Implementing Lean Material Management in an Extended Value Stream

By

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Submitted to the Sloan School of Management and the Department of Mechanical Engineering in partial fulfillment of the requirements for the degrees of

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and

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Abstract

American Axle & Manufacturing, Inc. (AAM) is still in the process of transitioning to a culture of "lean manufacturing" as opposed to the current culture of "mass production". This thesis involved working with AAM employees and suppliers at various locations to understand how material flows between and within AAM's plants, the reasons for and analysis of the current state of material management, and opportunities for improvement. Attention is also given to the cultural and business context in which this work takes place, and the issues relating to efforts to implement change in large industrial organizations.

This work produced two strategic-level products and one tactical-level product to improve lean material management at AAM described herein. Cultural observations are also provided.

At the strategic level, one project focused upon making extended value stream maps of material flow between AAM plants and suppliers/processors. This information allows all decision-makers at AAM to objectively examine a common set of information, information which was previously unavailable to any one individual. Extended value stream mapping allowed supply chain inventory and lead time-reduction opportunities to be identified.

The focus upon extended value streams increased awareness of the need to more fully account for costs in making part procurement decisions. Therefore, a second strategic project involved the development of a total cost decision tool, and its use in making sourcing decisions. This computer spreadsheet-based tool uses simple inputs to quickly produce a more all-encompassing estimate of the total costs of purchasing parts from a given supplier. Traditionally, only piece-price plus freight costs were used to determine sources of supply. Other, additional factors may alter the decision of which supplier to use if they are considered.

The tactical-level project involved implementation of a lean pull system. This project involved coordinating teams at two separate axle shaft manufacturing plants to

implement a more effective visual pull system between and within the plants, using lean concepts for material management and flow.

A final aspect of the thesis was to examine the current business context in which the lean systems are to operate, as well as the strategic, cultural, and political aspects that influence change management in large organizations.

One conclusion drawn from the internship is that the firm should start emphasizing visual control on the plant floor, and less supervisor work on paper in their offices after their shifts end. If the production boards and visual controls are in constant disarray, this needs to be resolved as quickly as a failed customer delivery, because it is fundamentally undercutting the ability of the organization to improve what it provides to customers through better quality and productivity. It also hinders efforts to reduce costs to bid for new work. Failing to attract new work is as damaging as a failed customer delivery, except that it will happen a year from now rather than today.

Thesis Advisor: Stanley Gershwin
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- HLS Consultant Earl Wilson

Note on Proprietary Information

In order to preserve confidentiality, the data presented throughout this thesis have been altered and do not represent the actual values at American Axle & Manufacturing, Inc. The financial and operational information have been disguised to protect competitive information.

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1. Introduction

American Axle & Manufacturing, Inc. (AAM) is a world leader in the manufacture, engineering design, and validation of driveline systems, chassis systems and forged products for trucks, buses, sport utility vehicles, and passenger cars. A consistently profitable tier-one supplier to both domestic and foreign OEM automobile manufacturers as well as other suppliers, AAM had revenues of approximately $3.4 billion in 2005. In addition to its U.S. locations in Michigan, New York, and Ohio, AAM also has offices or facilities in Brazil, the UK, China, Germany, Poland, India, Japan, Mexico, and South Korea.

AAM is organized into two product divisions: the Driveline Division and the Metal Formed Products Division. The Driveline Division generates the majority of AAM's revenue through the manufacture of front axles, rear axles, differentials, drive shafts, crankshafts, steering and suspension systems and integrated modules and systems. The Metal Formed Products Division generates revenue through the forging and machining of automotive components such as axle shafts, differential gear components, hypoid pinions and ring gears, stabilizer bars and other components [American Axle & Manufacturing, 2006].

The objective of this thesis was to understand material management for some of the value streams for AAM's products, and to implement the tools of lean material management to improve operating performance. Extended value stream mapping was used to define the current state of product flow between plants, suppliers, processors and customers. A total cost decision tool was developed to determine which suppliers to use for part procurement decisions, and used for actual business cases. A lean pull system and material markets were implemented at one plant location.

1.1 Thesis Motivation

AAM faces increasing global competition and cost pressures in both the driveline and the metal formed products businesses. Declining sales and market share of AAM's largest OEM customer, General Motors Corporation (GM), presents a major challenge. While 22% of AAM's revenue is non-GM derived and is growing [American Axle & Manufacturing, 2006], the long time span between new program concepts and production (up to four years) and the competitiveness of the industry mean that rapid increases in revenue cannot be achieved by developing new customers, although longer-term possibilities exist. Costs for many commodities and freight are increasing, and labor costs are difficult to reduce because of existing labor contracts (although buy-out offers recently presented to the hourly associates are intended to help reduce labor and benefits costs in the long-term). In this challenging business environment, use of "lean manufacturing" management practices offers one way to reduce inventory costs, improve productivity, and create a continuous-improvement culture that can adapt faster than the competition.

A major initiative of AAM's corporate operations management team is to implement lean manufacturing on a company-wide basis. The immediate goals are to achieve the so-called "50-in-5 goals" (Lean Manufacturing Challenge 2006-2010) over the next five years:

- 50% Reduction in hours per axle
- $50 M inventory reduction
- 50% reduction in dock-to-dock time
- 50% fewer direct suppliers
- 50% of sales from non-GM customers
- 500,000 ft^2 of floor space made available

The longer-term goals are to achieve a continuous, self-sustaining competitive advantage through the implementation of lean manufacturing and lean management principles.

Over the past one and one-half years, AAM has developed a lean group in the Corporate Materials Department to assist with training, the development of company-wide lean standards, and to provide guidance on initial implementation steps at the local plant level. The Corporate Materials group also works with other departments to identify opportunities for lean initiatives at the strategic level, such as for supplier sourcing decisions. AAM has reached the point where routine use of lean manufacturing principles has become common at many facilities, although inconsistent across the company as a whole. Substantial improvements towards the "50-in-5 goals" have been achieved. Many opportunities remain.

The goal of this thesis was to understand material management for some of the value streams for AAM's products, and to implement the tools of lean material management to improve operating performance.

1.2 Thesis Overview

The author made use of value stream and extended value stream mapping techniques, inventory theory and supply chain theory, lean manufacturing principles, basic financial analysis, and strategic sourcing analysis. Extended value stream mapping was used to define the current state of product flow between plants, suppliers, processors and customers. A total cost decision tool was developed to determine which suppliers to use for part procurement decisions, and used for actual business cases. A lean pull system and material markets were implemented at one plant location. An overview of the thesis projects are provided in Table 1.

Project	Objective	Tools
1. Extended Value Streams	Identify actual practices and opportunities for improvement, facilitate communication	• Extended value stream mapping • Supply chain theory
2. Total Cost Procurement Decision Tool	Produce and exercise a rapid, flexible cost estimating tool for various levels of refinement in program sourcing decisions	• Total Cost Model • Inventory Theory • Financial Analysis
3. Pull System Implementation	Facilitate the design and implementation of a material pull system within and between plants for one shaft machining center's parts	• Lean manufacturing systems • Material market calculator • Multi-part weekly forecast tool for triggered cell

Table 1.1: Project Overview

Key insights of this project included:

- Extended value stream mapping, and the communication that is required to perform it, is a valuable exercise for management. It is a valuable tool for highlighting opportunities for supply chain improvement and for providing objective means to evaluate the state of current operations, and highlights organizational "blind spots".

- Total cost analysis tools are useful, but their real value lies in engaging in dialogue with various departments to encourage teamwork and long-range thinking about supply chains and sourcing decisions.

- Some major lean accomplishments are visible, but not consistent across the firm

- Vital to obtaining the paradigm shift to a lean manufacturing culture and successful plant floor implementation are: training; compensation and measurement/management systems; and removing roadblocks.

- Stay objective, focus on the data and on communicating constantly in an honest, calm and open manner.

- Stay flexible.

1.3 Thesis Outline

This thesis is organized into eight chapters:

Chapter 1: An overview of the thesis, company, research approach and lessons learned.

Chapter 2: A description of the project setting including the industry, supply chain and company, and the motivation for the emphasis upon supply chains and lean manufacturing principles at AAM.

Chapter 3: This chapter provides a literature review for value stream mapping, lean concepts related to supply chains, lean manufacturing practices, and change management.

Chapter 4: A description of the extended value stream mapping of several supply chains, and opportunities for improvement.

Chapter 5: Description of total landed cost or "lean costs" for sourcing decision-making, development of the model used to evaluate total cost, and examples of its use.

Chapter 6: Presents the background of the pull system implementation effort, its design, tools developed to assist with the design, and the implementation.

Chapter 7: Consists of an overview of organizational and cultural aspects of lean manufacturing, change management, and policy deployment.

Chapter 8: Contains conclusions and recommendations for future work.

2. Company and Industry Background

This chapter provides a context for the thesis. The chapter describes the state of the domestic motor vehicle industry and its supply base. Major trends are discussed, and how they affect AAM. Most importantly, we focus on AAM and the reasons for an emphasis upon supply chains and lean manufacturing management.

2.1 U.S. Automobile Industry OEMs

The business environment for U.S. domestic automobile manufacturers has become increasingly challenging and competitive in recent years. The traditional "Big Three" domestic manufacturers, General Motors, Ford, and Chrysler (now Daimler Chrysler) have been consistently losing domestic market share, sliding from about 70% in 1998 to about 55% in 2006 [Ward's Auto, 2006]. Part of the decline in market share has been attributable to the declining sales of Sport Utility Vehicles and trucks, which the "Big Three" have traditionally focused upon producing and marketing more heavily than foreign firms. Quality, design, operations, and labor/benefit costs have also contributed to the historical drop in market share. Imports and increasingly "transplant" automobile plants from foreign firms are seizing market share. New OEM "transplant" plants are often located in the Southern Midwest or South U.S., for a variety of reasons including state incentives, lower labor costs, and less chance of difficulties or inflexibility arising from legacy union relations.

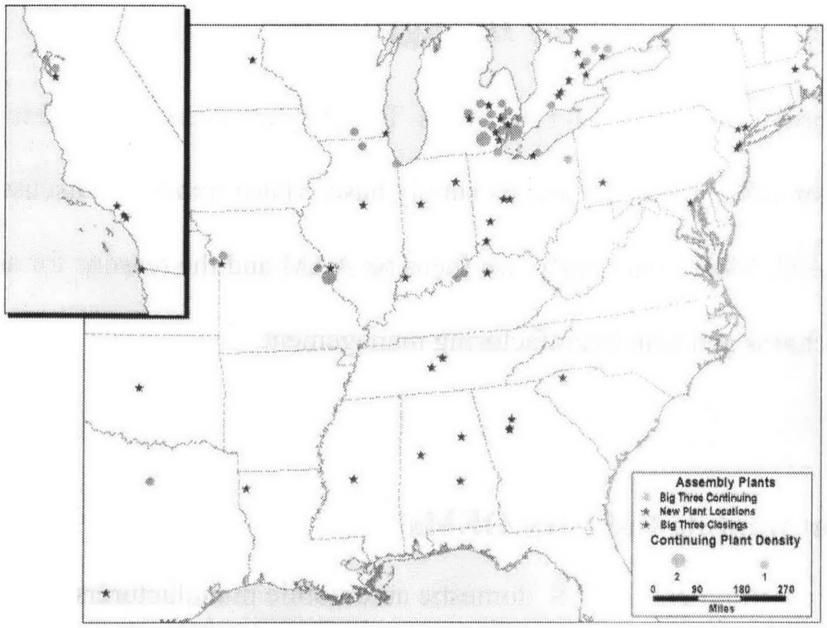

Figure 2.1: Automotive Assembly Plant Locations in the U.S. and Canada [used with permission of Thomas Klier, source: Klier and Rubenstein, 2006]

Faced with relatively fixed labor costs, large retiree benefit costs, and declining revenue, the domestic firms have seen a substantial decline in profitability. Ford Motor Company alone lost approximately $9 billion in 2006. Contributing to the competitiveness of the automobile market is the global overcapacity of the OEM industry, estimated at 20 % or more. Longstanding overcapacity and competitiveness has meant that stock market returns for OEMs and suppliers as a sector have been about half that of the S&P 500 since 1973, according to data collected by Martin N. Baily and Diana Farrell of McKinsey Global Automotive Practice. Industry consensus is that the "Big Three" are not nearly as relevant as they once were because of the globalization of the auto industry. Instead, a more accurate description of the automobile industry in the coming years would be the "Global Six" of General Motors, Ford, DaimlerChrysler, Volkswagen, Toyota, and Honda.

2.2 Supply Chain

The automotive industry supply chain is a major enterprise. Sixty two percent of the total motor vehicle and parts manufacturing industry employment is in parts [BLS, 2006]. By the end of the twentieth century the "Big Three" had spun-off many of their captive parts makers into independent firms. Additionally, the supply base is being reduced through competition, and through the desire of firms to more selectively develop suppliers who will assume more responsibility for product design and integration. The number of North American tier one suppliers is projected to shrink from several thousand in the 1970's to about 300 in the near future. "OESA estimates that there were 30,000 firms in the North American automotive supply chain tiers in 1990, but just 10,000 in 2000 and 8,000 in 2004. By 2010, their numbers may dwindle to no more than 5,000" [ITA, 2005]

The difficulties faced by the domestic OEMs have translated into great distress for the domestic supply chain, because as a supplier there is little that can be done in the short-term to increase sales if a major OEM customer faces decreased sales (unlike an OEM which can decrease price or increase functionality to stimulate sales). "The Original Equipment Suppliers Association, OESA, cites separate studies in 2003 by Plante & Moran and by A.T.Kearney that found that only 20% of a surveyed universe of small, medium, and large North American suppliers were generating operating margins above 8%. 15% of each group were losing money." [ITA, 2005] Dozens of major suppliers have declared bankruptcy over the past ten years because of these difficulties, most notable Delphi. While in the long-term possibilities do exist to increase sales to "transplant"

OEM plants, these relationships require time to develop and are often difficult to obtain if foreign firms already have preferred supplier firms that have also established new operations in North America.

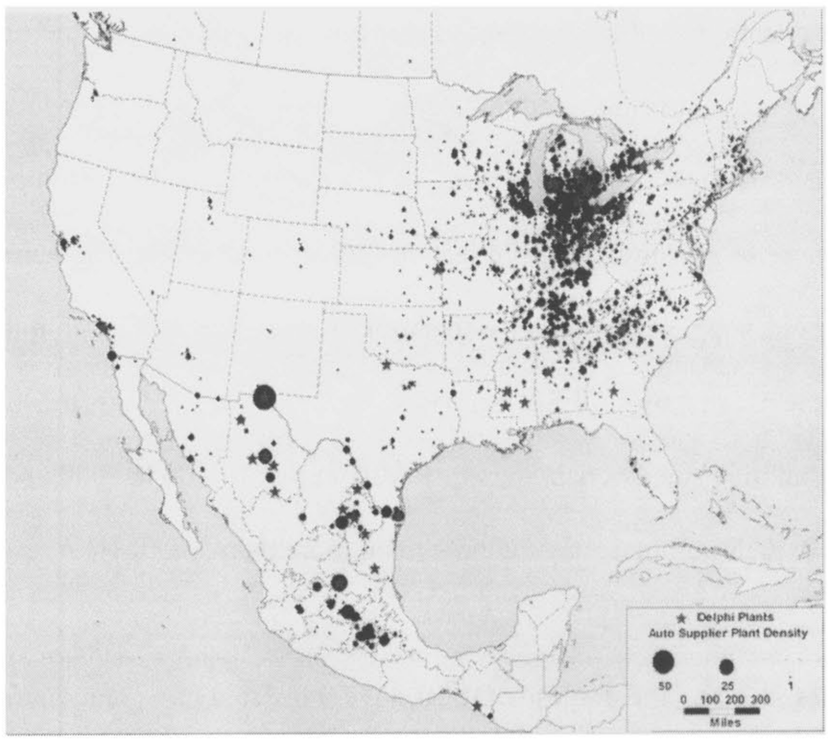

Figure 2.2: Motor vehicle supplier plant locations and Delphi plant locations [used with permission of Thomas Klier, source: Klier and Rubenstein, 2006]

The southward movement of new assembly plants and supplier firms is a major trend in the North American auto industry. Detroit was the traditional center of the motor vehicle and parts manufacturing industry, and 22% of all automobile or part manufacturing jobs are still located in Michigan [BLS, 2006]. Many of the newer supplier facilities have been located further south than the traditional Detroit/Midwest-based auto industry, in order to better serve the new "transplant" OEM plants within one day's driving distance.

A second major trend is the regionalization of supply chains, as foreign "transplants" work to develop regional (intra-continental) sources of supply to reduce supply chain risks, costs, and inventory in-line with lean principles. As a result of these efforts, many foreign firms produce vehicles with an equal or higher "domestic content" than domestic firms. For example, the Toyota Camry has been variously reported to have a domestic content of 70-85% depending upon model year, while total General Motors domestic content for all models is about 80% on average.

