for Step 3:

| Title                                   | Role in Step  | Theoretical Knowledge Required | Theoretical Knowledge Present |
|---|---|--------------------------------|-------------------------------|
| SMF Process Owner (Salary)              | Coordinate execution of step  | ✓                              | ✓                             |
| SMF Process Owner (Hourly)              | Coordinate execution of step  | ✓                              |                               |
| Lean Manufacturing Consultant           | Execute tasks where needed  | ✓                              | ✓                             |
| Ergonomics Representative               | Input on packaging decisions and their effect on ergonomics   |                                |                               |
| Division SMF Coach                      | Oversee execution of step and provide consulting on tasks   | ✓                              | ✓                             |
| Lean Manufacturing Expert               | Provide consulting on tasks   | ✓                              | ✓                             |
| Material Handling Engineer              | Provide support for packaging changes internal to the plant   |                                |                               |
| Packaging Engineer                      | Obtain and provide packaging information, work with purchasing and vendors to modify packaging where needed | ✓                              | ✓                             |
| Procurement and Distribution Supervisor | Obtain and provide shipping information, work with suppliers to modify shipping practices where possible    | ✓                              |                               |

**Figure 6.1: Needs Matrix for Determination of Packaging and Shipping Specifications**

## **6.2 Card versus Call Parts**

There are general descriptions which help to classify components as card or call parts. Card parts are generally small and light (easily held in one hand) with a full container weighing less than 40 pounds; whereas, call parts are large, heavy components which are packaged in containers that require a forklift in order to be delivered to the lineside.

The reason small parts are called card parts is because they will be replenished using the SMART card system (a kanban system) with each card in the system representing one container of parts. Call parts are referred to as such because the builder using the part literally “calls” for more parts when inventory falls below a certain level at the lineside. In the case of the purchased parts replenishment pull system, the call signal is a vocal request over a two way radio.

The ultimate determinate of whether a component is classified as a card or call part is packaging. For example, a bolt clearly falls into the category of a card part. Still, if a full container of bolts weighs in excess of 40 pounds, the bolt would have to be classified as a call part because of the ergonomic impact of the weight – it could no longer be delivered to the line by a route driver (in this case, the bolt would be a good candidate for repackaging). On the other hand, there are some components that clearly fall into the category of a call part and are packaged as such - a seat frame is a good example. A seat frame is large, taking both hands to hold, and weighs over five pounds. A container of seat frames is very large with a footprint of over 32 square feet and is moved to the line by a forklift.

In the middle ground between components that are clearly card parts and those that are clearly call parts exists “in between” components. These components are difficult to classify and therefore can justifiably be packaged in ways that would result in them being categorized as a card or call part. In between components need to be analyzed from a system perspective taking into account the cost of packaging, inventory levels, floor space implications, and ergonomics to determine whether it makes sense to package them as card or call parts.

## **6.3 Carry-Over versus New Parts:**

The 1999 Mustang seat is a new model which was developed using the 1998 model as a baseline. Components that make up the new model fall into 2 classifications - carry-over and new. Carry-over components existed in the previous model of the product, and, in general (unless suppliers are being changed), have existing packaging specifications that (in most cases) cost money to modify. In contrast, new components did not exist in previous models. New components are generally more free of packaging constraints and can be packaged “optimally” right from the start. It may cost more to package a new component optimally as opposed to simply accepting the supplier’s “standard” packaging



solution for the component. However, the increase in cost may be justified based on the ergonomic, average inventory, and storage space benefits that optimal packaging usually provides.

#### **6.4 Collect Packaging Specifications for Carry-Over Components:**

For carry-over components, the packaging engineer has access to packaging specification sheets called “1121’s”. The 1121’s detail the number of components per container (the container density), the dimensions and weight of the component, the dimensions and weight of a full container, the container type (either returnable or expendable), the cost of the packaging per unit, the size of the shipping pallet, and the number of containers that make up a “unit load”. For card parts, the unit load is the number of containers that are shipped on one pallet. In the case of call parts, the unit load is simply equal to one container. As a note, in the case of the purchased parts replenishment pull system, little effort was made to move to returnable containers from expendable (cardboard) containers. Again, this has to do with the lack of external logistics analysis and the absence of a Lead Logistics Provider. Logistics improvements such as milk runs (which are established by a Lead Logistics Provider) make returnable containers more feasible. Under the current shipping conditions, so many returnable containers would need to be purchased to fill the supply chain (because of dedicated shipments and infrequent deliveries) that the cost of the returnable containers outweighs the benefit gained from them.

Once the 1121’s have been collected for carry-over parts, the information they provide needs to be integrated into the plan for every part. By doing this, the plan for every part will be able to convey a very critical factor – the number of hours of demand that can be satisfied by one container of a given component. By dividing the container density by the hourly demand for the component, the “number of hours” per container can be calculated. An example of the plan for every part with most of the packaging information included is shown below (some of the information that was displayed in an earlier example of the plan for every part has been omitted due to space considerations).

| Lineside Address | Description                       | Base     | % Mix | Hourly Demand | Weight | Container Density | Hrs. / Container |
|------------------|-----------------------------------|----------|-------|---------------|--------|-------------------|------------------|
| HRLH             | Headrest Panel                    | 54611B54 | 100   | 42            | 55.5   | 600               | 14.29            |
| HRRH             | Headrest Panel                    | 54611B54 | 100   | 42            | 55.5   | 600               | 14.29            |
| RB2              | 17" Listing Wire for GT RSB Conv. | 7665447  | 44.5  | 75            | 13     | 500               | 6.67             |
| FB2LH            | Lumbar Bag                        | 6365500  | 53.6  | 23            | 40     | 100               | 4.35             |

**Figure 6.2: The Plan for Every Part with Packaging Specifications Included**

### ***6.5 Collect Shipping Specifications for Carry-over Components:***

The procurement and distribution supervisor has access to shipping specifications for carry-over components. Shipping specifications detail how frequently components are delivered from suppliers, when the deliveries normally occur, and the level of safety stock (called “float”) that is held in the plant for each component. Actual shipment sizes are based on the demand for a given component. For example, suppose a component is delivered to the plant once per week. If the demand for the component is 500 units per day, 2500 units would arrive at the plant when the once per week shipment occurred. However, if the demand for the component were to decrease to 250 units per day, then only 1250 components would arrive with the weekly shipment.

Shipping specifications determine levels of in-plant inventory. For example, if the delivery of a component occurs once per week and 2 days worth of safety stock is specified, the maximum level of in-plant inventory will be 7 days and the minimum 2 days. It is important to understand the maximum and minimum levels of in-plant inventory for each component. The maximum level of inventory dictates the design of the card and call part marketplaces. The marketplaces must be able to accommodate the maximum amount of inventory that will exist in the plant for any given component at any one time. The minimum level of inventory is used as an “alarm” in the visual management system. If the expected minimum level of inventory for a component is known, and the inventory falls below that point, then either demand has exceeded expectations or a delivery has not occurred on time (or both). In any case, violation of the minimum level prompts investigation by procurement into the cause of the violation after which corrective action can be taken.

Once the shipping specifications have been collected for the carry-over parts, the information provided needs to be integrated into the plan for every part. In the plan for every part the frequency of deliveries (the ship frequency) is expressed as the number of days between deliveries. For example, if a component was shipped to the plant once a week the ship frequency would be 5, or if the component was shipped to the plant every 2 days the ship frequency would be 2. This format facilitates the calculation of the maximum inventory levels by simply adding the ship frequency to the safety stock level. The minimum inventory level is simply the level of safety stock.

An example of the plan for every part with shipping specifications and the resulting maximum and minimum levels of inventory is shown below (some of the information that was displayed in an earlier example of the plan for every part has been omitted due to space considerations).

| Lineside Address | Description                       | Base     | Ship Frequency | Safety Stock | Min. Inventory | Max. Inventory |
|------------------|-----------------------------------|----------|----------------|--------------|----------------|----------------|
| HRLH             | Headrest Panel                    | 54611B54 | 5              | 3            | 3              | 8              |
| HRRH             | Headrest Panel                    | 54611B54 | 5              | 3            | 3              | 8              |
| RB2              | 17" Listing Wire for GT RSB Conv. | 7665447  | 5              | 3            | 3              | 8              |
| FB2LH            | Lumbar Bag                        | 6365500  | 5              | 2            | 2              | 7              |

**Figure 6.3: The Plan for Every Part with Shipping Specifications Included**

### ***6.6 Determine the Frequency of Delivery of Components to the Build Area:***

Card parts are delivered to the build area during frequent replenishment routes. The delivery of the card parts is executed by a material handler, called a route driver, who performs a pre-determined delivery route. This route, which starts in the card part marketplace, traverses the build area with stops at the lineside addresses corresponding to the parts to be delivered.

In order to choose an appropriate delivery frequency, referred to as a route time, several factors need to be considered. These include the location of the card part marketplace relative to the build area (this has an impact on travel time to and from the marketplace to the build area) and the number of components that the route driver is responsible for replenishing per route. Consideration of these factors helps to determine the load placed on the route driver – the amount of work to be done and the distance to be traveled during each route. Understanding the load placed on the route driver helps to define an appropriate time to be allocated for the completion of his route. It is important to note that as delivery frequency increases the level of inventory that needs to be held in the build area decreases. Therefore, from an inventory reduction standpoint, the more frequent the deliveries, the better. The relationship between delivery frequency and inventory levels will be explained in detail later.

In our case, the normal factors used in the determination route time present somewhat of a catch 22 scenario. We have yet to determine the location of the card part marketplace or finalize the packaging configurations for new components or for carry-over components that we wish to repackage. In the absence of totally sufficient information, the implementation team decided to estimate the load on the route driver by determining the number of containers of card parts the route driver would have to replenish per hour

given the packaging information that was available. This was done by inverting the “number of hours per container” metric so that it conveyed, on average, how many containers of a component would be used (and therefore need to be replenished) per hour. For example, if a full container of a certain component could satisfy 4 hours worth of demand, 0.25 containers would be used per hour.

By computing the “container exhaustion per hour” for all card parts and summing them, a estimation of the average number of containers exhausted per hour was made. It was determined that approximately 20 containers of card parts would need to be replenished per hour. A rough rule of thumb (provided by the lean manufacturing expert) is that a route driver should be able to replenish approximately 40 containers per hour. Therefore, theoretically, the Mustang seat build area could be replenished by way of a one hour route. However, the implementation team felt that because of the uncertainty of the location of the card part marketplace, the fact that the route driver would have to come up the learning curve, and the likelihood of an increased numbers of containers needing to be replenished per hour as packaging changes occurred, a two hour route should be implemented initially.

The delivery of call parts is performed by a material handler with a forklift (referred to as a hi-low). The frequency of delivery for a given call part is based solely on the exhaustion rate of a container of that component. As one container of the call part runs out, a new one is delivered. If the usage rate is low and there are a large number of parts per container, the delivery frequency for that call part will be low. Conversely, if the usage rate is high and there are relatively few parts per container, the delivery frequency for that part will be high. As was done with card parts, the “container exhaustion per hour” was calculated and summed for all call parts. It was determined that, on average, approximately 25 containers of call parts would have to be replenished per hour. The material handling supervisor felt that replenishing 25 containers of call parts per hour was too much for one person and chose to man the Mustang seat build area with two forklift drivers. Additionally, because of the possibility of multiple “calls” for replenishment at one time, it was decided that a new container should be called for when 20 minutes of usage remained in the container that was currently at the lineside.

### ***6.7 Theory Underlying Optimal Packaging and Shipping Specifications:***

The packaging and shipping information combined with the delivery frequency and hourly usage of each component begins to provide intuition about the performance of the pull system. Analysis needs to be performed to determine which carry-over components are good candidates for repackaging, what the packaging specifications for new components should be, and which shipping practices should be changed in order to optimize the performance of the pull system. Analysis of shipping practices is normally performed by the Lead Logistics Provider and is considered part of external logistics. Because of this, little analysis and modification of shipping practices occurred. However, the analysis that did occur will be discussed.

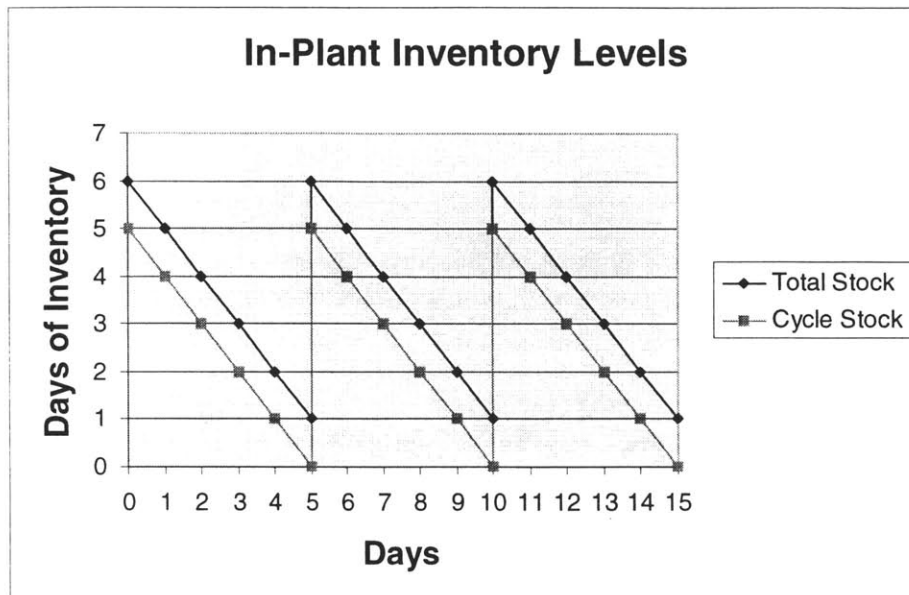
The inventory management theory presented in the following sections will help to develop intuition about “optimal” packaging specifications and shipping practices. Most of the examples used are based on the packaging of components that are clearly card parts. Analysis of packaging for components that are clearly call parts will mostly be ignored. To start, some basic inventory management principles will be reviewed to help develop some intuition about the effects that packaging and shipping specifications can have on inventory levels.

### **6.7.1 In-Plant Inventory Levels:**

At a high level, inventory within the plant takes two basic forms – safety stock and cycle stock. Safety stock is “extra” stock kept on hand to protect against variability in demand and delivery cycles. Cycle stock is stock that is *expected* to be used during the time interval between two adjacent deliveries from a supplier. Therefore, cycle stock levels are based on the expected demand for a component taking into account the delivery frequency from suppliers. For example, if the daily demand for a component is 500 units and deliveries of the component occur every 5 days, the cycle stock would be 2500 units – the ship frequency multiplied by the daily demand for the component. This makes intuitive sense. If the plant is going to get a delivery of stock once per week, the size of the delivery should be equal to a week’s worth of demand – enough stock to get the plant to the next delivery.

An example will help to show how safety stock and cycle stock contribute to the total level of inventory in the plant. Let’s assume that the safety stock is kept on hand but never required – demand is exactly as predicted and deliveries occur exactly on time. Further, let’s assume that deliveries occur once per week so that the cycle stock must satisfy 5 days worth of demand. In this case, just after a delivery there is 5 days worth of cycle stock and 6 days of stock total in the plant (assuming 1 day of safety stock). The 5 days worth of cycle stock is steadily “drained” by demand as the week goes on until there is none remaining at the end of the fifth day. At this point, a delivery arrives and the stock is replenished to its original level. This process repeats itself week after week.

Based on this example, a graph of the amount of inventory in the plant over a several week period is shown below.



**Figure 6.4: In-Plant Inventory Levels**

To provide additional insight, let's discuss average inventory levels. Assuming that safety stock is kept on hand but never used, safety stock will contribute exactly its set "value" to the average level of inventory in the plant. For example, if the safety stock is set to 1 day, it will contribute 1 day to the average level of inventory. The contribution of cycle stock to average level of inventory is somewhat different. Cycle stock contributes  $\frac{1}{2}$  of its "value" to the average level of inventory. For example, if the cycle stock satisfies 5 days worth of demand (as it does in the figure above), then the cycle stock will contribute 2.5 days to the average level of inventory in the plant. The midpoint of the "draining" process described above represents the average amount of cycle stock and hence the cycle stock's contribution to the average level of inventory. In this example, the total average inventory is then 3.5 days: the 1 day of average inventory due to safety stock plus the 2.5 days of average inventory due to cycle stock.

### 6.7.2 Packaging Impact on Inventory Levels:

So what do packaging and inventory levels have to do with each other? Let's say that 1 container of a component used in the assembly of Mustang seat sets can satisfy 5 days worth of demand. What is the average level of inventory of this component in the plant? It's not entirely clear. It could be as low as 2.5 days if only 1 container of the component exists in the plant at any point in time. However, for this to be the case there could not be any containers of safety stock held on hand and delivery of new stock to the plant would

have to occur just-in-time. More likely, there would be 1 container (5 days) of safety stock held on hand at all times and deliveries would occur at most every 5 days (it would make little sense to deliver the component more frequently than every 5 days given the container size). In this case, the average level of inventory for the component could be 7.5 days or greater.

If the component were repackaged so that a full container satisfies only 1 hour worth of demand, the level of inventory within the plant could be dramatically reduced. The first area that the change in packaging can impact is safety stock levels. With the new container size satisfying just 1 hour worth of demand, although more containers of safety stock may be kept on hand, the absolute level of safety stock can be greatly reduced, to 1 day for example. Even if the deliveries continue to occur every 5 days, the safety stock reduction would drive the average inventory down from 7.5 days to 3.5 days.

The smaller container size also provides flexibility with respect to the frequency of deliveries. By increasing the delivery frequency, cycle stock (and therefore overall inventory) levels in the plant can be reduced. With 1 container of a component able to satisfy 5 days worth of demand, it made no sense to receive deliveries any more frequently than once per week. However, with the new container size satisfying just 1 hour worth of demand, the delivery frequency can be based on total inventory management costs instead of being imposed due to packaging specifications. The optimal delivery frequency can be determined by analyzing at the tradeoff between the benefits of lower inventory levels and the transportation costs usually incurred with increased delivery frequency. Analysis may conclude that the delivery frequency should not be increased over the current condition which was based on the container size of 5 days worth of demand. However, the smaller container size provides the *opportunity* to increase the delivery frequency and reduce average inventory levels in the future as the supply chain evolves.

### **6.8 Optimizing Packaging Specifications:**

Now that we have started to build some intuition about how packaging (and shipping) effects the performance of the purchased parts replenishment pull system, we can begin to focus on determining the optimal packaging specifications for each component. There are several goals that the packaging specification should try to achieve: minimize lineside and in-plant inventory levels, minimize packaging costs, minimize builder waste, optimize ergonomics for material handlers and route drivers, and minimize floor space required for storage.

In the case of the purchased parts replenishment pull system, the approach that was taken to determine optimal packaging was to find the packaging specifications that would minimize levels of lineside inventory. Once this was done the optimal packaging specification would be checked against the other factors of interest (such as cost, ergonomics, floor space, etc.) and tradeoffs would be made where required. Given this approach, factors which affect the level of lineside inventory such as hourly demand for

the component and how frequently the component is delivered to the build area need to be considered.

### **6.8.1 Hourly Demand and the Frequency of Delivery:**

It seems pretty clear that smaller container sizes may be helpful in reducing the level of inventory in the plant and at the lineside. Building on the intuition that smaller may be better, there are two other factors that help to determine the right size for packaging from an inventory reduction standpoint - how frequently the component is delivered to the line and the hourly demand for the component. An example will help to show how frequency of delivery and the hourly demand for a component help to determine the right size packaging for that component.

Let's say that the route driver makes deliveries every 2 hours. Assuming demand exactly matches expectations and deliveries occur exactly when scheduled, how much stock is going to be used in the build area between deliveries? The answer is quite straightforward - 2 hours. Therefore (forgetting about safety stock for the moment), just after a delivery, the lineside must be stocked with 2 hours of a component in order to protect against running out of that component before the next delivery occurs (this exactly parallels the earlier discussion considering deliveries from suppliers to the plant). It should be clear that the delivery frequency controls how much cycle stock is needed at the lineside. As the delivery frequency decreases, the amount of cycle stock required increases.

Since we are interested in developing packaging specifications that minimize the inventory at the lineside, we certainly want to package components such that the least amount of "excess" stock exists per container. That is, we want container sizes that just barely satisfy the demand placed on them given a particular delivery frequency. For example, if deliveries occur every 2 hours, we would not want a single container to have more than 2 hours worth of stock in it. If it did, any "excess" over 2 hours would simply add to the average inventory level at the lineside. Therefore, given that deliveries occur every 2 hours, a container size that satisfies 2 hours of demand, or a "even" fraction thereof, will minimize the amount of inventory at the lineside. An "even" fraction is simply the 2 hours divided by an even number such as 2 or 4. This observation leads to the general rule of thumb for optimal packaging specifications.

*The optimal container size (in hours of inventory) for a component is equal to the time interval between adjacent deliveries of that component or an even fraction thereof.*

#### **Equation 6.1: Rule of Thumb for Optimizing Container Sizes**

An operational example comparing lineside inventory levels when "optimal" and "non-optimal" container sizes are used will help to show how non-optimal packaging can result in excess inventory. Given a 2 hour replenishment route, a container able to satisfy 2.5

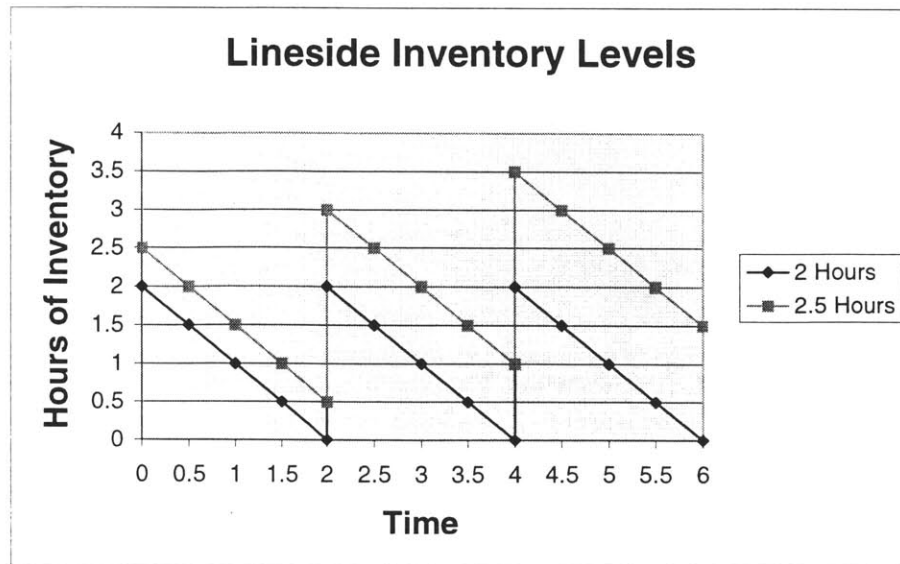


hours of demand is non-optimal and will result in excess inventory whereas, a container satisfying 2 hours worth of demand is optimal packaging. These 2 container sizes result in very different levels of lineside inventory given the same demand and delivery schedule. By tracing through a couple of delivery cycles, the resulting inventory levels can be observed.

Beginning with 1 full container able to satisfy 2.5 hours of demand, the amount of stock at the lineside steadily decreases during the first delivery cycle (the first delivery route being performed by the route driver) until there is 0.5 hours of stock remaining just before the first delivery occurs (the 2.5 hours originally in the container less the 2 hours of operation). The average inventory during the first delivery cycle is 1.5 hours of stock. After the first delivery, the inventory level rises to 3 hours. The 0.5 hours of “excess” inventory leftover from the first container causes an increase in the maximum inventory level at the line. During the second delivery cycle the level of inventory at the lineside falls from 3 hours at the beginning of the cycle to 1 hour just before the second delivery occurs. The average inventory during the second delivery cycle is 2 hours of stock – an increase of 0.5 hours over the first delivery cycle. The delivery once again increases the maximum level of inventory which is now up to 3.5 hours of stock. The process repeats itself and the average inventory slowly builds up. As will be shown in a later section, the SMART card system helps to control this build up.

Now let’s consider the lineside inventory level given an optimally sized container which satisfies 2 hours of demand. Beginning with a full container the amount of stock at the lineside steadily decreases during the first delivery cycle until there is 0 hours of stock remaining just before the first delivery occurs (the 2 hours originally in the container less the 2 hours of operation). The average inventory during the first delivery cycle is 1 hour of stock (.5 hours less than in the non-optimal case). After the first delivery, the inventory level rises to 2 hours. Unlike with the non-optimal packaging, the maximum level of inventory remains constant (at 2 hours) across the delivery cycles. During the second delivery cycle the level of inventory at the lineside falls from 2 hours at the beginning of the cycle to 0 hours just before the second delivery occurs. The average inventory during the second delivery cycle is 1 hour of stock – the same as it was during the first delivery cycle.

A graph of average inventory levels at the lineside given container sizes of 2 and 2.5 hours and a 2 hour replenishment route is shown below.



**Figure 6.5: Comparison of Lineside Inventory Levels Based on Container Size**

Having identified that the optimal container size for a component, in hours of stock, is equal to the time between adjacent deliveries (the route time) or a fraction thereof, the optimal number units per container can be calculated by multiplying the route time by the hourly demand for the component. For example, if the route time is 2 hours and the hourly usage of a component is 42 units, the optimal packaging size would be 84 units or an even fraction thereof.

Up to this point, the development of the optimal packaging specifications has been based on ideal system operation - we have ignored the need for safety stock by not considering demand and delivery variability. The next couple of sections will highlight some practical concerns that will influence the final determination of optimal packaging for components used in the pull system.

### 6.8.2 Safety Stock:

Packaging can affect the level of safety stock, and therefore the overall level of inventory, that is held at the line. Building on the example in section 6.8.1, let's assume that because of demand and delivery variability it is decided that 1 hour worth of safety stock needs to be held at the line in addition to the 2 hours of cycle stock. If component packaging is such that 1 container represents 2 hours worth of usage, then it is impossible to hold only 1 hour worth of safety stock at the line. The minimum safety stock that can be held at the line is 1 container or 2 hours worth of stock. This results in an average

inventory level of 3 hours as opposed to the optimal level of 2 hours given the requirement for 1 hour of safety stock. Because of this, the optimal container size (in hours) is not equal to the time between adjacent deliveries. In this case, packaging the component such that a full container satisfies 1 hour (not 2 hours) of demand would minimize the level of lineside inventory. Further, container sizes representing smaller fractions of the 2 hour route time, 0.5 hours for example, may be optimal because they will allow for future safety stock and cycle stock reductions. For example, if the route time was reduced to 1 hour and the safety stock level was reduced to 0.5 hours, a container size of 0.5 hours worth of demand would be optimal.

### **6.8.3 Packaging Costs:**

The metric used to track packaging cost is the “packaging cost per unit” of the component being packaged. The packaging cost is simply the cost of the container that the component is being packaged in and any dunnage that is required (such as dividers, sleeves, pallets, etc.). Generally, all else equal, the more components that can be fit into one container, the lower the packaging cost per unit will be. Of course a large container will cost more than a small one – say \$1 for the larger container and \$0.75 for the smaller one. However, there is not a constant cost per volume relationship when it comes to the cost of containers. Generally larger containers cost less per unit volume than smaller containers do. To show this, let’s assume that the smaller container can hold  $\frac{1}{2}$  of the volume that the larger container can. The total cost of 2 smaller containers (\$1.50) is more than the cost of 1 large container (\$1). Assuming that 50 units can be fit into the large container, the packaging cost if the large container is used will be \$0.02 per unit whereas the packaging cost will be \$0.03 per unit if the smaller containers are employed. This scenario highlights the driving force behind bulk packaging and the reason that many components are not optimally packaged.

