High-Mix, Low-Volume Lean Manufacturing Implementation and Lot Size Optimization at an Aerospace OEM

by

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Abstract

Hamilton Sundstrand provides the aerospace industry with both original equipment and aftermarket product support. This division of the United Technologies Corporation posted over $3 billion in revenues in 2001. Hamilton Sundstrand has manufacturing locations and service centers worldwide. In the wake of the events of September 11, 2002, the aerospace industry finds itself amid the largest downturn in the history of aviation. To cut costs and to streamline operations, Hamilton Sundstrand is introducing lean production techniques in their factories.

This thesis describes the implementation of lean manufacturing methods in the Windsor Locks, CT plant in the Air Management Systems Division. A description of the methodology used to introduce lean concepts as well as a comparison with the one advocated by MIT's Lean Aerospace Initiative appears within. In addition, this thesis provides examples of the implementation of lean methods in the Heat Exchanger Core Assembly Area. As a part of this work, the author developed an optimization technique for inventory lot sizing for a set of machines with high replenishment costs. Upon implementation, coordinated replenishment in the Fin Forming Area of the factory is projected to yield a one-time inventory reduction in excess of $100k in addition to annually recurring savings of $45k in holding costs and set-up costs.

This thesis also touches upon operations strategy by presenting the results of interviews with leading macroeconomists on the business climate in several emerging labor markets. In addition, the thesis presents a discussion of organizational factors related to the introduction of widespread change in an organization with specific examples related to the introduction of lean manufacturing methods in the Windsor Locks plant.

Last of all, this thesis offers recommendations for lean implementation, introduction of coordinated replenishment, and observations on domestic manufacturing.

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I dedicate this thesis to the memory of my father.

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Chapter 1: Introduction

Mass production of goods helped bring the United States out of the Great Depression, simultaneously won the Second World War, and then allowed Americans to enjoy an unprecedented period of prosperity following WWII. In the beginning of the Postwar Period, the American manufacturing sector faced no serious competition from overseas. Within a few decades, Japan and Europe rebuilt their infrastructures and refined production methods to such an extent that it enabled them to challenge American dominance. The OPEC crisis in the early 1970's ushered in a new era of competition, as lean manufacturing methods allowed Japanese companies to nimbly respond to customers, to reduce work in process, and to slash inventories.[1] American firms have noticed the great competitive advantages that lean manufacturing techniques confer to its adherents, and industry trends lean towards adopting lean techniques. Aerospace companies such as Hamilton Sundstrand in Windsor Locks, CT, are beginning to reap the benefits of lean production methods.

This chapter briefly introduces Hamilton Sundstrand, setting the stage for the lean transformation. It also provides a summary of accomplishments and outlines the organization of this thesis.

1.1 Hamilton Sundstrand

Hamilton Sundstrand (HS) is a division of United Technologies Corporation, a Dow Jones Industrial company. HS manufactures aerospace and industrial products and provides aftermarket services. Products include aircraft power generators (both auxiliary and emergency), propellers, pressurized cabin air management systems, wing de-icers, fuel and flight control systems, valves, compressors, and pumps. HS had revenues of $3.5 billion in 2001, of which 71% was commercial and 29% was military.[2]

During the largest aviation industry downturn ever, cutting costs is crucial for continued existence as an on-going entity. Decreased demand for aerospace products has led to the consolidation of production facilities as well as a reduction in workforce. In order to remain competitive, HS is undergoing a revolution in lean manufacturing. This thesis focuses on the lean efforts in the Heat Exchanger Core Assembly Area within the Air Management Systems Division of the Windsor Locks production facility. A wave of lean manufacturing is sweeping through the factory.

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[1] Richard P. Marek, Debra A. Elkins, and Donald R. Smith, "Understanding the Fundamentals of Kanban and CONWIP Pull systems using Simulation", Proceedings of the 2001 Winter Simulation Conference, 921 (accessed Oct. 10, 2002); available from http://www.informs-cs.org/wsc01papers/122.PDF.