2.3 Company Background

American Axle & Manufacturing, Inc. (AAM) was founded in 1994 by Richard E. Dauch, Chairman, Co-founder and CEO, and his partners through an asset buyout from GM. AAM went public on January 29, 1999 and its stock is traded on the New York Stock Exchange under the ticker symbol AXL. The workforce is unionized, represented by the United Auto Workers (UAW) or the International Association of Machinists (IAM) in the United States locations.

AAM is a world leader in the manufacture, engineering design, and validation of driveline systems, chassis systems and forged products for trucks, buses, sport utility vehicles, and passenger cars. A consistently profitable tier-one supplier to both domestic and foreign OEM automobile manufacturers as well as other suppliers, AAM had revenues of approximately $3.4 billion in 2005. In addition to its U.S. locations in

Michigan, New York, and Ohio, AAM also has offices or facilities in Brazil, the UK, China, Germany, Poland, India, Japan, Mexico, and South Korea.

AAM is organized into two product divisions: the Driveline Division and the Metal Formed Products Division. The Driveline Division generates the majority of AAM's revenue through the manufacture of front axles, rear axles, differentials, drive shafts, crankshafts, steering and suspension systems and integrated modules and systems. The Metal Formed Products Division generates revenue through the forging and machining of automotive components such as axle shafts, differential gear components, hypoid pinions and ring gears, stabilizer bars, truck hitch balls, and other components [American Axle & Manufacturing, 2006].

Figure 2.3: Rear axles manufactured by AAM [AAM internal corporate web site]

AAM has core competencies in:

- Engineering
- Forging
- Machining

- Assembly
- Welding
- Heat Treating
- Product Validation

AAM is facing intensifying global competition. Competition is coming directly from other tier one suppliers, and also indirectly through competition with General Motors. General Motors is the primary OEM customer for the heart of AAM's sales: components for body-on-frame SUV-type vehicles and trucks.

AAM Axle Competitors 1994	AAM Axle Competitors 2005
Dana	Dana
Getrag	Getrag
Ford made axles in-house	ZF
Chrysler made axles in-house	Chrysler made axles in-house
Japanese imports	Japanese imports
	Magna
	Hino
	Visteon

Table 2.1: AAM Axle Competitors

GM Truck Competitors 1994	GM Truck Competitors 2005
Ford	Ford
Chrysler	Chrysler
Toyota (small trucks only)	Toyota
Nissan (small trucks only)	Nissan
	Honda
	BMW
	Hyundai Kia
	Land Rover

Table 2.2: GM Truck Competitors

The need to reduce cost and increase operational efficiency to meet the challenges of global competition has spurred AAM's focus on lean manufacturing initiatives.

2.4 Lean Initiatives at AAM

A major initiative of AAM's corporate operations management team is to implement lean manufacturing on a company-wide basis. The immediate goals are to achieve the so-called "50-in-5 goals" (Lean Manufacturing Challenge 2006-2010) over the next five years:

- 50% Reduction in hours per axle
- $50 M inventory reduction
- 50% reduction in dock-to-dock time
- 50% fewer direct suppliers
- 50% of sales from non-GM customers
- 500,000 ft^2 of floor space made available

The longer-term goals are to achieve a continuous, self-sustaining competitive advantage through the implementation of lean manufacturing and lean management principles.

AAM began implementing lean manufacturing initiatives on a company-wide basis approximately five years ago, at the time calling this effort the "AAM Manufacturing System." This initial effort resulted in some false starts in terms of plant floor systems, as the implementation efforts were not supported across the company. In all fairness this was also a difficult time to implement lean systems, as the booming SUV market meant that AAM faced significant challenges meeting customer demand. Maximizing output became the goal, and other efforts took on secondary importance. Significant progress in productivity, quality, and cost was made, however, due to a continuous management focus on operations.

More recently Harris Lean Systems, a management consultant firm comprised of former employees of Toyota and other firms well-versed in lean manufacturing methods, has been advising AAM. Over the past one and one-half years, AAM has developed a lean group in the Corporate Materials Department to assist with training, the development of company-wide lean standards, and to provide guidance on initial implementation steps at the local plant level. The Corporate Materials group also works with other departments to identify opportunities for lean initiatives at the strategic level, such as for supplier sourcing decisions. AAM has reached the point where routine use of lean manufacturing principles has become common at many facilities, although inconsistent across the company as a whole. Substantial improvements towards the "50-in-5 goals" have been achieved. Many opportunities remain.

2.5 Project Goals

The expected product of the project will include strategic, tactical, and organizational (non-technical) components. Supply chain inventory and lead time-reduction opportunities will be identified via extended value stream mapping. A total cost part procurement decision tool will be developed and used in test business cases. Internal and interplant pull loops will be created, and material markets will be sized to handle typically experienced supply and demand variability. Finally, observations on the strategic, cultural, and political aspects of the organization will be provided.

Recommendations will be made regarding approaches to the continued adoption of lean manufacturing at AAM.

3. Literature Review

This chapter reviews basic concepts of lean manufacturing. This includes the origins of lean, the seven major forms of waste, and tools to identify and reduce waste. Major tools such as extended value stream mapping are discussed. The concept of total or lean purchased parts cost is introduced. Basic pull system concepts are referenced. Finally, issues revolving around change management in organizations are addressed.

3.1 Lean Manufacturing

"Lean manufacturing" is the label widely used to describe a set of practices and operating philosophies best exemplified by the Toyota Production System, but used by many firms throughout the world. Lean manufacturing had its origins in several developments from the mid-twentieth century, which came together in the Toyota Production System. Japanese firms such as Toyota were initially highly vulnerable and seeking forms of operational advantage in post-World War-II Japan. Making intelligent use of quality control, work modularization/breakdown, a focus on product flow, and other techniques (many of which were heavily utilized in U.S. industry during the war years but were subsequently de-emphasized), Japanese firms developed sustaining operational advantages.

Toyota especially recognized that traditional "mass manufacturing" techniques as practiced in the U.S. and epitomized by Ford would not be practical in Japan. The very capital-intensive, inventory-intensive approach of U.S. "mass producers" of the time utilized large dedicated machines with long changeover times between parts and large batch production runs for each part. Toyota recognized that these processes, while *locally* efficient in terms of maximizing utilization of expensive assets (large machinery), might be wasteful in *macro* or enterprise-wide terms. The waste could come from many forms: excess inventory, excess or uncoordinated production before it was necessary, unnecessarily time-consuming tooling changeover times to run different parts on one machine, etc.

The system developed by Toyota was later labeled "lean manufacturing" by John Krafcik [Marchwinski and Shook, 2004]. Toyota developed a series of systems and tools to: highlight waste and material flow through visual control; encourage the work force to work together to identify root causes of problems to avoid reoccurrence; and to standardize work and training to stabilize operations and quality. Especially helpful to this effort was the adoption and modernization of the Training Within Industry (TWI) methodology which had been developed in the U.S. during World War-II [Dinero, 2005]. TWI was developed to teach people how to effectively, consistently, perform on-the-job training for hourly associates, and to teach continuous improvement methods.

Over the long-term Toyota's efforts in highlighting and seeking forms of waste, addressing the root causes, and systematizing the process of doing so reaped enormous dividends. The long changeover times of machines and the large inventories traditionally needed to run a large motor vehicle manufacturing operation were dramatically reduced, and quality, cash flow and profitability was increased. "Lean manufacturing" received widespread recognition after the publication of a book about the global automobile industry titled *The Machine That Changed the World*, [Womack *et al*, 1991].

Lean strives for stability, reduced set-up times, and one-piece flow of material. Lean emphasizes building to the pace of customer demand, or takt time, and building only what is needed, when, and in the desired quantity. Lean manufacturing emphasizes striving to eliminate the "seven forms of waste":

- Excess inventory
- Overproduction
- Motion
- Handling
- Correction of Defects
- Overprocessing
- Waiting

3.2 Extended Value Stream Mapping and Supply Chains

Rother and Shook [2003] describe the lean tool of value stream mapping. Value stream mapping consists of a broad outline mapping of the material handling and the information flow within a plant. The intended purpose is to have a group of plant personnel walk the entire "value stream" within a plant, from receiving dock to shipping dock, collecting actual operational information along the way. Every major process, inventory accumulation, or handling step is outlined on the map with relevant lean measures such as days of inventory on-hand, cycle times, etc. Information flow describing how scheduling or customer interactions are accomplished is also included on the map.

The final result of in-plant value stream mapping is an accurate depiction of the "current state" of the operation, along with a description of customer demand, shipment information and takt time (for lean terms refer to Marchwinski and Shook [2004]). Opportunities for changing the value stream to a flow that is better oriented towards lean operating principles are identified and then used to make a "future state" map. This "future state" map can then be used to guide improvement efforts.

Jones and Womack [2003] demonstrate an extension of value stream mapping that is intended to cover the entire extended value stream. Extended value stream mapping should cover as much of the entire supply chain as possible, from the raw material provider to the final end customer. The extended value stream maps treat each individual plant as a single, simplified process. In this way the complexity of the in-plant value stream maps described above are reduced to a summary of the plant's contribution to supply chain material and information flow.

Extended value stream maps are powerful tools because they often map value streams that no one person has ever seen in its entirety. Extended value stream maps also involve the collection of different kinds of data. Variations in demand, standard pack sizes, travel distances, and other factors become of great interest in extended value streams. Major strategic and operational opportunities are usually made apparent by the development of extended value stream maps. Some of these opportunities might involve the re-sourcing of work to closer facilities or in-sourcing of work to reduce lead time and handling.

3.3 Total or Lean Purchased Parts Cost

Womack [2003] discusses the multiple added costs that can occur when sourcing components from distant locations or complex supply chains. Traditional sourcing decisions in large firms are made based on comparing piece price plus freight costs between foreign and local suppliers. Looked at only in this way, sourcing parts to distant countries with low labor costs often makes sense. Making a more thorough appraisal of the expected costs and risks involved in these long supply chains may change this perspective, however.

Costs for expediting, for dealing with quality spills, inventory holding costs, and other factors, become significant when sourcing from distant suppliers. In many cases sourcing parts to a distant, low-wage country such as China does not always make business sense when total, or lean supply chain, costs are considered. This may be one reason that lean manufacturing-oriented firms such as Toyota work to increase their local supply base and to improve the operations of local suppliers: shorter supply chains tend to have less risk and overhead. Short supply chains also allow for more opportunity for improvement in the form of frequent "milk-run" deliveries. Reducing the number of suppliers is another means to reduce risk (Womack and Jones, [2003]), although even a single, well-run supplier can pose substantial supply chain risks if located at a great distance from the customer.

D'Avanzo et al [2004] discuss supply chain strategy and its business implications. They note that research shows a positive correlation between firms with superior supply chain management strategies and positive compound annual growth rate (CAGR) of market capitalization compared to their industry's average CAGR. They also observe that leading firms make supply chain design part of their business strategy.

3.4 Pull System

Rother and Harris [2001] discuss the manufacturing cell or tactical-level aspects of lean manufacturing. The focus is on creating continuous flow through manufacturing cells by first making sure that the appropriate products are assigned to a cell or group of cells, and that production is arranged according to the pace of customer demand (takt time). Operator work balance, and machine capacity and arrangement, should be arranged to achieve both a balanced work load and improved material flow through the cell. Automation should be applied sensibly, and in many cases less automation should be considered rather than more because this allows for greater operational flexibility. Buffers of finished goods reduce variations in production orders at the pacemaker operation, which is the operation used to schedule production. Cells should be designed to allow gradual changes in staffing to accommodate gradual changes in customer demand. Implementation should begin with a small core team but as the project is deployed and adapts, continuous improvement and sustainment should rely on maximum operator involvement.

Harris et al [2003] presents a plant-level description of how to ensure material flow. This involves making a plan for every part (PFEP), a basic database or table listing major demand and physical storage attributes for every part handled in a plant. The development of this central repository of information allows for rapid planning and adaptation to changes in requirements. Material market sizing, locations, conveyance strategies, and continuous improvement efforts are also addressed.

Smalley [2004] reviews the steps needed to implement a plant-wide system for leveling pull across multiple part families. Pacemaker, market sizing, and production control are reviewed in detail in the context of batch production. Cycle stock, buffer stock and safety stock sizing is explained. Most useful in this discussion is a review of the many types of approaches available for handling a mix of high- and low-volume products, and the appropriateness of different types of kanban (pull) card signals.

3.5 Change Management

Many firms around the world have successfully applied lean manufacturing techniques to improve their businesses[Womack and Jones, 2003], and foreign "transplant" automobile industry plants in the U.S. have successfully applied these techniques with a domestic work force [Womack *et al*, 1991]. Also, TWI efforts were first developed and very successfully applied in the U.S [Dinero, 2005]. Therefore there is no intrinsic cultural element preventing the adoption of lean techniques to any firm in any country. Rather, management and company-specific cultural factors represent the issues to be resolved when deploying a lean manufacturing system at a firm.

When a strong pull or need is recognized by many stakeholders at a firm, as was the case in early post-World War-II Toyota, then alignment and change can come about more easily. When a strong unifying need is not present, or when cultural, political or strategic incentives may not be aligned - as in the case with labor and management at U.S. automobile OEMs in the recent past - change can be more difficult to implement. As [Klein, 2004] points out, organizational change seems most effective when a critical mass of company "insider-outsiders" develop sufficient exposure to new facts and ideas to remove their organizational blinders, allowing them to see the compelling need to change the organization while still respecting the ways in which the organization functions.

Byrnes [2006] notes that paradigm shifts in business operations tend to be most successful with extensive training, and with changes in compensation schemes. Employees tend to need both general familiarization training with new concepts, and specific training regarding their new functions. People will do what they are actually paid and promoted to do, so the "real litmus test" for change in a firm is: are you willing to change your compensation systems? [Byrnes, 2006]

Womack and Jones make the point that some individuals will not be able to make the transition to a new operating paradigm, and that a small portion of the managers and workforce will need to be removed for firms to successfully transition to lean manufacturing [Womack and Jones, 2003]. Collins focuses on the common factors behind companies that successfully transitioned from mediocre performance to sustained greatness. He found that getting the right people involved in management and removing those not capable of adapting to be important in these firms, even before deciding what direction to take [Collins, 2001].

Collins [2001] also found other important elements common to all firms that made a transition to great performance: a leader with humility and teamwork, not a larger-than-life personality; having the ability to acknowledge current realities while seeing a path towards success; selecting a business that you can be passionate about, best in the world at, and can establish an economic measurement system for; having a culture of discipline (discipline of people, thought, and action) that allows a firm to avoid the need for bureaucracy; and avoiding technology bandwagons, since technology is rarely the cause of greatness, but is only harnessed to help a company that is already headed in the right direction.

Organizational structure and management practices are also important factors in implementing change. Organizational structure affects how the change is deployed, who loses and who gains from operational change, and how many key managers must support the changes or have their compensation changed to support them. Organizational structure also directly affects the important element of accountability.

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4. Extended Value Stream Mapping

This chapter discusses the extended value stream mapping component of the thesis.

4.1 Current State of Supply Chain

The current AAM supply chain has grown over the years under a number of influences. Before AAM was formed in 1994 GM ran the majority of what is now AAM. General Motors and other customers still dictate supply sources in some cases where specific vendors or specialty materials available from only one firm are desired (a "directed buy"). In the majority of cases AAM has flexibility in choosing from multiple sources of supply or processing.

AAM has had a number of acquisitions over the years, and also utilizes outside processors. AAM has also traditionally been organized into different divisions: Driveline and Metal Formed Products. Each plant has operated in a relatively independent manner, effectively being an island of information and scheduling. Communication between plants is not always perfect, with IT systems sometimes showing orders at an AAM plant that differ from those sent by other AAM plants. Supply and processing decisions were made by a variety of commodity managers and plant managers, respectively, based upon local considerations instead of overall supply chain considerations.

The end result of all of this history and separation is that the supply chain is a traditional mass-production style supply chain. The supply chain exhibits a lack of overall understanding or planning, best exhibited by the fact that even the part number designation for the same product may change at every location throughout the value stream. This means that individuals at separate plants have difficulty understanding the specific part or product that is being talked about by employees at other locations.

4.2 Extended Value Stream Mapping of Supply Chain

American Axle & Manufacturing, Inc. has a major initiative underway to improve operations and achieve truly "lean manufacturing". As part of this initiative, value stream mapping activities have been performed for many local value streams within individual plants by materials and operations associates. During the internship it was decided that efforts should also be applied to mapping extended value streams between all of the AAM and supplier/processor plants. Managers at AAM felt that major strategic opportunities existed for identifying waste or misalignment in the value stream.

Two families of extended value streams were selected for the initial mapping effort: (a) parts flowing into Detroit Gear & Axle Plant Six (DGA 6); and (b) full-float axle shafts flowing out of Detroit Forge. DGA 6 assembly operations were deemed to have a large effect on the entire supply chain upstream of the plant, and therefore it was felt to be important to understand this set of value streams. DF shafts are sent to a variety of plants, processors, and customers, and a value stream mapping exercise was therefore though to be useful. There was also a nice tie-in to the tactical pull system implementation project, which involved machining of these full-float axle shafts in Detroit Gear & Axle Plant Three.