### **6.8.4 Realities of Packaging Solutions:**

Up to this point we have concluded that for any component the optimal container size, in hours of stock, is equal to the time between adjacent deliveries (the route time) or a fraction thereof. In reality it is very unlikely that packaging solutions can be developed to exactly meet this optimal requirement for all components. There are several reasons for this.

- *Cost and standards issues.* For example, it would be extremely expensive for a bolt to be packaged so that a full container would only satisfy 1 or possibly 2 hours worth of demand. Bolts are generally supplied in boxes of 10,000 or 15,000 units per container which, in some cases, represent over 300 hours worth of demand. However, because bolts are a low cost item and consume little space at the lineside, as long as the full container of 10,000 or 15,000 bolts weighs less than 40 pounds, there is very little reason to spend money to optimize the container size. In other instances it is difficult to justify an increase in packaging costs given the benefits of

doing so. This is especially true when repackaging of carry-over components is considered. An example cost-benefit analysis will be shown later.

- *Multiple location components.* Some multiple location components are used at varying levels at different lineside addresses. For example, the demand for a plastic part that is used in 2 different operations may be 80 units per hour at one process and 10 units per hour at the other. Which demand level should the optimal packaging be designed to meet? If the 10 units per hour level is chosen (assuming a 2 hour route time) there will be at least 16 containers of the component required at the first process. This is simply too many containers. On the other hand, if the 80 units per hour level is chosen, 1 full container will satisfy 8 hours worth of demand at the second process. The solution in this case is most likely in between the 10 and 80 unit size.
- *Weight and size.* Components may be too large or weigh too much to be optimally packaged. For example let's say that the demand for a large, plastic part which weighs only ¼ pound but is the size of a toaster oven, is 42 units per hour. In this case, a container with 2 hours of parts in it would weigh only 21 pounds, well below the ergonomic weight limit, but would be far too large for easy storage at the lineside. Packaging for this component would have to be made smaller, possibly choosing a container that would satisfy 0.5 or 1 hour worth of demand as the optimal packaging size. On the other end of the spectrum, 1 to 2 hours worth of a small, metal component (such as a seat recliner which weighs approximately 4 pounds) may fit into a reasonably sized container but would far exceed the ergonomic weight limit.

These points, in some cases, cause packaging to be more of an art than a science. The packaging engineer generally will make several iterations with the supplier before a packaging specification is finalized. However, knowledge of the theoretical optimal container size provides a solid jumping off point to start from.

### **6.8.5 Packaging Cost-Benefit Analysis:**

In some cases, there are measurable savings to be had by optimizing packaging. Optimized packaging will allow for increased ship frequency of components and the lowering of safety stock levels which reduces the level of inventory in the plant resulting in inventory carrying-cost and floor space savings. However, in the case of the purchased parts replenishment pull system, very little was done in the external logistics area so that most shipping practices remained as they were before the project began. Further, while some optimized packaging specifications allowed for reductions in safety stock, reductions were certainly not as large as they could have been had there been a higher level of comfort with reducing safety stock. In short, little inventory was actually removed from the plant. Because of this, it was very difficult to show any financial benefit provided by optimized packaging.

There are certainly benefits that are possible from optimized packaging in the absence of inventory savings. These include improved ergonomics, improved part presentation to the builders, flexibility in workstation organization, and flexibility for future reductions in inventory levels as external logistics improve. However, while these are all important benefits, none of them are tangible cost savings that would act to offset the possible packaging cost increases incurred by employing optimal packaging. The following example will show the cost-benefit analysis that was performed when the implementation team was investigating repackaging options or choosing between packaging options for new components. This example analyzes the cost of repackaging a component to convert it from a call part to a card part, significantly reducing the amount of inventory per container. The characteristics of the component and its original packaging are:

- average demand for component: 38 units per hour, approximately 145,000 per year
- component weight: 0.5 pounds
- component dimensions: 2" x 2.5" x 6"
- cost of the component per unit: \$1.08
- 2000 components per container (3 days of stock)
- full container weight: 1000 pounds
- container foot print: 16 square feet
- packaging cost per unit: \$0.011

The proposed packaging had the following characteristics:

- 50 components per container (1.3 hours)
- full container weight: 25 pounds
- container foot print: 1 square foot
- packaging cost per unit \$0.05

Several important observations can be made.

- With the original packaging, the minimum average inventory that can exist in the plant is 1.5 days with the corresponding maximum ship frequency of every 3 days. In actuality, the average inventory level was approximately 3 days because 2 containers of the component were kept in the plant at most times.
- 16 of the proposed containers can fit into the floor space taken by one of the original containers. Given a two hour replenishment route and 1 hour of safety stock, this leads to a savings of 13 square feet of floor space if the new container is employed.
- The new containers can be presented to the builder at an ergonomic height whereas the builder must bend down and reach into a large bin to retrieve components from the original container.
- The packaging cost if the proposed container is adopted is 5 times greater than the current packaging cost.

The following formula was used to determine the “hard” cost difference between the two packaging solutions taking into account packaging costs, inventory carrying costs, and floor space costs. The output of the equation is cost on a yearly basis.

***Total Packaging Cost (per year) =***

(packaging cost per unit × units used per year) +

(average in-plant inventory × cost per unit of component × 12.5% carrying burden) +

(floor space cost per square foot × square feet required for storage of the component at lineside)

### **Equation 6.2: Total Packaging Cost Equation**

For the original packaging specification the equation returns the following:

***Total Packaging Cost =***

$(0.011 \times 145,000) + (3 \text{ days} \times 1824 \text{ units per day} \times \$1.08 \text{ per unit} \times 0.125) + (16 \text{ square feet} \times \$125 \text{ per square foot}) = \$1595 + \$739 + \$2000 = \$4334$

For the proposed packaging specification the equation returns the following:

***Total Packaging Cost =***

$(0.05 \times 145,000) + (3 \text{ days} \times 1824 \text{ units per day} \times \$1.08 \text{ per unit} \times 0.125) + (3 \text{ square feet} \times \$125 \text{ per square foot}) = \$7250 + \$739 + \$375 = \$8364$

The proposed packaging would cost approximately twice as much per year as the current packaging. The increase in the packaging cost per unit more than offsets the floor space saving gained from the smaller container. Further, even though the proposed packaging provides the flexibility to increase ship frequency, the carrying cost is so small relative to the increase in packaging cost that decreases in carrying cost will never be able to offset the increase in packaging costs.

It seems that the logical choice here is to dismiss the packaging proposal. However, the packaging proposal was adopted. The main reasons that the proposal was adopted in the face of increased costs was the shortage of floor space in the build area and the high level of waste and poor ergonomics that the original packaging subjected the builder to. Adopting the packaging proposal in opposition to the results of the equation may indicate that the equation is incomplete since ergonomics and builder waste appear nowhere in the equation. Because of this, the implementation team used a case by case approach to approving packaging proposals using common sense and consideration of the “soft savings” (such as ergonomics) to balance the cost numbers that the packaging cost equation was generating.

## **6.9 Optimizing Shipping Specifications and Safety Stock Levels:**

*“Determination of how the float [procurement] system worked was an emergent and critical event in the development of SMF” - Procurement and Distribution Supervisor <sup>10</sup>*

As has been mentioned several times, because of the lack of a Lead Logistics provider, little was done to modify shipping practices. However, the implementation team did analyze the ship frequencies and safety stock levels as supplied by the procurement manager when calculating the minimum and maximum levels of inventory that would exist in the plant. Many of the team members were surprised at how much safety stock (called “float”) was being proposed for some components. In some cases, the float level was set equal to the level of cycle stock. For example, 5 days of safety stock was being proposed for a component that would be shipped to the plant once per week. The implementation team believed that the total inventory level of this component would fluctuate from a high of 10 days just after the receipt of a delivery to a low of 5 days just before the next delivery arrived.

The issue of high safety stock levels was raised to the procurement manager. The implementation team wanted to decrease safety stock levels where possible to reduce inventory levels and save storage space which decreases inventory management costs. The most important result of the request to reduce safety stock levels was that significant learning took place regarding the procurement system. It was found that the levels of safety stock were high in some instances because of a lack of understanding of how the “float” (safety stock) level set in the procurement system related to cycle stock. As described above, safety stock and cycle stock are additive – 5 days of safety stock and 5 days of cycle stock result in 10 days of inventory in the plant. However, some in the procurement department believed that “float” *included* cycle stock. In this case, if there were 5 days of float and deliveries occurred once per week it was believe that the total level of inventory in the plant would fluctuate between 5 days and 0 days as opposed to between 10 days and 5 days which was actually the case. From this perspective safety stock levels were already essentially set to 0 and setting the float any lower (less than the ship frequency) would guarantee running out of stock.

After better understanding of the procurement system was reached, the safety stock levels of many components were reduced. It is important to note that no scientific formula was used to determine the levels of safety stock. Safety stock levels were set by the procurement department based mainly on the characteristics of the supplier (how far away were they, how reliable had they been) and the cost of the component in question (less safety stock was kept on hand for higher cost components). The safety stock reductions that were made resulted in one time savings of approximately \$67,000 and saved significant storage space. Additionally, since safety stock levels were not reduced as fully as they could have been in some instances because the procurement department either didn't have experience with a supplier, or the component was very low cost, further safety stock reductions are certainly possible and will be pursued by the procurement department.

## **6.10 Chapter Summary:**

Packaging and shipping specifications have a large impact on in-plant inventory levels, storage space requirements, and material management costs. It is therefore important that they be considered very critically during the development of the pull system. While it is fairly straightforward to determine optimal packaging and shipping specifications based on some simple inventory management theory, the “answers” the theory provides only serve as a jumping off point from which to begin to explore more “realistic” packaging and shipping options. This is mainly because the theory fails to account for many of the “realities” that impact the final selection of packaging and shipping specifications. These realities include procurement’s “comfort level” with a vendor and the inability of cost models to account for “soft” savings derived from optimal packaging.

In the case of the development of the purchased parts replenishment pull system, significant learning occurred regarding the development of optimal packaging specifications and the difficulty associated with justifying the optimal specifications on a “measurable” cost basis. Most of the investigation into optimal packaging was performed by a small sub-set of the implementation team. For example, the rule of thumb for optimal packaging was developed by the lean manufacturing consultant alone. However, the work that was done raised most team member’s level of awareness of the importance of packaging. When the rule of thumb for optimal packaging was shared with the implementation team (along with information on how few components at the time were packaged optimally and the effects that the non-optimal packaging would have on inventory levels) many team members realized for the first time how packaging related to “lean”. In the past at Chesterfield, packaging was not considered to be as critical to plant operations as line layouts or float levels were. I believe that in the future, packaging will be considered prominently as the transformation to lean is carried out at Chesterfield.

Finally, the valuable learning regarding the operation of the procurement system itself should pay dividends far beyond the implementation of the purchased parts replenishment pull system.



## **Chapter 7: Step 4 – Development of SMART Card System Parameters and Determination of Lineside Inventory Levels**

This chapter reviews the process that was followed in order to determine the operational specifications for the pull system. For a card part, an operational specification consists of two main elements. First, it indicates the minimum and maximum lineside inventory levels that will exist as the result of pull system operation. Second, it specifies the number of SMART cards that need to circulate through the pull system in order to effectively meet demand. An operational specification for a call part indicates the minimum inventory level that triggers component replenishment and the maximum inventory level that should exist after delivery occurs. The majority of the focus in this chapter will be on the development of the operational specifications for card parts.

Review of this step is a good case study of the potential dangers associated with strictly following a task oriented implementation manual when the implementation team does not possess significant knowledge about the process they are implementing. In this specific case, strictly following the equations provided in the SMF implementation manual to determine operational specifications without understanding how the pull system would actually function would have resulted in “unexpected” pull system behavior that, depending on the reaction of the implementation team and other stakeholders, could have led to failure of the pull system implementation. The major issue here is not the equations however. Given the dynamic atmosphere in which the pull system operates, there are no equations that can develop “perfect” operational specifications and perfectly predict pull system performance. The major issue is how the equations are presented relative to the level of understanding of those the equations are being presented to.

The equations are presented as tasks to execute with no explanation as to why the factors that appear in the equations do so - the SMF implementation manual fails to provide the inventory management theory that underlies the calculations (this is a powerful example of the “what without the why” process that is characteristic of the cookbook approach to implementation). Also, the way the calculations are presented makes them appear as rules instead of guidelines because there is no mention that the pull system may not always perform as specified. When the implementation team lacks a good understanding of how the pull system works, by using the provided equations it is very easy to generate “numbers” that represent the operation of the pull system without any real understanding of why the results turned out they way they did. Even worse, when the pull system doesn’t behave as the numbers (operational specifications) predict, the implementation team and other stakeholders don’t know how to react.

In the end, if the implementation team has or can gain an understanding of pull system operation, heuristics or just plain “judgements” can be used to move pull system performance to the desired point after using the SMF implementation manual equations to develop the baseline operational specifications. More importantly, if knowledge exists, pull system performance that violates operational specifications will be understood to be “normal” and reacted to appropriately.

Given this discussion, there are five main goals that this chapter (and its associated appendices) hopes to achieve:

- provide analysis of the SMF implementation manual equations that helps to explain how the equations relate to pull system operation
- provide a general understanding of how the pull system behaves and the factors that effect its performance
- explain why actual pull system behavior deviates from that predicted by the operational specifications
- discuss the process that the implementation team went through to learn about pull system behavior
- highlight the likelihood that sub-optimal pull system implementation would have resulted if the implementation team had only followed the implementation manual and had not learned

This is done by first presenting the equations provided in the SMF implementation manual for the development of operational specifications and then analyzing what the factors in the equations represent. Next, examples are provided to help develop intuition about pull system operation in relationship to the operational specification equations. Examples are then reviewed that show actual pull system performance deviating from the performance predicated by the operational specifications. The factors that explain the deviation are then reviewed. The reader is then led through the “process of discovery” that the implementation team went through in order to understand actual pull system performance (which is a good example of the applied learning method of implementation). Finally, the much easier task of developing operational specifications for call parts is discussed.

**7.1 Needs Matrix for Step 4:**

| Title                         | Role in Step   | Theoretical Knowledge Required | Theoretical Knowledge Present |
|-------------------------------|--|--------------------------------|-------------------------------|
| SMF Process Owner (Salary)    | Coordinate execution of step   | ✓                              |                               |
| SMF Process Owner (Hourly)    | Coordinate execution of step   | ✓                              |                               |
| Lean Manufacturing Consultant | Perform inventory level and SMART card system parameter calculations | ✓                              |                               |
| Division SMF Coach            | Oversee execution of step and provide consulting on tasks            | ✓                              |                               |
| Lean Manufacturing Expert     | Provide consulting on tasks  | ✓                              |                               |

**Figure 7.1: Needs Matrix for Development of SMART Card System Parameters and Determination of Lineside Inventory Levels**

## **7.2 Review of Equations Provided to Determine Lineside Inventory Levels for Card Parts:**

As mentioned earlier, the SMF implementation manual includes equations that are to be used to determine levels of lineside inventory (in terms of the number of containers present at the lineside) that will exist as a result of pull system operation. The equations for determining the minimum and maximum lineside inventory levels for card parts are shown below.<sup>6</sup> The “roundup” factor is required because only full containers of stock are delivered to the line.

$$\textit{Minimum Inventory} = \text{roundup} \left( \frac{0.5 \times \text{Hourly Demand (units)} \times \text{Route Time (hours)}}{\text{Container Size (units)}} \right)$$

$$\textit{Maximum Inventory} = \text{roundup} \left( \frac{\text{Hourly Demand (units)} \times \text{Route Time (hours)}}{\text{Container Size (units)}} \right) + \text{Minimum Inventory}$$

### **Equations 7.1 and 7.2: SMF Implementation Manual Equations for Calculating Lineside Inventory Levels for Card Parts**

The results of the equations are important for three main reasons.

- First, the minimum (min) and maximum (max) inventory levels are intended to be used as a visual management tool. Labels are placed on lineside storage and conveyance racks that indicate the min and max levels of inventory. Inventory levels at the lineside falling below the min or exceeding the max are supposed to indicate a breakdown in the pull system. Violation of the min or max levels are to be communicated by the builder to the production supervisor who then involves the Material Replenishment Coordinator (the person responsible for monitoring the performance of the pull system) who seeks to determine the root cause of the problem and take corrective action. As will be shown later, following this policy based on the results of the above equations will lead to many unnecessary reactions to normal pull system behavior that is perceived as a system failure.
- Second, the maximum inventory levels are important to understand when it becomes time to develop part storage and presentation infrastructure. For example, if a flow-through rack is needed to store and present a component to a builder at the lineside, the rack will need to be able to accommodate the maximum level of inventory that may be expected at the lineside. Once again however, development of part storage and presentation infrastructure based solely on the above equations can lead to significant errors.

- Third, the equations are the basis for determining the number of SMART cards that will need to circulate through the pull system for any given component. As will be shown later, using alternate methods to calculate the number of SMART cards may result in better overall pull system performance.

### 7.2.1 Analysis of Inventory Level Equations:

In order to better understand what the minimum and maximum inventory levels actually represent it is helpful to transform them into the familiar terms of safety stock and cycle stock. A review of some basic inventory management theory will help with the transformation.

Theoretically, just before a delivery, the lineside inventory level is at its minimum point having used all of the cycle stock supplied from the last delivery - only the safety stock remains. Conversely, just after a delivery, having just received a full complement of cycle stock, the lineside inventory level is at its maximum point.

Applying this framework to the minimum and maximum inventory equations listed in the previous section, the equations can be rewritten in terms of safety stock and cycle stock. Transformation of the minimum inventory equation is straightforward, the resultant is simply renamed safety stock. Transformation of the maximum inventory equation is somewhat more involved but just as straightforward. The first step is to develop an equation for the calculation of cycle stock. As noted above, cycle stock is simply the maximum inventory less the safety stock. Therefore, if the addition of the minimum inventory is eliminated from the maximum inventory equation, what is left is a calculation of cycle stock. Maximum inventory is then just the safety stock added to the cycle stock. Rewriting the equations in terms of safety stock and cycle stock yields the following.

$$\text{Safety Stock} = \text{roundup} \left( \frac{0.5 \times \text{Hourly Demand (units)} \times \text{Route Time (hours)}}{\text{Container Size (units)}} \right)$$

$$\text{Cycle Stock} = \text{roundup} \left( \frac{\text{Hourly Demand (units)} \times \text{Route Time (hours)}}{\text{Container Size (units)}} \right)$$

$$\text{Maximum Inventory} = \text{Cycle Stock} + \text{Safety Stock}$$

### Equations 7.3, 7.4, 7.5: Inventory Equations Written in Terms of Safety Stock and Cycle Stock

*A detailed analysis of the above equations which highlights the factors that appear in the equations and the impact those factors have on lineside inventory levels is presented in the technical appendix under topic B.*

### **7.3 Review of the Equation Provided to Determine the Allocation of SMART Cards:**

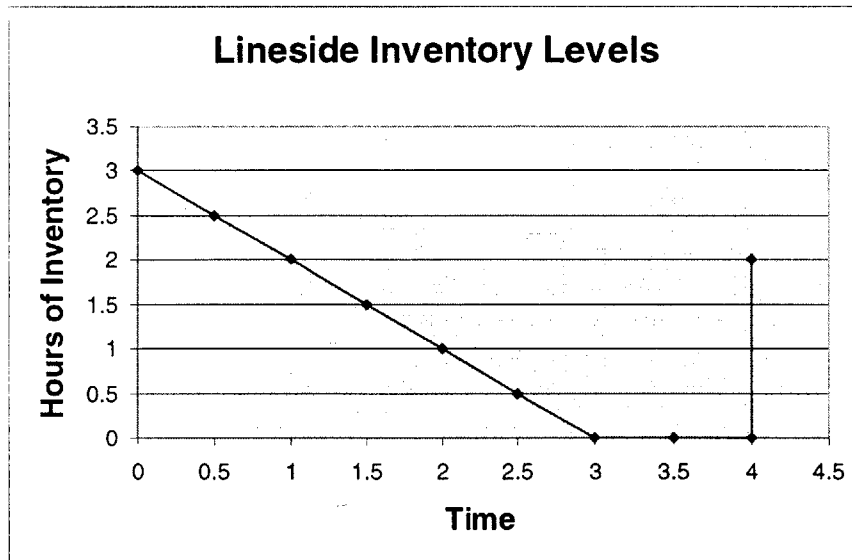
In the operation of a kanban system, each container of components is accompanied by a kanban card, or in our case, a SMART card. Therefore, each container that is being specified by the safety stock and cycle stock calculations will have a SMART card attached to it. However, calculating the number of SMART cards needed for operation of the pull system is not as straightforward as it may seem. Simply determining the maximum number of containers that will exist at the lineside and assigning an equal number of cards will result in failure of the pull system due to a stock out at the lineside.

Stock out will occur if the number of SMART cards is set equal to the predicted maximum inventory level because of the one cycle lag that exists between when an order is placed and when delivery of that order occurs - deliveries in one route are based on the cards picked up during the previous route. A simplified example will help to explain this concept.

Before production begins, the lineside is initially stocked with a full complement of safety stock and cycle stock. Each container of stock has a SMART card attached to it. The level of cycle stock initially present at the line is an amount sufficient to satisfy the demand during 1 replenishment cycle (2 hours of demand in our case). Once production begins, cycle stock is consumed and will not be replenished until new stock is delivered to the line. If only the containers of stock initially at the lineside have SMART cards associated with them, during the first replenishment cycle the material handler will not deliver any stock to the line because he was not "instructed" to do so. SMART cards provide the route driver with his instructions on what to deliver to the line during each replenishment cycle. Since he had no SMART cards "in hand" before production began, he was not instructed to deliver any containers of stock to the line during the first replenishment cycle. His only activity during the first replenishment cycle, in this case, would be to pick up the SMART cards that had been removed from the containers of cycle stock that were opened before his arrival.

In this case, since only enough cycle stock exists to satisfy the demand during 1 replenishment cycle, and replenishment of stock does not occur until the second replenishment cycle (based on the cards picked up during the first replenishment cycle), the safety stock would be exhausted before the first delivery arrived resulting in a stock out condition.

A graphical representation of this scenario is shown below (assuming 2 hours of cycle stock and 1 hour of safety stock).



**Figure 7.2: Stock Out Condition Caused by Misallocation of SMART Cards**

In order to avoid a stock out condition, the cycle stock consumed during the first replenishment cycle must be replenished by the end of the first replenishment cycle. In other words, stock must be delivered to the line during the first replenishment cycle which requires the route driver to have SMART cards “in hand” before production begins. The number of containers the route driver must deliver to the line during the first replenishment cycle is equal to the number of containers that are expected to be consumed during the first replenishment cycle. Therefore, if there are X containers of cycle stock, there needs to be X containers of stock delivered to the line by the end of the first replenishment cycle. This means that X number of additional SMART cards (above those associated with the stock initially placed at the line) need to be inserted into the pull system to support replenishment. The X additional SMART cards are given to the route driver before production begins so that he will make the proper delivery during the first replenishment cycle.

Given this understanding, a general equation for the calculation of the total number of SMART cards required for any component can be developed. This equation is shown below (the equation is also provided in the SMF implementation manual without the motivating theory).

$$\text{Total Number of SMART Cards} = \# \text{ of containers of safety stock} + 2 \times (\# \text{ of containers of cycle stock})$$

**Equation 7.6: Equation for Calculating the Total Number of SMART Cards**

A much more detailed analysis of this topic is presented in the technical appendix under topic C.

#### **7.4 Application of SMF Implementation Manual Equations to Develop Operational Specifications:**

By utilizing the equations provided for the calculation of the minimum inventory level (the safety stock), the maximum inventory level (the safety stock plus the cycle stock), and the number of SMART cards, an operational specification for each card part can be developed. An operational specification is supposed to indicate the minimum and maximum levels of lineside inventory that will result by employing the specified number of SMART cards.

The plan for every part contains all of the information required to develop the operational specifications for each card part. An updated plan for every part which includes min and max levels and the number of SMART cards for each component is shown below (some of the information that was displayed in an earlier example of the plan for every part has been omitted due to space considerations).

| Lineside Address | Description                       | Hourly Demand | Container Density | Hrs. / Container | Safety Stock (Min) | Cycle Stock | Max Stock | SMART Cards |
|------------------|-----------------------------------|---------------|-------------------|------------------|--------------------|-------------|-----------|-------------|
| HRLH             | Headrest Panel                    | 42            | 600               | 14.29            | <i>1</i>           | <i>1</i>    | 2         | 3           |
| HRRH             | Headrest Panel                    | 42            | 600               | 14.29            | 1                  | 1           | 2         | 3           |
| RB2              | 17" Listing Wire for GT RSB Conv. | 75            | 500               | 6.67             | 1                  | 1           | 2         | 3           |
| FB2LH            | Lumbar Bag                        | 23            | 100               | 4.35             | 1                  | 1           | 2         | 3           |

**Figure 7.3: The Plan for Every Part with Min, Max, and SMART Card Levels**

Proper interpretation of the entry in the above table for the headrest panel (italicized) would be: the minimum level of inventory (the safety stock) is 1 container, there is 1 container of cycle stock, the maximum level of inventory is 2 containers, and 3 SMART cards circulate through the pull system to support replenishment of the headrest panel.

As discussed in the introduction to this chapter, even when the pull system is functioning properly given its design, operation “outside” the operational specifications will occur. Unfortunately, the SMF implementation fails to provide any intuition on the actual operation of the pull system or any warning that the operational specifications may not be

accurate - it only provides the tools (equations) that are required to develop the operation specification.

The next section will help to build intuition about actual pull system behavior and begin to explain why it deviates from that predicted by the operational specifications.

### ***7.5 Operation of the Pull System:***

In order to observe the actual behavior of the pull system and the inventory levels that result, two examples employing Mustang card parts will be covered. In one example, the component under consideration, the latch bezel, is packaged almost optimally, with 1 container satisfying only 1.2 hours worth of demand. In the other example the headrest panel will be considered. The headrest panel is packaged such that 1 container can satisfy over 14 hours worth of demand.

#### **Example #1: Latch Bezel:**

For the latch bezel, the inventory and SMART card calculations yield the following operational specification: the minimum level of inventory is 1 container, there are 2 containers of cycle stock, the corresponding maximum inventory level is 3 containers, and there are 5 total SMART cards.

Tracing through 2 delivery cycles will show the actual inventory levels and pull system operation for the latch bezel. Initially there will be 3 containers of the latch bezel (with 1 SMART card attached to each) at the lineside – inventory is at its specified maximum level. Additionally, there will be 2 containers of latch bezels “in the route”, meaning that the route driver will deliver the containers during the first replenishment cycle. The 2 containers in the route, as described earlier, protect against stock out conditions occurring by ensuring that cycle stock is replenished during the first replenishment cycle.