[2] "Hamilton Sundstrand Overview", (United Technologies Corp. Hamilton Sundstrand presentation, 2002), 7.

1.2 Lean Manufacturing

John Krafcik of the MIT International Motor Vehicle Program coined the term *lean production*.[3] The concept of *lean* is the ability to do "more and more with less and less".[4] Tacit in this statement is the central concept of continuous improvement. Most people associate with lean manufacturing the elimination of waste, reduction of inventory, increase in productivity, and a focus on quality and value. Taiichi Ohno of the Toyota Motor Company assembled many of the fundamental contributions to the field of lean manufacturing into the Toyota Production System, a widely modeled, efficient manufacturing method.[5] Hamilton Sundstrand has developed its own efficient manufacturing system that produces according to the Market Rate of Demand (MRD). The MRD program has resulted in fewer inventories, higher quality, shorter cycle time, and reduced direct labor input in the manufacturing cells that practice lean principles. The next section reflects the results of the lean implementation.

1.3 Summary of Findings

All work performed and findings relate to the implementation of lean methods in the Fin Forming Area of Hamilton Sundstrand's Windsor Locks facility. The largest contribution is the derivation of an intuitive method for sequencing parts in the Fin Forming Area to reduce the number of set-ups. This method involves joint replenishment. It will result in a one-time inventory reduction of over $100,000 as well as recurring savings of $25,000 per year in avoided set-up costs per year and over $20,000 per year in avoided holding costs in the Fin Forming Area.

In addition, contributions were made in the implementation of lean manufacturing methods according to Hamilton Sundstrand's Market Rate of Demand method. This thesis compares this method with that of the Lean Aerospace Initiative (LAI), which is a consortium of aerospace entities dedicated to streamlining aircraft production. LAI established a Production Operations Transition-to-Lean Roadmap. Their Roadmap is comparable to the HS MRD method combined with United Technologies Corporation's ACE program. As part of this thesis, a Pareto Analysis was performed to determine which parts to pull through the Fin Forming Area. Work/wait boards that enable visual inventory management were prepared for a kanban system for the entire Heat Exchanger Core Assembly Area. Workers received training for pull methods. Materials and equipment were located at the point of use.

This thesis also addresses the globalization issues facing HS as posed by leading economists such as MIT Professor Lester Thurow. Interviews suggested Eastern Europe

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[3] James P. Womack, Daniel T. Jones, and Daniel Roos, The Machine That Changed the World, (New York: Harper Perennial, 1990), 13.

[4] James P. Womack and Daniel T. Jones, Lean Thinking, (New York: Simon & Schuster, 1996), 9.

[5] Kazuhiro Mishina, Toyota Motor Manufacturing, U.S.A., Inc., (Boston, MA: Harvard Business School Publishing), 1992.

and Brazil as attractive manufacturing locations overseas. Currency fluctuations may immediately make some factories uncompetitive, so leaving existing operations where they are currently located should be considered. Womack advocates a thorough evaluation of economic factors affecting the decision of production location in his teachings of "lean math".

Furthermore, this thesis addresses introduction of change from the perspective of a modified version of the Sloan Leadership Model. The original Sloan Leadership Model characterizes how leaders implement change initiatives. The lean transformation underway at HS is a primarily a cultural change, which is the most challenging and time consuming type of change. The seniority aspect of unions encourages the propagation of existing cultural norms, and over the next decade seniority will result in a loss of human capital. As a result, some manufacturing work will be forced to move elsewhere, assuming that the existing operations remain cost competitive.

1.4 Organization of Thesis

The layout of this treatise follows a pattern: starting from a very high level look at manufacturing history, the thesis moves on to lean transformation and progressively focuses on the Heat Exchanger Core Assembly Area. Later chapters discuss the future of manufacturing and of labor relations, tying these topics in with a model for organizational change.