The extended value stream mapping was intended to capture high-level strategic information, not tactical-level details within the plants. The goal of the effort was to highlight major alignment and operating issues. In addition to focusing on traditional value stream mapping measures, such as inventory and communication paths, special focus was given to information more relevant to the extended value stream. Delivery schedules, standard package sizes, part number nomenclature, and order variability were some of the factors that were collected when available.

Mapping of extended value streams was accomplished using local information available in Detroit and also with extensive telephone conversations and e-mail exchanges.

4.3 Results and Future Opportunities

Family (a) parts flowing into Detroit Gear & Axle Plant Six (DGA 6)

The parts families that flow through DGA Plant 6 which were mapped are shown in the simplified flow diagram below.

Extended value stream maps were created for many specific parts flowing into DGA Plant 6. Major part families were selected for mapping, as shown in the simplified diagram below. Each path represents one major part family on the diagram. In some cases a part family consists of several medium- or high-volume parts.

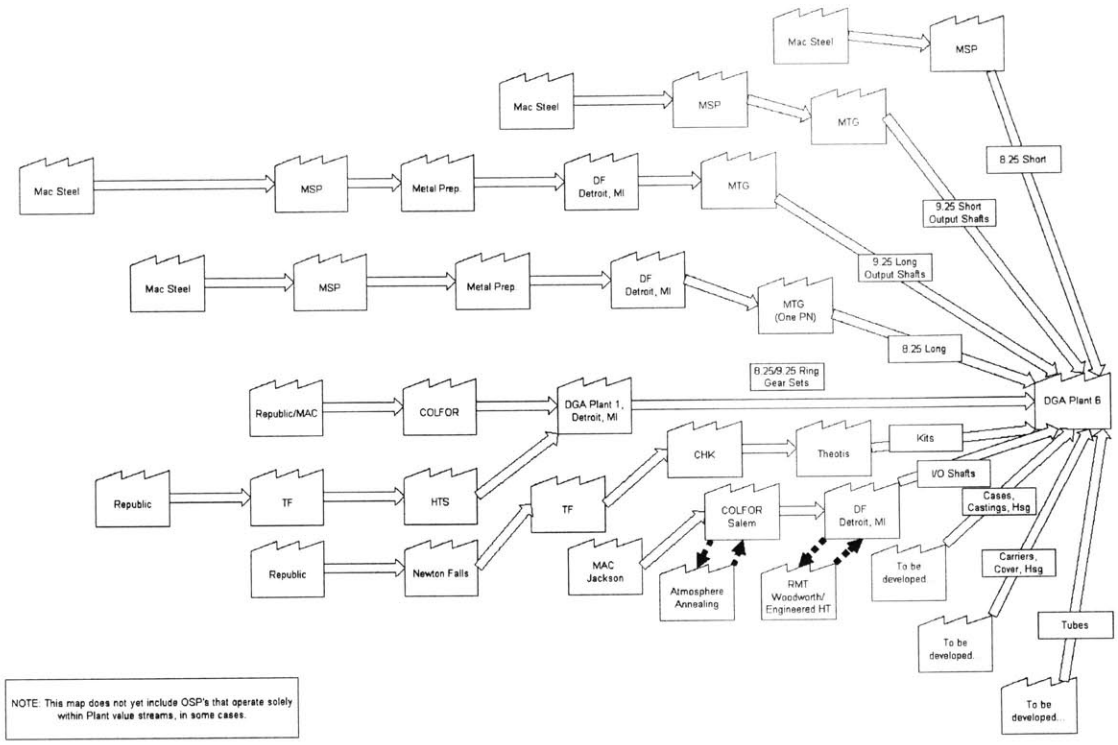


Figure 4.1: DGA Plant 6 part families simplified flow diagram

Once a part family was targeted for mapping, extended value stream data for each major part number was collected in that family. The final product of the mapping work resulted in detailed maps for individual part numbers.

In some cases it may make more sense to perform mapping of an entire part family, or even groups of part families. This is a valid point emphasized by some of the lean literature and also by employees at AAM. This would be the case if equipment utilization or processes suggest that all of the included parts can be considered to be part of the same related family or facility-limited value stream. To keep the first mapping exercises simple, to avoid "hiding" large variations between high-volume and low-volume inventory "days on hand", and to be able to handle the great communication difficulties experienced when dealing with parts that had changing part numbers and sometimes divergent paths throughout the value stream, mapping was done for individual part numbers on the final detailed maps, not for whole families of parts.

For the sake of brevity only one detailed example for an individual part is shown below.

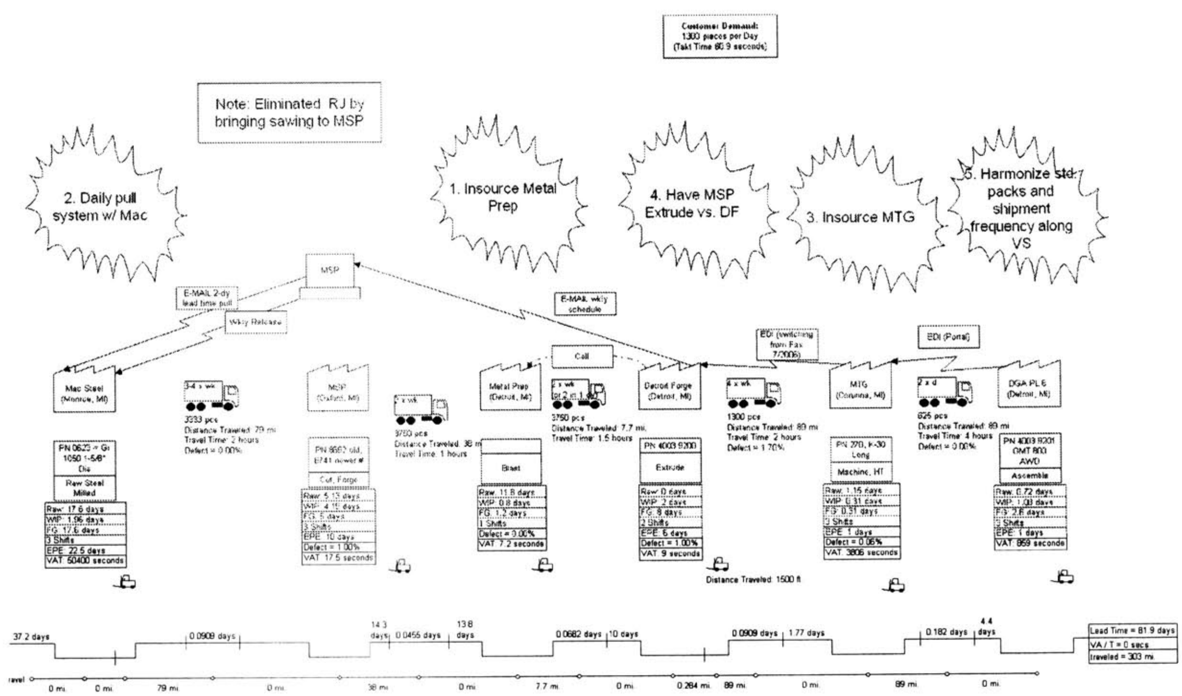


Figure 4.2: Long Output Shaft extended value stream map

Several improvement opportunities have been suggested on the map. One of these opportunities, in-sourcing of sawing operations, was already in progress while the value stream map was being completed.

Data tables were also assembled for each value stream. These tables were developed to present information suggested both at AAM and by Jones et al [2003] which is not typically included on local value stream maps and is not conveniently presented in the IGrafx value stream mapping software used. The detailed table for this value stream is shown below. Note especially the uncoordinated standard package and shipment size throughout the value stream. Also note that variability in order sizes tends to increase the farther upstream one looks. More transparent ordering and inventory management systems would help to reduce the magnitude of this "bullwhip effect" (see Sterman [2000]).

9.25 Long Output Shaft Extended Value Stream Map Scorecard														
Mac Steel	**Shipment**	**RJ Herman Eng.**	**Shipment**	**MSP Industries**	**Ship ment**	**Metal Prep.**	**Ship ment**	**Detroit Forge**	**Ship ment**	**Machine Tool and Gear (MTG)**	**Shipment**	**DGA Plant 6**	**Total**	Firm
Monroe, MI	Truck	Romeo, MI	Truck	Oxford, MI	Truck	Detroit, MI	Truck	Detroit, MI	Truck	Corunna, MI	Truck	Detroit, MI	Customer	Location
Raw Steel		Cut (if excess cap. Needed)		Forge		Blasting		Extruding		Machining, Ht Treat		Assembly		Process
Mac	MSP	MSP	MSP	MSP	MSP	MSP	DF	DF	MTG	MTG	DGA	DGA		Owner
0623 = 1050 1-5/8" bar				**8692, 8741 past month**				**4003 9200**		**#270 K-30 Long**		**4003 9201 GMT 800 9.25 Long AWD**		**Part #**
-	-	-	-	-	-	-	-	-	-	-	-	-	1300	Daily Demand
-	-	-	-	-	-	-	-	-	-	-	-	-	12	Part weight (lb)
667	3333	3333	3333	400	3750	200 batch /400 bin	3750	275	1300	300 batch/ 117 FG	625	117	-	Std Pack, Batch, or Shipment Batch Size (pcs)
8000	40000	40000	40000	4800	45000	#VALUE!	45000	3300	15600	#VALUE!	7500	1404	-	(lb)
RJ Pulls for deliver		Daily Pull from MSP		Email wkly schedu		Call from DF		Fax going to EDI		EDI (Portal) from PL 6			-	Pull or Order Signal
-	0.7	-	1	-	0.4	-	0.4	-	0.8	-	2	-	-	Ship Frequency (#/dy)
-	3.5	-	5	-	2	-	2	-	4	-	10	-	-	Shipments per Week
17.6	-	3	-	5.13	-	11.8	-	0	-	1.15	-	0.72	39.5	RM (dy)
1.96	-	0.1	-	4.19	-	0.8	-	2	-	0.31	-	1.08	10.4	WIP (dy)
17.6	-	2	-	5	-	1.2	-	8.0	-	0.31	-	2.60	36.8	FG (dy)
3	-	1	-	3	-	1	-	2	-	3	-	3	-	Shifts/dy
5	-	5	-	5	-	5	-	5	-	5	-	5	-	Days/wk
22.5	-	1	-	10	-	?	-	6.0	-	1	-	1.00	-	EPEI (dy)
37.2	-	5.1	-	14.3	-	13.8	-	10.0	-	1.8	-	4.4	86.6	Total in-plant Lead Time (dy)
50400	-	15	-	17.5	-	7.2	-	9	-	3806	-	859	55114	Value-creating time (sec)
0.583	-	0.0002	-	0.000	-	0.000	-	0.0001	-	0.044	-	0.010	0.638	Value-creating time (dy)
-	2	-	0.75	-	1	-	1.5	-	2	-	4	-	11.3	Total Shipping and Load/Unload Time (hr)
-	-	-	-	-	-	-	-	-	-	-	-	-	0.47	(dy)
15	1	6	1	?	1	2	1	11	1	18	1	?	58.0	Total Steps
4	0	1	0	1	0	1	0	1	0	6	0	?	14.0	Value-creating Steps
Summary measures for extended value stream from "Seeing the Whole":													87.10	Total lead time (dy) = in-plant time + shipping time
													0.74%	Value Percentage of Time (time creating value)
													24%	Value Percentage of Steps (steps creating value)
													3	Inventory Turns = 260 dy/yr / total lead time
Can't say	-	0%	-	1%	-	0%	-	1%	-	0.06%	-	?	-	Internal Defects or Scrap (%)
0%	-	0%	-	1%	-	1%	-	0.5%	-	?	-	0%	-	Defects or Scrap Shipped to next step(%)
-	-	-	-	-	-	-	-	-	-	-	-	-	?	Quality Screen (defects at the downstream end / upstream end)
-	0%	0%	?	-	0%	-	0%	-	1.7%	-	1.9%	-	-	Defective Deliveries (%)
-	-	-	-	-	-	-	-	-	-	-	-	-	?	Delivery Screen (% defective shipments at the downstream end / % at the upstream end)
?	-	52%	-	52%	-	?	-	37%	-	29%	-	3.6%	?	Std dev demand/mean demand; amplififcation index = value at end of EVS/other end
?	84	0.019	14.4	?	38	?	7.7	0.28	89	?	89	?	322.40	Product Travel Distance (miles)

Table 4.1: Extended Value Stream Map Scorecard

Family (b) full-float axle shafts flowing out of Detroit Forge

A simplified flow diagram of the full-float axle shaft extended value stream (shafts flowing out of Detroit Forge) is shown below.

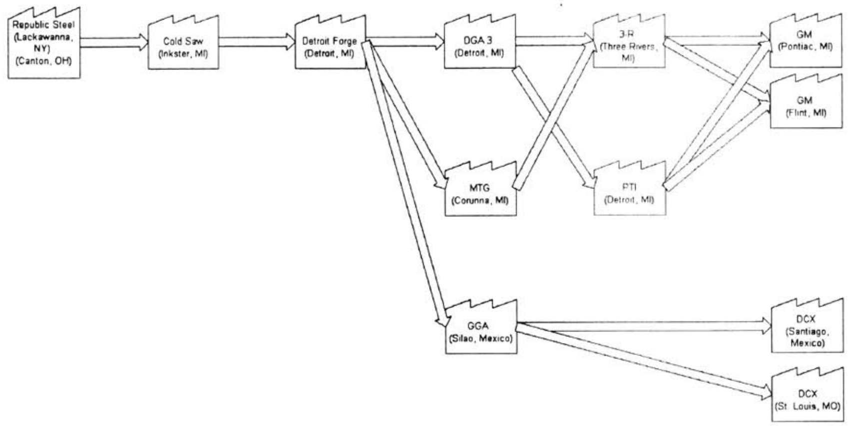


Figure 4.3: Full-float axle shaft simplified value stream flow diagram

The complexity of this value stream (for one part family!) is apparent from the detailed map shown below. Steel from the mill is sawn, then is forged, blasted and straightened. The raw forged shafts are then sent on to be machined at either DGA 3 or in AAM's GGA facility in Mexico. Capacity constraints at DGA 3's machining group caused by downtime and other issues have led to outsourcing of the machining of some low-volume parts ("low-runner" parts in AAM parlance). Overtime costs are high enough that outsourcing of machining is a lower-cost option than machining of shafts in-house if overtime production is required to meet demand. The finished shafts are then assembled into complete rear axle assemblies in AAM plants, and are either painted in-house or at PTI. The finished axles are then shipped to the OEM customer.

Until this map was made no single individual within the enterprise comprehended the entire value stream flow. Maps like this now help highlight improvement opportunities or disconnects in current operations. Recently, AAM Corporate has held a series of day-long workshops with representatives from materials management at every step in several extended value streams. The workshops have highlighted some of the major opportunities or disconnects in the enterprise. They have also jump-started productive communication and problem-solving efforts among the value stream stakeholders.