As production begins, the first container of latch bezels is opened and the SMART card attached to that container is removed and placed in the mailbox as an order for replenishment. After 1.2 hours of production the first container of latch bezels is exhausted, the second container is opened, and the SMART card associated with the second container is placed in the mailbox along side of the card the was removed from the first container. After at most 2 hours, delivery of the 2 containers of latch bezels that were “in the route” occurs (delivery could occur earlier depending on the point in the delivery route at which the particular lineside address that is receiving the delivery is located) and the 2 SMART cards in the mailbox are picked up, ensuring delivery of 2 containers of latch bezels during the second replenishment cycle. Since only 1 container of latch bezels has been used by this point (a second has been opened but is still partially full), after delivery of the 2 new containers of latch bezels, 4 containers will be present at the line – 3 full containers and 1 partially used container. Is this a violation of the maximum inventory level? The short answer is yes. There is more inventory at the lineside than the maximum inventory calculation suggests there should be. It is certainly



reasonable to believe that the pull system is behaving improperly and that corrective action needs to be taken. However, the system is operating just as it should given its design.

After approximately 2.4 hours of production, the second container of latch bezels is exhausted, the third container is opened, and the card from it is placed in the mailbox. At this point the inventory level falls back to the prescribed maximum of 3 containers. After 3.6 hours of production, the third container is exhausted, the fourth container is opened, and the card from it is placed in the mailbox. The inventory level falls to 2 containers, still above the minimum level of 1 container. After at most 4 hours of production the second delivery occurs, adding 2 more containers to the lineside inventory. Once again the maximum inventory level is exceeded with 4 containers of stock at the line. In summary, the maximum inventory level is exceeded during both delivery cycles with the inventory level never falling to the projected minimum point.

#### Example #2: Headrest Panels

For the headrest panel, the inventory and SMART card calculations yield the following operational specification: the minimum level of inventory is 1 container, there is 1 container of cycle stock, a corresponding maximum inventory level of 2 containers, and there are 3 total SMART cards.

Tracing through 2 delivery cycles will show the actual inventory levels and pull system operation for the headrest panels. Initially there will be 2 containers of headrest panels at the lineside - inventory is at its specified maximum level. Additionally, there will be a third container of headrest panels in the route.

As production begins, the first container of headrest panels is opened and the SMART card attached to that container is removed and placed in the mailbox as an order for replenishment. After at most 2 hours, delivery of the container of headrest panels that was "in the route" occurs and the SMART card in the mailbox is picked up. Since 1 container of headrest panels can satisfy 14.29 hours of demand, there is no way that by the time of the first delivery a full container of headrest panels will have been consumed. Therefore, after delivery of the new container of headrest panels, 3 containers of headrest panels will be present at the line - 2 full containers and 1 partially used container. Once again, the maximum inventory level has been violated and once again the system is operating just as it should given its design.

During the second replenishment cycle (hours 3 and 4 of production), headrest panels will continue to be consumed by production. However, even after 4 hours of production only approximately 25% of the first container of headrest panels will have been used. In other words, when the delivery associated with the second replenishment cycle arrives there will still be 3 containers of stock at the lineside with the container being delivered driving the total number of containers of stock at the line to 4 (3 full containers and 1 partially full container). The max inventory level has now been exceeded by 2 containers.

In both examples, the pull system failed to operate as specified. What would the reaction of the line supervisor be to this type of perceived failure? After only 4 hours of operation, the pull system is “out of control”. If the SMF implementation manual equations are followed and there is no understanding of how the pull system actually functions, what type of answers are the implementation team and material replenishment coordinator going to be able to provide to the upset production supervisor? Telling the production supervisor that “the equations say it should work” is certainly not sufficient. It is entirely possible that after just 4 hours of production in the minds of the builders and the production supervisor, the pull system is a failure. What are the right answers? What is actually going on with the pull system? In fact, there are several answers, several factors that are causing the unexpected performance of the pull system.

### **7.6 Factors that Cause Unexpected Pull System Performance:**

There are three main factors that cause unexpected pull system performance:

- non-optimal packaging resulting in the buildup of “excess” stock
- over-replenishment of stock during the first replenishment cycle
- variability in demand and replenishment cycles

Although the effects of the three factors are not isolated from one another, independent analysis will help to highlight the specific effects of each factor.

#### **7.6.1 Non-optimal Packaging:**

Non-optimal packaging results in each container having “excess” stock. Excess stock accumulates as deliveries replenish more cycle stock than is actually being used resulting in a violation of the maximum inventory level. The following equation can be used to determine the amount of excess that exists in a container of stock.

*Excess stock per container* = the amount of stock in the actual container - amount of stock in an optimal container

#### **Equation 7.7: Calculation of Excess Stock per Container**

In the above equation, an optimal container is defined as a container that can satisfy the demand expected during one half of the replenishment cycle (one hour in our case). This is consistent with the definition of optimal container size as derived in section 6.8.1.

A simplified example will help to show the effect that excess stock has on pull system operation. Let’s assume that the demand for a given component is 42 units per hour and that 1 container of the component holds 50 units, or 1.2 hours worth of stock. This results in each container having 8 units or 0.2 hours of excess stock. The 50 unit

container size results in the following operational specification: a minimum inventory level of 1 container, a maximum inventory level of 3 containers, and 5 total SMART cards circulating through the pull system.

During the first replenishment cycle at most 2 hours of cycle stock can be consumed; however, 2 containers of stock are delivered to replenish what has been used (because of the 2 SMART cards that the route driver had in hand at the start of the first replenishment cycle). Since less than 2 containers of stock have been consumed but 2 full containers of stock are being delivered, there will be a violation of the maximum inventory level equal in magnitude to the amount of excess stock that remains in the open container when the delivery arrives (16 units in our case). In fact, as production continues, at some point, the maximum inventory level will be violated by 2 containers of stock (1 of which will be full and 1 of which will be partially full) resulting in 5 containers of stock at the lineside.

*A more thorough example that shows the impact that excess stock has on the operation of the pull system is presented in the technical appendix under topic D.*

#### **7.6.1.1 Accumulation of Excess Stock:**

The amount of excess stock begins at a “initial level” accumulates to a “critical point”, decreases, and then begins accumulating once again. The “initial level” is the amount of excess stock due to the cycle stock initially placed at the line. In the example in section 7.6.1, when production began there were 2 containers of cycle stock at the line. Since each container held 8 units of excess stock, an initial level of 16 units of excess stock was established. It is important to note that by the end of the first delivery cycle the 16 units of excess stock had been consolidated into the open container at the line.

Consolidation is caused by the fact that containers of stock are used sequentially to satisfy demand. This can be seen using the operation specification developed for the example in section 7.6.1. If 84 units of the component are demanded during the first replenishment cycle, 1 container of stock will be opened and completely exhausted before a second container is opened and 34 of its 50 units are consumed. This leaves 16 units of excess stock in 1 container at the end of the second hour of production. The production process has acted to “consolidate” into 1 container the 8 units of excess stock that existed in each of the cycle stock containers. Because each container holds 8 units of excess stock, for each delivery cycle where 2 containers are delivered, 16 additional units of excess stock are accumulated.

At any point in time the amount of accumulated excess stock can be determined by comparing the amount of cycle stock at the line with the expected demand during the next delivery cycle.

*The accumulated excess stock = cycle stock at the lineside - predicted demand during the next replenishment cycle*

### **Equation 7.8: Equation for Accumulated Excess Stock**

Continuing the example from above, after the first replenishment cycle is completed there would be 116 units of cycle stock at the lineside - 16 units of excess stock in the open container, and the 100 units of stock from the delivery. Since only 84 units of stock are expected to be used during the next replenishment cycle, there are 32 units of accumulated excess stock.

#### **7.6.1.2 The Critical Point of Accumulation of Excess Stock:**

Excess stock does not accumulate indefinitely. When the “critical point” is reached, the pull system adjusts the deliveries made to the line in order to deplete some of the excess stock that has accumulated.

It makes intuitive sense that at some point enough excess stock will accumulate so that the quantity of stock delivered by the route driver can be decreased without effecting production. The accumulated excess stock can be used to supplement the “smaller than normal” delivery such that sufficient cycle stock will exist to satisfy demand. When the excess stock is used to supplement the cycle stock in this way, its level decreases as production occurs and its accumulation is abated. Once the amount of accumulated excess stock has fallen, normal deliveries will have to resume in order to satisfy demand and accumulation will begin again.

*Specifically, the critical point is reached when there is enough excess stock accumulated in 1 container so that only 1 container of stock is opened during a given replenishment cycle. This can be seen using the operation specification developed for the example in section 7.6.1. Opening just 1 container results in the generation of only 1 SMART card (instead of the usual 2) and therefore the delivery of just 1 container of stock during the subsequent replenishment cycle. The delivery of only 50 units of stock (1 container) depletes the accumulated excess stock by 34 units - the net difference between the 84 units that were actually consumed during the replenishment cycle and the 50 units that were delivered to replenish it. This depletion pushes the excess stock below the critical point where it begins to accumulate again and the process repeats itself. In this way, excess stock does not result in the indefinite accumulation of stock at the lineside but does cause continual violations of the maximum inventory level.*

*A detailed explanation of the factors that influence when the critical point is reached and a review of the specific mechanics of the pull system that result in the abatement of the accumulation of excess stock is included in the technical appendix under topic E.*

### **7.6.2 Over–Replenishment of Stock:**

The second main factor that causes unexpected pull system performance is the over-replenishment of stock during the first replenishment cycle. Over-replenishment simply means that more stock is delivered than required based on actual consumption which leads to violations of the maximum inventory levels. Over-replenishment may sound similar to the accumulation of excess stock that was presented in the previous sections; however, it differs in one critical way. Over-replenishment occurs even when optimal packaging exists.

Over-replenishment is caused by the fact that during the first replenishment cycle a fixed amount of stock is delivered to the line based on the maximum amount of cycle stock that can be consumed by the time the first delivery arrives. For example, if the duration of the replenishment cycle is 2 hours, at most 2 hours worth of stock can be consumed by the time the first delivery arrives. To protect against the maximum consumption of stock, 2 hours of stock must be delivered to the line to avoid violations of the minimum inventory level and the use of safety stock.

Up to this point we have been assuming that all deliveries occur at the very end of the replenishment cycle. For example, if the route time is 2 hours, we have been assuming that deliveries occur after 2 hours of production, 4 hours of production, etc. Assuming that deliveries occur at the end of the replenishment cycle simplifies explanation of the operation of the pull system and assures that by the time a delivery arrives the maximum amount of inventory that can possibly be consumed during a replenishment cycle will have been consumed. In reality, deliveries to different lineside addresses occur at different points in time within the replenishment cycle.

Because there are many different delivery points along the delivery route that is traversed each replenishment cycle, most lineside addresses receive their deliveries before the end of the replenishment cycle. Processes at these “early” delivery points have consumed less than maximum amount of stock by the time the first delivery arrives. Because enough stock is being delivered to replenish the lineside as if the maximum amount of stock had been consumed, more stock is delivered than is required to replenish actual consumption. The magnitude of over-replenishment (and therefore the magnitude of the violation of the maximum inventory level) is determined by comparison of the actual consumption of stock by the time the first delivery arrives and the amount of stock that is being delivered.

A simplified example will help to clarify how over-replenishment of stock occurs and the effect over-replenishment has on pull system operation. Let’s say that demand for a component at a given lineside address is 42 units per hour. Let’s also assume that the

component is packaged optimally, satisfying exactly 1 hour of demand. Given these parameters and a 2 hour replenishment route, the operational specification for the pull system in this case is for a minimum inventory level of 1 container, a maximum inventory level of 3 containers, and 5 total SMART cards circulating through the pull system. Finally, let's assume that the route driver arrives at the lineside address 1 hour and 15 minutes into his route. For example, if production begins at 6 A.M. replenishment of stock would occur at 7:15 A.M. Replenishment would not occur again until 9:15 A.M., 2 hours after the first delivery arrived.

When the route driver arrives at the lineside at 7:15 A.M., only 1 container of stock will have been completely exhausted. However, he will deliver 2 new containers of stock as replenishment for what has been consumed (based on the 2 SMART cards he had in hand before the first replenishment cycle) resulting in over-replenishment. The magnitude of over-replenishment is 45 minutes of stock - the 2 hours of stock delivered less the 1 hour and 15 minutes of stock that had been consumed by the time the delivery arrived. Over-replenishment drives the level of lineside inventory up to 4 containers of stock (3 full and 1 three quarters full) and causes a violation of the maximum inventory level. Since 2 containers of stock were opened before the route driver arrived (1 when production began and then a second 1 hour into production), 2 SMART cards were generated during the first replenishment cycle. The route driver will pick up the 2 cards as a signal for replenishment of 2 containers of stock during the second replenishment cycle.

At 9:15 A.M. the route driver will arrive at the lineside address for a second time. When he arrives there will be a total of 2 containers of stock at the line, 1 full container and 1 three quarters full (the same condition that he found when he made his first delivery). The route driver will again deliver 2 containers of stock (based on the 2 SMART cards he picked up during the first replenishment cycle). The delivery of 2 containers of stock again causes a violation of the maximum inventory level in the amount of 45 minutes worth of stock.

The key observation is that the 45 minutes of "extra" stock that resulted from over-replenishment during the first replenishment cycle remains "in the system". In fact it will continue to remain in the system at steady state and cause violations of the maximum inventory level each time a delivery is made. This is because, from the second replenishment cycle on, each delivery of stock replenishes the exact amount of stock that was consumed since the previous delivery. For example, between the first and second deliveries, 2 hours of stock are consumed. The amount of stock that was consumed is completely replenished when 2 hours of stock are delivered to the line when the second delivery arrives. This leaves no opportunity for the 0.75 hours of extra stock delivered during the first replenishment cycle to be consumed.

The table below helps to visualize the over-replenishment that occurs during the first delivery cycle. The over-replenishment of 0.75 hours of stock is identified in the column titled “Replenishment less Consumption” and occurs when 2 hours of stock are delivered when only 1.25 hours of stock had been consumed. It can be seen that for every replenishment cycle after the first, the amount of stock delivered exactly matches the amount of stock consumed keeping the extra stock in the system.

| Replenishment Cycle | Number of SMART cards generated | Number of Containers Delivered | Stock Consumed at Time of Delivery (hrs) | Stock Consumed Since Previous Delivery (hrs) | Stock Replenished (hrs) | Replenishment less Consumption (hrs) |
|---------------------|---------------------------------|--------------------------------|--|--|-------------------------|--------------------------------------|
| 1                   | 2                               | 2                              | 1.25                                     | 1.25   | 2                       | 0.75                                 |
| 2                   | 2                               | 2                              | 3.25                                     | 2  | 2                       | 0                                    |
| 3                   | 2                               | 2                              | 5.25                                     | 2  | 2                       | 0                                    |
| 4                   | 2                               | 2                              | 7.25                                     | 2  | 2                       | 0                                    |

**Figure 7.4: Summary of Stock Usage and Replenishment**

Other lineside addresses would have different amounts of over-replenishment due to their unique position in the delivery route. For example, a lineside address that receives deliveries just before the one in the example would have more “extra” stock whereas a lineside address that receives deliveries just after the one in the example would have less “extra” stock.

*A more detailed example of over-replenishment which includes analysis of multiple lineside addresses is included in the technical appendix under topic F.*

### **7.6.3 Variability:**

The last of the three main factors that cause unexpected pull system performance is variability in demand and replenishment cycles. The other two factors, non-optimal packaging and over-replenishment, generally only cause violations of the maximum inventory level. Variability, on the other hand, can cause violations of the minimum inventory level as well. Even if packaging is optimal and the delivery point is such that no over-replenishment occurs, variability in demand and in the replenishment cycle assures that the pull system will not perform as expected.

#### **7.6.3.1 Demand Variability:**

Variability in demand is inevitable. There are bound to be instances where the build area shuts down because of a machine breakdown or quality issue decreasing the demand for components during that hour of production. In other cases, such as when there is poor

component quality resulting in a high scrap rate, demand will be greater than expected. In any case, during some hours of production, demand for components will be higher than expected and in other hours demand will be lower.

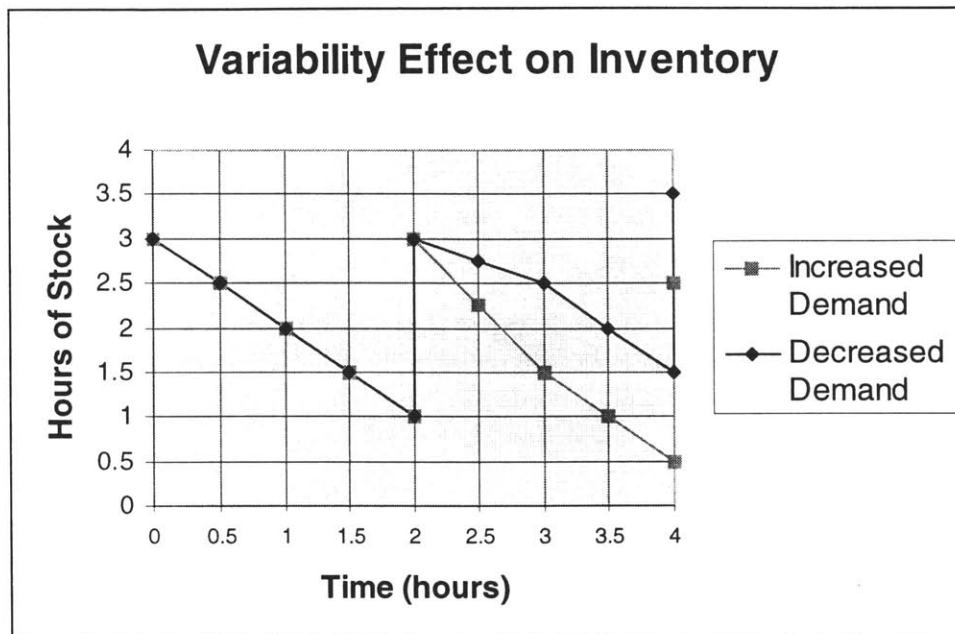
Unfortunately, higher than average demand very rarely cancels out lower than average demand when it comes to pull system operation and violations of the minimum and maximum inventory levels occur. This is because operation of the pull system is based on replenishment cycles which are short enough in duration that increases or decreases in demand often impact the operation of the pull system before an offsetting decrease or increase can occur. Therefore, net increases or decreases in demand that occur during the two hour replenishment cycle will cause the pull system to behave unexpectedly. The following example will help to clarify how demand variability impacts pull system performance.

To simplify the example let's assume that average demand is 42 units per hour, packaging is optimal, and deliveries occurs at the end of the 2 hour replenishment cycle (this assumption isolates the effects of demand variability). Let's say that during the first 2 hours of production demand is exactly as expected. The pull system functions as expected and the level of lineside inventory fluctuates between the calculated minimum and maximum levels. During the third hour of production, demand is 21 units less than expected due to a machine breakdown but returns to the expected level during the fourth hour of production. In this case, during the second replenishment cycle, 21 units of stock that were expected to be consumed were not. Because of this, when the second delivery arrives a 21 unit violation of the maximum inventory level will occur.

Conversely, if demand during the third hour of production is 21 units greater than expected (because of a component quality issue for example) but returns to the expected level during the fourth hour of production, a violation of the minimum inventory level will occur. In this case, a short time before the second delivery arrives, the last container of components at the lineside (the safety stock) will have to be opened in order to support production. By the time the second delivery arrives there will be a 21 unit violation of the minimum inventory level.



The graph below shows both the increased and decreased demand scenarios.



**Figure 7.5: Effects of Variability on Pull System Operation**

Sometimes fluctuations in demand be canceled out within the 2 hour replenishment cycle. For example, if during the third hour of production demand is 21 units less than expected but during the fourth hour of production demand is 21 units greater than expected, then the fluctuations in demand will cancel out and the pull system will operate as expected. In reality this type of scenario rarely occurs and increases and decreases in demand do not cancel out.

### 7.6.3.2 Replenishment Cycle Variability:

In addition to the variability in demand, there is variability in the elapsed time between adjacent deliveries to the same lineside address. Up to this point we have assumed that, after the first replenishment cycle, a given lineside address receives its deliveries exactly every 2 hours. In reality, because of factors such as variable numbers of containers needing to be delivered during different replenishment cycles, some replenishment cycles take longer to execute than others. This results in there being variability in the duration of replenishment cycles.

The effect the variability replenishment cycles is that in some instances, deliveries occur “early” and in other instances, deliveries occur “late”. All else equal, early deliveries can result in violations of the maximum inventory level whereas late deliveries can result in violation of the minimum inventory level.

### ***7.7 Summary of Pull System Performance:***

It is fair to say that, because of the three factors discussed in section 7.6, the pull system will never perform as predicted by the SMF implementation manual calculations. That, in itself, is not a major issue. The major issue is that a lack of foreknowledge of how the pull system is going to perform can lead to ill advised reactions to normal but unexpected system conditions and poor decision making about process modifications meant to correct the system “problems”. At the extreme, lack of understanding can lead to failure of the pull system.

If an understanding of how the pull system is going to perform (and why it is going to perform that way) can be gained, then the fact that the SMF implementation manual calculations do not yield accurate results becomes more of a footnote than the possible implementation killer that it is when no understanding exists.

Unfortunately, it is very difficult to gain the required understanding by simply following the tasks listed in the SMF implementation manual. In the next section, the actual learning process that provided the implementation team with an understanding of actual pull system operation is reviewed.

### ***7.8 Gaining Knowledge and Applying Learning:***

In the absence of sufficient theoretical understanding of pull system operation, calculation of lineside inventory levels and the number of SMART cards required for each card part is all that would be done in order to generate the operational specifications for the pull system. That is, development of operational specifications for the pull system would have concluded after the relevant information for each card part was plugged into the equations provided by the SMF implementation manual and the results logged.

In fact, this is exactly what initially occurred. The relevant information for each card part was taken from the plan for every part and plugged into the equations provided by the SMF implementation manual. The results of the calculations were taken at face value and then added to the plan for every part. The implementation team then moved on to the next step in the process and began developing part storage and presentation infrastructure.

It is entirely possible that no true understanding of pull system operation would have been gained had it not been for the need to develop part storage and presentation infrastructure. In fact, had learning not occurred during the development of part storage and presentation infrastructure, most likely the “true” operation of the pull system would not have been understood until the pull system was implemented and containers of stock failed to fit into the lineside racks. In other words, learning would not have occurred until it was too late.

### 7.8.1 The Learning Process:

When developing part storage and presentation infrastructure it is important to understand how many containers of a component will need to be stored at the lineside so that the rack or shelf can be designed properly. For example, if the maximum inventory of a certain component that is going to be stored in a flow through rack is 3 containers, the rack needs to be large enough to hold 3 containers of stock. It was during the development of part storage and presentation infrastructure that it was discovered that the card part replenishment pull system did not behave as specified by the SMF implementation manual calculations. This learning occurred during some very simple back of the envelope simulations that were being performed to ensure that the lineside storage racks that were being designed were going to be large enough to accommodate the maximum inventory levels at the line.

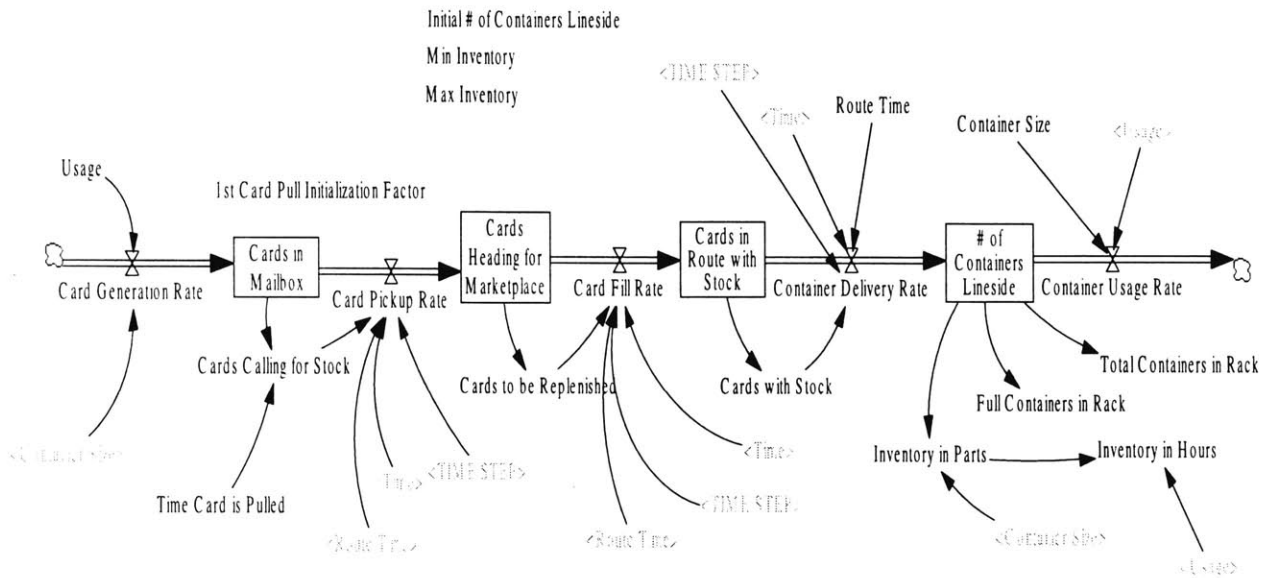
The simulations were initially performed to test some intuition that had developed. It seemed as though stock was going to accumulate at the line for components that were packaged in extremely dense containers. For example, it seemed fairly obvious that there was no way that a container of 10,000 bolts could be fully consumed during the first replenishment cycle (the first 2 hours of production). Therefore, when a new container of bolts was delivered to the lineside during the first replenishment route (as prescribed by the SMART card calculations), an immediate violation of the specified maximum inventory level would occur. Additionally, and more importantly at the time, there would be no room in the lineside storage rack for the container of bolts that was being delivered. This intuition was confirmed by the simulations.

The initial simulations raised many questions about the performance of the pull system. When these questions were brought to the implementation team it is fair say that no team member truly understood how the pull system would operate for every component. Once presented with the scenario of the large container of bolts, it seemed fairly intuitive to most team members that under *some* conditions, stock would accumulate at the line. But what were the conditions? Was there some universal set of rules that governed the operation of the pull system that could be applied to each card part? Weren't the equations provided by the SMF implementation manual the set of universal rules? Consideration of this question raised more questions and soon it seemed as though the operation of the pull system was totally unclear.

To help to answer the questions that were being raised and to build intuition within the implementation team about pull system performance, a Vensim computer model was developed to simulate pull system operation.

### 7.8.1.1 Simulation Model Development:

A visual representation of the model that was developed to simulate the operation of the pull system is shown below.