In the following thesis, Chapter 2 introduces the problem statement and reviews literature relevant to lean manufacturing, effectively setting the stage for work performed at Hamilton Sundstrand. Chapter 3 examines the implementation of lean methods according to various transition models. Then Chapter 4 illustrates the Hamilton Sundstrand lean method with specific examples from the Heat Exchanger Core Assembly Area. Consistent with lean thinking, Chapter 5 discusses selected aspects in inventory management and specifically lot sizing for joint replenishment. Interviews with leading economists appear in Chapter 6, which delves into some aspects of manufacturing strategy. Chapter 7 discusses organizational change and the Sloan Leadership Model. Chapter 8 relays the relationship between management and the labor union, which is critical for the transition to lean to occur. Finally, Chapter 9 presents results, recommendations, and conclusions.

Chapter 2: Project Description and Literature Review

This chapter defines the challenge facing Hamilton Sundstrand, introduces the lean transformation project, and reviews literature on lean transformations. It sets the stage for further chapters on lean implementation in the Windsor Locks facility.

2.1 Problem Statement

During the current turbulent economic period featuring the largest downturn in the aviation industry ever, it is essential for companies such as HS to eliminate waste wherever possible in order to remain competitive in the marketplace. Efforts are underway at HS to implement lean manufacturing techniques in the Windsor Locks, CT plant. A more competitive HS will help to sustain parent company United Technologies Corporation's profitability.

2.2 Project Description

Hamilton Sundstrand's MRD (Market Rate of Demand) group is responsible for implementing lean manufacturing in HS's various mechanical and electronic manufacturing sites. The objective of MRD manufacturing is to standardize and to simplify processes while simultaneously improving quality and responsiveness to customer demand. To reach these objectives, HS is actively implementing a pull system for the procurement of materials and the manufacture of products; changing the lay-out of its factories to accommodate single piece flow; and slashing WIP (Work In Process) and inventory levels considerably.

The goals of the MRD implementation are to improve the following metrics:

- Cycle Time
- Productivity
- Inventory
- Quality (as measured by cost of scrap, rework, and repair)
- Customer On-Time Delivery
- Safety (OSHA Recordables)[6]

In specific, the goal of this internship is to assist with the implementation of lean manufacturing practices in the Heat Exchanger Area of the Air Management Systems (AMS) group at the UTC-Hamilton Sundstrand Windsor Locks facility. This task involves transitioning from a "push" (MRP) system to a "pull" system for the procurement of materials and the manufacture of products.

[6] "Design Review Heat Exchanger Business", (United Technologies Corp. Hamilton Sundstrand presentation, 05/21/02), 4.

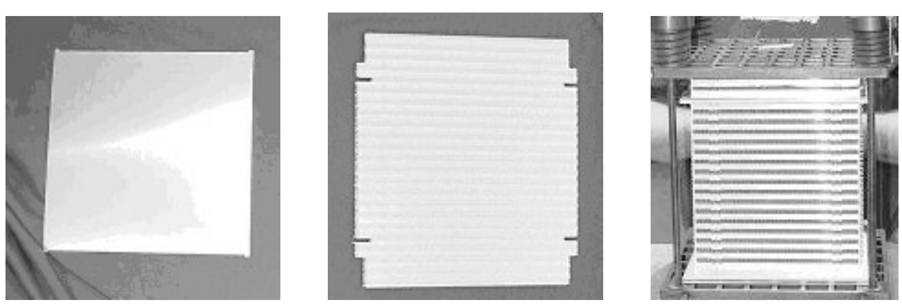
The AMS division produces air management systems for both military and commercial jet airplanes. The below figure represents an air conditioning pack. It contains heat exchangers, a compressor, and several valves.