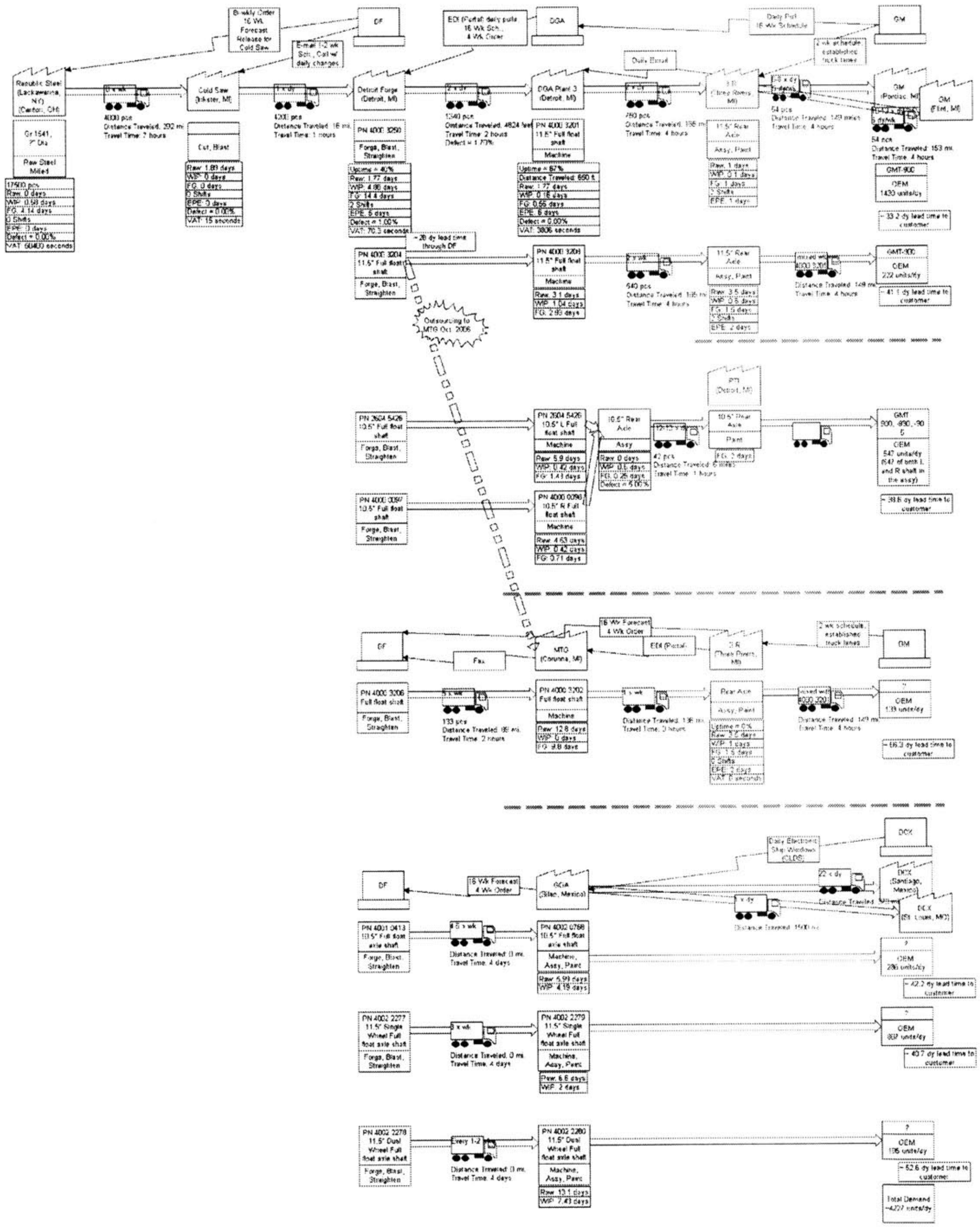


Figure 4.4: Full-float axle shaft extended value stream map (detailed)

5. Total Cost Decision Tool

This chapter discusses the total cost decision tool component of the thesis. The focus at AAM upon extended value streams has also raised awareness of the need to more fully account for costs in making part procurement decisions. Therefore a second strategic project involved examining total costs of purchased parts from suppliers.

5.1 Traditional Procurement Cost Estimating

Traditionally, only piece-price plus freight costs were used to determine sources of supply at AAM and most other "mass-production"-style firms. Commodity managers and buyers operated under goal costs per part for raw material or supplier part cost, freight cost, etc. There was no centralized approach to cost of sourced material: interested parties were allotted percentages of total part costs and asked to stay within these targets.

Tooling costs sometimes factored into sourcing decisions, or suppliers would offer discounts on other parts already supplied to AAM if a new part was sourced in such a way as to more fully utilize a supplier firm's plants. Communication between various departments regarding engineering, dunnage, logistics, and other parties was slow and did not lead to a strong, holistic understanding of sourcing decisions.

5.2 Lean or Total Cost Estimating

Lean manufacturing emphasizes taking an enterprise-wide, or holistic view of a given business or value stream. As part of this perspective, lean thinking emphasizes that piece price and freight are but two of many sourcing-related costs (Womack, [2006]). Other, additional factors may alter the decision of which supplier to use - if they are considered. These factors include such items as: the costs of expediting from far-away suppliers; unreliable supply chains; and reusable dunnage requirements, to name a few.

Materials Management has been taking a lead role in fostering better communication between interested parties at AAM regarding total cost (sometimes known as total landed cost). As part of this effort, a simple tool was desired to allow for rapid appraisals of total cost for making more informed sourcing decisions. This effort is described below.

5.3 Total Cost Decision Tool

A total cost supplier decision tool has been developed to allow more rapid, thorough evaluation of true costs of parts coming from suppliers. The tool was used in making several sourcing decisions, and is now required as part of all sourcing council decisions. This computer spreadsheet-based tool uses simple inputs to quickly produce a more all-encompassing estimate of the total costs of purchasing parts from a given supplier.

The tool provides an estimate of the total system cost to obtain a part from a supplier. It includes piece price and standard freight, as well as other items including the following examples: other standard costs (repack); internal costs (inventory and in-transit carrying cost, floor space, capital and repair costs for dunnage); overhead costs (legal or customs, logistics scheduling); risk or containment (supplier visits, expedite, quality spill, etc.)

Basic inputs are entered as shown in the table below, with default values used when detailed information is not yet available for a particular program.

Basic Part Information
- Part number
- Piece price
- Weekly demand
- Weight
- Dimensions

Plant Operating Data
- Days, shifts, hours running

Material Market Data
- Desired service level
- Safety stock delay period
- Floor space req'd. per cntr.
- Annual and capital cost per ft^2

Transit Route Data
- From, to names, locations
- Route distance
- Regular transport mode
- Expedite transport mode
- Regular cost or cost/lb
- Regular weight, dimension limit
- Regular lead time or speed
- Regular std. dev.
- Expedite weight, dimension limit
- Expedite lead time
- Expedite std. dev.
- Frequency of expediting

Repack Data
- Lead time for repack
- Location
- Parts/hr repack rate
- Labor rate for repack
- Supervisor:employee ratio
- Floor space per container on hand

Dunnage Data
- Days on hand at plant
- Dunnage dimensions
- Dunnage weight
- Part spacing (used when dunnage not designed, to est. std. pack size)
- Dunnage return:mat'l delivery ratio
- Days on hand at supplier
- Dunnage new price
- Annual % new value for repair and replacement
- Floor space per container stored

Risk Data
- Cost of quality spill:pipeline value
- Chance of quality spill
- Cost of other risks on route (financial, labor, climate)
- Chance of other risks on route

Supplier and Logistics Data
- % of transit suppl'r. carries inv.
- % of full load on avg.
- Duty and customs above freight
- 3PL/Warehousing

Supplier Reliability Information
- Scale of reliability 1-10
- Local and US AAM visits, time
- Cost of local, US visits

Tooling, Financial Data
- Tooling
- Cost of working capital
- Program life

Overhead Factors
- Legal costs, demurrage
- Overhead for logistics/scheduling
- Senior executive visit
- Lost time while traveling

Table 5.1: Input to the Total Cost Model

A few examples of the usefulness of this tool may be in order:

(1) Based upon existing data for delivery variability and lead time for different routes, the material market sizes needed to handle this degree of lead time variability are determined. The total floorspace and total dunnage required are also affected by this calculation. Dunnage also requires annual maintenance and replacement, so there are multiple capital and annual expenses associated with increased delivery variability.

(2) Interviews with AAM employees allowed approximate estimates to be made of the number of personnel, the length of stay, and the costs for visiting suppliers with various stability ratings. A rating of 1 signifies a large, reliable, stable supplier, while a rating closer to ten might indicate a new, small, unreliable supplier or a very compressed launch of a new product at a supplier. By simply assigning a rough grading of supplier stability, the tool automatically calculates the cost of annual supplier visits.

(3) When choosing a source of supply and a mode of transit, a drop-down menu lists available modes of transit, or allows the user to enter in a custom mode. If a default mode of transit is selected, the approximate cost per shipment is provided from known default values (which must be updated on a routine basis). If a custom mode of transit is selected, the user may enter in a quote of their own, and provide the dimensions of the cargo container. Then, based upon either dunnage size and capacity provided by engineering, or using an estimate of dunnage size and capacity based upon part size and pallet size, the shipment weight or volume limit is automatically calculated. Total shipments per year, shipment frequency in days, and annual freight costs are automatically determined.

This approach was compared with known data for a route to AAM's facility in Mexico, and the difference between estimated shipment capacity determined by the tool, and the exact values was found to be less than 5%. It is expected that the total freight costs could vary by 30-50% from default estimate values due to fuel surcharges, route-specific fare changes, etc. Nevertheless, the fact that capacity estimates are close to actual values, and that freight represents only a few percent of total landed cost for most programs, means that the estimates provided even using default values provide a good general estimate of total landed costs. This estimate is also available at a much earlier stage of program decision-making than previously.

The purpose of the tool is to determine if there are large differences between total costs for two sourcing options - say greater than 10% or perhaps $100,000. The accuracy of the tool is not sufficient to allow decisions to be made with the fidelity of a few percent or just a few tens of thousands of dollars. When total cost differences between two options start to become small, qualitative factors relating to perceived risks for different sources of supply can become paramount. For example, the cost to resolve a quality spill issue (return and repair all affected material) can amount to approximately half of the dollar value of all material in the pipeline, according to observations of experienced employees. Also, customs issues can cause weeks or delays and tens of thousands of dollars of legal expenses.

5.4 Example Business Case

An example used to illustrate the use of the total cost tool is presented below. The part used here is a pinion flange sourced either from the US or from China.

This example highlights the complexity in making sourcing decisions: for instance, the more local supplier has higher dunnage costs because dunnage travels throughout the value stream back to the supplier. The China supplier sends material in disposable packaging that requires repacking at a local site into AAM dunnage. The repacking costs are somewhat uncertain, depending upon how well utilized and managed the repacking staff is. The China option also had delivery freight costs built into the piece price quotation (it was actually quoted under DDU, not FOB INCO terms).

What is apparent from this example total cost analysis is that the China sourcing option is less expensive - regardless of whether the traditional costs of piece-price plus freight are evaluated, or whether the total costs are evaluated. Even with a low value commodity item (heavy metal parts are not microprocessors), the total cost analysis reduced the cost differential between the options from 48% to 36%. There is also a great deal of uncertainty in the "other risks" category for China: labor, financial, and political issues. Overall, this example highlights the complexity of the problem, and the need to consider factors external to the analysis, such as risk and capacity utilization.

DCX 9.25 Pinion Flange TDM Indiana - GGA		DCX 9.25 Pinion Flange SG Auto China - GGA		Option Description
Value		Value		
Summary Equivalent Total Annual Costs:				
Standard Operating (Ideal World) Transaction Costs				
	14.56		9.98	Piece price FOB supplier's dock
$	2,512,328	$	1,722,049	Annual part purchasing cost FOB at supplier dock
$	73,050	$	-	Annual parts freight costs + Annual dunnage return freight costs
	$0		$17,255	Annual duty, customs costs not included in freight
	$0		$0	3PL/Warehousing costs not included in freight
$	-	$	8,446	Annual repack labor costs from disposable to reusable
$	-	$	96	Annual cost of floor space for repack
$	**2,585,378**	**$**	**1,747,846**	Subtotal
	148%		100%	Percent of Min Total Cost Option
Internal Costs, Carrying Costs				
$	6,310	$	12,172	Avg. Market Inventory carrying cost
$	4,781	$	-	In-transit Inventory carrying cost that firm pays vice supplier
$	6,066	$	353	Annual dunnage principal and financing cost over program lifetime
$	3,494	$	203	Annual dunnage replacement or repair cost
$	-	$	654	Holding cost of inventory at repacker
$	384	$	1,056	Building floor space for market carrying cost
$	133	$	44	Annual cost of dunnage floor area
$	-	$	-	Equivalent annual cost to finance tooling
$	**21,169**	**$**	**14,483**	Subtotal
Overhead Costs				
$	-	$	-	Legal costs to deal with local customs official problems, demurrage
$	-	$	2,000	Overhead allocation to handle logistics and scheduling
$	-	$	-	Senior executive visit
$	-	$	-	Lost time of personnel during long-distance travel
$	**-**	**$**	**2,000**	Subtotal
Risk or Containment Costs (Expected Values)				
$	700	$	1,800	Supplier issue visit costs
$	1,857	$	51,816	Annual expedite costs
$	252	$	1,565	Quality spill risk
$	2,000	$	100,000	Other risks on this route
$	**4,808**	**$**	**155,181**	Subtotal
Grand Total				
$	**2,611,355**	**$**	**1,919,511**	**Total Annual Cost**
	136%		100%	Percent of Min Total Cost Option
$	15.13	$	11.12	Total landed piece price

Table 5.2: Summary total costs for sourcing from two different sources of supply

First Year Cash Flow			
$ 2,611,355	$ 1,919,511		Grand total from above
			Minus:
$ 6,066	$ 353		Annual dunnage principal and financing cost over program lifetime
$ -	$ 96		Annual cost of floor space for repack
$ 384	$ 1,056		Annual carrying cost of floor space for market
$ -	$ -		Equivalent annual cost to finance tooling
			Plus:
$ 23,293	$ 1,356		Value of dunnage (new)
$ 6,400	$ 17,600		Market area capital acquisition cost
$ 2,213	$ 738		Dunnage area capital acquisition cost
$ -	$ -		Total tooling cost
$ 2,636,811	**$ 1,937,699**		**Total first year cash flow req't**
Following Years Cash Flow			
$ 2,636,811	$ 1,937,699		Total first year cash flow req't
			Minus:
$ 23,293	$ 1,356		Value of dunnage (new)
$ 6,400	$ 17,600		Market area capital acquisition cost
$ 2,213	$ 738		Dunnage area capital acquisition cost
$ -	$ -		Total tooling cost
$ 2,604,905	**$ 1,918,006**		**Following years cash flow**
Other Summary Information			
$ 23,293	$ 1,356	$	Value of dunnage (new)
$ 4,543	$ 264	$	Total dunnage scrap value
85.9	5.0	dy	Max lead time or cycle time for dunnage through system
$ 54,788	$ 58,626		Annual parts freight costs
$ 18,263	$ -		Annual dunnage return freight costs
5.0	45.5	dy	Avg. In-Transit Parts Inventory
6.6	18.6	dy	Avg. Market Parts Inventory
0.0	1.0	dy	Avg. Repacker inventory
$ 50,327	$ 313,100	$	Avg. In-Transit Parts Inventory
$ 66,426	$ 128,126	$	Avg. Market Parts Inventory
$ -	$ 6,888	$	Avg. Repacker inventory
41.7	41.7	sec	Takt Time
11.1	11.1	sec	Achievable Take Time with Current Production at Our Plant
17.9	17.9	dy	Ship period, how often a shipment is sent

Table 5.3: Summary financial and other information for sourcing from two different sources of supply

6. Pull System Implementation

This chapter describes the tactical-level design and implementation of a pull system at Detroit Gear & Axle Plant 3, Group F (10.5" Full float axle shaft machining job). This project involved coordinating teams at two separate axle shaft manufacturing plants to implement a more effective visual pull system between and within the plants, using lean concepts for material management and flow.

One goal of the tactical project was to improve the stability of operations within the plants. Raw and finished goods material markets were sized and deployed to accommodate typical demand and production variability. An internal pull system was introduced to limit WIP levels and to rationalize the production changeover schedule. Continuous improvement efforts, especially efforts focused on downtime and material delivery from the supplying plant, still need be used to reduce inventory and overtime. Buffer sizes within the processing group at one of the plants may need to be increased to help increase overall production. Currently there is insufficient buffer space available between operations to handle typical downtimes (on the order of fifteen to twenty five minutes or longer). Some improvements were made to the lathes during the last two months of the project which reduced unplanned downtime at those operations.

Another goal was to smooth the flow of material between the plants by using pull signals and regular scheduled deliveries, reducing the "bullwhip effect" (amplification of demand variation) through several stages of material handling. This has not yet been accomplished, primarily due to middle management resistance and delay in obtaining the necessary tugger carts, and the lack of priority this project had relative to other initiatives at the site. The carts need to be custom ordered months ahead of time, since they must be designed to handle heavy loads of axle shafts.

The approach used was to gather baseline information about existing operations, discuss current practices with teams from the plants of interest, and develop future state goals that can be implemented. Plans were then developed for the operating system and the daily auditing of the system. After training the workforce, an initial implementation was made. Some refinements were suggested based upon operational lessons learned, and should be implemented by management in the future.

6.1 Current State

The Group F shaft job was selected as a candidate for implementation of a pull system for several reasons.

Firstly, the operation receives very erratic shipments of raw materials. The shaft machining job (Group F) receives raw forged shafts from the Detroit Forge facility. Group F stores several days of raw material from a neighboring plant (Detroit Forge) that is physically connected by a roof to the building housing Group F (DGA Plant 3). There is little obvious need to store several days of material when deliveries can be made in ten minutes from the sister plant. Currently the Forge sends trucks with highly variable quantities of raw shafts to DGA Plant 3, based upon pull signals sent over an electronic system. These signals are manually adjusted by schedulers at DGA Plant 3.

Second, the internal material management and production management of the job could be improved. All of this is exacerbated by high unplanned downtime, which means that daily crisis-management overshadows longer-term planning and improvement efforts.

As shown in the figure below, the communication systems around Group F's operations are causing a classic "bullwhip effect" in the supply chain (Sterman [2000]). Daily and especially weekly demand for each of the four different part numbers machined in Group F does not vary greatly. The only exception is when long-term ramp-up or ramp-down of models occurs (but this is known in advance from 16-week customer projections).