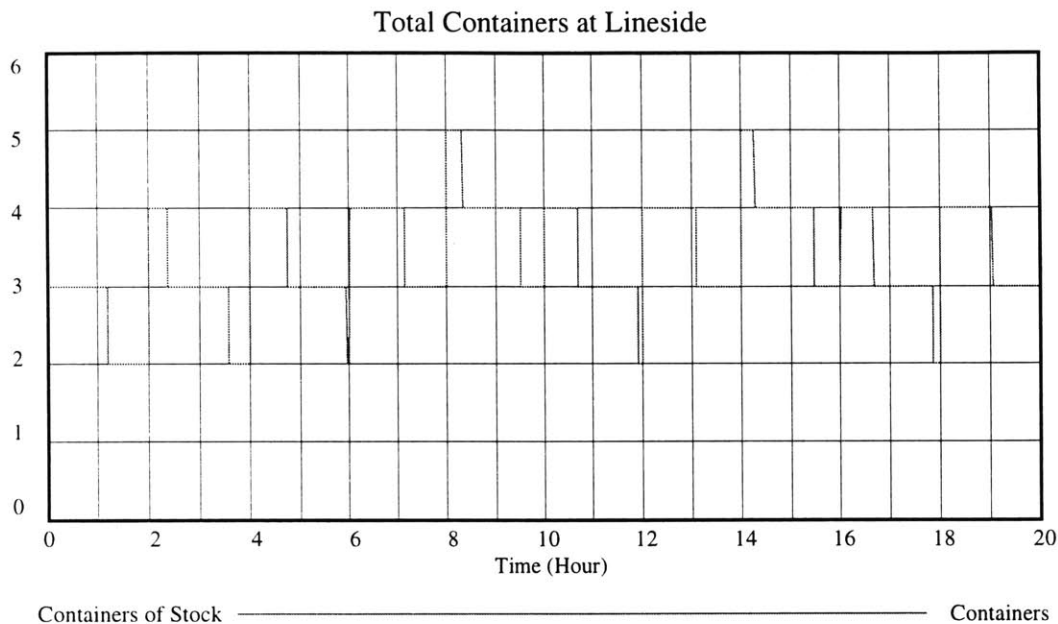


**Figure 7.6: Visual Representation of Vensim Model that Predicts Pull System Performance**

There are two sets of “input” variables to the model. The first set of input variables defines the initial condition of the pull system and provides a starting point for the simulation. These variables include the initial amount of inventory at the lineside and the number of SMART cards in the system. As a note, the number SMART cards in the system is not an explicit variable in the model but is determined from manipulation of the minimum and maximum inventory level variables that do appear in the model. The values entered into the model for the first set of variables reflect the results of the operational specification developed for each component based on the SMF implementation manual calculations.

The second set of inputs to the model are the variables that control runtime pull system performance. These variables include container size, route time, and usage rate. Manipulation of the second set of variables by the model provides the runtime data needed to predict actual pull system performance. By determining when containers are emptied (based on the container size and usage rate), and when SMART cards are collected and new containers of stock are delivered (based on the route time) a true picture of lineside inventory levels is generated.

The model simulates the actual performance of the pull system given the operational specification generated by the SMF implementation manual calculations. The output of the model is simply the actual level of lineside inventory at any point in time. The output can be displayed in many forms including total containers at the lineside, full containers at the lineside, lineside inventory in units, or lineside inventory in hours. As an example, when the operation specification for the latch bezel and the runtime variables are entered into the model, the following results are produced. The output is in the form of the total number of containers of inventory at the lineside.



**Figure 7.7: Sample Output from the Pull System Operation Simulation Model**

### 7.8.1.2 Value of the Model:

*“I learned a lot [during this step of the development process]. I learned about the realities of the SMART system and about some of the linkages [between the different elements of the pull system].” - Salary SMF Process Owner<sup>9</sup>*

Once the model was developed and validated, simulations were run to try to gain an understanding of how the pull system performed under a variety of scenarios. The output of the simulations was important along two different axis. First, the simulations provided information about the actual maximum inventory levels that could be expected to exist at the lineside for a given component. This was very important and practical knowledge which was critical to the design of the part storage and presentation racks needed for each component.

*Secondly, and more importantly, the output of the simulations supported the learning process.* The model helped in the identification of the three factors discussed earlier that cause unexpected pull system performance. That is, the model facilitated the identification of the three factors that cause the pull system to perform as it should given its design but in violation of the operation specification set forth by the SMF implementation manual calculations. The model helped to answer the “why is this happening” questions that motivated its development in the first place.

Additionally, the model helped to develop intuition about the levers that could be used to affect pull system performance. For each component the model allowed for experimentation with different container sizes, initial lineside inventory levels, quantities of SMART cards, etc. which helped to generate an understanding of how the modification of each factor could effect pull system operation. This “what if” scenario analysis also helped in the development heuristics (which will be discussed later) which allow for *intelligent* modification of the SMF implementation manual driven operational specifications.

In summary, the knowledge developed through interaction with the simulation model allowed for learning to be applied to the process of determining pull system operational specifications. Additionally, a far greater understanding of how and why minimum and maximum inventory levels fluctuate over time, how packaging and route time effect pull system performance, and what levers are available for continuous improvement was developed during the learning process. However, even if none of the learning that occurred was applied to the development of the pull system, there would still be tremendous benefits from the learning process. At a minimum, after learning occurred, members of the implementation team understood that the pull system would operate outside of the specifications that were supposed to govern it and that the “violations” that were bound to occur were expected and acceptable. It is highly unlikely that this philosophy regarding “unexpected” pull system performance would have been in place had the implementation team not ventured beyond the tasks presented in the SMF implementation manual.

### ***7.9 Modification of Operational Specifications:***

With the new knowledge that had been gained from the simulations, it was possible to modify the operational specifications generated by the use of SMF implementation manual calculations to refine pull system performance. The modifications that were implemented took three basic forms.

1. *For some card parts with very dense packaging, maximum and average inventory levels were reduced by decreasing the number of SMART cards by 1 from the level that had been specified.* In these cases even though less than the specified number of SMART cards were going to be circulating through the pull system, the minimum inventory levels as designated by the SMF implementation manual calculations would not be violated. Additionally, in most cases the actual maximum inventory levels still exceeded those predicted by the SMF implementation manual calculations. To assure

proper visual management, the actual maximum inventory levels were documented and displayed on labels at the lineside.

2. *For some card parts, because of space considerations, the number of SMART cards was decreased by 1 or 2 from the level that had been specified resulting in occasional violations of the specified minimum inventory level.* In some cases, there was simply not enough space at the lineside to accommodate the stock that would accumulate given the operational specification provided by the SMF implementation manual calculations. In these cases the number of SMART cards was decreased from the level that had been specified and the resulting actual minimum and maximum inventory levels were documented. In most cases where this was done, an original minimum inventory level of 2 containers of stock was specified because of the relatively low number of components that were included in each container. These low density containers, which usually house large, light, plastic components, result in the need for a large amount of storage space at the line to house the large number of containers that are needed to satisfy demand. In these cases the number of SMART cards was decreased by 1 or 2 from the specification which sometimes resulted in an actual minimum inventory level of 1 container as opposed to the specified minimum of 2 containers.
3. *For some card parts with near-optimal packaging, the only change that was made to the operational specifications was to document the actual maximum inventory level to assure proper visual management at the lineside.* Even in cases where packaging is near-optimal, at some point the predicted maximum inventory level is exceeded by 2 containers of stock (1 full and 1 partially full). However, in these cases, if the number of SMART cards is decreased from the number specified by the SMF implementation manual calculations, violations of the minimum inventory level can occur. Therefore, if there is sufficient space at the lineside for a storage rack that can accommodate the maximum inventory level as predicted by the simulation model, the number of SMART cards should not be decreased from the level specified. In this case the only modification that should be made is to update the maximum inventory level to its true value.

Once all of the changes were made, the modified operational specifications were documented in the plant for every part.

The modifications described above were facilitated by heuristics which were developed as learning occurred during the simulation process. Below are two examples of the heuristics that were employed to guide operational specification modifications.

Example #1:

*Classification of Modification: Type 1* - For card parts with very dense packaging, maximum and average inventory levels were reduced by decreasing the number of SMART cards by 1 from the level that had been specified.

- *Heuristic that facilitated modification:* If 1 container of stock can satisfy  $\geq 2$  replenishment cycles (4 hours) worth of demand, reduce the number of SMART cards from 3 to 2.
- *Example Component:* Pivot bolt - 1 container of stock is able to satisfy 5.95 hours of demand.
- *Original operational specification:* Minimum inventory level of 1 container of stock, maximum inventory level of 2 containers of stock, and 3 SMART cards total circulating through the pull system.
- *Actual performance of pull system:* Maximum inventory level of 4 containers of stock.
- *Modification to operational specification:* Number of SMART cards reduced from 3 to 2.
- *Performance of pull system after modification:* Maximum inventory level of 3 containers of stock.

Example #2:

Classification of Modification: *Type 2* - For some card parts, because of space considerations, the number of SMART cards was decreased by 1 or 2 from the level that had been specified resulting in occasional violations of the specified minimum inventory level.

- *Heuristic that facilitated modification:* If 1 container of stock can not satisfy the demand expected during  $\frac{1}{2}$  of the replenishment cycle (1 hour), reduce the number of SMART cards by 1 or 2 if required due to space considerations.
- *Example Component:* Power Seat Switch Bezel - 1 container of stock is able to satisfy only 0.86 hours of demand.
- *Original operational specification:* Minimum inventory level of 2 containers of stock, maximum inventory level of 5 containers of stock, and 8 SMART cards total circulating through the pull system.
- *Actual performance of pull system:* Maximum inventory level of 7 containers of stock.
- *Modification to operational specification:* Number of SMART cards reduced from 8 to 7.
- *Performance of pull system after modification:* Maximum inventory level of 6 containers of stock.

### **7.10 Determination of Operational Specifications for Call Parts:**

For call parts, the process for determining the appropriate number of containers to keep at the lineside is somewhat subjective and is based mostly on the storage space available at the line. The SMF implementation manual suggests that a minimum of one container and a maximum number of containers corresponding to “[the amount] that can be stored at lineside within the constraints of lineside racking and / or visual factory line of sight principles”<sup>6</sup> results in appropriate lineside inventory levels for call parts.



In the case of the purchased parts replenishment pull system, no racking existed for the storage of call parts at the lineside - all call part were presented in large, standalone, containers that were placed directly on the assembly floor. Because of this, lineside racking was not a constraint to the maximum number of containers of call parts that could be stored at the lineside. Additionally, because of the layout of the build area, there were very few instances where storage of multiple containers of a call part would result in a violation of visual factory line of sight principles. Therefore, the only real factor constraining the number of containers of a given call part that could be stored at the lineside was the amount floor space available in the build area for call part storage.

Because of the limited amount of floor space available for part storage in the Mustang seat build area and the implementation team's desire to keep the level of lineside inventory as low as possible, in most cases only one container of each call part was kept at the line at any one time. This resulted in a maximum inventory level for most call parts of one container of stock. The minimum inventory level in these cases was equal to the quantity of stock that remained at the lineside when the builder received a new container of stock from the material handler. The implementation team provided a matrix to the builders that, for each call part, indicated the number of units that could satisfy 20 minutes worth of demand. When the amount of inventory in the container a builder was working out of fell below the "20 minute level", the builder would call for a new container of components. Because it was estimated that it could take as long as 10 minutes for the new container of components to be delivered to the line once it was requested, the minimum inventory levels resulting from this process ranged anywhere from 20 to 10 minutes worth of stock.

In some cases two containers of a given call part were stored at the lineside. This was done, space permitting, when each container of the call part under consideration held relatively little inventory. In these cases the maximum inventory level was two containers of the call part and the minimum inventory level was variable depending on the amount of stock that remained at the lineside when replenishment occurred.

### ***7.11 Chapter Summary:***

This step is a good case study of the potential dangers associated with strictly following a task oriented implementation manual when the implementation team does not possess significant knowledge about the process they are implementing. The learning process that occurred was very powerful and allowed for a far more optimal implementation than would have resulted if only the SMF implementation manual would have been followed.



## Chapter 8: Step 5 – Development of Lineside Part Storage and Presentation Infrastructure

*“I like these [flow through] racks a lot. They organize the area and help to keep stuff off of the floor. It allows you to get parts closer to you so you spend less time looking for parts. They are an extreme improvement. This area is better than every other area by far.” - Mustang Seat Builder<sup>11</sup>*

*“[The] flow through racks are great. The hourly [employees] like that their ideas are being heard, it makes them feel like part of the team. Will still have a lot to learn though, we can still improve.” - Union Bargaining Representative<sup>12</sup>*

This chapter reviews the process that was followed in order to develop lineside part storage and presentation infrastructure. Part storage and presentation infrastructure is anything that is used to store or display card parts at the lineside. In the case of the purchased parts replenishment pull system, flow through racks and shelves mounted on workstations made up the majority of the part storage and presentation infrastructure that was used. In general, builders interact with the part presentation infrastructure every time they do their job. Therefore it is extremely important that it be developed with the builders input to eliminate waste from their jobs and minimize ergonomic issues.

### 8.1 Needs Matrix for Step 5:

| Title                         | Role in Step   | Theoretical Knowledge Required | Theoretical Knowledge Present |
|-------------------------------|--|--------------------------------|-------------------------------|
| SMF Process Owner (Salary)    | Coordinate execution of step   | ✓                              | ✓                             |
| SMF Process Owner (Hourly)    | Coordinate execution of step   | ✓                              | ✓                             |
| Lean Manufacturing Consultant | Execute tasks where needed   | ✓                              | ✓                             |
| Ergonomics Representative     | Input on ergonomic impact of storage and presentation infrastructure |                                |                               |
| Division SMF Coach            | Oversee execution of step and provide consulting on tasks            | ✓                              | ✓                             |
| Lean Manufacturing Expert     | Provide consulting on tasks  | ✓                              | ✓                             |
| Material Handling Engineer    | Provide support for the development of infrastructure                |                                |                               |
| Seat Builders                 | Assist in the design process   |                                |                               |

**Figure 8.1: Needs Matrix for Development of Lineside Part Storage and Presentation Infrastructure**

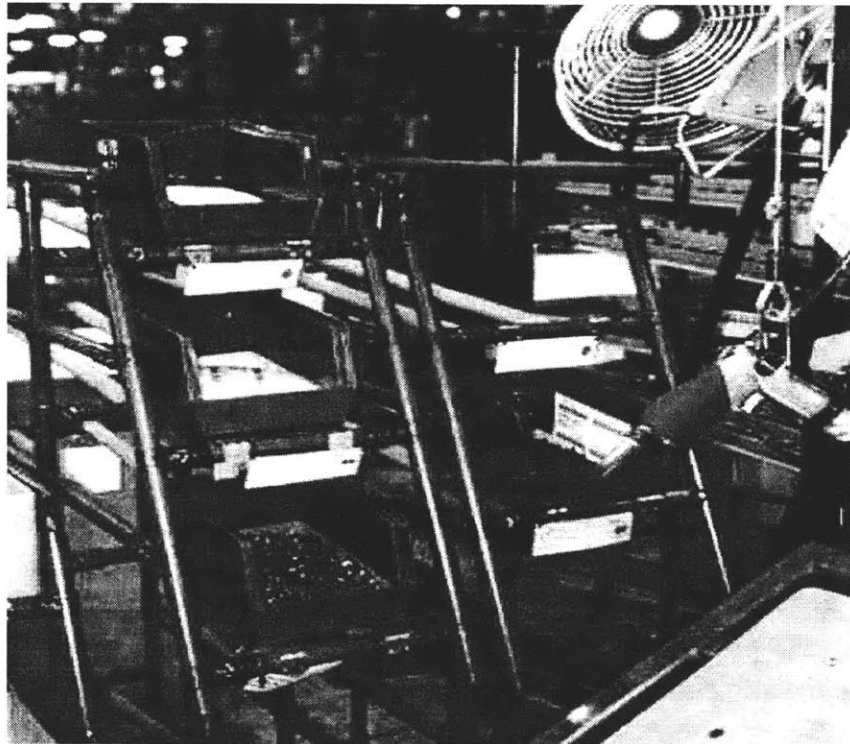
## **8.2 Basic Infrastructure Types:**

There are three basic types of part storage and presentation infrastructure that were developed as part of the purchased parts replenishment pull system.

- flow through racks that store parts
- flow through racks that store and present parts
- workstation add-ons that present parts

### Flow Through Racks that Store Parts:

A flow through rack is a rack in which parts can be loaded in one end (the back) and retrieved from the other end (the front). In the operation of the pull system, the route driver loads card parts in the back of the flow through rack and the builder retrieves the parts from the front. The flow through rack gets its name from the movement of the containers that are placed in the rack. Once loaded into the rack, the containers automatically advance forward, or “flow through”, to the front of the rack (as the containers in front of them are exhausted) using gravity feed assisted by rollers or slide bars. The figure below shows two flow through racks which are located next to a workstation in the Mustang seat build area.

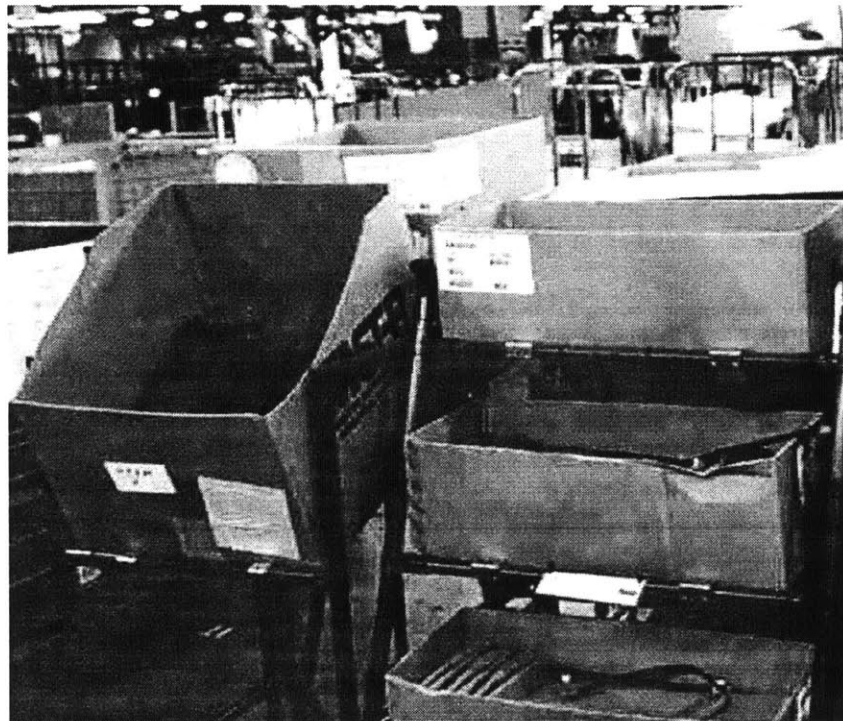


**Figure 8.2: Two Flow Through Racks Located in the Mustang Seat Build Area**

As its name suggests, a flow through rack that stores parts is used only as a storage medium – the builder removes the container of stock from the rack before he begins using the components in the container. For example, bolts are generally feed to the builder via a “storage only” rack. The builder removes the container of bolts from the storage rack and places it on the workstation table or shelf where he will work out of the container until it is consumed. In this way, the builder only “interacts” with the storage rack once every several thousand cycles when he must retrieve a new container of bolts to replace the one he has just exhausted. Storage only racks are most generally used for small parts in dense packaging that can easily be placed on a workstation table or shelf. The two flow through racks that are pictured in figure 8.2 are good examples of storage only racks.

#### Flow Through Racks that Store and Present Parts:

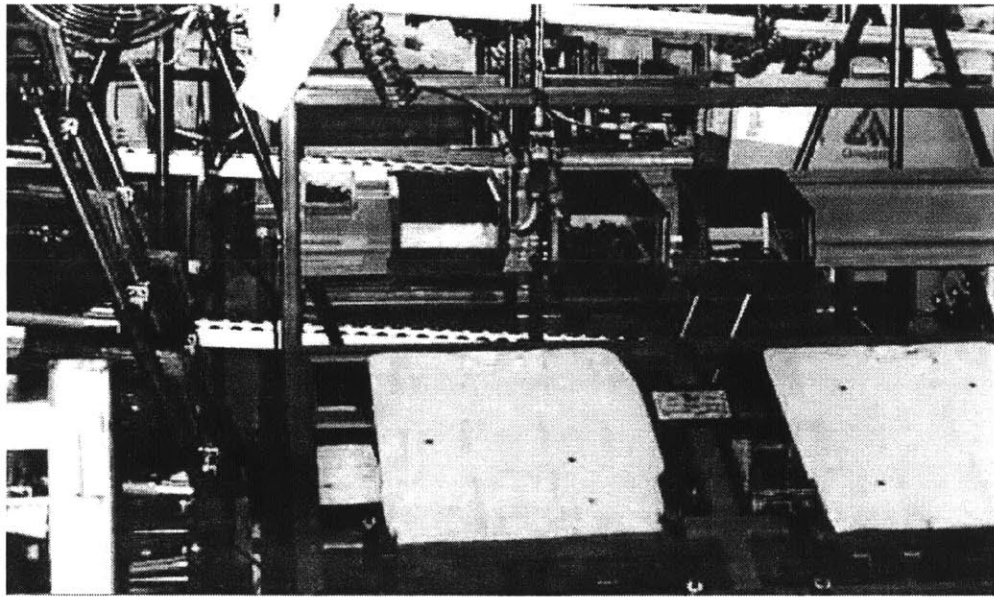
In addition to the storage capabilities described above, a storage and presentation rack also presents the part to the builder during each cycle. Because the builder interacts with the storage and presentation rack every cycle, the rack design must support ergonomic retrieval of the parts being presented. Storage and presentation racks are generally used for components that are packaged in larger containers which can not easily be moved to alternate storage locations. The figure below shows two storage and presentation flow through racks located in the Mustang seat build area.



**Figure 8.3: Part Storage an Presentation Flow Through Racks Located in the Mustang Seat Build Area**

### Workstation Add-ons that Present Parts:

In some cases where storage only racks are used, additional infrastructure must be provided in order to ergonomically present to the builder the parts that have been removed from the storage rack. In general the infrastructure takes the form of a workstation add-on such as a shelf. Because the builder interacts with the workstation add-on during each cycle, it is extremely important the add-on support ergonomic retrieval of the parts being presented. The figure below shows one such add-on, a shelf that was developed to display the components stored in the racks shown in figure 8.2.



**Figure 8.4: Shelf used to Present Bins of Parts to Builders**

### ***8.3 Basic Design Rules:***

Ergonomics and waste minimization are the driving forces behind the design of part storage and presentation infrastructure. While the effort expended by the material handler when loading the racks is important, the stakeholder of focus in the design of storage and presentation infrastructure is certainly the builder. A large majority of the waste (non-value added work) that exists in the assembly of seat sets is due to builder retrieval of parts. Each cycle, the builder must reach here and walk there to get the components he needs to perform his job. Well designed parts presentation infrastructure can help to minimize the time it takes for builders to retrieve parts (thereby minimizing waste) while improving the ergonomics of the retrieval process.

With proper ergonomics and waste minimization as overarching goals, there were some basic design rules that the implementation team followed in order to develop part storage and presentation infrastructure.

- *Design part storage and presentation racks to accommodate the maximum inventory level as predicted by the modified operational specifications.* In general, because their design was based on actual pull system operation, the racks were designed to hold an additional 1 to 2 containers of stock above the maximum inventory level specified by the SMF implementation manual calculations.
- *Group as few parts as possible in any 1 rack.* The goal of a lean manufacturing is to eliminate waste from the manufacturing process. As waste is eliminated, work is sometimes reorganized and redistributed. This can result in a relocation of the point of use of some components used in the assembly process. If all of the components consumed at a given workstation are grouped together in the same rack, then relocating 1 or a few of the components requires modification of the existing rack or construction of a new rack to allow for storage and presentation of the components at their new point of use. Grouping as few components as possible into 1 rack allows for less constrained relocation of the components used in the assembly process. In the extreme, in terms of flexibility, the most optimal rack design is one in which each component is stored or presented in its own rack. However, in reality, space constraints and cost generally prohibit a “1 component per rack” design philosophy from being implemented.

If grouping of components must occur, then an approach to grouping which affords the same type of flexibility that the “1 component per rack” design philosophy provides is desirable. This type of flexibility can be achieved if only components that are not likely to be distributed among different processes, no matter the organization of work, are grouped together. For example, a bolt and nut that are used in concert to join 2 other components are not likely to be divided between 2 processes.

- *Use commercially available workstation add-ons where possible.* There are several companies that supply “standardized” workstation add-ons. The development of customized workstation add-ons can be extremely time consuming and yield little benefit over the commercially available solutions. The use of commercially available workstation add-ons also allows for more time to be spent on the development of flow through racks where the extra time spent can yield significant benefits due to the customized nature of the racks.

## **8.4 Design Process:**

The implementation team followed a five step process to develop part storage and presentation infrastructure.

- review seat assembly process and solicit part presentation ideas from builders
- determine part storage and presentation needs and develop preliminary designs
- develop preliminary rack layout and modify the preliminary designs where necessary
- present preliminary rack designs, rack layout, and workstation add-ons to the builders for feedback
- submit design specifications to rack vendor for detailed design and manufacture and order workstation add-ons

### Review Seat Assembly Process and Solicit Part Presentation Ideas from Builders:

It is a good idea to review the seat assembly process with a group of builders. This helps to insure that the lineside addresses that have been established for each card part are accurate, helps to define which parts can be logically grouped together, and also provides an opportunity to solicit ideas on how to best present the parts to the builders.

### Determine Part Storage and Presentation Needs and Develop Preliminary Designs:

The plan for every part can be used to determine the specific part storage and presentation needs for the build area. Each entry in the plan for every part represents a unique storage and presentation need. In the case of the purchased parts replenishment pull system, there were over 100 entries in the plan for every part representing card parts which needed storage and presentation infrastructure developed for them.

By sorting the plan for every part by lineside address, an assessment of the storage and presentation needs at each workstation can be gained. In some cases, several logical groupings of parts (as discussed in section 8.3) will be obvious and multi-component racks can be considered with the additional constraint that for multiple components to be grouped into the same rack, the containers they are packaged in must be approximately the same size. For other components, groupings will not be so obvious. In these cases racks that support individual components are more fitting. Also, at this point consideration as to whether a component is simply going to be stored in a lineside rack or whether it will be stored and presented in the lineside rack should begin. If a workstation add-on is needed, an appropriate add-on can be selected from one of the many catalogs through which they are sold.

This process helps to determine the number of racks that will be needed to support the build area. In the case of the purchased parts replenishment pull system, 40 racks were installed in the build area, 14 of which supported only one component.



A portion of the sorted plan for every part with the information that is needed in order to develop part storage and presentation infrastructure is shown below.

| Smart Number | Lineside Address | Description                           | L (in.) | W (in.) | H (in.) | Weight (lbs.) | Container Density | Max Stock |
|--------------|------------------|---------------------------------------|---------|---------|---------|---------------|-------------------|-----------|
| 68           | FCD2             | Power Seat Switch Bezel               | 16.5    | 13      | 12      | 25            | 36                | 6         |
| 69           | FCD2             | Power Seat Switch                     | 20      | 17      | 12      | 30.3          | 64                | 4         |
| 70           | FCD2             | Seat Harness, Power or Manual, Lumbar | 17.75   | 15.5    | 13.5    | 24.8          | 60                | 3         |
| 71           | FCD2             | Seat Harness, Power                   | 17.75   | 15.5    | 13.5    | 38.9          | 150               | 3         |
| 72           | FCD2             | Lumbar Switch                         | 19.25   | 12.25   | 9.38    | 5             | 144               | 3         |
| 73           | FCD2             | Bezel to Frame Screw                  | 9       | 9       | 5       | 33            | 5500              | 3         |
| 74           | FCD2             | Power Seat Switch to Bezel Screw      | 9       | 9       | 7       | 35            | 15000             | 3         |
| 75           | FCD2             | Track Bolt                            | 9       | 9       | 7       | 39.85         | 1500              | 3         |

**Figure 8.5: The Plan for Every Part with Information Needed to Design Part Storage and Presentation Infrastructure**

An example will help to clarify how the information from the plan for every part (along with some process knowledge) is used to develop preliminary rack designs. The power seat switch bezel (SMART number 68) and the power seat switch (SMART number 69) must both be assembled to the seat set in the same process - they are not going to be distributed among different processes, no matter the organization of work. This fact makes them a good candidate for grouping. The components are packaged in similarly sized containers so that a two-tiered rack approximately 17 inches wide could accommodate both containers. The overall length of the rack would need to be approximately 80 inches to accommodate 6 containers of bezels (at 13 inches long each) and the 4 containers of switches (at 20 inches long each). Finally, since the footprints of the containers that the components are packaged in are fairly large, it is unlikely that there will be room to place them on the workstation table of a shelf for presentation; therefore, the rack that houses them must be both a storage and presentation rack. We now have a preliminary design for a two-tiered storage and presentation rack that is 17 inches wide by 80 inches long.