Figure 1. Photograph of Air Conditioning Pack for Commercial Jet

Three main areas compose the AMS division: Valves, Heat Exchangers, and Air Cycle Machines. The implementation of lean manufacturing practices is staggered in these areas as to minimize the disruptions caused by changes in practice. The Valve Group already implemented lean manufacturing processes. The Heat Exchanger Division is amid implementation. Air Cycle Machines comes next; their transition to lean is currently being planned.

This thesis concentrates on the implementation of lean manufacturing in the Heat Exchanger Division's Core Assembly Area. This area manufactures parting sheets and fins, which are components in the core of cross-flow heat exchangers found in the air management systems of jet aircraft. Photographs of parting sheets, fins, and a heat exchanger core for the air conditioning pack of an environmental control system appear below in Figure 2. Upon manufacture, these parts get transferred to storage before being stacked into heat exchanger cores, which get brazed and then finally sent to the next area for completion. The work involves a high amount of touch labor and custom fitting.

Figure 2. Parting Sheet, Fin, and Heat Exchanger Core.



All work performed relates directly to the Heat Exchanger Core Assembly Area. The work performed for this thesis is described by the following:

- Implementation of visual inventory management control system (Performed Pareto analysis to identify high-volume items; helped locate goods at point of use; constructed work wait boards; trained operators; etc.)

- Developed lot size optimization method for coordinated replenishment by part sequencing based on economic order quantity and applied it to fin production
- Examined low cost manufacturing environments to contribute to the manufacturing strategy of all HS products
- Interviewed leading economists from MIT and the World Bank about emerging production markets
- Interviewed labor relations expert at Hamilton Sundstrand to better understand the context of lean transformation

In addition, some smaller projects were undertaken that are not a major part of the thesis, but are mentioned in Chapter 7. These projects are:

- Performed capital budgeting exercise of new fin forming equipment featuring reduced set-up times.
- Analyzed cost and benefits of coil stock decoilers for use with fin forming machines; safety considerations and a highly positive NPV led to procurement.
- Modified braze alloy coating machine to increase reliability; calculated effect of modifications as positive NPV.
- Provided manufacturing engineering support to the fin form area (identified need for new dyes, worked to have fin forming machines overhauled, capital budgeting analysis of new stock decoilers, etc.).

All of these smaller projects supported the larger, lean implementation activities. The goal of lean is to lower total costs while maintaining exceptional quality, rapid delivery, and customization. The next sections delve into how Hamilton Sundstrand is meeting their goals.

2.3 History of Lean Manufacturing at Hamilton Sundstrand-Windsor Locks

In the mid-1980's, lean concepts had made their way into the manufacturing philosophy at Hamilton Sundstrand's Windsor Locks plant in the form of a set-up reduction program. Experiments with focus factories were carried out, but did not survive past a change of management in the economic downturn in the early 1990's. Around that time, the director of the propulsion area enthusiastically set-up a pull system for propeller components, which worked well until upper management reverted back to a push system. Under the same roof, the Precision Machining Facility was organized into cells and flow lines according to the Pratt & Whitney model in 1991. Over the course of the past 15 years, productivity dramatically increased as the total number of labor hours declined. Routine manufactured components were transferred to lower cost manufacturing environments during this time. Significant progress in operational improvements had been made prior to the start of a formal lean manufacturing program.

Lean manufacturing efforts at sister company, Pratt & Whitney, are well known and described in Chapter 8 of Womack and Jones' book, Lean Thinking.[7] The lean efforts

[7] James P. Womack and Daniel T. Jones, Lean Thinking, (New York: Simon & Schuster, 1996), 151-188.