Production varies much more than customer demand for several reasons. Demand is not clearly indicated through visual control systems. Instead, area managers and production supervisors make personal production decisions based upon required build numbers on a printout that primarily they see. This printout is in turn the product of an MRP system and some possible manual schedule manipulation by the Materials Department.

Raw material delivery is even more erratic than the production in Group F. Raw material is theoretically ordered whenever material is consumed by Group F, or "scanned empty" in the company-wide electronic pull system. A variety of factors can cause problems with this process, including missed scans, manual manipulation of the pull signals to handle expected weekend or shutdown periods, or other errors.

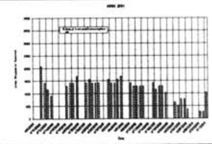
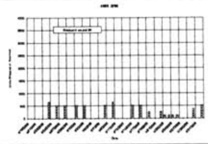
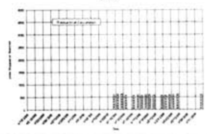
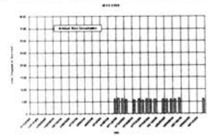
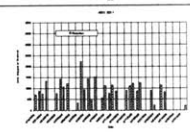
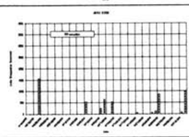
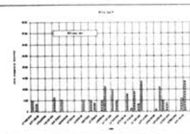
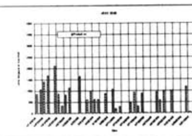
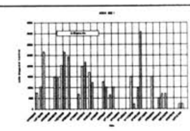
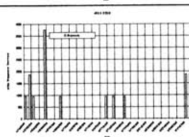
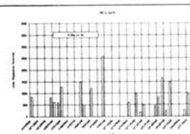
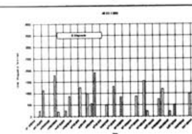
Part:	4000 3201	4000 3208	2604 5426	4000 0096
Demand:				
Production:				
Raw Mat'l. Provided to Plant:				
Std Dev. At each step (non-zero days only); (all days)	150/582/492; 608/708/999	143/481/457; 384/473/599	66/441/384; 585/743/677	66/473/374; 585/818/579;

Figure 6.1: Weekday demand, production, and raw material shipments for Group F

The end result was that the current state of operations at the start of this project amplified demand variation through the organization. This meant that more material was required to be stored at each stage of the operation to handle the current level of demand variability.

Average production was fairly stable even though Group F had high unplanned downtime. The production mix was not stable on a daily or weekly basis. These trends are shown in the figure below.

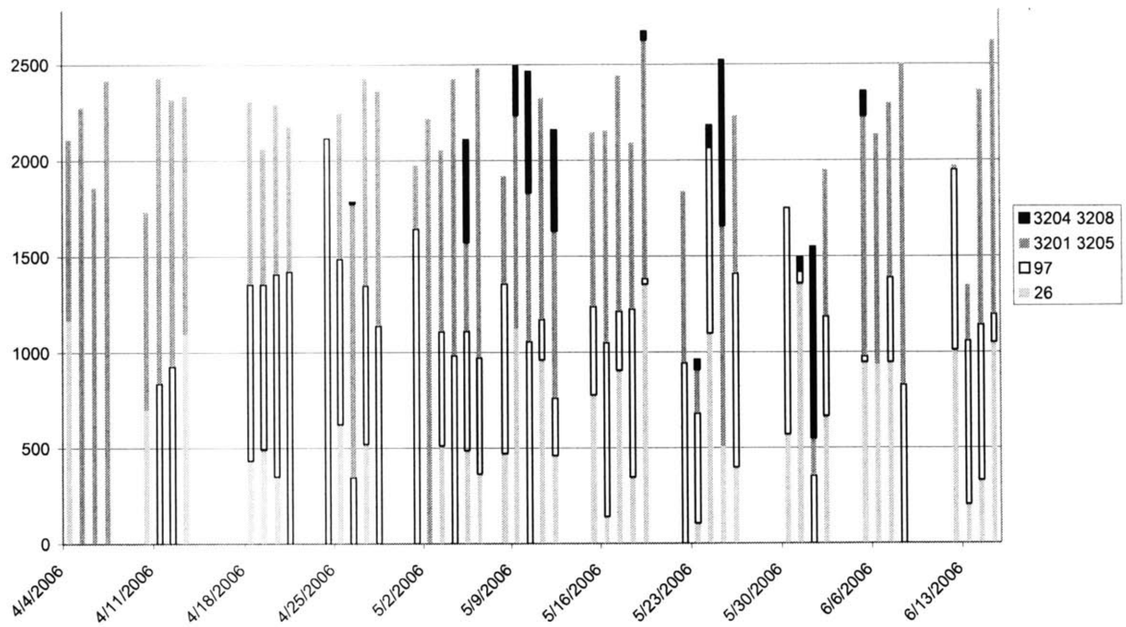


Figure 6.2: Weekday production of all part numbers at Group F

A current state value stream map had been produced for Group F just prior to the project. This value stream map, along with personal observations and downtime studies provided by the Industrial Engineering Department provided a starting point to understand the operations. Additional data, presented in the figures above, was collected from employees throughout the organization to develop a more accurate picture of the actual customer demand, scan empty (ordered), shipped, and scan full (received) cycle.

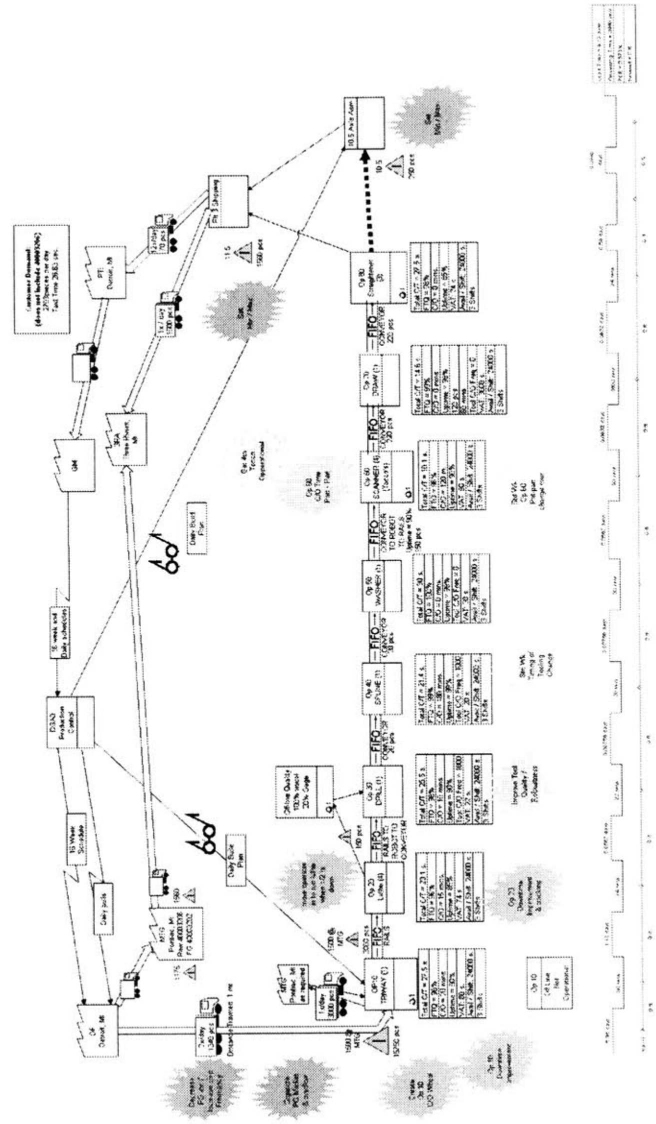


Figure 6.3: Group F current state map

6.2 Future State

The future state map is shown below. It was based upon discussion with the lean implementation team, with an estimate of what was achievable in the near-term (six months to one year).

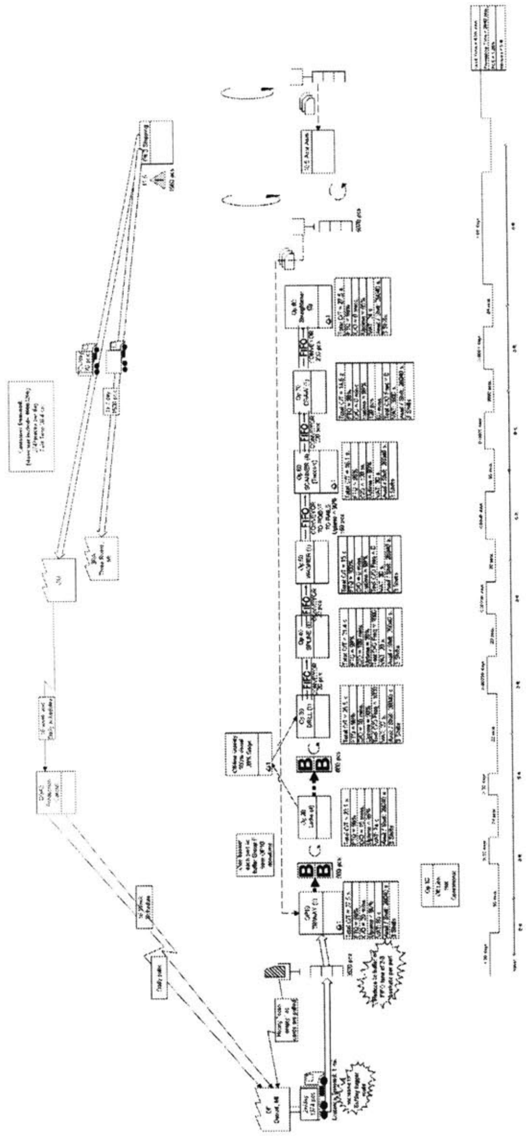


Figure 6.4: Group F future state map

6.3 Design

The pull system design was based upon principles described by Smalley [2004], Rother and Harris [2001], and Harris et al [2003]. Rather than relying upon electronic MRP and electronic pull systems, which are not visual and are constantly subject to error, the plan was to implement a set of more visual material management pull systems. The visual pull card system can better handle the daily fluctuations expected in typical operations, and provide visibility to problems in a timely manner.

The pull system implementation was intended to be achieved in two steps. The implementation was planned in steps for reasons of simplicity, and to allow for the lead time required to obtain custom carts for the Detroit Forge-to-DGA Plant 3 delivery route.

The first step to be implemented would be the establishment of finished goods (FG) markets immediately after Group F machining is completed, and the use of pull cards as material is withdrawn from this market to signal the need for more production. Pull cards would be attached to each machined pack of shafts in the material market. As customer orders led to finished packs being withdrawn from the FG material market, the FG cards would be removed from the packs and placed in a drop box. Every couple of hours a driver would collect any cards seen in the drop box and bring them to the Group F trigger board or pull board. There the supervisor would be able to tell how full or empty the FG market was from the number of cards of each part number on the board. Scheduling decisions for which part to changeover to next could also be made, and the appropriate cards placed on a schedule or sequence board to signify for the operators and supervisors when changeovers were expected to occur. As shafts were machined and packed ready to be delivered to the FG market, they had a FG pull card from the schedule or sequence board attached to them, ready to begin the cycle again.

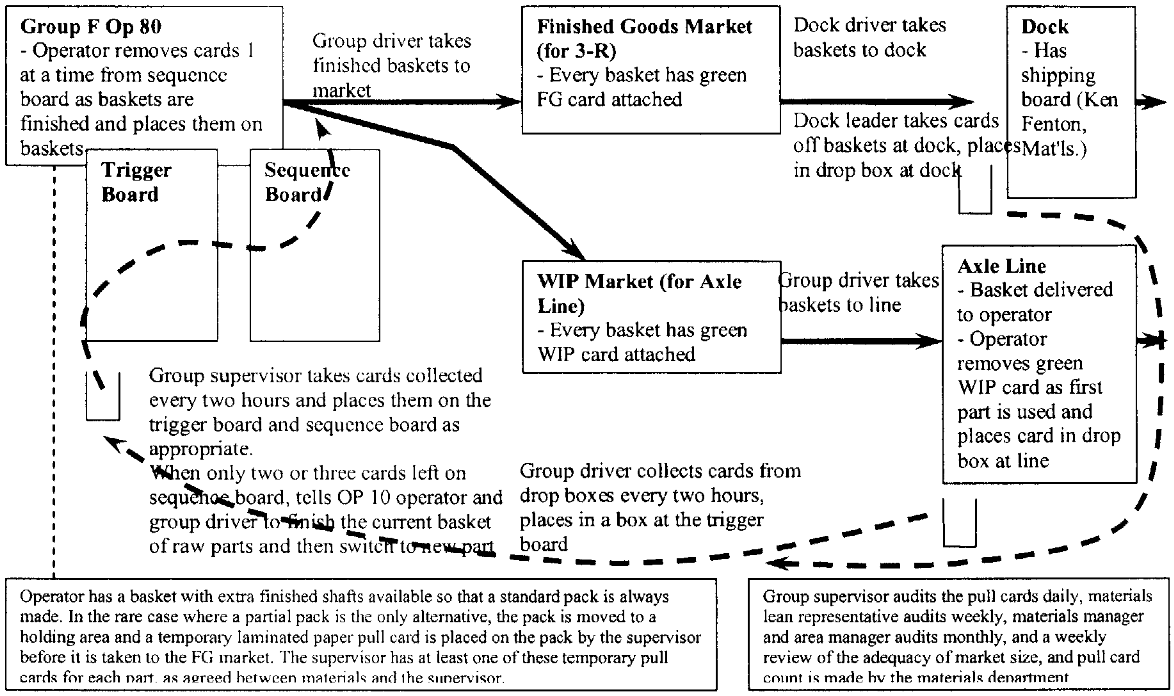


Figure 6.5: WIP/FG Material Loop From DGA Plant 3 Group F and External Customers/Axle Assembly Line

The second step to be implemented would be the creation of a scheduled tugger route between Detroit Forge and DGA Plant 3. A raw material market would be set up near Group F, and each basket of raw shafts in the market would have a pull card attached to it. As each basket of raw material was withdrawn from the market to be machined in Group F, the pull card would be removed from the basket and placed in a drop box. The tugger driver would take these pull cards and return to the Detroit Forge, planning to replenish DGA Plant 3's raw material market with as many baskets of each part number as were collected in the drop box. This second step of the pull system implementation was not yet complete at the end of the project.

The material markets were sized to handle approximately 95% of the typically encountered variability (a 95% service level), based upon the available variability data.

This represents short-term, daily variability. Any major changes in the following would require resizing the markets, changing the number of pull cards in the systems and also changing the signs and production trigger levels: longer-term (weekly) average demand, daily variability of use, supplier delivery or performance, or production uptime.

Trigger levels were also calculated to provide a 95% service level. Example calculations for material market sizing and reorder point (trigger point) are shown below.

It should be noted that several complications made this job less amenable to simple pull system implementation than might be expected. The job could be arranged to produce two different parts in parallel for much of the line, meaning that most of the time the highest-volume part was produced on half of the line. Equipment problems meant that the theory of two independent, parallel production operations was not always achieved in practice. Many unplanned downtime issues (which were being slowly resolved over the course of this project) reduced productivity on certain machines. Changes in downtime patterns over several months also led to changing opinions on the best way to handle certain situations which might occur when using the pull system. Many of these issues were still being resolved and improved upon as the project ended.