Develop Preliminary Rack Layout and Modify the Preliminary Designs where Necessary:

This step is most easily executed with the aid a CAD layout of the build area. Each proposed rack can be drawn into the layout to determine how well it fits within the space that is available. If the preliminary designs do not readily fit into the space that is

available, modifications to the designs can easily be made and then evaluated using the CAD layout.

For example, let's say that a storage and presentation rack is designed to hold a single component packaged in a container which is 17 inches long by 12 inches wide. Additionally, the maximum lineside inventory level for the component is 4 containers of stock. The rack is originally designed so that the widthwise edge (the 12 inch edge) of the container is facing the builder resulting in a rack that is 12 inches wide by 68 inches long. Unfortunately, when the rack is drawn into the layout the original design proves to be too long in that the rack partially blocks a fork lift isle. An alternate design that may solve the rack length problem involves "turning" the container in the rack so that the lengthwise edge (the 17 inch edge) of the container faces the builder. This results in a rack that is 17 inches wide but only 48 inches long - 20 inches shorter than the original design. This new configuration can then be drawn into the layout to see if the rack now fits into the space that is available.

This process can be executed for all components until a layout has been developed where all racks fit into the space available for them and builder waste due to part retrieval is minimized. Once this is accomplished, the preliminary designs and layout can be presented to the builders for feedback.

#### Present Preliminary Rack Designs, Rack Layout, and Workstation Add-ons to the Builders for Feedback:

The builders are a tremendous source of feedback as to how well the proposed rack designs, rack layout, and workstation add-ons will actually work. The proposals are presented in the build area so that the containers of components can be laid out to match the proposals. By having the builders act out the part retrieval process, poor rack designs, ineffective workstation add-ons, and poor rack organization can be identified and improved. Once again, the overarching goal of the part storage and presentation infrastructure is to remove waste from the builders job. Therefore, the time it takes the builder to retrieve parts while acting out a particular scenario is one of the key decision factors as to if the design, add-on, or layout is optimal.

Several improvements were made to the preliminary designs during the review process. For example, in several cases containers of components had been oriented so that the longest edge of the container was facing the builder. This was done to reduce the distance the builder would have to reach into the container in order to retrieve parts. However, orienting the containers this way increased the width of the presentation racks which increased the builder's walking time when many racks were needed to support the components used at one workstation. The builders suggested that the orientation could be reversed so that the shorter edge of the container would be facing them. They proposed that once every several cycles they could reach into the back of the container and pull parts forward so that, on average, the distance they would need to reach would not be significantly greater than if the container was oriented as originally proposed. Where

feasible, the builders' suggestion was implemented which resulted in an overall reduction in part retrieval time.

#### Submit Design Specifications to Rack Vendor for Detailed Design and Manufacture and Order Workstation Add-ons:

Once the generic rack designs have been finalized internally and the workstation add-ons have been approved, the rack vendor can perform the detailed design and manufacture of the racks and the workstation add-ons can be ordered. Creform was chosen to supply the flow through racks needed to support the purchased parts replenishment pull system. Creform was selected over similar vendors because they provide outstanding engineering support and are experts in ergonomics. Generic design specifications were given to Creform whose engineers transformed them into detailed designs while focusing on ergonomics.

A typical specification given to Creform included:

- the number of components that needed to be stored in a given rack
- the width, length, height, and weight of 1 container of each of the components
- the orientation of the components within the rack (which edges of the containers should face the front of the rack)
- the number of containers of each component that would need to be stored in the rack (the rack capacity)
- the approximate width and length of the rack based on component orientation and required rack capacity

Once the detailed designs were completed, they were presented to the implementation team for approval. Once the designs were approved, manufacture of the racks began.

### **8.5 Chapter Summary:**

Proper development of lineside part storage and presentation infrastructure is extremely important because the design of the infrastructure can have a tremendous impact on the amount of waste in the builder's job. In the case of the purchased parts replenishment pull system, the process for developing the infrastructure involved determining the storage and presentation needs, developing preliminary designs and layouts, refining the designs, and then handing of the designs off to an outside vendor for detailed design and manufacture.

In order to properly develop the infrastructure, the builders that are going to be supported by it must be involved in the design process. This is critical for two reasons. First, the builders can apply their knowledge of the assembly to process to the development of the infrastructure which results in designs that are superior (in terms of functionality and waste reduction) to those developed by material handling engineers that possess limited knowledge of the assembly process. Secondly, involving the builders in the development

process helps to generate up front “buy in” of the new infrastructure. Instead of being something that the engineers forced on them, the infrastructure is seen by the builders as something that they helped to create. In the case of the purchased parts replenishment pull system, a handful of builders were very willing to participate in the infrastructure development process. Their involvement resulted in significant improvements to the preliminary designs that were developed by the lean manufacturing consultant (the author).

## Chapter 9: Step 6 – Development of Card and Call Part Marketplaces and Material Replenishment Routes

*“A major event in the process was the allocation of space to the marketplace. It was a visible sign of change” - Plant Manager*

This chapter reviews the process that was followed in order to design the card and call part marketplaces and the associated material handling routes.

### 9.1 Needs Matrix for Step 6:

| Title                              | Role in Step   | Theoretical Knowledge Required | Theoretical Knowledge Present |
|------------------------------------|--|--------------------------------|-------------------------------|
| SMF Process Owner (Salary)         | Coordinate execution of step   | ✓                              | ✓                             |
| SMF Process Owner (Hourly)         | Coordinate execution of step   | ✓                              | ✓                             |
| Lean Manufacturing Consultant      | Execute tasks where needed   | ✓                              | ✓                             |
| Material Replenishment Coordinator | Assist in the development of marketplaces  | ✓                              | ✓                             |
| Division SMF Coach                 | Oversee execution of step and provide consulting on tasks  | ✓                              | ✓                             |
| Lean Manufacturing Expert          | Provide consulting on tasks  | ✓                              | ✓                             |
| Health and Safety Representative   | Provide call part stacking regulations, provide input on marketplace configuration to ensure safety of workers |                                |                               |
| Material Handling Supervisor       | Assist in the development of marketplaces and routes   | ✓                              | ✓                             |
| Route driver                       | Assist in the development of card part delivery route  |                                |                               |
| Forklift driver                    | Develop call part delivery routes  |                                |                               |
| Material Handling Engineer         | Provide support for procurement of racking   |                                |                               |

**Figure 9.1: Needs Matrix for Development of Card and Call Part Marketplaces and Material Replenishment Routes**

### 9.2 Overview of the Marketplaces:

The card and call part marketplaces act as intermediate storage locations within the plant – between the receiving docks where the components are received and the lineside where the components are consumed. Components are kept in the marketplaces until they are “pulled” to the lineside to replenish stock that has been consumed.

Card and call part marketplaces differ in their configuration and operation. Card part marketplaces are generally made up of multiple rows of three tier racking with pallets of

card parts set on each tier. Each card part occupies a specific location within the marketplace and has a marketplace address assigned to it. When shipments of card parts are received at the plant, the components are immediately moved to their proper location within the card part marketplace, being set on the top tier of the racks to which they are assigned. To replenish the card parts consumed at the lineside, components are taken from the bottom tier of the racks (the “active level”) by the route driver and delivered to the lineside via predefined routes at regular time intervals. As components are consumed, the bottom tier becomes empty and the pallets on the upper levels of the racks (the “reserve levels”) are moved down to fill the open spots. In this way, first-in first-out material management is accomplished. Generally, the need to move pallets down from the upper levels is signaled by the use of a “fill active” card. The fill active card is very much like SMART card and is placed in a particular mailbox in order to signal the forklift driver that action needs to be taken. For the purchased parts replenishment pull system fill active cards were not used. Instead, red flags were attached to each rack and were raised when pallets needed to be shifted in the racks.

The card part marketplace also contains an “overflow” area where stock that can not fit into its designated rack(s) is placed. Stock needing to be placed in the overflow area is an indication that there is more inventory in the plant for that component than was expected. This may be a one time event due to an early delivery or less than expected demand, or it may be a frequent event which indicates an error either in the design of the marketplace or in the procurement of stock; in which case corrective action will need to be taken. Finally, a “SMART” office is located within the card part marketplace from which the material replenishment coordinator monitors the operation of the pull system. The figures below show two views of a typical card part marketplace. Figure 9.2<sup>6</sup> presents the marketplace from an overhead view while Figure 9.3<sup>6</sup> presents the view that a person standing in the marketplace would have when looking at a storage rack.

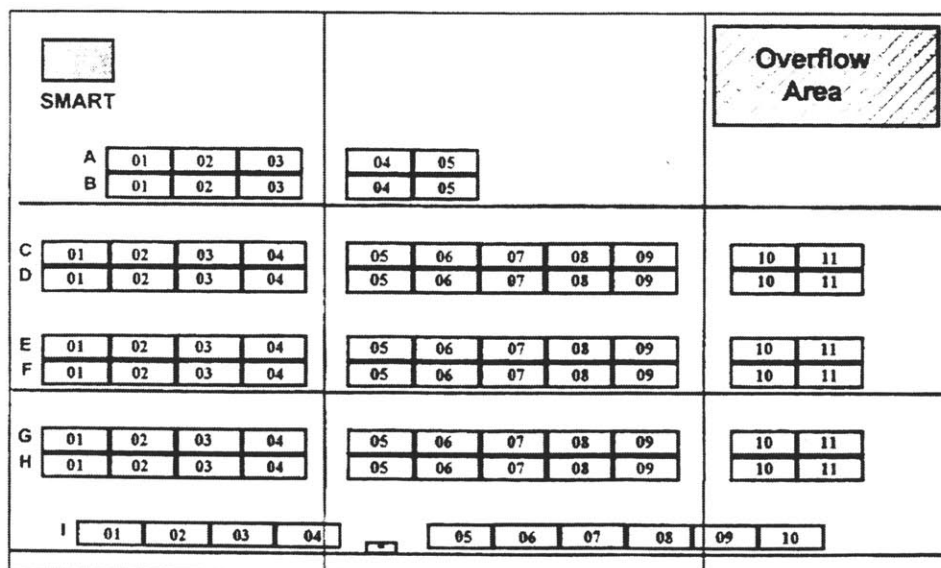
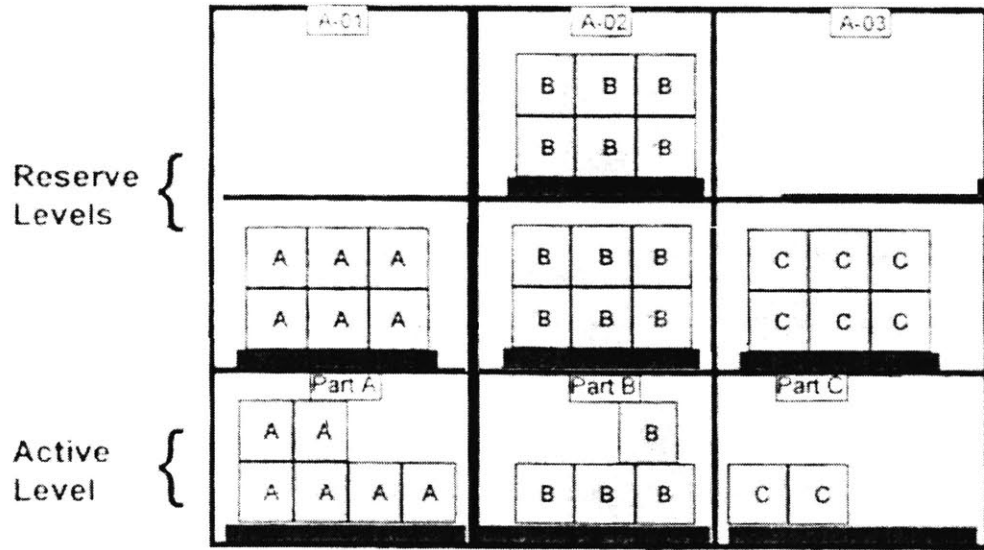
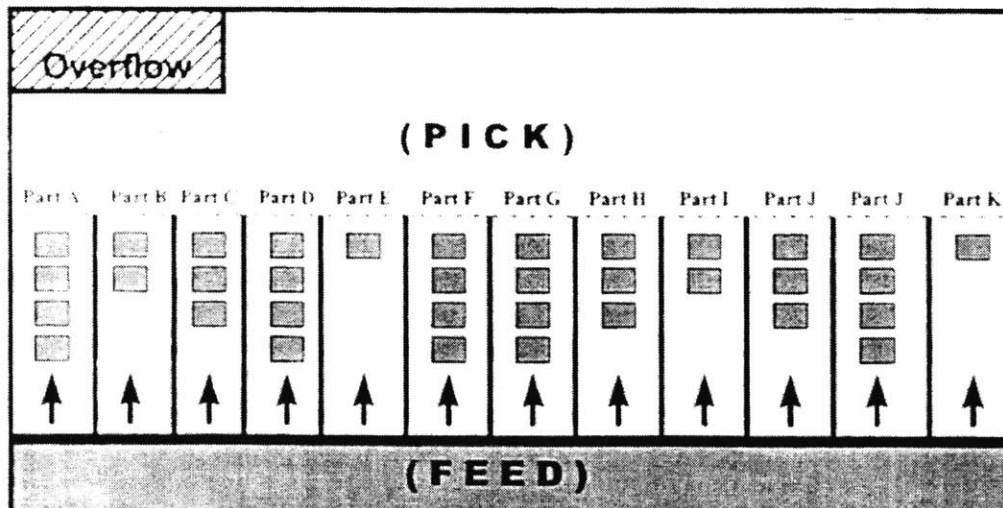


Figure 9.2: Overhead View of a Typical Card Part Marketplace



**Figure 9.3: Typical Storage Rack in the Card Part Marketplace**

Call part marketplaces are simply organized collections of call parts with like components stacked on top of each other. Call parts are generally placed directly on the floor into predefined rows or spots. The figure 9.4<sup>6</sup> below shows a typical call part marketplace.



**Figure 9.4: Typical Call Part Marketplace**

When shipments of call parts are received at the plant, the components are immediately moved to their proper location within the call part marketplace. The just delivered components are placed in the “feed end” of the rows which facilitates first-in first-out material management. To replenish the call parts consumed at the lineside, components are removed for the “pick end” of the marketplace by a forklift driver and delivered directly to the point of use at the lineside. In the case of the purchased parts replenishment pull system, the forklift driver is signaled that replenished is needed by call over a two way radio requesting a new container of parts. The call part marketplace also contains an “overflow” area which serves the same purpose as the overflow area in the card part marketplace does.

### **9.3 Determine Marketplace Storage Requirements:**

The first step in the development of the card and call part marketplaces is to determine just how large they need to be in order to provide adequate storage for the components used in the assembly process. Since marketplaces are designed to be the only intermediate storage locations for the purchased parts used in the assembly process, the total amount of stock that exists within the plant for any given component is divided between the marketplace in which the component is stored and the lineside address at which the component is consumed. Because of this, marketplaces must be large enough to store the maximum amount of stock that will exist in the plant at any point in time, less the stock that is kept at the lineside. Therefore, in order to determine the storage requirements placed on the marketplaces, the maximum amount of inventory that is going to exist in the plant must be calculated.

#### **9.3.1 Determination of Maximum In-Plant Inventory Levels:**

The factors that determine the maximum in-plant inventory level for any given component are:

- the frequency with which the component is delivered to the plant
- the amount of safety stock that is kept on hand
- the average daily usage of the component

As discussed in section 6.7.1, the maximum level of inventory for a given component exists just after delivery of that component has occurred. For example, if a component is delivered to the plant every 5 days and 2 days of safety stock are kept on hand, just after a delivery is received there will be 7 days worth of the component in the plant - the maximum amount that should exist at any point in time. A days worth of stock is simply the amount of stock that is expected to be consumed by production in a given day; therefore, the daily usage rate can be used to convert from days of stock to units of stock.



The equation that is used to calculate the maximum in-plant inventory level for a component in terms of units of stock is shown below.

***Maximum In-Plant Inventory Level (units of stock) =***

(Number of Days Between Deliveries + Number of Days of Safety Stock) × Daily Usage Rate

### **Equation 9.1: Calculation of the Maximum In-Plant Inventory Level**

It is important to remember that the daily usage rate term that appears in equation 9.1 is based on the average production rate per scheduled hour of 38 seat sets per hour (please refer to section 5.3.1 if clarification is required).

Although calculation of the maximum in-plant inventory seems very elementary given the above equation, variability in the daily usage rate makes the determination of the maximum in-plant inventory level less straightforward than it may first appear. For example, if the average production rate is 38 seat sets per hour and production runs for 16 hours per day, then the daily production rate is 608 seat sets per day. If 2 of a certain component are used per seat set, the daily usage rate for that component would be 1216 units per day. However, if production were to run for 20 hours instead of 16, then the daily production rate would be 760 seat sets per day. The same component that was previously consumed at a rate of 1216 units per day is now consumed at a rate of 1520 units per day. If the maximum in-plant inventory level is 7 days worth of stock, depending on which of the two possible daily usage rates was in effect, the 7 days worth of stock could be equivalent to 8512 units or 10,640 units.

The two scenarios described above are very relevant to the *operation* of the marketplaces which support the Mustang seat build area. As mentioned in section 5.2, the Mustang seat build area will be in production between 16 and 20 hours per day depending on the level of demand that exists at the time. Since Mustang sales are seasonal, it is realistic to believe that the expected swings in the daily production rate (and hence daily usage rate) will certainly occur. This will result in differing maximum in-plant inventory levels throughout the year. *While the marketplaces must be designed based on the maximum daily usage rate, the actual level of inventory in the marketplaces at any point in time will be based on the daily usage rate that exists at the time.* Unfortunately, the variability in actual in-plant inventory levels throughout the year makes it difficult to effectively employ visual management techniques in the marketplaces.

In any case, since the marketplace must be designed to accommodate the maximum amount of inventory that could exist in the plant at any point in time, the *maximum daily usage rate*, the usage rate that results from 20 hours of production per day, must be used in equation 9.1. The plan for every part contains all of the information required to determine the maximum in-plant inventory level for all card and call parts.

A portion of the plan for every part with the information that is needed in order to calculate the maximum in-plant inventory level for each component is shown below.

| Description                           | Usage Per Seat Set | % of Mix   | Days Between Deliveries | Safety Stock (days) | Maximum Inventory (days) |
|---------------------------------------|--------------------|------------|-------------------------|---------------------|--------------------------|
| Power Seat Switch Bezel               | 1                  | 100        | 5                       | 3                   | 8                        |
| <i>Power Seat Switch</i>              | <i>1</i>           | <i>100</i> | <i>5</i>                | <i>3</i>            | <i>8</i>                 |
| Seat Harness, Power or Manual, Lumbar | 1                  | 53.6       | 5                       | 5                   | 10                       |
| Seat Harness, Power                   | 1                  | 100        | 5                       | 5                   | 10                       |
| Lumbar Switch                         | 1                  | 53.6       | 5                       | 4                   | 9                        |

**Figure 9.5: Plan for Every Part with the Information Needed to Calculate Maximum In-Plant Inventory Levels**

The use of equation 9.1 to calculate the maximum in-plant inventory level for the power seat switch (italicized above) given the information in the plant for every part is shown below.

**Maximum In-Plant Inventory Level (units) =**

$(5 \text{ days} + 3 \text{ days}) \times (38 \text{ seat sets per hour} \times 20 \text{ hours of production per day} \times 1 \text{ power seat switch per seat set}) = 6080 \text{ units}$

### 9.3.2 Conversion of Maximum Inventory into Storage Requirements:

Once the maximum in-plant inventory level has been calculated for each component, the space required to store the inventory can be determined. There are 4 main steps to this process:

- convert inventory from units of stock into containers of stock
- adjust inventory levels to account for lineside inventory
- for card parts - convert from containers of stock to racks of stock based on component packaging configurations
- for call parts - convert from containers of stock to columns of stock

#### Conversion from Units of Stock to Containers of Stock:

The maximum in-plant inventory level in terms of containers of stock can be calculated by dividing the maximum in-plant inventory level in units of stock by the container size of the component in question and then rounding up.

An example is shown below based on the maximum inventory of power seat switches which was calculated in section 9.3.1.

$$\text{Maximum In - Plant Inventory Level (containers)} = \left( \frac{6080 \text{ units}}{64 \text{ units per container}} \right) = 95 \text{ containers}$$

This process can be executed for all card and call parts.

Adjust Inventory Levels to Account for Lineside Inventory:

Since at all times there will be at least one container of each component at the lineside (unless a stock out condition has occurred), the marketplaces will not have to store all of the inventory indicated by the maximum in-plant inventory level calculation. In fact, theoretically, the amount of each component at the lineside should never fall below the minimum inventory level that was specified during the development of the pull system operational specifications. Therefore, in order to determine the number of containers of each component that require storage, an adjustment to the maximum in-plant inventory level must be made by subtracting from it the expected minimum lineside inventory level. The equation that is used to calculate the number of containers of each component that require storage is shown below.

***Inventory Requiring Storage (containers) =***

Maximum In-Plant Inventory (containers) – Minimum Lineside Inventory (containers)

**Equation 9.2: Calculation of the Amount of Inventory that Requires Storage**

An example of this process based on the maximum inventory of power seat switches and the specified lineside minimum of 1 container of stock is shown below.

***Inventory Requiring Storage (containers) = 95 containers – 1 container = 94 containers***

This process can be executed for all card and call parts.

Conversion from Containers of Stock to Racks of Stock for Card Parts:

Components are stored on pallets within the racks in the card part marketplace. Generally 1 pallet of a given component is stored on each tier of the racks as shown in figure 9.3. Because the racks used in the marketplace have 3 tiers, for every 3 pallets that need to be stored, 1 “column” of storage space will be required where a column is defined as 3 vertically adjacent tiers of a rack. For example, the racks shown in figure 9.3 would provide 3 columns of storage space. Depending on the configuration of the storage racks that are being used, a single rack may be able to provide as few as 1 or many as 4 columns of storage space. In the case of the purchased parts replenishment pull system, each rack provided 2 columns of storage space. This said, in order to determine how many racks will be needed in the card part marketplace, the number of

pallets that require storage must be calculated. This can be done with the aid of the packaging specification for each component.

In section 6.4, the “1121’s” that detail the packaging specifications for each component were discussed. The 1121 for each component includes the number of containers that are shipped on 1 pallet - the “unit load”. This information can be used to convert the amount of inventory that requires storage from containers of stock to pallets of stock. This is done by dividing the number of containers that require storage by the number of containers that make up a full pallet and then rounding up. An example of this process is shown below using power seat switches.

$$\text{Inventory Requiring Storage (pallets)} = \left( \frac{94 \text{ containers}}{12 \text{ containers per pallet}} \right) = 7.83 \approx 8 \text{ pallets}$$

Once the inventory has been converted to pallets, the number of pallets can be divided by 3 (because the racks used in the marketplace have 3 tiers) to determine the number of columns of storage space that are required. An example of this process is shown below using power seat switches.

$$\text{Inventory Requiring Storage (columns)} = \left( \frac{8 \text{ pallets}}{3 \text{ pallets per column}} \right) = 2.66 \approx 3 \text{ columns}$$

This process can be repeated for all card parts.

Once the number of columns of storage space that are required for each component has been determined, the requirements can be summed to find the total storage space that is needed. In the case of the purchased parts replenishment pull system approximately 60 racks (120 columns) were required in order to provide sufficient storage space in the card part marketplace. Knowing the footprint of the individual racks, an estimate of the total space required for the card part marketplace can be made. However, since there are generally 10 to 12 foot isles between the rows of storage racks that exist in the marketplace, the actual amount of space required will depend on the final configuration of the marketplace.

#### Conversion from Containers of Stock to Columns of Stock for Call Parts:

A given call part can be stacked 3 to 4 containers high in the call part marketplace. Therefore, to determine the actual number of spaces on the floor that are needed for storage of a given component, the number of containers that need storage is divided by how high that component can be stacked. This gives the number of “columns” of stock that need to be stored in the call part marketplace. The equation that is used to calculate the number of columns of each call part that require storage is shown below.

$$\text{Inventory Requiring Storage (columns)} = \left( \frac{\text{\# of containers requiring storage}}{\text{stack height of the component (container)}} \right)$$

### **Equation 9.3: Calculation of the Storage Space Requirements for Call Parts**

The actual floor space required for the storage of a given call part can then be determined by multiplying the footprint of the container the call part is packaged in by the number of columns that need to be stored. This process is shown below using a seat frame packaged in a 108 inch by 48 inch steel container as an example.

$$\begin{aligned} \text{Storage Space Required (square feet)} &= 4 \text{ columns of stock} \times 36 \text{ square feet per column} \\ &= 144 \text{ square feet of storage space} \end{aligned}$$

This process can be executed for all call parts. Summing the storage space requirements for each of the call parts does provide an estimate of the total size of the call part marketplace. However, from this process alone it is difficult to determine the exact amount of space that is required for call part storage because the actual configuration of the marketplace (including forklift isles, etc.) has a large impact on the space that is consumed.

## **9.4 Determination of the Location and Configuration of the Marketplaces:**

Because of the different factors that drive the locations of the card and call part marketplaces (these factors will be discussed throughout this section), there is generally only one card part marketplace within the plant while several call part marketplaces exist. In the case of the purchased parts replenishment pull system, one card part marketplace and two call part marketplaces were employed.

### **9.4.1 Card Part Marketplace:**

#### Location of the Marketplace:

There are several factors that impact the decision on where to locate the card part marketplace within the plant. These factors include: the number and location of receiving docks, the number of assembly processes that are served or could be served by the marketplace, and the space available in the plant.

If only one assembly process is ever going to be served by the marketplace and only one receiving area exists, the two main options for the location of the card part marketplace are:

- 1) close to the receiving dock
- 2) close to the assembly process being served

These options are not mutually exclusive. In an ideal environment the receiving dock is located adjacent to the build area and the marketplace is then both close to the receiving dock and close to the build area. In most cases however, receiving and assembly are separated. If this is the case, there are arguments that support both of the options described above. Having the card part marketplace located near receiving reduces the time required to move newly delivered parts from the receiving docks to the marketplace. This reduces receiving's pull system support related workload. Having the card part marketplace located near the assembly process that is being served reduces the route driver's transit time between the marketplace and the lineside. Transit time is important because it can become a limiting factor when reductions in route time are considered. In more complex situations more factors need to be considered.

Generally, in a plant that has fully implemented SMF, many different assembly processes will be supported by one card part marketplace. If many assembly processes are being served and only one receiving area exists, it makes sense to locate the marketplace close to the receiving area as long as that does not result in unreasonable route driver transit times. If many assembly areas are being served and many receiving areas exist, it makes sense to locate the marketplace centrally in an attempt to balance the load on receiving and the route driver's transit time.