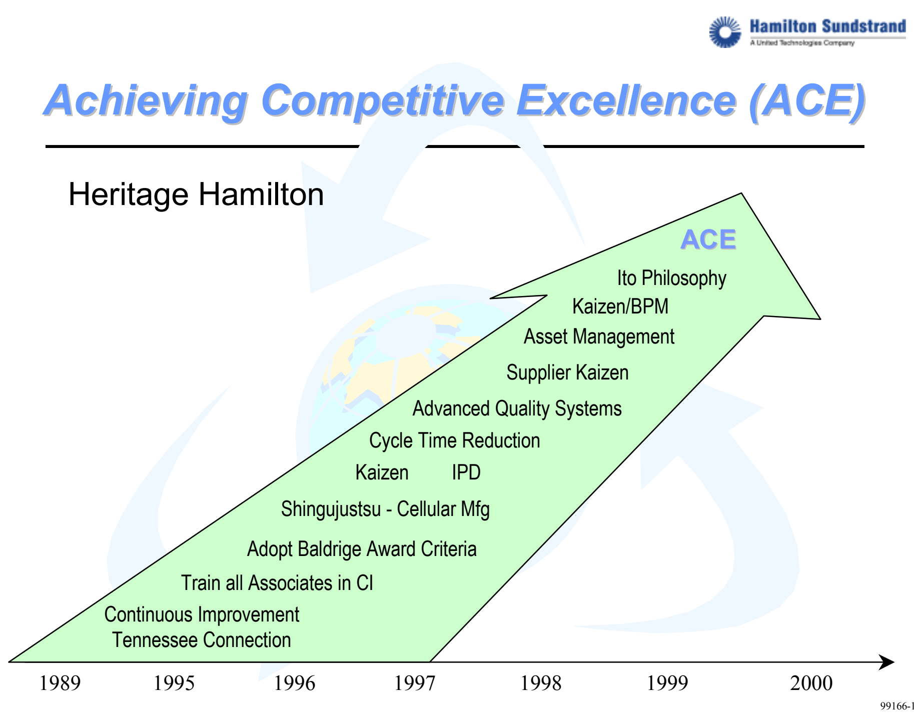
there did not carry over to what was then Hamilton Standard. Only when Hamilton Standard acquired the Sundstrand Corp in June of 1999 forming a new entity called Hamilton Sundstrand did a formalized program to institute lean efforts catch on at Hamilton Sundstrand. Some elements of lean already existed since the early 1990's in the form of the ACE program, as the next section describes.

2.4 ACE: Achieving Competitive Excellence

ACE is UTC's quality focused, strategic business format. Its mission is to achieve improvements in quality and productivity that result in customer satisfaction and efficient operations. To do so, every organizational unit strives to meet higher achievement levels (bronze, silver, gold) according to specific performance criteria. The first line supervisors lead area teams. ACE embodies a continuous improvement culture.

ACE grew out of predecessor programs emphasizing continuous improvement and cycle time reduction. Figure 3 shows a timeline representing the evolution of ACE into a corporation wide entity.

Figure 3. The evolution of ACE: Achieving Competitive Excellence.[8]



[8] Kathy L. Paro, "Improving the Supply Chain Hamilton Sundstrand Supplier Symposium", (United Technologies Corp. Hamilton Sundstrand presentation, 3/20/2000), 3.

ACE uses various tools to attain its mission. They fall under the classification of Foundation, Quality, Productivity and Design Elements.

<u>Foundational Elements of ACE</u>

1. 5S: Efficient workplace organization and visual control

sort	remove unnecessary items from area
straighten	organize required items logically in area
scrub	thoroughly clean plant
standardize	establish similar procedures
sustain	repeat above regularly

2. Total Productive Maintenance (TPM): regular maintenance to ensure equipment availability

<u>Quality Elements of ACE</u>

3. Quality Clinic Process Charts (QCPC): tool to identify problems and turnbacks
4. Market Feedback Analysis (MFA): analyze customer feedback to track product performance and improve its quality and reliability
5. Root Cause Analysis: prevent reoccurrence of problems by getting to true source
6. Mistake-Proofing: ensuring that a task is always performed properly
7. Process Certification: standardization of procedures to minimize variation

<u>Productivity Elements of ACE</u>

8. Set-Up Reduction: save labor input during machine changeovers
9. Standard Work: make processes repetitive leads to efficiency and effectiveness