FG Material Market Sizing for DGA PL 3 Group F									
Part									
	2604 5426	4000 0096	4000 3201	4000 3202	4000 3208			Part # PL 3	
	same	4000 0097	4000 3205	4000 3206	4000 3204			Part # DF	
Demand									
Averages	**2736**	**2736**	**7150**	**665**	**1111**		**R (wk)**	**Avg. Weekly Demand**	From Phil Ross forecast data
	5	5	5	5	5	dy/wk		Days per week	
	547	**547**	1430	**133**	**222**	**units/dy**	**R or D**	**Avg. Daily Demand**	=Avg. weekly demand / days per week
	3	3	3	3	3	shifts		Operating shifts	
	8	8	8	8	8	hr/shift		Clock Operating time	
	24	24	24	24	24	hr		Total clock oper. Time/day	
	23	23	60	6	9	units/hr		Avg. hourly demand	=Daily demand / Total clock oper time/day
	130	**130**	**130**	**130**	**130**	**units**	**Ctr Qty**	**Std. Cntr. Qty.**	
	0.18	0.18	0.46	0.04	0.07	cntr/hr		Avg. Container use/hr	Containers used per hour, avg. = Hrly demand /Std. cntr. Qty.
Production									
	7.2	7.2	7.2	7.2	7.2	hr		Shift length	8 hrs - 2 x 23 min breaks
	3.0	3.0	3.0	3.0	3.0	shifts		Shifts	
	88.5%	88.5%	88.5%	88.5%	88.5%	%		Efficiency during runs (repre	=1-(15.8+14+20 min changeovers on avg)/(7.2wkng hrs*60) per Dana's production data for tool replacement/C/O
	11.5%	11.5%	11.5%	11.5%	11.5%	%		Routine downtime	
	16.5%	16.5%	16.5%	16.5%	16.5%	%		Unplanned downtime	Breakdowns excluding tooling, C/O
	72%	72%	72%	72%	72%	%		OEE w/o part changeovers	=1 - ("planned" routine tool replacement downtime + unplanned downtime)
	24.0	24.0	24.0	24.0	24.0	sec/unit	C/T	Production bottleneck C/T	OP 10 per Dana
	2343	2343	2343	2343	2343	units/dy		Max. daily production rate	The maximum average rate that production can produce in a day w/o part C/O = OEEw/opartC/O x hrsx shifts x 3600sec/hr / 24 sec/unit. Used to determine what is needed to ensure a supply of a given part during supply interruptions.
	781	781	781	781	781	units/shift			
	98	98	98	98	98	units/hr			
Mean Lead Time									
	2.2	2.2	0.2	2.0	2.0	dy	LTR	Lead Time to Repl.	Lead Time to Replenish. Varies with production plan . High-runner always running, assume at most a 1/2-shift delay
Cycle Stock									
	1186	**1186**	**238**	**266**	**444**	**units**	**CS**	**Cycle Stock (traditional)**	Cycle Stock = Avg. Daily Demand x Lead Time to Replenish
	1186	**1186**	**238**	**266**	**444**	**units**	**CS**	**CS Used**	
Variation in Demand = Buffer Stock Req'ts.									
	66	**66**	**66**	**66**	**66**	**units**	ηR	**Std. dev. Demand (daily)**	Assume no major variation in actual shaft consumption than for variation for part 2604 5426, also accounts for the OEE variation
	0.02	0.02	0.02	0.02	0.02	days	ηL	Std. deviation lead time	Guess 1/2 hr
	547	547	1430	133	222	units/dy	R		
	98	98	40	93	93	units	ηLTD	Std. dev. Of LTD	=sqrt (L sigmaR^2 + R^2 sigmaL^2)
	95%	95%	95%	95%	95%	-	SL	Svc. Level	Desired % of time variations handled by buffer
	1.645	1.645	1.645	1.645	1.645	#	z	Cumulative std. normal distri	Multiples of std deviation to cover desired % of cases, (inverse of the cumulative standard normal distribution)
	161	161	66	154	154	units		Buffer Stock	Buffer Stock per HLS (demand variation buffer) =z x sigmaLTD
	161	**161**	**66**	**154**	**154**	**units**	**BS**	**Buffer Stock Actually used**	
	14%	14%	28%	58%	35%	-		Percent of cycle stock	

Table 6.1: Material Market Sizing

Safety Stock (to handle delivery interruptions)									
	0.67	0.67	0.67	0.67	0.67	dy		Total downtime	Possible downtime requiring safety stock at 95% confidence level, estimate 16 hr per Steve Boudrie
	365	365	953	89	148	units		(Traditional) Safety Stock	Safety Stock (Worst case scrap, rework, downtime). Used avg daily demand x downtime
	365	**365**	**953**	**89**	**148**	**units**	**SS**	**Safety stock used**	
	27%	27%	313%	21%	25%				Safety Stock as % cycle+buffer stock
Market Levels									
Max									(Maximum level that should be reached in order to fully provide all buffers)
	1712	1712	1258	509	747	units		Max Inventory Level	Goods to Hold in Market = Cycle Stock + Buffer Stock + Safety Stock
					5938	**units**		**Combined total inventory**	
	14	14	10	4	6	cntrs.		Max Cntrs.	=rounded up (Max inventory/std. cntnr. Qty.)
					48	**cntrs.**		**Combined total baskets**	
Average									
	1119	1119	1139	376	525	units		Avg inventory level	=1/2 CS + BS + SS
					4278	**units**		**Total Avg inventory level**	
	9	9	9	3	5	cntrs.		Avg Cntrs.	
					35	**cntrs.**		**Combined total baskets**	
	547	547	1430	133	222	units		Avg. daily demand	From above
	2.04	2.04	0.80	2.83	2.36	days		Total Avg inventory level	=Avg inventory / avg. daily demand
	$ 11.97	$ 13.60	$ 12.73	$ 13.92	$ 14.64	$		Item value	
	$ 13,394	$ 15,218	$ 14,499	$ 5,234	$ 7,686	$		Value of items = # items x value each	
					$ 56,032			**Total inventory value**	
Min									(Critical level below which production will be disrupted)
Reponse Calculation for Emergency Expedite									
	0.33	0.33	0.33	1.00	1.00	dy	LTRexp	Lead Time to Repl., expedite	Lead Time to Replenish, for emergency expedite, 8 hrs in-plant, 24 hrs for 3-Rivers, might switch to 4 hrs for time to get one new basket made
	183	**183**	**477**	**133**	**223**	**units**		**Min Inventory Level (tradit**	**Min Inventory Level (traditional)=Lead time to replenish x avg daily demand**
	183	**183**	**477**	**133**	**223**	**units**		**Min inventory used**	
					1199	**units**		**Min inventory used**	
	2	2	4	2	2	cntrs.		Max Cntrs.	=Max inventory/std. cntnr. Qty.
					12			**Baskets**	
Reorder Point									
	2.17	2.17	0.17	2.00	2.00	dy	L	Mean lead time, L or LTR	
	1186	1186	238	266	444	units	Theta	Mean demand during mean lead time = L x D	
	1.645	1.645	1.645	1.645	1.645	-	z	Cumulative std. normal distribution	
	66	66	66	66	66		σR, σD	Std. dev. Demand (daily)	Assume no major variation in actual shaft consumption than for variation for part 2604 5426, also accounts for the OEE variation
	0.02	0.02	0.02	0.02	0.02		σL	Std. deviation lead time	Guess 1/2 hr
	547	547	1430	133	222	units	R, D	Mean demand per dy	
	98	98	40	93	93		σLTD	Std. dev. Of LTD	=sqrt (L sigmaR^2 + R^2 sigmaL^2)
	1346	1346	304	420	598	units	R*	Optimal reorder point	=Theta + z x σLTD
	130	130	130	130	130	units	Ctr Qty	Std. Cntr. Qty.	
	11	**11**	**3**	**4**	**5**	**cntnrs**	**R***	**Optimal reorder point**	**Sized to minimize chance of stockouts**

Table 6.1: continued

	Summary of FG Market Sizing							
						units		
	Assumes a lead time delay from production of each part of:							
	2.2	2.2	0.2	2.0	2.0	days		
	Number of Baskets of Each Part in the Market:							
	2604 5426	4000 0096	4000 3201	4000 3202	4000 3208	Part # PL 3		
	same	4000 0097	4000 3205	4000 3206	same	Part # DF		
	14	14	10	4	6	**Max**		
	9	9	9	3	5	**Avg**		
	2	2	4	2	2	**Min**		
					44	Max without part 4000 3202/3206		
					48	Max all five parts		
	11	11	3	4	5	cntnrs		Optimal reorder point

Table 6.1: continued

Another tool that was developed for the project was a visual inventory forecast for the coming week. This spreadsheet-based tool took known starting inventory, known daily demand schedules, trigger points and average achievable production rates to forecast how inventories would vary over the course of the week. This tool proved valuable at times when it became clear that larger starting inventories would be required to launch the pull system implementation than some production personnel had hoped. It also was helpful for "what-if" scenarios, such as varying trigger levels to trigger changeover to other parts. An example is shown in the figure below.

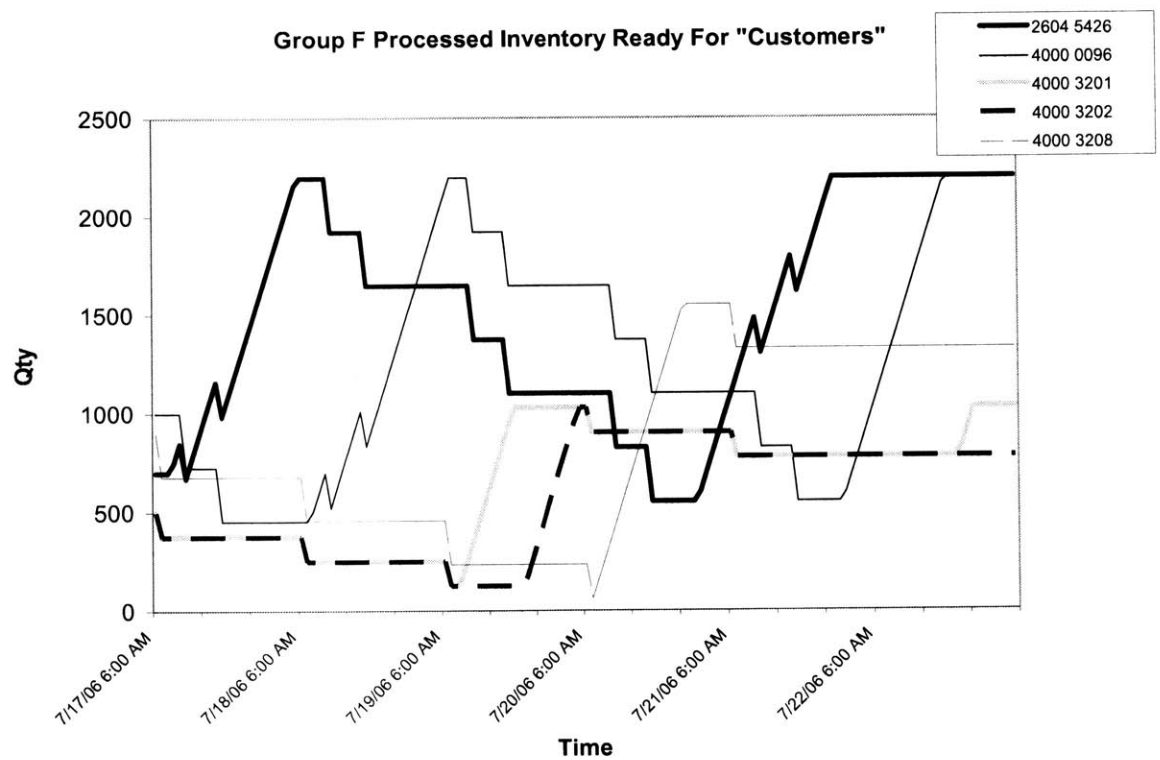


Figure 6.6: Group F Weekly Inventory Forecast Chart

6.4 Training

Training for the new pull system involved several steps. First, introductory sessions were held to explain the basic concept of pull systems to operators and supervisors, and suggestions were sought. Helpful in this regard was a miniature pull board and pull cards, which allowed demonstration of the pull loop system in meetings.

Next, as the time approached to implement the pull system, each shift was requested to stay for one extra hour for training. In this way, all three shifts could be trained within a ten or twelve hour period of time by a group of several lean coordinators and the intern. Training involved briefly discussing the system, walking the floor to demonstrate the use of pull cards and the locations of the drop boxes and boards, and providing a simple flow diagram describing the system.

As the boards and cards were deployed in anticipation of implementing the pull system several suggestions were provided to improve the system. One in particular made the trigger board much clearer to those not highly familiar with the concept from past experience. The suggestion which was implemented involved providing green, yellow, and red striping on the trigger board to indicate: no need to produce, tripped and produce when done with current part, and danger zone with risk of starving customer of parts.

6.5 Implementation

Implementation of the pull system's first step - establishment of FG markets and a trigger board pull card loop - was accomplished during the internship period. Material markets for both FG and for raw material were created well ahead of time. The FG market material levels were not raised to required levels until immediately before the week of implementation.

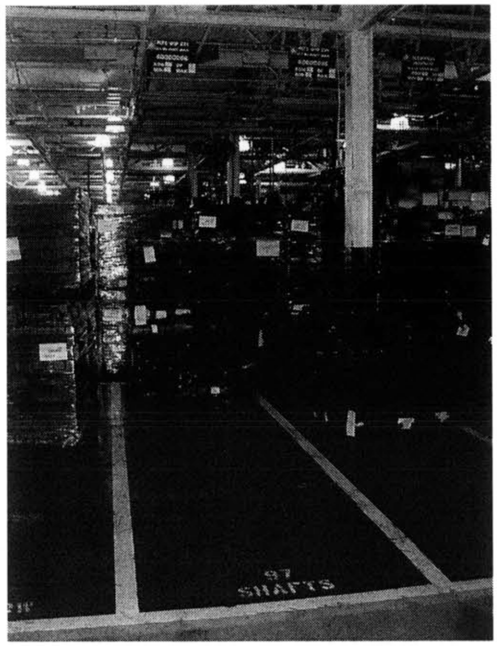


Figure 6.7: Finished Goods Material Market

The actual implementation was started on a Monday first shift, after a pre-shift walk during which pull cards were placed on all of the finished goods packs. The instructions and layout of the pull boards were changed over several weeks to reflect suggestions from operators, supervisors, and management. Temporary plastic pull cards were available instead of the regular metal pull cards, for cases where regular cards were lost or for other occasions when supervisors required the flexibility to continue producing one or two more standard packs of shafts before switching over.

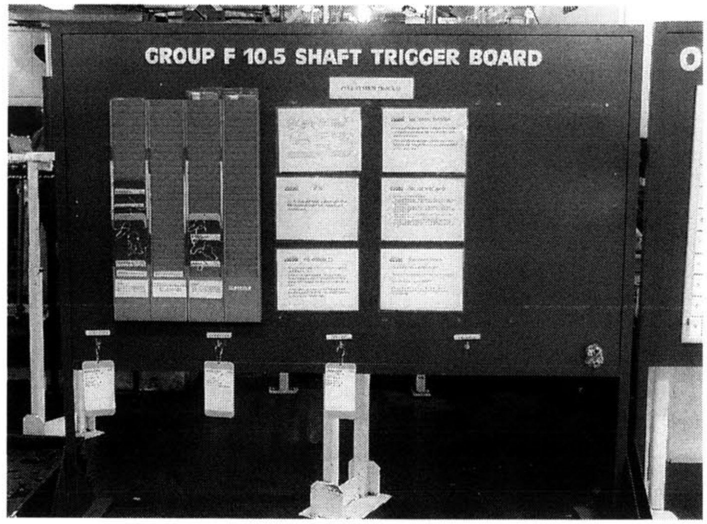


Figure 6.8: Trigger (or pull) Board

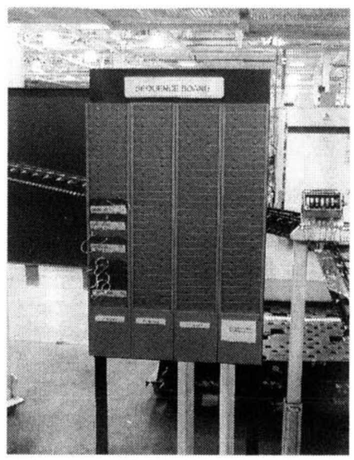


Figure 6.9: Sequence (or schedule) Board

Initially there were some misplaced pull cards, and other issues. Sometimes cards were thrown under the topmost piece of plastic dunnage on a standard pack, instead of being hung on the side of the packs. Over time these types of issues were raised and the pull cards were audited by the plant's lean analyst and by Group F supervisors, to reduce their occurrence. There was also hesitation on the part of some supervisors and managers to rely on the system instead of their traditional spreadsheet-based "build sheets".

Even with all of the startup issues typical with implementing a new pull system in a plant unfamiliar with lean manufacturing practices, some notable improvements were immediately apparent in the operation of Group F. The variation between maximum and minimum production of the highest-volume part was substantially reduced, as seen in the figure below. Training and preparatory activities began at the end of October and the start of November, but it really was not until early November when a significant number of personnel started to operate even partially according to the pull system production rules. Even at the end of the project, supervisors were not fully operating according to the system.