In the case of the card part marketplace for the purchased parts replenishment pull system, the choice of location was driven more by space availability than proximity requirements. There was a vacant area within the plant which was large enough to provide the required storage space and could most likely be expanded as other build areas were converted to the pull system. The area was also attractive because it was fairly close to a primary receiving dock.

#### Configuration of the Marketplace:

Configuring the card part marketplace involves locating the storage racks, the SMART office, and the overflow area within the space that has been allocated for the marketplace. Additionally, components and marketplace addresses must be assigned to the storage racks.

Locating the racks, the SMART office, and the overflow area within the marketplace is best done with the aid of a CAD drawing. A drawing of the space that has been allocated to the marketplace can be constructed making sure that building columns and existing aisle ways are included. Potential configurations of the marketplace can be developed by experimenting with different locations for the racks, SMART office, and overflow area

while keeping in mind the need for proper spacing (10-12 feet) between the rows of racks. In the end, the best design is the one that provides ease of use for the route drivers and material handlers that work in the area while minimizing the floor space consumed.

The last step in the configuration of the card part marketplace is the assignment of components to specific storage racks (marketplace addresses). However, before parts can be assigned to specific racks, the delivery route that the route driver will follow must be developed. This is because, to minimize waste in the route drivers job, components need be assigned to particular racks so that the “pickup” sequence that the route driver executes when traveling through the marketplace mirrors the delivery sequence that the route driver executes at the lineside. In other words, the marketplace should be designed such that the first part that is picked up in the marketplace is the last part that is delivered to the build area and visa versa. The reason for this is simple. Because of the stacking of boxes that occurs when the route driver loads his vehicle, the last part that is picked up will be stacked on top of parts picked up earlier. Therefore, when the route driver makes his first delivery at the lineside the part that is needed will be on top of the stack and easily accessible to him. For example, let’s say that the material handler’s route takes him by lineside address FCD2, then FCD1, and then RB2. Components should be assigned to racks in the marketplace so that as the route driver travels down the rows of marketplace, the first component that is available for him for pick up is the component used at RB2, followed by the component that is used at FCD1, and then the component that is used at FCD2.

#### Design of the Delivery Route:

There are several factors to consider when designing the card part delivery route. These factors include existing traffic patterns within the plant, the precedence of assembly processes within the build area (you may want to deliver parts used at the beginning of the line before parts used at the end of the line), and the minimization of wasted transit time such as backtracking in the route. In the end, the best design is the one which minimizes wasted transit time while balancing the other factors of concern. Once the delivery route has been finalized, the card parts can be allocated to the racks in the marketplace and marketplace addresses can be assigned.

### **9.4.2 Call Part Marketplace:**

#### Location of Marketplace:

The location of the call part marketplaces is less arbitrary that the location of the card part marketplace. Because deliveries from the call part marketplaces to the lineside are generally more random and occur at higher frequencies than the regimented card part deliveries, it is advantageous to have the call part marketplaces as close to the lineside as possible. The closer the call part marketplaces are to the lineside, the greater the “time buffer” material handlers have to respond to requests for replenishment. For example, a general rule of thumb for call part replenishment is to have the builders call for new stock

when there are 20 minutes worth of parts remaining at their workstations. Now, if the call part marketplaces are a 10 minute round trip from the build area, the material handlers really only have 10 minutes to react to the builder's request. This may seem like plenty of time, and it would be if the material handlers were only replenishing a few parts. However, the material handlers in these situations are generally responsible for replenishing 20 or more parts with the statistical possibility that many could need replenishment within a very short span of time. If the call part marketplaces were moved closer to the lineside so that they were a two minute round trip from the build area, the "effective" time the material handlers have to react to the request for replenishment increases from 10 minutes to 18 minutes. Additionally, having the call part marketplaces closer to the build area decreases the total travel time material handlers have to spend to retrieve call parts.

In the case of the purchased parts replenishment pull system, because of the large amount of inventory that needed storage, two call part marketplaces were developed. The majority of the call parts were stored in the larger of the two marketplaces (the primary marketplace) which was located within the space allocated to the Mustang seat build area. The remainder of the call parts were stored in a secondary marketplace which was located directly adjacent to the card part marketplace.

#### Configuration of the Marketplaces:

The first step in the process of configuring the call part marketplaces was to determine which components would be assigned to which marketplace. The main factors that influenced component allocation were the frequency at which the component under consideration would need to be replenished and the number of columns of the component that needed to be stored.

The less demand that one container of a given component can satisfy, the more frequently that component will have to be replenished at the lineside. For example, if 1 container of a given call part can satisfy 1 hour of demand, a new container of that component will need to be delivered to the lineside each hour. If 1 container of a given call part can satisfy 20 hours of demand, then a new container of that component will only need to be delivered to the line every 20 hours. From this example it is clear that if all call parts can not be stored near their point of use (as is the case in the 2 marketplace scenario) it makes sense to locate the components that require the most frequent replenishment nearer to their point of use while locating components that require less frequent replenishment in alternate locations. This helps to minimize the total travel time involved in the replenishment of call parts.

In order to determine which call parts would require replenishment most often a measurement of the number of "containers consumed per hour" for each call part was made. The number of containers consumed per hour is simply the inverse of the number of hours of demand that one container of a given component can satisfy. For the call parts this measure ranged from 0.1, meaning that replenishment would only be required every 10 hours, to 2.1, meaning that just over 2 containers would need be delivered to the



line each hour. Based on this analysis, call parts requiring the most frequent replenishment were tentatively allocated to the primary call part marketplace while those requiring less frequent replenishment were allocated to the secondary marketplace.

Unfortunately the initial allocation of call parts was not very optimal because of the relatively few number of components that were assigned to the primary marketplace. It turned out that some of the components that were initially assigned to the primary marketplace required significant storage space so that they consumed a large portion space available in the marketplace. This led to only a handful of components being allocated to the primary marketplace while a significant number were allocated to the secondary marketplace. Because of this, many components that required frequent replenishment were relegated to the secondary marketplace. This scenario would have resulted in frequent trips to the secondary marketplace and a tremendous amount of transit time for the material handlers.

To help to improve the initial allocation, tradeoffs were made where components which required more frequent replenishment were reallocated to the secondary marketplace to free up significant storage space so that several components that required slightly less replenishment could be allocated to the primary marketplace. For example, 1 particular call part required 40 columns of storage space because relatively few components were held in each container. Although this component required frequent replenishment at the lineside, if it was allocated to the primary marketplace it would have consumed nearly 60% of the space that was available there. This component was reallocated to the secondary marketplace and 4 components which were initially allocated to the secondary marketplace were stored in its place in the primary marketplace. Another option would have been to split the inventory of the component that required the large amount of storage space between the two marketplaces. However, doing so would have violated one of the main principles of the marketplace concept. One of the primary goals of the marketplace concept is to have just one location within the plant (other than the lineside) where a component can reside. Therefore, the inventory of a given component should never be split between multiple storage locations, or in this case, between multiple marketplaces.

Once the allocation process was completed, the call parts were assigned to specific locations within each marketplace and the short delivery routes needed to deliver the components to the lineside were developed.

### ***9.5 Chapter Summary:***

The development of card and call part marketplaces and the associated replenishment routes is a very detailed process which requires many tradeoffs to be made. In the case of the purchased parts replenishment pull system, most of the stakeholders involved in the development of the marketplaces and routes had a good grasp of the theory underlying the process which allowed tradeoffs to be made effectively.



## Chapter 10: Step 7 – Training

*“When you get into a new process without training and education, if things go wrong what do you do? No one knows how to solve the problems which just introduces frustration and people quit believing in the process” - Material Planning and Logistics Manager<sup>13</sup>*

This chapter reviews the training that was given to various stakeholders as part of the development of the purchased parts replenishment pull system.

### **10.1 Stakeholder Groups:**

The stakeholders that received training can be broken into three groups:

- builders - the hourly employees that assemble Mustang seat sets
- production supervisors - the salary employees responsible for the supervision of the builders and management of the build area
- “others” – the hourly employees that play a support role such as the material handlers assigned to the Mustang seat build area and the material replenishment coordinators that are responsible for managing the pull system once it is implemented

None of the stakeholder groups received exactly the same training regiment. For each group (and within group) different topics were covered at varying depths. The specific training stakeholders in each group received will be discussed in detail in a later section.

### **10.2 Training Needs:**

Generally, by the time SMF is implemented in an area, other elements of FPS are already in place. In the case of the Mustang seat build area, many of the elements of FPS were implemented simultaneously. Because of this, stakeholders in the purchased parts replenishment pull system not only needed to receive training specific to SMF, but they also needed training related to other elements of FPS. The training stakeholders needed can therefore be broken into two segments: general FPS training and SMF specific training.

#### General FPS Training:

The FPS team within the plant developed a structured training program that provided a strong foundation in FPS principles. The program specifically focused on providing the background needed to successfully pass the stability phase of the five phase FPS implementation process (discussed in section 2.3). Although the training program focused on facilitating stability, it was comprehensive enough to provide those receiving

the training with a sufficient background to be able to effectively absorb SMF specific training.

The general FPS training program included the following training modules.

- Continuous Improvement Work Groups (32 hours)
- Ford Total Productive Maintenance (16 hours)
- Quality Process Sheets (8 hours)
- Visual Controls (8 hours)
- Error Proofing (8 hours)
- Quick Changeover (8 hours)
- FPS Measurables (2 hours)

The Continuous Improvement Work Group module helps to develop teamwork and problem solving skills with a focus on the employees' role in the continuous improvement effort. The next five modules focus on specific elements of FPS. In each module the purpose of the FPS element that is being discussed is explained followed by hands-on experience in executing the tasks associated with the element of interest. In this way the training is a mixture of classroom lectures and hands-on reinforcement. The last module, FPS Measurables, communicates the metrics that are used to measure (and drive) the performance of the lean system. This is a very important module which helps to ingrain a "lean manufacturing" mindset into those being trained. Important concepts such as building exactly to customer demand and throughput time are discussed and examples of their measurement are shown.

#### SMF Specific Training:

The SMF implementation manual describes three possible levels of training for each stakeholder with the appropriate level of training depending on the "interaction" the stakeholder has with SMF. The three levels of training are <sup>6</sup>:

- Awareness
- Understanding
- Working Level Knowledge

As it's name suggests, awareness training is intended "make people aware" of SMF. Awareness training is mostly an exercise in communication and should touch everyone that will be at all effected by the implementation of SMF. Almost everyone in the plant is a candidate for awareness training. Understanding training is needed for those stakeholders that will be directly effected by SMF but will not necessarily be executing the process. The goal of understanding training is to communicate to various stakeholders the basics of SMF, their role in the SMF process, and how they can effect and be effected by it. A production supervisor is a good example of a stakeholder that should receive understanding training. The most exhaustive training is working level knowledge training. Stakeholders that execute the SMF process, such as a route driver, need to have working level (or in depth) knowledge of the process they are performing.

Working level knowledge training is generally specifically targeted to the task the stakeholder being trained is going to perform. For example, the working level knowledge training that the route driver would receive would focus specifically on internal logistics and the SMART card process.

In the case of the purchased parts replenishment pull system, training was not provided to the level prescribed by the SMF implementation manual in most cases. This was due mostly to time pressure. Stakeholders that should have technically received working level knowledge training, such as the route drivers, received understanding training in its place. After receiving training these stakeholders did not have in depth understanding of the process they were executing (as would be the case if they had received true working level knowledge training). However, they did understand the tasks they were supposed to perform. For example, while the route drivers did not have in depth knowledge of how the pull system operated, they did understand that the cards they were picking up represented orders and if they didn't fill the orders the build area would run out of stock.

Awareness training, although not formally planned, was accomplished by word of mouth within the plant. Understanding training was delivered by the SMF Process Owners and the Division SMF Coach. Understanding training took the form of one hour long small group sessions or one-on-one training depending on the topic. For example, the SMF process owners instructed small groups of builders on the operation of the pull system whereas the route drivers were trained on a one-on-one basis. For some stakeholders the formal training they received was supplemented by involvement in the development of the purchased parts replenishment pull system where they received more in depth exposure to SMF.

### ***10.3 Execution of Training:***

Each group identified in section 10.1 received different combinations of the FPS and SMF training protocols. The builders received the general FPS training and SMF understanding training which focused on the pull system and the responsibility they had for generating requests for material replenishment. In the "other" category, the material handlers (including the route drivers) received the general FPS training and SMF understanding training which focused on the pull system and the responsibility they had for receiving replenishment requests and delivering parts to the line. The material replenishment coordinators received general SMF understanding training and working level knowledge training on the SMART card system (the software program that is used to create and print SMART cards). Production supervisors received only general SMF understanding training mostly through exposure to the pull system development process.

The initial training was reinforced by "walk through" consulting sessions and by training supplements left in the build area (such as the famed "Top 5 questions asked about SMART cards" flyer).

#### **10.4 Issues with Training:**

The training described above was fairly effective at facilitating smooth operation of the pull system. Most of the “problems” that occurred once the pull system was launched were anticipated (this will be discussed in more detail in the next chapter). For example, it was fully expected that although the builders knew that they needed place the SMART cards into the collection mailboxes in order to request material replenishment, initially some builders would occasionally forget to do so.

There were two sources of “problems” however, that were clearly the result of either insufficient or failed training. The first source of problems was “supplemental” builders that had not received training. The training described above was given to the builders that were assigned to the Mustang seat build area full time. When there was absenteeism or overtime was needed, builders from other areas who had not received training were brought into the Mustang seat build area to fill in. In some instances these builders were brought up to speed by the production supervisor or other builders in the area on what they needed to do to request replenishment for the stock they were consuming. However, at other times no instruction was provided. In these cases the supplemental builders would fail to request new stock by either discarding the SMART cards or simply leaving them in the empty containers. Discovery that a supplemental builder had not received training would generally only occur when the production supervisor or material replenishment coordinator was alerted by the builder that he was nearly out of stock. At that point the supplemental builder received a “quick and dirty” training session on how to request replenishment of stock.

The second source of problems associated with either insufficient or failed training was builders who were building out of process or “building ahead”. This occurred because lean manufacturing concepts such as single piece flow and building exactly to customer demand had not been fully internalized and were therefore not being practiced. This caused actual demand to significantly exceed expected demand resulting in near stock out conditions at the lineside. To correct out of process building, the production supervisors reinforced the proper assembly process with the builder and the material replenishment coordinator further explained the relationship between the amount of stock at the line and the expected demand. However, building ahead continued to be a reoccurring problem. This reflects the powerful effect of engrained behavior patterns and provides a good example of the difference between going through the motions of training and really understanding the concepts the training is attempting to communicate.

#### **10.5 Chapter Summary:**

Training is obviously one of the most critical steps in the implementation of SMF. Without sufficient training of the stakeholders that control and effect the process, even the most perfectly designed pull system will fail. In the case of the purchased parts replenishment pull system, the initial level of training that was provided to stakeholders

was “sufficient”; however, benefits certainly could have been gleaned from more in-depth training.

Unfortunately, there was limited time to train the majority of the of the stakeholders (with the exception being those on the “lean team” or the SMF implementation team). For example, most builders were assigned to the Mustang seat build area only a short time before the area was to launch so that most of their time was spent learning the assembly process. This left little time for FPS and SMF training. Additionally, the material replenishment coordinator (the person responsible for monitoring the performance of the pull system) was not assigned to the implementation team until just before launch. In general, stakeholders were receptive to training. However, it is sometimes difficult to quickly convince people to do things in a dramatically different way than they have been doing them for years.





## Chapter 11: Step 8 – Implement

*“At first I was definitely a skeptic, but this system works. The significant thing was when we started up everything worked the way it was supposed to.” - Production Supervisor, Mustang seat build area<sup>14</sup>*

This chapter reviews the transformation of the purchased parts replenishment pull system from a process design into a functioning process. Of particular interest is the procedure that the implementation team and the material replenishment coordinator put in place to help achieve smooth implementation of the process.

### **11.1 Preparation for Implementation:**

The seven process development steps that have been discussed to this point only position the pull system for successful implementation. Even when tangible results begin to appear from the work that was done during the development process - the part storage and presentation racks are in place at the lineside, inventory and SMART cards have been deployed, marketplaces have been set-up, etc. - there is still no guarantee that the pull system will “work” once launched.

In order to improve the chances for a successful implementation, the implementation team and the material replenishment coordinator took a critical eye to the pull system and tried to imagine what events could cause the implementation to stumble. The goal of this process was to identify the factors that could lead to pull system failure so that a “procedure” which would help to prevent pull system failure could be implemented.

The group identified three primary factors that had the potential to lead to pull system failure.

- 1) stakeholders not properly executing tasks (such as builders not placing SMART cards in the mailboxes)
- 2) errors in the design of the pull system (such as a misallocation of SMART cards or a improper estimate of the demand for a component)
- 3) surprises

In the next section the specific procedure that was developed to address the factors listed above is discussed.

### **11.2 The Walk Through Procedure:**

The “walk through” procedure was developed primarily to address the concern that during the initial stages of implementation, builders and route drivers would not consistently execute the tasks required for smooth pull system operation. Additionally, it

was also expected that the walk through procedure would help to identify errors in the design in the pull system and quickly highlight “surprises”.

As its name suggests, to execute the walk through procedure the SMF process owners and the material replenishment coordinator (called “consultants” from this point forward) would walk through the build area approximately every two to three hours. In these walk through sessions the consultants would examine the “condition” of the pull system and answer any questions that stakeholders may have. The walk through procedure was expected to help prevent pull system failures by either curbing the behavior that could lead to a system failure or by identifying a looming system failure as early as possible so that there was sufficient time to take corrective action.

On their walk-throughs, the consultants would check to make sure that components were being delivered to the proper lineside addresses by inspecting all of the lineside racks, they would stop by each workstation to assure that builders were handling SMART cards properly, they would answer any questions that builders had and solicit feedback about “how things were going”, they would check for violations of the minimum and maximum inventory levels, and they would talk to the route driver and the material handlers who were delivering call parts to see if they were having any problems. In short, the consultants looked for anything and everything that could go wrong at the lineside and lead to pull system failure.

The expectation of the implementation team was that the need for walk-throughs would diminish over time as the stakeholders moved down the learning curve and the errors in the design of the pull system were corrected. Initially, however, there was significant benefits from employing the procedure. The consultants often found several “problems” each time they walked through the build area. The most common problems encountered are listed below.

- “lost” and improperly handled SMART cards
- components delivered to the incorrect location
- insufficient amounts of inventory at the line

#### Lost and Improperly Handled SMART cards:

It was fully expected that some SMART cards would be lost resulting in the need for additional cards to be inserted into the pull system as a replacement for those that had disappeared. SMART cards were lost for a variety of reasons. Some cards were found in the garbage having been thrown away. Cards were generally thrown away by supplemental builders (which were discussed in chapter 10) who had not been properly trained and had confused the SMART cards with a “disposable” component identification device such as a packing list. SMART cards were also found on the floor presumably after having fallen out of the container of components they were originally attached to.

Mishandling of SMART cards also occurred. Initially, as expected, many builders simply forgot to place SMART cards in the collection mailboxes. In these cases, cards

would generally collect in plies on a workstation or in a builder's back pocket. There were other cases where the mishandling of cards took a more unexpected form. Some builders would remove the SMART cards from the containers in the lineside storage rack prematurely, thereby requesting replenishment of stock before it was needed. For example, in some cases as soon as a delivery of 2 containers of stock was made, the builder would remove the SMART cards from both containers and place the cards in the mailbox to request replenishment. This “premature” generation of SMART cards led to more containers of stock being delivered to the lineside than were needed to support actual demand.

The consultants tried to lessen the occurrence of lost and mishandled cards by providing training to the supplemental builders in proper card handling procedures and by reinforcing the same procedures with all of the builders.

#### Components Delivered to the Incorrect Location:

As expected, route drivers would sometimes deliver components to the incorrect lineside address. Most times this occurred with components that were used in multiple locations within the build area. For example, bolts that were used in multiple processes were sometimes delivered to the incorrect lineside address. This issue stemmed from the fact that the route drivers were focusing primarily on a component’s part number when they were making deliveries. As discussed in section 5.3.5, components that are used in multiple locations within the build area have unique SMART numbers assigned to them for each lineside address at which they used. Because of this, a component’s part number, its SMART number, and the lineside address to which it should be delivered all appear on the SMART card for that component. For a proper delivery to be made, all three “identifiers” need to match those on the label at the lineside delivery point.

In most cases where improper delivery occurred, deliveries were made without certifying that the SMART number and lineside address on the SMART card matched those on the lineside label where the part was being delivered. In these cases, if the part number that appeared on a SMART card matched the part number on the label attached to the lineside rack or workstation, the part was delivered without concern for the SMART number or lineside address. In other words, route drivers focused on part numbers when deciding on where to deliver components without paying sufficient attention to SMART numbers and lineside addresses. To help eliminate incorrect deliveries, the consultants reinforced to the route drivers the importance of all three identifiers.

#### Insufficient Amounts of Inventory at the Line:

While the loss and mishandling of SMART cards was the major source of violations of the minimum inventory level, the misallocation of SMART cards also led to near stock out conditions. In some cases too few SMART cards were assigned to a given component because the allocation of SMART cards was based on an “old” packaging specification.

The initial allocation of SMART cards for a given component was based on the packaging specification that existed at the time the pull system was launched. However, many of the packaging changes that were requested by the implementation team as part of the packaging optimization process did not take effect until after the pull system was operational. Because of this, at various points in time a component's packaging would change which would require an increase in number of SMART cards allocated to that component (the reallocation always took the form of an increase because the "new" packaging held less inventory per container than the "old" packaging).

Unfortunately, some changes in packaging were not identified before the new packaging found its way to the lineside. Because of this, in some cases there was a mismatch between the number of SMART cards that were required for smooth operation of the pull system and the number of SMART cards that were actually circulating through the pull system. When situations where the allocation of SMART cards was based on an outdated packaging specification were discovered, the material replenishment coordinator would immediately increase number of SMART cards allocated to the component of interest.

### **11.3 Lessons Learned:**

Many lessons can be taken from the implementation process. However, the main lesson learned was that a proactive stance towards problem identification can help to keep an implementation from becoming an exercise in crisis management.

There are two distinctly different approaches to identifying the problems that are going to occur during any implementation - the "wait and see" approach and the "proactive" approach. The wait and see approach advocates a reactionary stance to problem identification. When employing the wait and see approach, problem solving begins only once a problem has become evident, usually through some sort of system failure. Once the problem has been identified, a solution is sought in order to bring the system back on line. However, in most cases where this approach is taken, a second problem crops up before the first has been solved. Before long, the system is mired in problems and any "quick and dirty" solutions that will fix the problems, even temporarily, are adopted. In the end, most problems are solved but stakeholders have little faith in the robustness of the system or in the skill of those running it.

Conversely, the proactive approach prescribes active investigation of predefined areas of concern in order to uncover problems before they effect system performance. This is the approach that was taken during the implementation of the purchased parts replenishment pull system. By anticipating possible causes of system failure and seeking them out, the implementation team was able to identify problems before they "announced" themselves by causing the pull system to fail. By identifying problems while they are "small" and before they caused system failure, time and energy can be spent on solving the problems. When the "wait and see approach" is taken, most of the time that is available to solve problems is instead spent responding to the questions of upset stakeholders such as the production supervisor who's area is not meeting schedule because there is a shortage of

parts. The proactive approach kept the implementation team out of the reactionary mode of problem solving which allowed the team to solve problems instead of manage crisis's .



## Chapter 12: Conclusions

The conclusions drawn from this research project can be separated into two main groups. The first group of conclusions is based on the needs matrices that have been developed throughout the thesis. In this chapter the needs matrices are consolidated and analyzed which yields some observations about resource involvement, knowledge requirements, project planning, and the learning process. The second group of conclusions are more general in nature and are drawn from the implementation as a whole. The second group of conclusions is not directly linked to analysis of the consolidated needs matrix although some overlap between the two groups exists.

### 12.1 The Consolidated Needs Matrix:

The needs matrices that were presented at the beginning of most chapters provided a sense of the resources required and the tasks that the resources needed to execute during various steps in the development process. In addition, the needs matrices provided an indication of where theoretical knowledge was needed in order to optimally execute the tasks associated with a given step and where “what to do” knowledge was required. Consolidation of the needs matrices provides a “big picture” view of the resource and knowledge requirements for the pull system development process. The consolidated needs matrix is shown below.

| Title                                   | Stakeholder Group               | Status  | Theoretical Knowledge Required, Present |           |           |           |           |
|---|---------------------------------|---------|---|-----------|-----------|-----------|-----------|
|   |                                 |         | Step 2(a)                               | Step 3(b) | Step 4(c) | Step 5(d) | Step 6(e) |
| SMF Process Owner (Salary)              | Ford Production System          | Core    | X, O                                    | X, X      | X, O      | X, X      | X, X      |
| SMF Process Owner (Hourly)              | Ford Production System          | Core    | X, O                                    | X, O      | X, O      | X, X      | X, X      |
| Lean Manufacturing Consultant (Intern)  | Mustang Seat Build Area         | Core    | X, X                                    | X, X      | X, O      | X, X      | X, X      |
| Ergonomics Representative               | Ergonomics                      | Support |   | O, O      |           | O, O      |           |
| Material Replenishment Coordinator      | Ford Production System          | Support |   |           |           |           | X, X      |
| Division SMF Coach                      | Ford Production System          | Support | X, X                                    | X, X      | X, O      | X, X      | X, X      |
| Lean Manufacturing Expert (Consultant)  | Ford Production System          | Support | X, X                                    | X, X      | X, O      | X, X      | X, X      |
| Health and Safety Representative        | Health and Safety               | Support |   |           |           |           | O, O      |
| Material Handling Supervisor            | Material Handling               | Support |   |           |           |           | X, X      |
| Material Handler - route driver         | Material Handling               | Support |   |           |           |           | O, O      |
| Material Handler - forklift driver      | Material Handling               | Support |   |           |           |           | O, O      |
| Material Handling Engineer              | Material Handling               | Support |   | O, O      |           | O, O      | O, O      |
| Pre-production Analyst                  | Material Planning and Logistics | Support | O, O                                    |           |           |           |           |
| Production Supervisor                   | Mustang Seat Build Area         | Support | X, X                                    |           |           |           |           |
| Seat Builder                            | Mustang Seat Build Area         | Support |   |           |           | O, O      |           |
| Packaging Engineer                      | Packaging Engineering           | Support |   | X, X      |           |           |           |
| Procurement and Distribution Supervisor | Procurement                     | Support |   | X, O      |           |           |           |
| Plant Bargaining Representative         | Union Management                | Support |   |           |           |           |           |

X = required or present

O = not required or absent

(a) Step 2 – Determination of Lineside Demand

(b) Step 3 – Determination of Packaging and Shipping Specifications

(c) Step 4 – Development of SMART Card System Parameters and Determination of Lineside Inventory Levels

(d) Step 5 – Development of Lineside Part Storage and Presentation Infrastructure

(e) Step 6 – Development of Card and Call Part Marketplaces and Card Part Replenishment Routes

**Figure 12.1: The Consolidated Needs Matrix**

The format of the consolidated needs matrix differs somewhat from that of the needs matrices that were presented in earlier chapters. For each step the “Theoretical Knowledge Required” and “Theoretical Knowledge Present” columns have been collapsed into one column titled “Theoretical Knowledge Required, Present”. For a given step and stakeholder, if a check existed in the “Theoretical Knowledge Required” column of the earlier needs matrix, an X appears as the first entry in the “Theoretical Knowledge Required, Present” column of the consolidated needs matrix. If a check existed in the “Theoretical Knowledge Present” column, an X appears as the second entry in the “Theoretical Knowledge Required, Present” column of the consolidated needs matrix. For example, if theoretical knowledge was both required and present, an entry of X, X appears in the “Theoretical Knowledge Required, Present” column. If theoretical knowledge was required but was not present, an entry of X, O appears in the “Theoretical Knowledge Required, Present” column. If “what to do” knowledge was required for a given stakeholder to execute a task in a given step, an entry of O, O appears in the “Theoretical Knowledge Required, Present” column of the consolidated needs matrix (please refer to section 4.2 if clarification is required).