<u>Design Elements of ACE</u>

10. Passport: review and approve new designs in a systematic way

ACE also incorporates a set of achievement levels. Every work area has a criteria checklist that ensures a specific quality level. Completion of items on the checklist will qualify an area for a specific rating. Once each area in a factory has a specific rating, the factory is then certified to that level. The levels are as follows:

Qualifying	Awareness of ACE process and tools, collection of key data
Bronze	More detailed understanding and utilization of all tools, achievement of results, elevated pride & morale
Silver	Significant business improvements result from initiatives
Gold	Excellence

In summary, ACE is a method to achieve quality and productivity improvement to increase customer satisfaction and production efficiency. It is an integrated initiative that involves core business teams, cells, and support personnel to align cost with quality, resulting in long-term improvement and better utilization of resources. With ACE, all of UTC is focused on consistently meeting metrics in order to improve competitiveness.[9]

2.5 MRD: Market Rate of Demand

Lean manufacturing efforts have been underway since the late 1980's at Sundstrand (prior to the acquisition by Hamilton Standard) in the form of statistical process control and continuous improvement. Then in the early 1990's, a downturn in the economy paved the way for more drastic changes such as self-directed work teams. This step allowed the removal of layers of management in one Sundstrand facility. From 1993-1996, an effort to group parts into families according to material and function allowed the restructuring of manufacturing at various plant sites. Simultaneously, concepts such as kaizen events, cycle time reduction, working capital (inventory) reduction, and Just-In-Time gained support throughout the company. In 1996, Sundstrand underwent a series of lean initiatives including a core/non-core analysis, linking the supply chain, and a pilot implementation of manufacturing cells ensued in 1996 with a company wide rollout thereafter. At this point, the lean efforts were collectively known as the Supply Chain Improvement (SCI).[10] Following Hamilton Standard's acquisition of Sundstrand in 2000, SCI became known as MRD. Figure 4 on page 18 depicts the evolution of MRD.

Over the course of the past decade, MRD has matured into a process that spans the value chain and encourages lean production. Its primary objective is to improve customer satisfaction with on-time delivery, competitive costs and exceptional quality. MRD features single piece flow of work pulled with kanbans through production cells where point of use materials and tooling are located.

MRD espouses several principles:

- Respect for people
- Teamwork
- Elimination of waste
- Simplification of product flow
- Standardization of product flow
- Management of the process, not the product to attain quality
- Produce to demand
- Single piece flow

These principles combine to form a methodology for the introduction of lean practices to an organization. Chapters 3 and 4 provide details of the MRD method.

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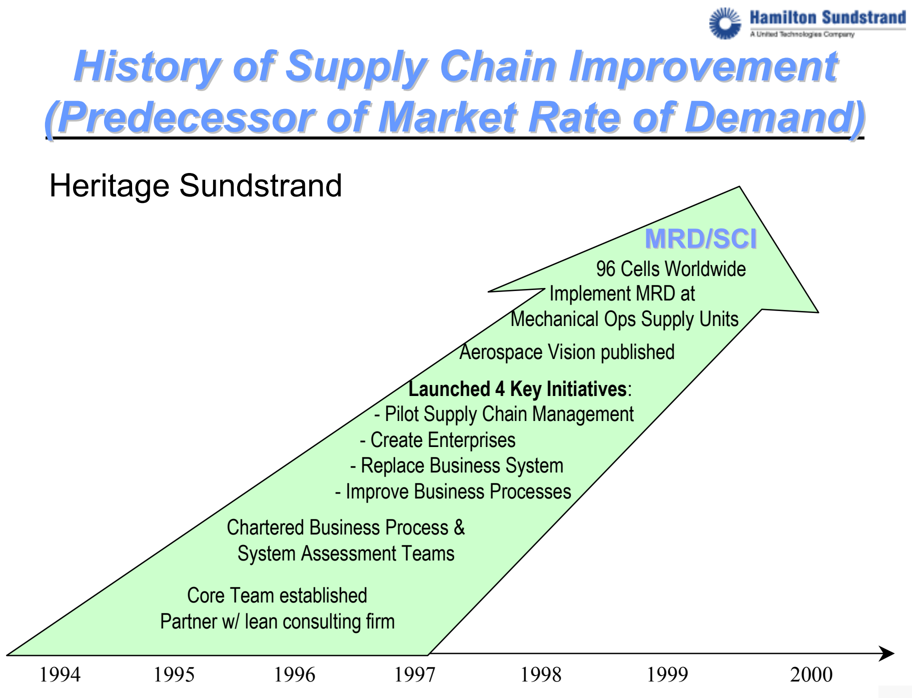
[9] "Ace Overview Manufacturing Qualifying Level", (United Technologies Corp. presentation, rev. B), 5/27/00.