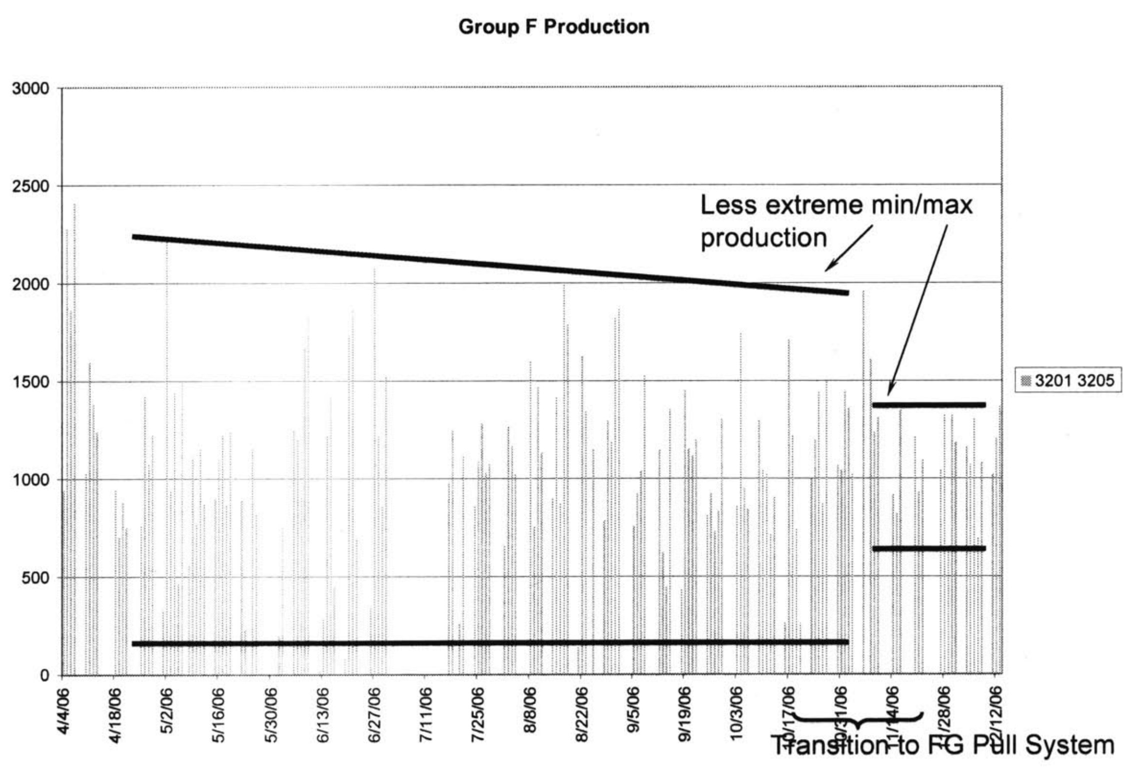


Figure 6.10: Weekday Production of High-Volume Part

Part of the reduction in variability producing this part can be attributed to the existence of the FG material market, which created a buffer between customer demand variations and daily production requirements. The stability was probably also increased by the presence of the trigger board and pull cards, which gave a new visibility to true stock and demand issues. In the words of one operator, when supervisors made part changeover decisions that did not make sense according to the visual management systems, the operators would sometimes challenge the decision. Note that there is a prolonged summer plant shutdown period which accounts for the gap in the data.

Although less dramatic, there was also an improvement in the stability of production of the lower-volume parts, produced in alternating batches, as shown in the figure below. The company holidays during November slightly complicate the comparison shown here. Note that one very low-volume part was outsourced to reduce overtime before the pull system was implemented. This outsourcing reduced the complexity of part changeover decisions and somewhat reduced the impetus behind using the trigger board.

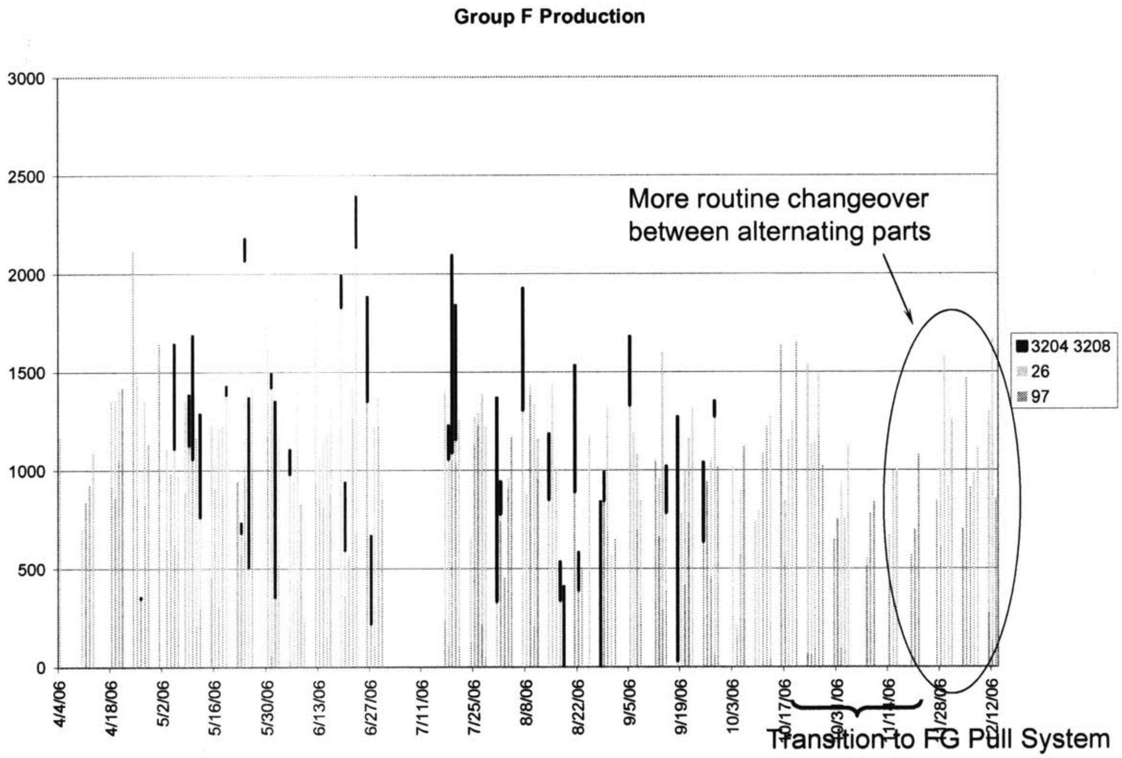


Figure 6.11: Weekday Production of Low-Volume Parts

Total production did not experience any major swings after implementation of the pull system, as shown in the figure below. Some major increases in volume were predicted due to long-term increases in projected customer demand.

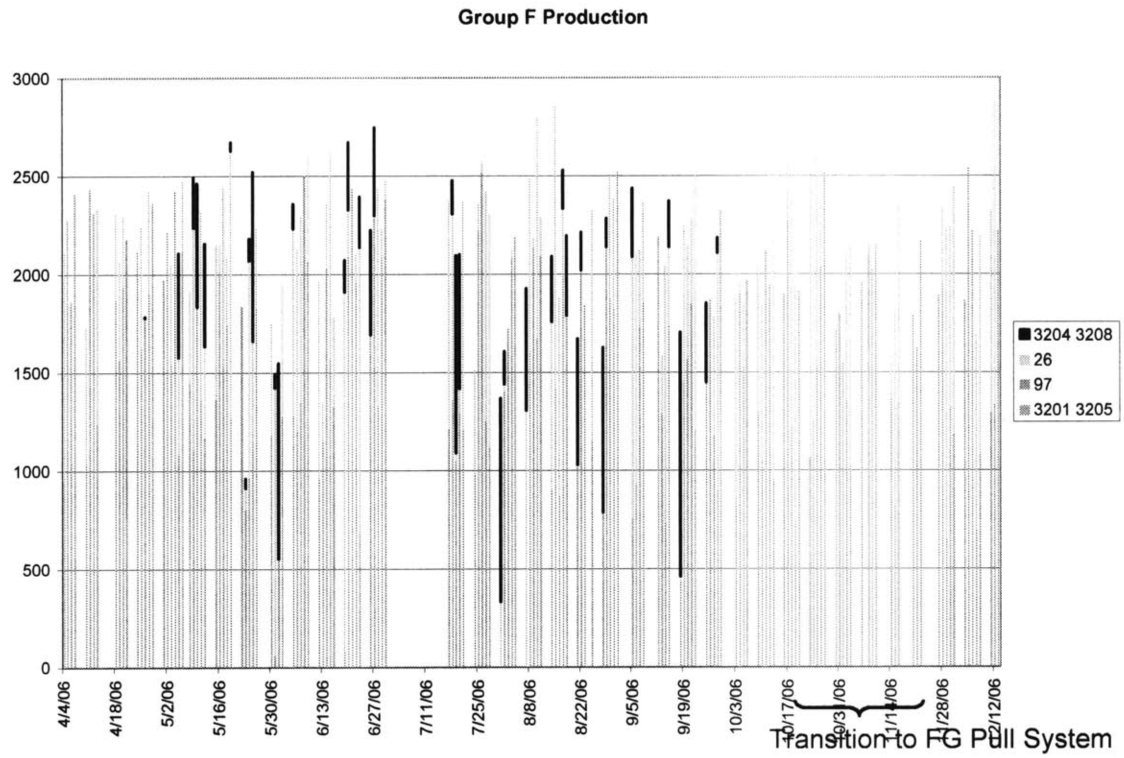


Figure 6.12 Weekday Production of All Parts

7. Lean and Organizational Behavior

A final aspect of the thesis was to examine the current business context in which the lean systems are to operate, as well as the strategic, cultural, and political aspects that influence change management in large organizations. These represent the non-technical yet vitally important features of how and why organizations operate the way that they do. Observations on the strategic, cultural, and political aspects of the organization are provided below. Recommendations are also made regarding approaches to the continued adoption of lean manufacturing at AAM.

7.1 Culture: Current and Future State

Lean Initiatives

AAM began implementing lean manufacturing initiatives on a company-wide basis approximately five years ago, at the time calling this effort the "AAM Manufacturing System." This initial effort resulted in some false starts in terms of plant floor systems, as the implementation efforts were not supported across the company. Total landed cost models were also developed several years ago to allow more informed sourcing decisions to be made. These models fell by the wayside. In all fairness this was also a difficult time to implement lean systems, as the booming Sport Utility Vehicle (SUV) market meant that AAM faced significant challenges meeting customer demand. Maximizing output became the goal, and other efforts took on secondary importance. Significant progress in productivity, quality, and cost was made, however, due to a continuous management focus on operations.

More recently Harris Lean Systems, a management consultant firm comprised of former employees of Toyota and other firms well-versed in lean manufacturing methods, has been advising AAM. Over the past one and one-half years, AAM has developed a lean group in the Corporate Materials Department to assist with training, the development of company-wide lean standards, and to provide guidance on initial implementation steps at the local plant level. The Corporate Materials group also works with other departments to identify opportunities for lean initiatives at the strategic level, such as for supplier sourcing decisions. AAM has reached the point where routine use of lean manufacturing principles has become common at many facilities, although inconsistent across the company as a whole. Substantial improvements towards the "50-in-5 goals" have been achieved. Many opportunities remain.

Focus Upon Local Interests

The strategy of the work unit at Corporate Materials is to deploy lean manufacturing principles company-wide, to gain continuous productivity improvements and therefore a competitive advantage. The strategy of much of the management at the local plants is to "meet the numbers" for their local facilities (as opposed to the enterprise as a whole), which can pit them against other AAM plants or principles of lean manufacturing.

Politically, the interests of stakeholders in lean implementation efforts at some of the plants are not compatible in the short-term. Changing the incentive system would help to encourage teamwork and flexibility across the enterprise. Power is broken up at a very high level within the organization by divided departmental and plant lines of authority. Little coordination is forced upon the various participants on a daily basis. Disputes about how to implement lean systems sometimes are not effectively resolved because strong leadership sometimes does not exists at the working level, and because there is little sense of teamwork. Value stream managers have been "injected" in a parallel chain of management by corporate headquarters, instead of in a line-command position, so their power is very limited without the existence of highly cooperative plant or area managers. The value stream managers have a role that is more similar to corporate staff rather than line management. They are placed within a culture that most highly values direct line management rather than advisory corporate staff employees.

The legacy culture and operations that AAM inherited still exhibit some of the characteristics of the past. One important characteristic is decentralization and fiefdoms, resulting in a lack of seeing or understanding the entire operation. Every plant is run, to a great extent, as its own firm. Every scheduler, every area and plant manager, follows a different procedure. Decisions are personality-driven rather than being standardized and systems-driven. Decisions are sometimes not made objectively according to the data in hand.

As suggested by Womack and Jones [2003], the company can establish dedicated product teams responsible for an entire value stream. These teams should then focus on a few simple goals or processes for improvement, and slowly roll this across other processes. To some extent this is already underway, as evidenced by the extended value stream meetings and other strategic meetings held between stakeholders from many plants and supplier facilities. Substantial progress is also being made in mapping the extended value streams. This mapping will allow everyone to understand the operations and to see opportunities for improvement.

Communication

Communication is very poor at some levels of the organization. There does not appear to be much communication from less powerful parties to much higher-power parties. For example, it is unlikely that executive management would really think that lean implementation projects are being perceived as a priority by some middle managers when timely maintenance response and resolution, cleanliness, and other workplace discipline issues are still in need of improvement in certain locations. There is little effort to clearly depict issues on boards during group meetings at some plants. People like to hoard information at many levels throughout the company. This is just one example of how wide dissemination of information is lacking. True dialogue and understanding is also lacking at many plant-level meetings. Also, there is a lack of complete honesty and openness about the true state of operations among some managers and employees: ask how something is done and depending upon the level of the hierarchy you ask, one will get a very different answer.

These breakdowns in communications are probably a result of a very hierarchical management style, a very large organization, and the intense daily pressure to keep the customer supplied with sufficient product at almost any cost. Individuals do not have much power and so they have both negative reasons to block communication (fear of reprisal for sticking out) and positive reasons to block communication (increased power or leverage). Greatly reducing the number of management layers would help improve communication within the company. Company incentives and management tactics probably also need to be altered to achieve a true lean culture.

Historical Contributors

Several employees noted that the current culture was a result of the needs of the past. When first formed, the company desperately needed to achieve basic stability, control, and authority. In other words, power-type management tools were necessary to drive through needed improvements. By installing a strong, hierarchical culture, a bias for accomplishing short-term, pressing goals was achieved. Operational performance measures were greatly improved over what they had been in the past under GM's management. However, two trends have occurred since then.

One trend is that these original managers have been promoted. Some of the newer managers have not had the business pressure, the micro and macro-level pull, to perform with the same level of discipline. Some of the newer managers also were not mentored or trained as well as their predecessors were. Supervisors on the plant floor are often no longer knowledgeable in the jobs that their subordinates are performing. The supervisors are therefore less effective. This deficiency has been identified and other recent internship projects have been focused upon understanding the current state of training and knowledge in the plants, and devising a more standardized training plan for the entire firm.

The other trend is that the management style and organizational structure has not significantly changed. To paraphrase one employee: "We had the right system for the founding of the company, but the business situation has changed since then. We should be on like our fifth management style by this point in the company's life." The employee's point seems to have been that basic stability and discipline was needed in the beginning, but the need now is for more refined forms of continuous improvement rather than managing to achieve basic stability of results. While AAM as a whole is moving towards lean manufacturing, some individuals are greatly retarding this transition. The lack of a change in upper management's style - towards one better suited to lean manufacturing - makes it harder for management to properly identify and handle the roadblocks to lean implementation.

Summary

In summary, the current culture at AAM could be characterized in the following manner: Personality-driven, hierarchical, own-plant focused, with imperfect communication and teamwork, and management time-frames of weeks and often months. The goal of achieving a "lean culture" would be achieved by driving the culture towards: systems-driven management, managing objectively according to the data at hand, with a high degree of communication and teamwork, and an enterprise-wide viewpoint. A continuous improvement culture that can improve faster than the competition is the ultimate goal.

7.2 Training

Byrnes [2006] notes that paradigm shifts in business operations tend to be most successful with extensive training, and with changes in compensation schemes. Employees tend to need both general familiarization training with new concepts, and specific training regarding their new functions. DeLuca [1999] stresses that from a practical viewpoint, new ideas should not be raised in group meetings unless the majority of those present already understand the idea being discussed. On some occasions this rule was violated during lean meetings at AAM, as many of those present either had not been trained or had not fully understood and incorporated the training.

Some of the lean practitioners at AAM believe that they should use a training element of lean manufacturing: the Training Within Industry (TWI) program. The TWI program was developed in the U.S. during World War II (Dinero [2005]). It was developed to teach people how to effectively and consistently perform on-the-job training for hourly associates, and to teach continuous improvement methods. Like Deming's quality-control methods, TWI was adopted by Japanese industry. In fact, it became integral to Toyota's operations. TWI represents the tactical-level heart of lean operations – what the associate and trainer on the floor needs to understand and use on a daily basis. To better implement lean manufacturing, AAM should identify the best trainers in the firm and then use them to train others how to instruct in TWI methods.

A goal should be to develop a lean, problem-solving culture at AAM, to become a learning organization that adapts faster than any competitor. AAM can create strong support for a lean culture by driving lean through leadership from the top-down. This means starting at the top of the organization with executive training, and successively requiring each management layer below to receive training, demonstrate understanding of the training, and be managed according to lean manufacturing measures of performance. Basic lean concepts training should be required for the entire organization at the plants as well, working from the top-down at each plant. (One suggestion provided from managers was to hold multi-day, off-site training sessions that guarantee better attention from attendees.) TWI-style training should be deployed at the operating level to teach the basics of a lean culture.

7.3 Compensation and Measurement/Management Systems

Using the Right Measures

Compensation and measurement systems at AAM are still oriented towards traditional "mass-production" operations. A switch to more transparency, and more incentives and compensation according to lean measures, would be very helpful in the journey to lean. People will do what they are actually paid and promoted to do, so the "real litmus test" for change in a firm is: are you willing to change your compensation systems? (Byrnes [2006]) The key is to get performance measures that relate to lean concepts on the plant floor, and to manage to them.