It is important to note that somewhat different theoretical knowledge is needed at different steps in the pull system development process (this can be seen in several cases in the consolidated needs matrix where a particular stakeholder possesses the theoretical knowledge required for one step but lacks it for another step). For example, the theoretical knowledge that is required in order to develop the operational specifications for the pull system is different that the theoretical knowledge required to properly design material replenishment routes.

Analysis of the development of the purchased parts replenishment pull system relative to the consolidated needs matrix yields several conclusions.

- *Members of the core team need to possess comprehensive theoretical understanding of Synchronous Material Flow and be able to apply that knowledge throughout the development process. Because of this, investments in the development of core team members’ theoretical knowledge and application skills are necessary and should pay dividends through successful implementation.*
- *In some cases, while theoretical knowledge was important, the “practical” (what to do) knowledge that certain implementation team members possessed was just as critical to the successful execution of a given task or step. For example, theoretical knowledge of pull system operation was required in order to properly “size” the racks and other parts presentation infrastructure developed during step 5. While the builders and ergonomics representative that were involved in the development of the parts storage and presentation infrastructure may not have understood how rack size related to the operation of the pull system, the practical knowledge that they brought to the development process was invaluable. The input provided by the builders and ergonomics representative significantly improved the initial infrastructure design proposals which were mostly based on “theory”. For example, the builders’*



knowledge of the “realities” of the assembly process led to modifications of the infrastructure which reduced part acquisition time and therefore reduced waste.

- *When planning for Synchronous Material Flow implementation, consideration needs to be given to the fact that at some points, time will be required to gain and transfer knowledge.* In some cases, members of the implementation team may need to develop theoretical knowledge in order to properly execute a task. For example, in order to complete step 4 (Development of SMART Card System Parameters and Determination of Lineside Inventory Levels) members of the implementation team needed to learn about pull system operation. Significant time was expended in the development of the computer model which assisted in the learning process. In other cases, the practical knowledge that exists on the implementation team may need to be tapped and transferred to other team members. For example, in order to complete step 5 (Development of Lineside Part Storage and Presentation Infrastructure) the practical knowledge that the builders possessed needed to be tapped so that the part storage and presentation infrastructure could be designed properly. The knowledge transfer was not immediate - more than one “session” was required before the practical information was thoroughly communicated. When the need for knowledge development or knowledge transfer will arise is somewhat difficult to predict with the exact amount of time the process will take being even harder to estimate. Because of this, it is unlikely that the implementation of a “new” process (one that requires learning) such as SMF will follow a linear timeline which is based only on the tasks that need to be executed and the expected amount of time that is required for the “physical” execution of each task.
- *In general, members of the implementation team had a greater understanding of the theory underlying the later steps of the development process relative to their understanding of the theory pertinent to the earlier steps. This was in part due to team members’ greater intuitive understanding of the theory underlying the later development steps and in part due to learning that occurred during the development process.* For example, the basic theory underlying the development of the call part marketplaces and replenishment routes is that components which require frequent replenishment should be stored as close to their point of use as possible in order to minimize the total transit time required to retrieve and deliver the components (see section 9.4.2 if clarification is needed). This type of logic made intuitive sense to most team members since they structure many of their “everyday” activities in much the same way. For example, team members who run errands on Saturdays plan their route to minimize the time it will take them to make all of their stops while other team members organize their desks so that items they use most frequently are kept closest to them. By contrast, it was more much more difficult for team members to intuitively understand the “true” operation of the pull system or “actual” versus average demand. The learning that occurred and the mindset that was developed during the early steps of the development process also helped implementation team members to better grasp the theory relevant to the later steps. The waste reduction mindset that was stressed early in the development process gave team members a good foundation on which to build an understanding of the later steps.

- *In general, only a limited number of stakeholders needed to possess theoretical knowledge at every step of the development process. Several stakeholders participated in only one or two steps - sometimes needing theoretical knowledge and sometimes needing “what to do” knowledge in order to contribute. This all suggests that a stakeholder by stakeholder approach is required when trying to anticipate the resource, knowledge, and learning needs for each step in the development and implementation process.*

## **12.2 General Conclusions:**

- *In some cases, strictly following the cookbook approach could result in failed implementations. It would be extremely difficult for an implementation team that was completely devoid of theoretical understanding of the principles behind SMF to be able to successfully implement it if the only tool at their disposal was the SMF implementation manual. In some cases the SMF implementation manual fails to provide the user with all of the information that is required to properly execute the tasks that create the elements of the pull system (this was discussed at length in section 7.8). In other cases, the manual fails to present the theory that underlies the tasks which makes it difficult to see the linkages that exist between various elements of the pull system. The lack of a system view becomes an issue when the team needs to make decisions regarding the tradeoffs that must inevitably be made during the development and implementation of any new process. These facts make it difficult for an “unknowledgeable” implementation team to develop a well functioning pull system based on the SMF implementation manual alone. Furthermore, since the manual is more of an instruction book than a teaching tool, it is difficult to learn about the fundamentals behind SMF simply by executing the tasks in the implementation manual. Because of this, an unknowledgeable implementation team will have difficulty reacting to unexpected pull system performance and sustaining the system once it is launched. Unfortunately, failed implementations of this type may be extremely detrimental to the long-term viability of lean manufacturing techniques within Ford. Generally, if the initial application of a new process is not successful, it is extremely difficult to convince the stakeholders effected by the process to “give it a second chance.”*
- *Not everyone that participates in the implementation of SMF has to be an “expert” in lean manufacturing principles; however, for the implementation to be successful, theoretical knowledge must exist in some key stakeholders. In the case of the purchased parts replenishment pull system, one of the core team members and two of the support team members understood the principles behind the process that was being implemented. The knowledge that these stakeholders possessed helped to facilitate the learning process for those stakeholders with less understanding of lean manufacturing principles and helped to “fill in the gaps” in the SMF implementation manual. In this way, the members of the implementation team that understood the theory behind SMF were able to provide sufficient knowledge transfer so that “gaps” in knowledge that could have resulted in failed process implementation were closed.*

- Learning can occur during the implementation process which will result in future implementations following more of an applied learning approach.* As mentioned above, simply executing the tasks in the SMF implementation manual does not generate significant learning. However, learning can occur during the implementation process in two other ways. First, members of the implementation team can learn from each other. In order for this to take place some team members must initially possess fundamental understanding of SMF. These knowledgeable team members can teach those that have less experience with the process. Second, the implementation team can learn together by going “beyond” the implementation manual. This occurred during the development of the purchased parts replenishment pull system with the creation of the computer model that simulated pull system operation. As learning occurs and the overall level of knowledge on the implementation team grows, the team will become less reliant on the implementation manual and more reliant on their own knowledge. Because of this, future implementations involving members of the original implementation team will be driven more by experience and knowledge than by tasks in the implementation manual.
- The process of pull system development lowered the water to uncover some rocks.* The development of the pull system involved detailed analysis of every purchased part that goes into the production of Mustang seat sets. The critical eye that this analysis took to the processes involved in procuring, storing, and consuming purchased parts uncovered several sources of waste. For example, as was discussed in section 6.9, an investigation of the procurement process revealed a lack of understanding of the procurement system. In the end, this learning resulted in significant reductions in safety stock. In general, the detailed nature of pull system development raises questions about the processes that currently exist in the plant. Simply raising the questions often leads to the discovery of inefficiencies and waste.
- When developing a pull system, the “linkages” that exist between the various elements of the system are important to understand but are often not obvious and sometimes very detailed in their nature.* For example, in order to “synchronize” the flow of components to the build area with the rate at which the components are being consumed, the material handlers that are responsible for replenishing the lineside should be idle when the build area is idle (see section 5.3.1 if clarification is required). It is not intuitively obvious that synchronization is required to properly control lineside inventory levels. Because of this, the need to coordinate the activities of the material handlers with the schedule of the build area they are replenishing is not traditionally recognized. A second example of the subtle nature of the linkages that exist between the elements of the pull system has to do with the application of visual management techniques in the marketplaces. It is fairly obvious that the amount of stock in the marketplaces at any point in time is related to the activities of the procurement department and the build area. However, it is not so obvious that variability in the daily usage rate of the components housed in the marketplaces makes it extremely difficult to employ visual management techniques (see section 9.3.1 if clarification is required).



## Chapter 13: Technical Appendix

### ***Topic A) Calculation of the Actual Production Rate:***

In section 5.3.1 a quick method for determining the actual production rate was shown. In this section a more explicit method of calculating the actual production rate is reviewed. The reason for the more explicit treatment in this section is that in some cases production rate information will not be available in the easily manipulated form that it was for the Mustang seat build area. In fact, it is by following the explicit process detailed in this section that the Mustang lean team generated the production rate information that was provided to the pull system implementation team.

In order to determine the actual production rate we must first determine the takt time. The takt time is a measure of how often one unit of finished goods must be produced in order to meet customer demand. Takt time is calculated by determining the available production time during a certain time interval and dividing that amount by the customer demand during the same time interval.

$$\text{takt time} = \frac{\text{available production time}}{\text{customer demand during production time}}$$

#### **Equation A.1: Calculation of Takt Time**

Early on in the development of the Mustang seat build area the lean team calculated the takt time for the build area. The first step was to determine the available production time or uptime. That is, for how much of the day would the build area actually be available to produce seat sets? The only downtime that lean team considered was break time - they ignored other planned downtime activities such as preventative maintenance (the assumption was made that activities such as preventative maintenance would be done on an overtime basis). Knowing that there was a 22 minute rest break every 4 hours of production, for a total of 88 minutes of break time over a 16 hour day, the lean team calculated that there were 872 minutes (16 hours less the 88 minutes of break time) of available production time during a 16 hour day. The 872 minutes of production time over the 16 hour day results in 54.5 minutes of available production time per hour. The next step was to determine customer demand over the same 16 hour period. Dearborn stated that they would require 38 seat sets per hour. Over a 16 hour period the demand rate of 38 seat sets per hour results in a total demand of 608 completed seat sets. With this information, the lean team calculated the takt time to which the build system must produce in order to meet customer demand. The calculation is shown below

$$\text{takt time} = \frac{872 \text{ minutes}}{608 \text{ seat sets}} \approx 1.43 \text{ minutes (or 86 seconds) per seat set}$$

In other words, the Mustang seat build area must produce a completed seat set every 86 seconds of continuous operation.

The actual production rate can then be determined by inverting the takt time and multiplying by 3600 seconds to present the rate in units of seat sets per hour. The calculation of the actual production rate is shown below.

$$\textit{Actual Production Rate} = \frac{3600 \text{ seconds per hour}}{86 \text{ second takt time}} \approx 42 \text{ seat sets per hour}$$

#### **Equation A.2: Calculation of the Actual Production Rate**

Finally, the average production rate can be calculated by dividing the average number of seconds available for production in a scheduled hour by the takt time. Remembering that there is an average of 54.5 minutes of production per hour, the calculation of the average production rate is shown below.

$$\textit{Average Production Rate} = \frac{3270 \text{ available seconds per hour}}{86 \text{ second takt time}} \approx 38 \text{ seat sets per hour}$$

#### **Equation A.3: Calculation of the Average Production Rate**

**Topic B) Analysis of the SMF Implementation Manual Inventory Level Equations:**

This section presents a detailed analysis of the equations initially presented in section 7.2.1 (shown below). The analysis highlights the factors that appear in the equations and the impact those factors have on lineside inventory levels. A brief “intuition building” review of what factors that “should” be used to determine lineside inventory levels is also presented.

$$\text{Safety Stock} = \text{roundup} \left( \frac{0.5 \times \text{Hourly Demand (units)} \times \text{Route Time (hours)}}{\text{Container Size (units)}} \right)$$

$$\text{Cycle Stock} = \text{roundup} \left( \frac{\text{Hourly Demand (units)} \times \text{Route Time (hours)}}{\text{Container Size (units)}} \right)$$

$$\text{Maximum Inventory} = \text{Cycle Stock} + \text{Safety Stock}$$

**Equation B.4, B.2, B.3: Inventory Equations Written in Terms of Safety Stock and Cycle Stock.**

Before analyzing the equations listed above, let’s think about what factors should be used to determine levels of safety stock and cycle stock from a common sense point of view. Safety stock is defined as extra stock that is needed to protect against demand and replenishment cycle variability. Therefore, factors representing the variability in demand and replenishment cycles would seem to be appropriate in an equation that would calculate safety stock. As the variability in demand and replenishment cycles increase, you would expect the calculated level of safety stock to increase. Cycle stock is stock that is *expected* to be used during the time interval between two adjacent deliveries. Therefore, factors representing the average demand for a component and the time between adjacent deliveries would seem to be appropriate in an equation that would calculate cycle stock. As the demand decreases and delivery frequency increases, you would expect the calculated level of cycle stock to decrease.

With this framework in mind, let’s analyze the stock and inventory equations listed above.

- **The level of safety stock is determined without consideration of demand and replenishment cycle variability.** As noted above, one would expect that demand and replenishment cycle variability would be taken into account when determining levels of safety stock. This is not the case when employing the SMF manual supplied

equation for safety stock. There are no terms in the equation that represent either demand or replenishment cycle variability. Instead, factors that represent the average hourly demand and the average replenishment cycle (the route time) are included. This is good proxy only if the assumption that variability in demand and delivery cycles scale with the magnitude of demand and length of the delivery cycle is valid. This is a weak assumption at best. All of this said, when a new product and a new inventory management system are being launched it is difficult to know the variability in demand or delivery cycle; therefore, it seemed reasonable to the implementation team to use the type of estimation that is prescribed by the above safety stock equation as a starting point.

- **The level of safety stock is set so that, if needed, it can satisfy 50% of the demand that is expected during the replenishment cycle.** For example, if the route time (the replenishment cycle) is 2 hours, the safety stock must be able to satisfy 1 hour worth of demand. This is a result of the “0.5” and “route time” terms in the safety stock equation. The other terms in the equation - average hourly demand and container size - when taken as a ratio express safety stock in the form of “containers of stock used per hour”. The 0.5 and route time terms transform the ratio from containers of stock used per hour to “containers of stock used in ½ of the route time”
- **The level of safety stock will be at least 1 full container of components regardless of the container density.** The roundup factor in the safety stock equation insures that there will be an integer number of containers of safety stock with a minimum of 1 container. The approach of limiting safety stock to an integer number of containers is taken mostly to assist in visual management of the pull system. It is assumed that the builder will most reliably react to violations of the minimum level of inventory if the minimum level is represented by full containers of stock. The belief is that the improved precision of reaction to inventory level violations that full containers of safety stock provide is worth the uplift in safety stock that is sometimes required in order to removed judgement from the reaction process. The negative side effect of this policy is that it results in unnecessarily high levels of safety stock when components (such as bolts) are packaged in very high density containers.
- **The level of safety stock will be set to exactly 1 container if the container can satisfy 50% of the demand that is expected during the replenishment cycle.** The numerator of the safety stock equation yields, in units, the expected demand for a component during ½ of the route time. If the number of components in 1 container is greater than the expected demand during ½ of the route time, the denominator will be greater than the numerator, yielding a fraction that is less than 1. The roundup factor will increase the safety stock to 1 full container. Obviously, the smaller the container size the greater the number of containers of safety stock that will be required.
- **The level of cycle stock is based on the replenishment cycle and the hourly demand.** This makes sense given our analysis of the factors that should make up the cycle stock equation. As the route time and the hourly demand increase the calculated level of cycle stock increases.



- **There will be an integer number of containers of cycle stock.** As with the safety stock calculation, the roundup factor insures that cycle stock will be based on an integer number of containers of stock.
- **The level of cycle stock will be set to exactly 1 container if the container can satisfy the demand that is expected during the replenishment cycle.** The numerator of the cycle stock equation yields, in units, the expected demand for a component during the route time. If the number of components in 1 container is greater than the expected demand during the route time, the denominator will be greater than the numerator, yielding a fraction that is less than 1. The roundup factor will increase the cycle stock to 1 full container. Obviously, the smaller the container size the greater the number of containers of cycle stock that will be required.

### **Topic C) Determination of the Number of SMART Cards:**

This section presents a detailed treatment of the information covered at a high level in section 7.3.

In the operation of a kanban system, each container of components is accompanied by a kanban card, or in our case, a SMART card. Therefore, each container that is being specified by the safety stock and cycle stock calculations will have a SMART card attached to it. However, calculating the number of SMART cards needed for operation of the pull system is not as straightforward as it may seem. Simply determining the maximum number of containers that will exist at the lineside and assigning an equal number cards will result in failure of the pull system due to a stock out at the lineside.

Before explaining why the pull system will fail if the number of SMART cards in the pull system for a given component is based on the maximum number of containers of that component at the line, a brief review of the operation of the purchased parts replenishment pull system is in order.

In order to replenish card parts, route drivers follow a fixed route through the build area every 2 hours. As they travel through the build area they collect SMART cards that have been placed in “mailboxes” within the build area, with each card representing 1 container of a specific part. SMART cards are “generated” whenever a new container of card parts is opened in the build area. When a new container of parts is opened the SMART card is removed from the container and placed it in a mailbox. After the route driver has collected the SMART cards, in effect collected his order, he travels back to the card part marketplace and fills the orders as instructed by the SMART cards. The route driver attaches the SMART cards to the containers of purchased parts that match the descriptions on the cards and heads back for the build area repeating the process every 2 hours.

By tracing through a replenishment cycle, it can be shown why the pull system will fail if the number of SMART cards in the pull system for a given component is based on the maximum number of containers of that component at the line. Given a 2 hour route time and a demand rate of 42 units per hour, let’s assume that 1 container of a given component can satisfy exactly 1 hour of demand. Substituting these parameters into the safety and cycle stock equations (equations 7.3, 7.4, 7.5) yields the following results.

**Safety Stock** = roundup  $((0.5 \times 42 \times 2)/(42))$  = roundup (1) = 1 container of safety stock

**Cycle Stock** = roundup  $((42 \times 2)/(42))$  = roundup (2) = 2 containers of cycle stock

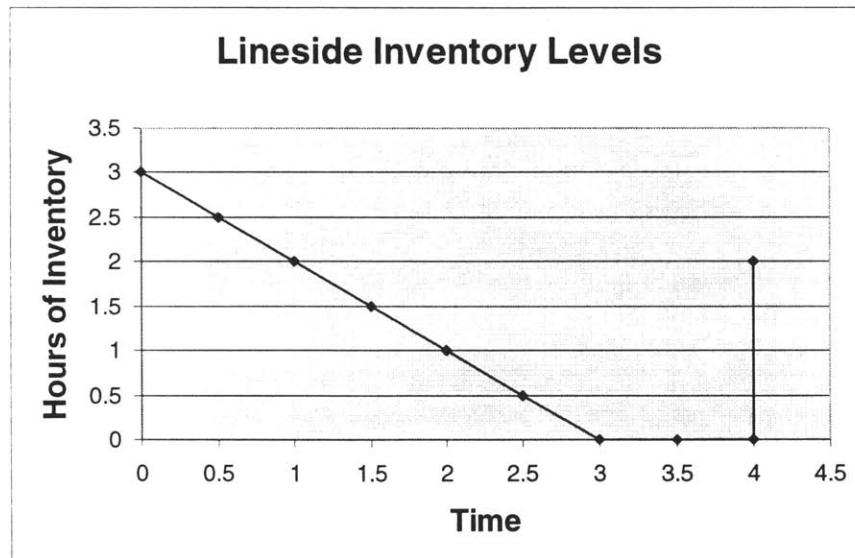
**Maximum Inventory** = 2 + 1 = 3 containers of stock at the lineside

The equations specify 1 container of safety stock, 2 containers of cycle stock, and a maximum inventory level of 3 containers of stock in total. Now, if 1 SMART card is

assigned to each container there will be a total of 3 SMART cards circulating through the pull system supporting the replenishment of the component. The line will be initially stocked (before production begins) with the full complement of safety and cycle stock - 3 containers in all.

As production begins, a SMART card will be removed from the first container of stock that is opened and placed in the SMART card mailbox (the collection point for SMART cards). As the second hour of production begins, the first container of components will be exhausted and a second container will be opened (because each container can support 1 hour of demand). As the second container is opened, the SMART card attached to that container will be placed in the SMART card mailbox along side of the card taken from the first container of stock. At the end of the second hour, the route driver arrives at the line to pickup the cards and deliver new stock. However, the route driver has no stock to deliver because he had no SMART cards, and therefore, no orders to fill.

After collecting the SMART cards, the route driver heads back to the marketplace to fill the order for 2 containers of the component and will not return to the line again until the end of the fourth hour of production. During the third hour of production, the third container of stock, the safety stock, will be used. At the end of the third hour of production a stock out condition will occur, and unless immediate expediting action is taken, the condition will exist until the next delivery occurs. A graphical representation of this scenario is shown below.



**Figure C.1: Stock Out Condition Caused by Misallocation of SMART Cards**

Why did the stock out condition occur? It occurred because of the 1 cycle lag between when an order is placed and when delivery of that order occurs. The deliveries in one route are based on the cards picked up during the previous route. In our case, the route

driver had no cards, and therefore no orders for stock replenishment, from a previous route because he was performing the first delivery route in the production process. Knowing this, how do we calculate the number of SMART cards that are required for smooth operation of the pull system while satisfying the safety stock requirements that have been prescribed? To answer this let's go back to the example.

If the route driver had had either 1 or 2 containers of components to deliver on his first route, the stock out condition would not have occurred. Delivery of 1 or 2 containers of stock would have increased the lineside inventory level to 2 or 3 hours respectively. Two or 3 hours of lineside inventory would have been sufficient stock to support production until the next delivery occurred (at the end of the fourth hour of production) when 2 containers would be have been delivered (based on the 2 SMART cards that were generated during the first delivery cycle). However, if only 1 container had been delivered during the first replenishment route, a zero stock condition would have occurred at the end of the fourth hour of operation. Delivering 1 container of stock during the first delivery cycle, while helping to avoid a stock out condition, clearly does not prevent violation of the minimum inventory level and the required use of safety stock in order to continue production.

If 2 containers of stock are delivered during the first delivery cycle, minimum inventory levels would not be violated. In fact, the pull system would operate smoothly fluctuating between the minimum and the maximum inventory levels as prescribed by the inventory level calculations. In other words, the integration of 2 additional SMART cards (for a total of 5 SMART cards) into the pull system allows for smooth operation of the card part replenishment pull system. This makes intuitive sense. As has been discussed many times, cycle stock needs to be replenished each replenishment cycle. The 2 cards that were generated during the first 2 hours of production represent the use of cycle stock. Therefore, delivering any less than 2 containers of stock during the first replenishment cycle will not be sufficient to replenish the cycle stock used during that cycle. This will result in the use of safety stock and a possible stock out condition. Given this understanding, a general equation for the calculation of the total number of SMART cards required for any component can be developed. This equation is shown below.

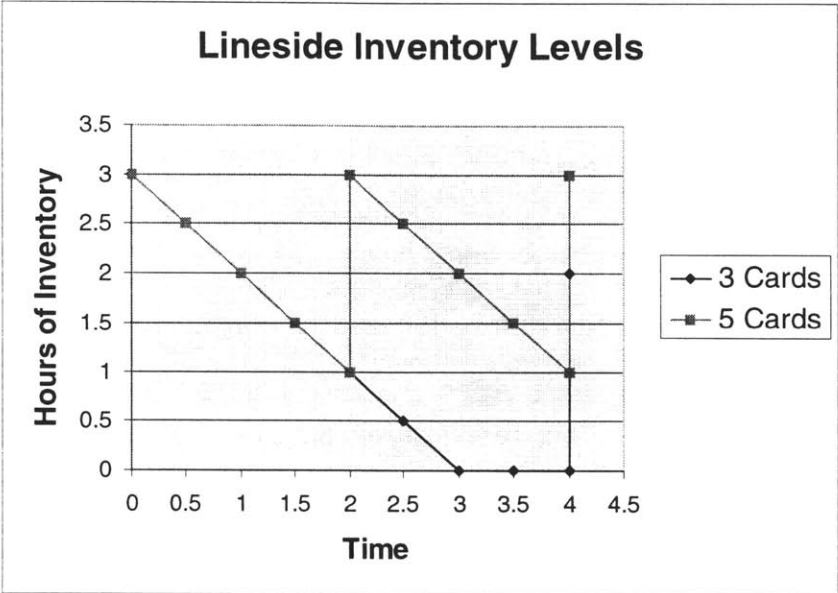
$$\textit{Total Number of SMART Cards} = \# \text{ of containers of safety stock} + 2 \times (\# \text{ of containers of cycle stock})$$

#### **Equation C.5: Calculation of the Total Number of SMART Cards**

This equation is also provided in the SMF implementation manual without the motivating theory. Substituting the parameters given in the example into the equation yields the following results.

$$\textit{Total Number of SMART Cards} = 1 + 2 \times (2) = 5$$

In our example, the 2 additional cards specified by equation C.1 (over the number of cards specified if only the maximum inventory level had been considered) allows for the pull system to function smoothly even though the 1 cycle lag exists. The additional cards begin “in the route” and allow for cycle stock to be replenished during the first delivery cycle. A graphical representation of the operation of the pull system with 3 cards and 5 cards is shown below.



**Figure C.2: Comparison of Pull System Operation Given Different Numbers of SMART Cards**

### **Topic D) The Effect of Excess Stock on Pull System Operation:**

In section 7.6.1 excess stock is defined. This example will help to explain the impact that excess stock has on the operation of the pull system.

Given that demand for a certain component is 42 units per hour, a full container holding 50 units of stock can satisfy 1.2 hours of demand. The operational specification for the pull system given these parameters is for a minimum inventory level of 1 container, cycle stock of 2 containers, a maximum inventory level of 3 containers, and 5 total SMART cards circulating in the pull system. In this case, each container of components contains 8 units of excess stock - the actual container size of 50 units less the optimal container size of 42 units.

For this example it is assumed that that deliveries to the lineside occur at the end of the 2 hour replenishment cycle, that is after 2 hours, 4 hours, etc. of production. Assuming that deliveries occur at the end of the replenishment cycle assures that by the time a delivery arrives the maximum amount of inventory that can possibly be consumed during a replenishment cycle will have been consumed.

Regardless of the number of SMART cards in the system, it makes intuitive sense that at the end of the first replenishment cycle 2 containers of stock (100 units) must be delivered to the lineside in order to replenish the 84 units of cycle stock that were consumed during the 2 hour replenishment cycle. Although 2 containers of stock are more than enough to replenish the stock that was consumed, if only 1 container of stock is delivered, a net deficit of 34 units will occur, the minimum inventory level will be violated during the second replenishment cycle, and safety stock will have to be used to support production.

As our intuition suggested, based on the SMART card calculations, 2 containers of stock are delivered to the line during the first and most other replenishment routes; however, the delivery of 2 containers of stock causes a violation of the predicted maximum inventory level. The reason for this is quite straightforward – for the first 2 hours of production 2 containers of stock are delivered to the line while less than 2 containers have been consumed.