[10] Tony Flippo, Hamilton Sundstrand Windsor Locks Plant Manager, conversation on Dec. 4, 2002 and Todd Johnson, Hamilton Sundstrand Vice President Operations, conversation on Dec. 9, 2002.

Figure 4. The evolution of MRD: Market Rate of Demand.[11]



The mechanics of MRD involves two types of production cells:

1. MRD - High/regular volume; fits standard process; pull production
2. MRP - Low/volatile volume; does not fit standard process; push production; uses materials requirements planning

In the MRD cells, pull production occurs in the following way: the MRP software is retained for planning purposes, whereas kanbans are used for execution. Consumption triggers replenishment. Work in process decreases as lead time decreases. The flow of WIP occurs in a visual manner. Details and tooling are kept at their point of use.

With the acquisition in 2000, Sundstrand employees brought their formal program of lean manufacturing techniques to Hamilton. This program is now called MRD for Market Rate of Demand. It complements the already existing ACE (Achieving Competitive Excellence) program, which focuses on quality and productivity. The implementation of MRD follows a well developed method described below gained from experimentation over time.

[11] Kathy L. Paro, "Improving the Supply Chain Hamilton Sundstrand Supplier Symposium", (United Technologies Corp. Hamilton Sundstrand presentation, 3/20/2000), 7.

MRD Implementation Method

1. Kick-off of cross functional team / overview training
2. Initial Data Collection
    - 80/20 Volume Breakdown
    - Bill of Material Analysis
    - Demand Pattern
    - Baseline Metrics
3. Process Analysis
    - Process Flow Maps
    - RBWA's (Routing By Walk Around)
    - Part/Process matrix
    - Design, Quality, Supplier, Material issues
    - OEE (Overall Equipment Effectiveness)
4. To-Be Process Definition
    - Part Families
    - Standard Processes
    - MRP Cell
5. Resource Requirement Calculations
6. Kanban Design Analysis
7. Define Cell Layout / Simulation
    - MRD Cells
    - MRP Cell
8. Final Presentation
9. Equipment Procurement / Transition Plan
10. Implementation[12]

This method alone is not a recipe for lean manufacturing. Additional elements such as 5S and set-up reduction are not explicitly expressed in the MRD methodology implemented in the Windsor Locks facility since these elements already exist in the ACE program.

2.6 Lean Manufacturing Literature Review

The following section reviews the lean manufacturing in a historical context, building up to the Toyota Production System. It further discusses the work of Womack et al. and provides a review of past LFM theses.