In all fairness, the use of lean measurement systems for a large company relates to major issues revolving around finance, accounting, and how Wall Street analysts assess firm performance. An issue that was only barely mentioned so far during AAM's transition to lean manufacturing is that lean really requires that a new kind of accounting system be implemented in the long run, in order to provide incentives for the right "lean" behaviors at even the corporate finance level (Womack and Jones [2003]).

Currently, managers are evaluated by build attainment numbers. While these build attainment numbers are intended to faithfully reflect how well the plants are fabricating according to actual daily customer quantity and product mix demand, they can be somewhat misleading. The numbers can be misleading in that a major under-build of a low-runner part might not result in a major slip in aggregated build attainment percentages for a plant as a whole, even if it is a major event for the customer. Machine performance is measured using Overall Equipment Efficiency (OEE) numbers that combine planned and unplanned downtime into one measure. An emphasis upon OEE is prevalent at all of the plants. These measures are both in opposition to lean principles. One should strive to produce exactly what your customer wants when they want it. Measurements of unplanned downtime (which cannot be controlled except by long-term equipment improvement efforts) should be separated from planned downtime (which can be controlled). A basic concept of lean manufacturing is that total system efficiency may be increased even if that results in reducing the total uptime of any one machine.

Audits

Most importantly, layered, frequent management audits of each layer in the organization should be performed to identify successes and also areas that require immediate attention. Audits represent a key element of successful lean enterprises. As lean practitioners such as Harris Lean Systems emphasize, you get the type of performance out of a plant that reflect what you measure and audit on a frequent basis. Measurement and auditing represent feedback that is critical to sustaining continuous improvement in any firm.

Production Analysis Boards

An area in which AAM is making advances in measurement is in the use of production analysis boards at each manufacturing cell. These boards compare hourly planned versus actual production, and the reasons for shortfalls or overages. The boards also include top action items and schedules for completion by responsible parties. The production analysis boards are helpful tools for highlighting problem areas and for keeping everyone goal-oriented on the top performance issues of the cells.

One problem with the current use of production analysis boards is that their use is not uniform throughout the company: some boards are up-to-date and prove helpful in addressing issues, while other boards are not properly maintained. Better auditing by management would help to instill a sense of discipline in these cases.

Discipline

A necessary ingredient for many highly successful companies has been the creation of a culture of discipline (Collins [2001]). By discipline, Collins does not imply a mindless adherence to commands. Instead, what is meant by discipline is enough discipline of thought and action instilled by management and culture that a company can run itself. Bureaucracy is not necessary when the employees of a company have enough discipline to take care of daily matters and follow up on minor tasks. This discipline leaves management free to focus on more important issues. Better training and management auditing would help instill more discipline. Management by objectivity and systems, not personality, is the goal. It is this tactical-level discipline that represents a fundamental part of efforts to transition to lean manufacturing on the plant floor.

7.4 Change Management

Self-Reinforcing Cycles

Collins [2001] identifies a virtuous cycle apparent in many firms that make sustained transitions to great performance. The cycle consists of maintaining stability in management long enough to accumulate visible results or improvements. Once these improvements become apparent, other people recognize the potential for further improvement along the same line of action, and become aligned with the initiative. More and more progress is made, further increasing the visible results. A self-sustaining virtuous cycle, dubbed the "flywheel effect" by Collins, results. This is also the sort of self-sustaining effect that is seen in manufacturing facilities that effectively make the transition to lean manufacturing (Womack and Jones [2003]).

In contrast, Collins [2001] notes that many firms suffer from the opposite sort of effect, wherein management increasingly frustrated by disappointing results reacts without understanding, making decisions that are erratic and fail to maintain alignment or direction. The result is dubbed the "doom loop".

Power

One possible contributing factor to this style of management was described by Kanter [1979]. Kanter suggests that employees at all levels, even executives, may feel that they occupy positions of powerlessness. The feelings of powerlessness can be caused by lack of supplies, support, or information. It is possible that this sense of powerlessness (whether conscious or unconscious) is at work for some of the individuals trying to implement lean manufacturing. There are several possible reasons.

The organization is very hierarchical and divided along many lines of authority at a very high level. This makes it difficult to rapidly martial support for integral changes to operating practices. The high degree of hierarchy (and also the current culture) act against free flows of information and transparency. Politically, company tradition has been that those who don't push for radical change are promoted. Issues relating to unionization, such as the large number of job classifications (and the concomitant number of people who are required to perform some seemingly simple tasks such as fabricating and posting signs) can cause frustrating delays (on the order of months). Also, the plants have a long history and many close personal relations among members at all levels of the organization. These relations can act to shield people from the need to change because they garner the political support of a higher-level associate.

A lack of company-wide lean training and measurement/compensation systems also work to reduce the power of those who implement lean manufacturing. The end result is that some managers trying to implement lean manufacturing are frustrated by the slow pace of progress. Their instinct is sometimes not to tackle the systemic issues, but to quickly issue goals and stretch assignments that are rarely tracked or followed-through upon. This works to create a "doom loop" when what is really desired is a "flywheel effect".

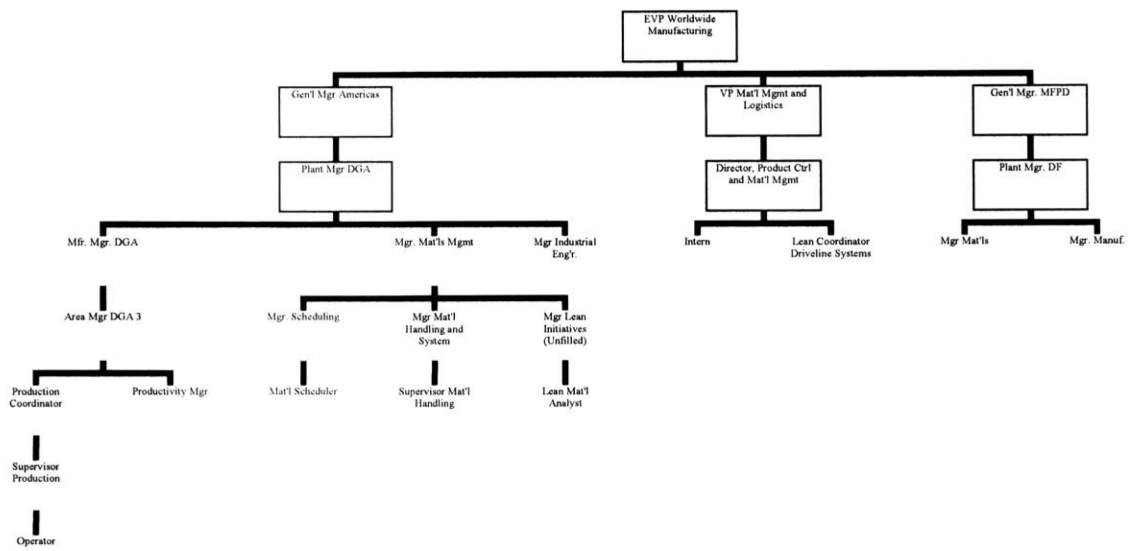


Figure 7.1: Formal Structure of the Organization and the Intern's Position Relative to Key Individuals

Roadblocks

Another theme in the change management literature appears to be that some people within the organization will not be able to adapt. Some individuals will need to be replaced if they are unwilling to be flexible and to work together towards new goals important to the survival of the firm [Womack and Jones, 2003][Collins, 2001]. AAM has been hesitant to make this sort of hiring and firing decision. The result is that major roadblocks to change exist in the organization. Despite the flagging profits of traditional "mass-production" firms and the success of many "lean manufacturing" firms, these individuals are unwilling to entertain the possibility that lean manufacturing may offer substantial operational improvements. Until these roadblocks are removed or marginalized, true organizational change will be very difficult indeed.

Critical Mass of Understanding

Another theme of change management from Klein [2004] is that effective organizational change seems to be most effective when a critical mass of company "insider-outsiders" develop sufficient exposure to new facts and ideas to remove their organizational blinders, allowing them to see the compelling need to change the organization while still respecting the ways in which the organization functions.

Observations of managers throughout the organization suggest that the "seeds of change" have been planted in the form of many insiders who see the value in at least some aspects of lean manufacturing principles. They are hindered, however, by problems with measurement, compensation, and training.

For example, hundreds of employees have received lean management training. Often, these individuals readily understand the concepts and believe in their efficacy, but vocalize their frustration at management practices that hinder true change towards lean manufacturing. One major example of this problem is with how higher management and finance treats material markets. Material markets should be maintained within specific levels according to lean principles. If markets are not properly maintained, even at the cost of spending some overtime budget, then the entire advantage of having these markets to buffer other customers, and to stabilize one's own production, is lost. Management does not treat material markets like the customer, instead treating markets as a luxury. Sometimes overtime work is not approved by management to allow maintenance of proper market sizes. A vicious cycle of crisis management is begun wherein a short-term avoidance of overtime to maintain these valuable buffer stocks causes more costly long-term overtime and production issues.

The organization is very hierarchical in nature so these "insider-outsiders" or agents of change are not able to make major, independent steps towards lean manufacturing and are limited in their abilities to align and incentivize others. Until the organization is better aligned towards training for and encouraging lean behaviors, the effectiveness of these "insider-outsiders" is limited. Another concern is that delays in aligning the organization towards lean management principles will alienate the "insider-outsiders", driving them away to other firms in a case of adverse selection.

Locations of Successful Change

Visual inspection and discussions with employees suggested that the greatest headway in lean implementation appears to have been made in AAM plants that felt the need or pull for change in the form of great business pressure, and that tended to be further away from the Detroit union culture (although plants are still unionized at other locations). New plants probably also had an easier time adopting lean because there was no pre-existing culture to change. The least success has been at the Detroit area plants, where a sense of entitlement and a long history of work have provided a sense of relative security.

7.5 Recommendations For Transitioning to Lean Manufacturing

Overview

Much of what determines how a firm runs eventually comes back to what incentives and feedback employees receive. People and culture are important factors as well, but these also relate to incentives and feedback. Culture is based upon employees' perspectives and habits forged over a long history of incentives, feedbacks, and tasks or challenges. In a large organization, most tasks that employees see are not direct tasks provided to the customer, but are internally-defined tasks that hopefully result in an end product or service for the customer.

The culture, incentives and feedback that the firm has in place are appropriate for meeting past challenges. They may not be as appropriate for meeting the challenges that AAM is likely to face in the future. The challenge for the future is to have a continuous improvement culture that improves faster than the competition. Attempting to implement a very different operating procedure - lean manufacturing - without making similarly large changes to incentive and feedback procedures will probably be ineffective. While AAM as a whole is moving towards lean manufacturing, some individuals are greatly retarding this transition. The lack of a change in upper management's style - towards one better suited to lean manufacturing - makes it harder for management to properly identify and handle the roadblocks to lean implementation.

Cultural Change

Christensen discusses organizational culture and the means to change it in a series of research notes drawing on his work and that of Schein and others [Christensen (2006 Culture, 2006 Capabilities, 2005 Cooperation)]. Paraphrasing these notes, the major points are as follows. Culture is a learned response to a set of recurring problems faced by an organization. When an organization faces a set of problems and tasks often enough, employees develop solutions and at some point no longer explicitly question what the right approach is. It is at this point that a culture develops.

Culture becomes very difficult to change in a head-on manner. Instead, culture can be more easily changed through other methods. One method to change a culture is to create a crisis, forcing the organization to acknowledge that past solutions are no longer appropriate to the new challenges which the organization faces. Another method is to create a new business unit, which must face new challenges and develop a new culture. Christensen emphasized that the task is the starting point for cultural change, because culture is a response to recurring tasks. Shifting the level of accountability in an organization is another good means for driving cultural change, because it changes the nature of tasks employees must perform [Christensen (2006 Culture, 2006 Capabilities, 2005 Cooperation)].

AAM could use the following approaches to create a culture more inclined to embrace lean manufacturing:

- Give employees new tasks different than the old, such as building to material bank sizes or to level production boards, rather than to truck shipments. Emphasize that the bank is now their customer, not the outbound truck shipments. Overtime should be required to maintain the banks. When this is done no one will need to work overtime to meet outbound truck shipments, and the entire operation will be much more stable and robust.
- Shift the levels of accountability in the organization. Push responsibility as close to the floor, to the operators, as possible. Most of the operators quickly understood the broad outline of the visual pull systems even when their supervisors resisted or when training was incomplete. It also helped to have more eyes focused on the visual control systems than only one set of eyes on the supervisor's paper build plans.
- Give the managers new tasks and responsibilities, such as two-level pull system audits of those below them on a frequent basis, and make their performance auditing just as important as their other roles. The results achieved are what you measure for and what you pay for.
- Deliver on promises and mandates instead of letting them slide. In other words, follow just a few key mandates and make sure that they are achieved before moving onto others. This will change the problems and solutions required of middle managers from head-ducking and paper solutions presented at operating reviews, towards better long-term progress.

- Incentivize employees with new measures of evaluation and new management approaches. Stop judging performance based on very broad measures such as total production. Start focusing on lean measures that directly relate to what is happening on the plant floor. Start using objectivity and systems in management, removing personality from decision-making.
- Start emphasizing visual control on the plant floor, and less supervisor work on paper in their offices after their shifts end. If the production boards and visual controls are in constant disarray, this needs to be resolved as quickly as a failed customer delivery, because it is fundamentally undercutting the ability of the organization to improve what it provides to customers through better quality and productivity. It also hinders efforts to reduce costs to bid for new work. Failing to attract new work is as damaging as a failed customer delivery, except that it will happen a year from now rather than today.
- Set new long-term expectations and therefore tasks. Ask not only for production quotas, but also for evidence of continuous improvement. Is the plant not showing quality or productivity improvement, or is it varying substantially each day, week, or month? Is this happening even though resources are provided that are similar to those of other plants? Are the managers really devoted to continuous improvement? If so, why do effective lean manufacturing firms like Pratt & Whitney and Harley Davidson manage to move on the order of 1000 machines in each of their plants in a couple of years, but virtually no machines have been moved in the past two years in one of AAM's Detroit plants?

- Have managers require open communication and do everything possible to help in this regard. Reduce the number of management layers. Emphasize the use of visual tools such as white boards or paper easels in meetings to get people focused on objective items rather than on individuals' comments.
- Build awareness of the coming crisis in competitiveness. Emphasize that the crisis-management practices of the past were appropriate for old problems, but will not be as effective at tackling the competitiveness problems of the future. Emphasize the achievements, both within the company and at other US and foreign firms, in using lean manufacturing methods. Take people on plant tours. It costs only $500-$1000 to take people to Mexico or to other US plants, but it could save thousands or millions of dollars if it changes the behavior of just a few managers.
- Consider using new forms of teams, such as true heavyweight value stream teams that are given responsibility and authority for cross-functional collaboration and delivery of an entire product line that might span several plants.

Detailed Change Plan

There are many good sources for detailed lean manufacturing action plans. These include Womack and Jones [2003], the Lean Enterprise Institute guide books, and operator-level training described in Dinero [2005]. Collins [2001] also has some good high-level management commentary which another CEO who successfully turned a company around recommended as a good read. A detailed lean manufacturing change plan could be based upon these references and others, and should be tailored to the business and cultural context of the firm.

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8. Conclusions and Recommendations

8.1 Results

The major strategic accomplishments of this project included the following:

- Highlighted improvement opportunities in value streams, developed detailed knowledge of eight extended value streams
- Developed a tool to allow evaluation of the true costs of sourcing, applied it to five business cases

The major tactical accomplishments included:

- Facilitated creation of a pull system that brings visual management to DGA Plant 3, Group F

Various supporting tasks and roles were also accomplished, including assisting in the development and deployment of training material, and participating in workshops and operations reviews.

8.2 Key Lessons Learned

Key insights of this project included:

- Extended value stream mapping, and the communication that is required to perform it, is a valuable exercise for management. It is a valuable tool for highlighting opportunities for supply chain improvement and for providing objective means to evaluate the state of current operations, and highlights organizational "blind spots".

- Total cost analysis tools are useful, but their real value lies in engaging in dialogue with various departments to encourage teamwork and long-range thinking about supply chains and sourcing decisions.

- Some major lean accomplishments are visible, but not consistent across the firm.

- Vital to obtaining the paradigm shift to a lean manufacturing culture and successful plant floor implementation are: training; compensation and measurement/management systems; and removing roadblocks.

- Stay objective, focus on the data and on communicating constantly in an honest, calm and open manner.
- Stay flexible.

8.3 Recommendations for Future Work

Future work regarding the transformation to lean manufacturing at AAM could be pursued in a number of areas. Although tactical-level, plant floor techniques and tools often garner the most attention when lean is discussed, other issues may be more profitably pursued as well. In some cases, focusing on the details of implementing lean manufacturing may be premature. Investigation of the higher-level cultural and management practices lying behind successful cases of lean implementation, both at AAM and at other firms, could be a profitable area of research.

Taking more employees on tours of very "lean" facilities at AAM and elsewhere may also be helpful to generate ideas and dialogue.

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