In order to avoid a maximum inventory level violation, both containers of cycle stock (100 units of stock) would have to be completely consumed during the first 2 hours of production. In our case, unless actual demand far exceeds predicted demand, only 84 units will be consumed. This leaves 16 units of *accumulated excess stock* from the first 2 containers of cycle stock that can be used for production during the next replenishment cycle.

To picture this visually, let's assume that the lineside storage rack for the component is just large enough to hold the predicted maximum inventory level of 3 containers. If 2 containers of stock are delivered to the line and there is only space in the storage rack for

1 of the containers (because only 1 container of stock has been completely consumed during the first replenishment cycle) then there has been a violation of the maximum inventory level. Although 1 container did not “fit” into the rack, the magnitude of the maximum inventory level violation is less than 1 full container of stock. Since there is an open container in the storage rack, the magnitude of the violation of the maximum inventory level is simply the 16 units of accumulated excess stock in the open container.

If each container held only 42 units of the component, no excess stock would exist, and assuming that deliveries occurred at the end of replenishment cycle, no violations of the maximum inventory level would occur. Exactly 2 containers (84 units) of cycle stock would be consumed during each delivery cycle and exactly 84 units would be delivered to replenish it. Additionally, the pull system would behave as specified with lineside inventory levels fluctuating between the predicted minimum and maximum inventory level of 1 and 3 containers respectively. From this example it is clear that excess stock and the corresponding maximum inventory level violations are a result of non-optimal packaging.

### **Topic E) Critical Point of Accumulation of Excess Stock:**

This section presents a detailed treatment of the information covered at a high level in section 7.6.1.2.

The following discussion will help to explain in detail the factors that influence when the critical point of accumulated excess stock is reached and review the specific mechanics of the pull system that result in the abatement of the accumulation of excess stock. The discussion is based on the example provided in section 7.6.1.

Just after a delivery has arrived the excess stock that exists at the lineside is spread across multiple containers. For example, at the end of the first replenishment cycle the 32 units of excess stock are spread across 3 containers. The open container in the rack, referred to as the “consolidated” container, holds the 16 units of excess stock that were pooled as a result of production during the first replenishment cycle. The other 16 units of excess stock are divided between the 2 containers that were delivered at the end of the replenishment cycle. As production continues during the second replenishment cycle, the excess stock will again be consolidated into one container by the production process. Once the second delivery arrives, however, the excess stock will again be spread across multiple containers.

Each replenishment cycle begins with demand being satisfied by the stock in the open (consolidated) container. Therefore, in order for the critical point to be reached and only 1 new container of stock to be opened (and therefore only 1 SMART card to be generated), the consolidated container must be able to support the demand expected during the replenishment cycle with the help of only 1 new container of stock. For example, given that 84 units of a component will be demanded during the replenishment cycle, the consolidated container has to contain at least 34 units of stock in order for it and only 1 new container to be able to support the demand over the replenishment cycle. Based on this analysis, it is not the total number of units of accumulated excess stock that is of interest, *it is the accumulated excess stock that exists in the open (consolidated) container, that controls the critical point.*

If there were 48 units of accumulated excess stock but only 32 units of it were in the open container, 2 new containers would have to be opened during the replenishment cycle. The open container could satisfy the first 32 units of demand but a new container would have to be opened to satisfy the next 50 units of demand and a second new container would have to be opened to satisfy the last 2 units of demand. 2 SMART cards would be generated, 2 containers of cycle stock would be delivered, and the excess stock would continue to accumulate. If the open container held 48 units, it and only 1 new container could satisfy the demand experienced during the replenishment cycle. Only 1 SMART card would be generated and, during the next replenishment cycle, only 1 container of cycle stock would be delivered depleting the accumulated excess stock.



The equation below defines the amount of stock that must exist in the consolidated container in order to reach the critical point of accumulated excess stock.

**Stock Required in Consolidated Container =**

*Expected Demand During Replenishment Cycle – Stock in 1 Full container*

**Equation E.6: Equation for Determining Amount of Stock that Must Exist in the Consolidated Container in Order for Critical Point to be Reached.**

The table below represents the operation of the pull system for the example that we have been discussing. The key entry in the table, the “accumulated excess stock in the consolidated container”, highlights the replenishment cycle in which the critical point threshold is broken. All of the entries in the table represent the values at the end of the replenishment cycle under consideration.

| Replenishment Cycle | Number of SMART cards generated | Number of Containers Delivered | Units of Stock at Line | Accumulated Excess Stock | Accumulated Excess Stock in Consolidated Container | Number of Containers at the Lineside |
|---------------------|---------------------------------|--------------------------------|------------------------|--------------------------|--|--------------------------------------|
| 1                   | 2                               | 2                              | 166                    | 32                       | 16   | 4                                    |
| 2                   | 2                               | 2                              | 182                    | 48                       | 32   | 4                                    |
| 3                   | 2                               | 2                              | 198                    | 64                       | <b>48</b>  | 4                                    |
| 4                   | 1                               | 2                              | 214                    | 80                       | 14   | 5                                    |
| 5                   | 2                               | 1                              | 180                    | 46                       | 30   | 4                                    |
| 6                   | 2                               | 2                              | 196                    | 62                       | 46   | 4                                    |

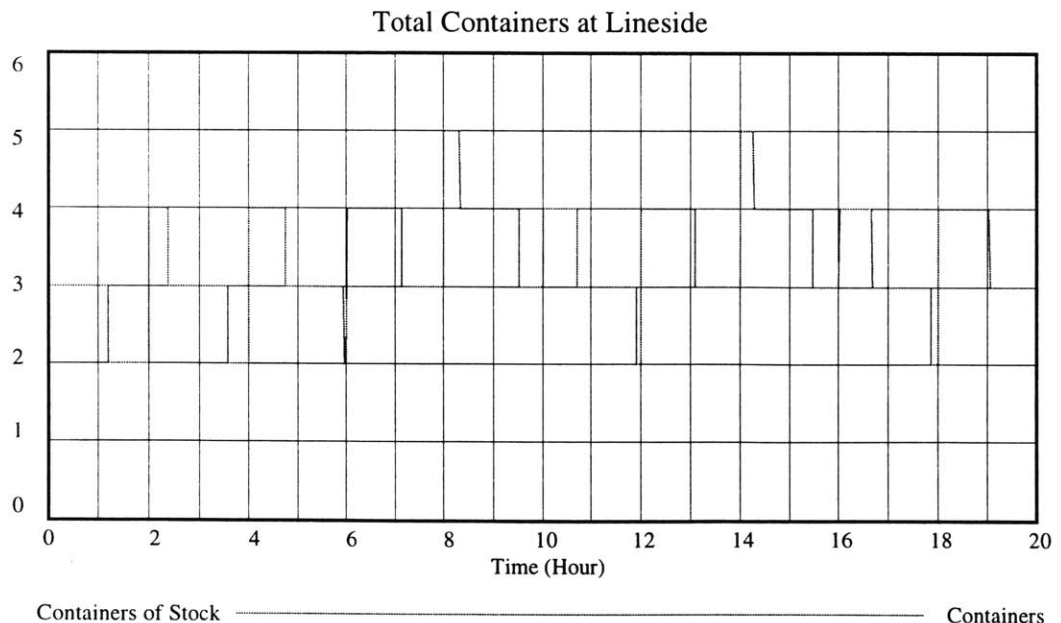
**Figure E.3: Characteristics of Pull System Operation**

Inspection of the table allows for two important points to be made having to do with the mechanics of the pull system.

- **The level of accumulated excess stock continues to rise for 1 replenishment cycle after the critical point is reached.** This is because of the 1 cycle delay between order placement and order delivery. Reaching the critical point during the third replenishment cycle causes only 1 SMART card to be generated during the subsequent replenishment cycle - the order generated during the fourth replenishment cycle is smaller than usual. However, at end of the fourth replenishment cycle 2 containers, not 1, of stock are delivered because deliveries received during one replenishment cycle are based on the SMART cards generated during the previous replenishment cycle. Therefore, since 2 SMART cards were generated during the third replenishment cycle, 2 containers will be delivered at the end of the fourth replenishment cycle. It is not until the fifth replenishment cycle that the effects of the “smaller order” are observed when only 1 container of stock is delivered to the line and the level of accumulated excess stock is decreased.

- The number of containers of stock at the lineside peaks 1 replenishment cycle after the critical point is reached.** This is because of the container exhaustion process. During most replenishment cycles in our example, 2 containers are exhausted and 2 new containers are delivered. For example, during the second replenishment cycle 1 container is exhausted after 2.4 total hours of production and a second container is exhausted after 3.6 total hours of production. During most replenishment cycles the exhaustion pattern causes the number of containers at the line to fluctuate between a minimum of 2 just before a delivery occurs and a maximum of 4 just after a delivery. However, during the fourth replenishment cycle, the cycle that occurs immediately after the critical point has been reached, only 1 container of components is completely exhausted. Because of this there are 3 containers at the line when the delivery arrives at the end of the fourth replenishment cycle. Since the number of containers that are delivered is based on the number of cards generated during the previous replenishment cycle, although 2 containers were not exhausted, 2 containers are delivered. This causes the inventory level to rise to its highest point of 5 containers. The delivery of only 1 container of stock at the end of the next (fifth) replenishment cycle will adjust the maximum inventory level back downward to 4 containers of stock.

A graphical representation of the example that has been discussed is shown below. The information conveyed is the total number of containers of stock at the lineside - full or otherwise. The accumulation of excess stock in the consolidated container can be observed by the increasing length of time the container that is open at the beginning of the delivery cycle is able to satisfy demand.



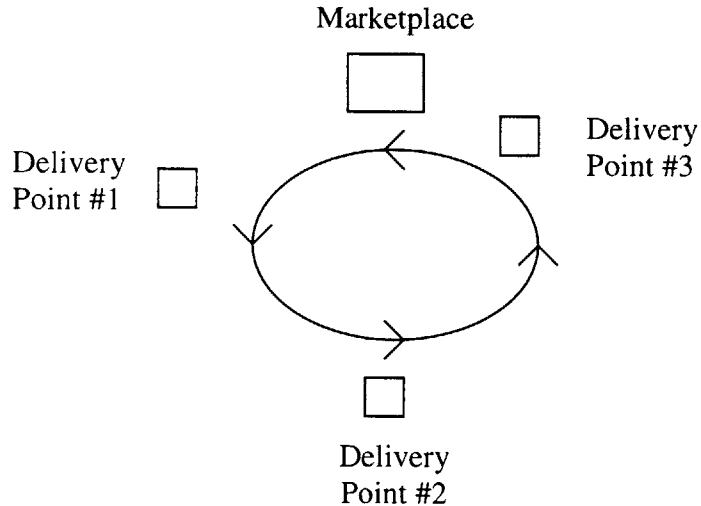
**Figure E.4: Graphical Interpretation of Pull System Operation**

### **Topic F) The Effect of Over-replenishment on Pull System Operation:**

A brief review of over-replenishment was presented in section 7.6.2. In this section a more detailed analysis of over-replenishment is presented.

Over-replenishment is caused by the fact that during the first replenishment cycle a fixed amount of stock is delivered to the line based on the maximum amount of cycle stock that can be consumed by the time the first delivery arrives. For example, if the duration of the replenishment cycle is 2 hours, at most 2 hours worth of stock can be consumed by the time the first delivery arrives. To protect against the maximum consumption of stock, 2 hours of stock must be delivered to the line to avoid violations of the minimum inventory level and the use of safety stock.

An example based on the simplified delivery route shown in the figure below will help to show the effect that over-replenishment has on the operation of the pull system.



**Figure F.5: Simplified Card Part Delivery Route**

For this example let's assume that demand for the components at delivery points 1, 2, and 3 is 42 units per hour. Let's also assume that each component is packaged optimally, satisfying exactly 1 hour of demand. Given these parameters and a 2 hour replenishment route, the operational specification for the pull system in this case is for a minimum inventory level of 1 container, cycle stock of 2 containers, a maximum inventory level of 3 containers, and 5 total SMART cards circulating through the pull system. Finally, let's assume that the route driver arrives at the 1<sup>st</sup> delivery point 30 minutes into his route, the 2<sup>nd</sup> delivery point 1 hour and 15 minutes into his route, and the 3<sup>rd</sup> delivery point at the end of his 2 hours route (as we have been assuming for all examples up to this point). For example, if production begins at 6 A.M. replenishment of stock to the 1<sup>st</sup> delivery point in the route would occur at 6:30 A.M., just 30 minutes after production began.

Replenishment of the 1<sup>st</sup> delivery point would not occur again until 8:30 A.M., 2 hours after the first delivery arrived.

If the 1<sup>st</sup> delivery point receives replenishment 30 minutes after production begins, no containers of stock will be completely exhausted when the first delivery arrives. Even with the optimal packaging, an immediate violation of the maximum inventory level will occur. After just 30 minutes of production there will be 5 containers of stock at the first delivery point instead of the predicted maximum of 3 containers.

When the route driver arrives at delivery point #2 (after 1 hour and 15 minutes of production) only 1 container of components will be completely exhausted. The delivery of 2 new containers of stock will drive the level of lineside inventory up to 4 containers of stock and cause a violation of the maximum inventory level.

After 2 hours of production the route driver will arrive at the 3<sup>rd</sup> delivery point. Unlike the condition at the other 2 delivery points, by the time the route driver arrives 2 containers of stock will be exhausted. Delivery of 2 new containers of stock will exactly replenish what has been used during the replenishment cycle and the level of lineside inventory will rise to its predicted maximum level.

Analysis of the three scenarios described above shows differing performance of the pull system depending on where in the replenishment route the delivery point is. This information is summarized in the table below.

| Delivery Point | Hours into Replenishment Route | Number of SMART Cards Generated by Time of Delivery | Number of Containers Delivered | Number of Containers at the Lineside Just After Delivery | Number of Hours of Stock Just After Delivery | Number of Hours of Stock at End of Replenishment Route |
|----------------|--------------------------------|---|--------------------------------|--|--|--|
| 1              | 0.5                            | 1   | 2                              | 5  | 4.5  | 3  |
| 2              | 1.25                           | 2   | 2                              | 4  | 3.75   | 3  |
| 3              | 2                              | 2   | 2                              | 3  | 3  | 3  |

**Figure F.6: Characteristics of Different Delivery Points**

It is interesting to note that by the end of the first replenishment cycle, there is the same amount of inventory at all three delivery points. This may lead you to believe that the violations of the maximum inventory level were just a transient effect during the first delivery cycle and that the pull system will perform as prescribed from the second replenishment cycle forward. This is not the case. To see the actual performance of the pull system let's trace through the second delivery cycle.

At 8:30 A.M. the route driver will arrive at the 1<sup>st</sup> delivery point once again. When the route driver arrives there will be a total of 3 containers of stock at the line, 2 full containers and 1 half full container. The route driver will delivery 1 container of stock since only 1 SMART card was picked up at the 1<sup>st</sup> delivery point during the first

replenishment cycle. The delivery of 1 container of components will cause a violation of the maximum inventory level as the inventory rises to 4 containers of stock.

At 9:15 A.M. the route driver will arrive at the 2<sup>nd</sup> delivery point. When the route driver arrives there will be a total of 2 containers of stock at the line, 1 full container and 1 three quarters full container. The route driver will deliver 2 containers of stock since 2 SMART cards were picked up at the 2<sup>nd</sup> delivery point during the first replenishment cycle. The delivery of 2 containers of components will cause a violation of the maximum inventory level as the inventory rises to 4 containers of stock.

At 10 A.M. the route driver will arrive at the 3<sup>rd</sup> delivery point. Unlike the condition at the other 2 delivery points, by the time the route driver arrives there is only 1 container of stock at the line. The route driver will delivery 2 containers of stock since 2 SMART cards were picked up at the 3<sup>rd</sup> delivery point during the first replenishment cycle. Delivery of 2 new containers of stock will exactly replenish what has been used during the replenishment cycle and the level of lineside inventory will rise to its predicted maximum level of 3 containers.

The table below summarizes the performance of the pull system at the different delivery locations during the second replenishment cycle.

| Delivery Point | Hours into Replenishment Route | Number of SMART Cards Generated by Time of Delivery | Number of Containers Delivered | Number of Containers at the Lineside Just After Delivery | Number of Hours of Stock Just After Delivery | Number of Hours of Stock at End of Replenishment Route |
|----------------|--------------------------------|---|--------------------------------|--|--|--|
| 1              | 0.5                            | 2   | 1                              | 4  | 3.5  | 2  |
| 2              | 1.25                           | 2   | 2                              | 4  | 3.75   | 3  |
| 3              | 2                              | 2   | 2                              | 3  | 3  | 3  |

**Figure F.7: Characteristics of Different Delivery Points**

As was predicted, violations of the maximum inventory level occurred again during the second replenishment cycle. Let's look at one more replenishment cycle to see if conditions change again or stabilize and come to equilibrium.

At 10:30 A.M. the route driver will arrive at the 1<sup>st</sup> delivery point for a third time. When the route driver arrives there will be a total of 2 containers of stock at the line, 1 full containers and 1 half full container. The route driver will delivery 2 containers of stock since 2 SMART cards were picked up at the 1<sup>st</sup> delivery point during the second replenishment cycle. The delivery of 2 containers of components will cause a violation of the maximum inventory level as the inventory rises to 4 containers of stock.

At 11:15 A.M. the route driver will arrive at the 2<sup>nd</sup> delivery point for a third time. When the route driver arrives there will be a total of 2 containers of stock at the line, 1 full

container and 1 three quarters full container. The route driver will delivery 2 containers of stock since 2 SMART cards were picked up at the 2<sup>nd</sup> delivery point during the second replenishment cycle. The delivery of 2 containers of components will cause a violation of the maximum inventory level as the inventory rises to 4 containers of stock.

At 12 P.M. the route driver will arrive at the 3<sup>rd</sup> delivery point. Unlike the condition at the other 2 delivery points, by the time the route driver arrives there is only 1 container of stock at the line. The route driver will delivery 2 containers of stock since 2 SMART cards were picked up at the 3<sup>rd</sup> delivery point during the first replenishment cycle. Delivery of 2 new containers of stock will exactly replenish what has been used during the replenishment cycle and the level of lineside inventory will rise to its predicted maximum level of 3 containers.

The table below summarizes the performance of the pull system at the different delivery location during the third replenishment cycle.

| Delivery Point | Hours into Replenishment Route | Number of SMART Cards Generated by Time of Delivery | Number of Containers Delivered | Number of Containers at the Lineside Just After Delivery | Number of Hours of Stock Just After Delivery | Number of Hours of Stock at End of Replenishment Route |
|----------------|--------------------------------|---|--------------------------------|--|--|--|
| 1              | 0.5                            | 2   | 2                              | 4  | 3.5  | 2  |
| 2              | 1.25                           | 2   | 2                              | 4  | 3.75   | 3  |
| 3              | 2                              | 2   | 2                              | 3  | 3  | 3  |

**Figure F.8: Characteristics of Different Delivery Points**

Analysis of the tables characterizing the second and third replenishment cycle indicates that the pull system has reached equilibrium. Specifically, the last two columns of the tables did not change between the second and third replenishment cycle, indicating that inventory levels have stabilized.

Therefore, at steady state, the magnitude of the violation of the maximum inventory level is dependent on when during the first replenishment cycle a specific delivery point receives its first delivery. This is evidenced by the different steady state inventory level characteristics of delivery points 1 and 2.

Analysis of Differences Between Delivery Points:

As discussed earlier, the relationship between the amount of stock that is delivered during the first replenishment cycle and the amount of stock that has been consumed at the time of delivery causes violations of the maximum inventory level and causes the discrepancy between steady state inventory levels among different delivery points. Detailed analysis of the delivery points discussed in the previous section will help to clarify why the magnitude of over-replenishment differs among delivery points.

For the 2<sup>nd</sup> delivery point, the inventory level fluctuates between 1.75 and 3.75 hours of stock. At both ends of the spectrum, the inventory is 0.75 hours higher than predicted by the SMF manual supplied inventory level calculations. It seems as though an “extra” 0.75 hours of inventory has somehow been injected into the pull system at the 2<sup>nd</sup> delivery point. The table below details the amount of stock that is consumed and replenished at the 2<sup>nd</sup> delivery point during the first 4 replenishment cycles.

| Replenishment Cycle | Number of SMART cards generated | Number of Containers Delivered | Stock Consumed at Time of Delivery (hrs) | Stock Consumed Since Previous Delivery (hrs) | Stock Replenished (hrs) | Replenishment less Consumption (hrs) |
|---------------------|---------------------------------|--------------------------------|--|--|-------------------------|--------------------------------------|
| 1                   | 2                               | 2                              | 1.25                                     | 1.25   | 2                       | 0.75                                 |
| 2                   | 2                               | 2                              | 3.25                                     | 2  | 2                       | 0                                    |
| 3                   | 2                               | 2                              | 5.25                                     | 2  | 2                       | 0                                    |
| 4                   | 2                               | 2                              | 7.25                                     | 2  | 2                       | 0                                    |

**Figure F.9: Summary of Stock Usage and Replenishment at the 2<sup>nd</sup> Delivery Point**

The key observation that can be made from inspection of the table is that during the first delivery cycle 2 hours of stock are delivered when only 1.25 hours of stock are consumed. This “over-replenishment” of 0.75 hours of stock is identified in the column titled “replenishment less consumption”.

The extra stock resulting from over-replenishment during the first replenishment cycle remains “in the system” and will cause violations of the maximum inventory level each time a delivery is made. This is because from the second replenishment cycle on, each delivery of stock replenishes exactly the amount of stock that was consumed since the previous delivery. For example, between the first and second deliveries 2 hours of stock are consumed. The amount of stock that was consumed is completely replenished when 2 hours of stock are delivered to the line when the second delivery arrives. This leaves no opportunity for the 0.75 hours of extra stock delivered during the first replenishment cycle to be consumed.

It is important to note that the situation at the 1<sup>st</sup> delivery point (where the first delivery occurred after only 0.5 hours of production) does not follow exactly the analysis laid out above. From the analysis above, it would seem that the 1<sup>st</sup> delivery point would have 1.5 hours of extra stock at steady state. However, at steady state, the first delivery point only has 0.5 hours of extra stock.

The table below helps to identify the source of the discrepancy.

| Replenishment Cycle | Number of SMART cards generated | Number of Containers Delivered | Stock Consumed at Time of Delivery (hrs) | Stock Consumed Since Previous Delivery (hrs) | Stock Replenished (hrs) | Replenishment less Consumption (hrs) |
|---------------------|---------------------------------|--------------------------------|--|--|-------------------------|--------------------------------------|
| 1                   | 1                               | 2                              | .5                                       | .5   | 2                       | 1.5                                  |
| 2                   | 2                               | 1                              | 2.5                                      | 2  | 1                       | -1                                   |
| 3                   | 2                               | 2                              | 4.5                                      | 2  | 2                       | 0                                    |
| 4                   | 2                               | 2                              | 6.5                                      | 2  | 2                       | 0                                    |

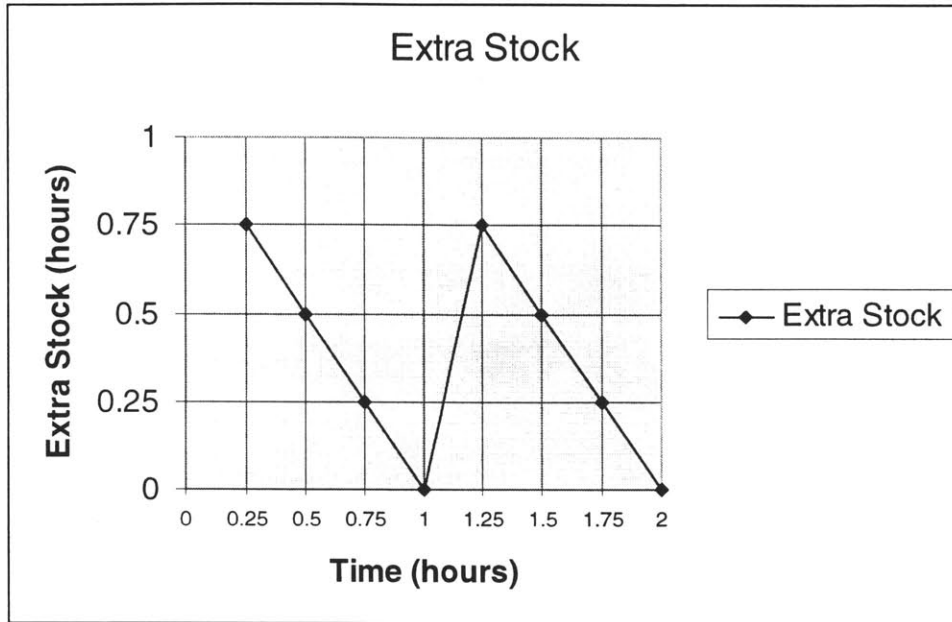
**Figure F.10: Summary of Stock Usage and Replenishment at the 1<sup>st</sup> Delivery Point**

The key observation is that although the first delivery does result in 1.5 hours of extra stock (as we would predict), the extra stock is partially consumed during the second replenishment cycle. Specifically, because only 1 SMART card is generated by the time of the first delivery, only 1 container of stock is delivered during the second replenishment cycle. This results in only 1 hour worth of stock being delivered during the second replenishment cycle when 2 hours of stock are consumed. Because of this, 1 hour of the initial 1.5 hours of extra stock is consumed to support production during the second replenishment cycle. From the third replenishment cycle on the behavior at the 1<sup>st</sup> delivery point exactly follows that which was described for the second delivery point - 2 hours of stock are consumed between deliveries and 2 hours are delivered to replenish what was consumed.

A general observation can be made that, within the 1 hour segments of the replenishment cycle, the earlier that the first delivery occurs, the greater the amount of extra stock that will exist at steady state. The result of this is that different delivery points have different steady state inventory levels.



The graph below shows the level of extra stock at 8 delivery points along a 2 hour replenishment route.



**Figure F.11: Extra Stock at Different Delivery Points**



## References

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- <sup>2</sup> Shingo, Shigeo, A Study of the Toyota Production System From an Industrial Engineering Viewpoint, Productivity Press, 1989.
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- <sup>5</sup> Rinehart, Huxley, Robertson, Just Another Car Factory? Lean Production and Its Discontents, IRL Press, 1997.
- <sup>6</sup> Ford Production System Institute, "SMF Working Knowledge Workshop" manual, April, 1998.
- <sup>7</sup> Data Provided by Ann I. Jordan, Division SMF Coach, Visteon Interior Systems Division.
- <sup>8</sup> Framework based on personal conversations with Dr. Joel Cutcher-Gershenfeld regarding the research done by the Lean Aircraft Initiative Implementation Team on an implementation "Field Book".
- <sup>9</sup> Quote taken from an interview of the Salary SMF Process Owner which was performed by the author on December 4, 1998.
- <sup>10</sup> Quote taken from an interview of the Procurement and Distribution Supervisor which was performed by the author on December 1, 1998.
- <sup>11</sup> Quote taken from an interview of a Mustang Seat Builder which was performed by the author on December 14, 1998.
- <sup>12</sup> Quote taken from an interview of a Union Bargaining Representative which was performed by the author on December 11, 1998.
- <sup>13</sup> Quote taken from an interview of the Material Planning and Logistics Manager which was performed by the author on December 1, 1998.
- <sup>14</sup> Quote taken from an interview of a Mustang seat build area Production Supervisor which was performed by the author on December 1, 1998.