2.6.1 The Origins of Lean Production

In the book, From the American System to Mass Production, author David Hounshell demonstrates that some lean manufacturing concepts have been around for quite some time. For example, flow comes from the Chicago meatpackers "disassembly lines" as

[12] "MRD Supervisor Training", (United Technologies Corp. Hamilton Sundstrand presentation, 2002).

described in Upton Sinclair's The Jungle in 1906.[13] The origin of the standardization of parts stems from the early 1800's United States Ordnance Department, who insisted that small firearm parts be interchangeable. Processes similar to those used to make weapons could also be used to make bicycles and sewing machines. In the 1880's, a focus on quality in the manufacture of sewing machines provided a competitive advantage for I. M. Singer & Co. At Singer, a directive stated that defective parts do not move onward unless they were dimensionally acceptable.[14] In automobile manufacturing, which Peter Drucker later coined "the industry of industries", Henry Ford was among the first to take a holistic view at value creation. In Ford's factories in Detroit, MI, manufacturing transformed from a centuries old craft activity to mass production.[15] At the Ford Motor Company, Ford integrated his supply chain, co-located several activities on one site to avoid shipping expenses, and maintained a core capability of designing machine tools in house.[16] Ford pioneered customer satisfaction. In his autobiography, he writes: "A manufacturer is not through with his customer when a sale is completed. He has then only started with his customer."[17] Ford also foresaw Just-In-Time production: He wrote: "If transportation were perfect and an even flow of materials could be assured, it would not be necessary to carry any stock whatsoever. That would save a great deal of money, for it would give a very rapid turnover and thus decrease the amount of money tied up in materials."[18]

At General Motors, William Knudsen became the father of flexible manufacturing by building an organization and production system with general-purpose tools that could readily handle change. This former Ford employee learned his lesson by observing Ford's changeover in production in 1927-1928 in a disastrous, months-long plant shutdown that resulted in a 25% loss in market share. In 1929, Knudsen ensured that Chevrolet change its engine line over from four to six cylinders on the order of weeks, which was then record time, while simultaneously boosting output up by one half million units. General Motors factories evinced the flexibility to initiate the annual model change.[19]

In the paper, "The Evolution of Manufacturing Control – What Has Been, What Will Be", Kenneth N. McKay discusses a host of so-called modern manufacturing methods and references them to the earliest known literature on the topics. Some concepts commonly associated with Toyota Production System in the 1970's are actually a

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[13] David A. Hounshell,, From the American System to Mass Production, 1800-1932 : the Development of Manufacturing Technology in the United States, (Baltimore, Johns Hopkins University Press, 1985), 241.
[14] Ibid., 3-6.
[15] James P. Womack, Daniel T. Jones, and Daniel Roos, The Machine That Changed the World, (New York: Harper Perennial, 1991), 11.
[16] David A. Hounshell,, From the American System to Mass Production, 1800-1932 : the Development of Manufacturing Technology in the United States, (Baltimore, Johns Hopkins University Press, 1985), 232.
[17] Henry Ford, My Life and Work, (Garden City, New York: Doubleday, Page & Co., 1922), 41.
[18] Ibid., p. 143.
[19] Ibid., 263-267.

renaissance of concepts stemming from previous eras. A partial list of "modern" methods follows:

- Cloning of factories (1800's)
- Design For Manufacturing (1830's)
- Treatment of downstream departments as customers (1910's)
- Focus on inefficiency and waste (1910's)
- Sampling and quality control (1920's)
- Pull of material through factory (1920's)
- Flow Lines (1920's)
- Just-In-Time (a.k.a. Hand-To-Mouth) (1920's)
- Supply chain management (1920's)
- Co-location of horizontal elements of supply chain (1930's)
- Link between remuneration and productivity (1930's)
- Identifying and working out bottlenecks (1940's)[20]

Although all of these lean manufacturing concepts were well known for decades prior to the advent of the Toyota Production System (TPS), nobody had put them all together. Necessity in the bleak aftermath of World War II forced Japanese engineers to be inventive in order to catch up with the West let alone survive. Starved for capital, Japanese manufacturing lines had to be flexible in order to produce a large mix of low cost parts on the same production line, which represented a deviation from the Ford model featuring a line dedicated to a specific product. The rundown post-war conditions gave birth to a series of innovations such as flexible factory layouts, coordination between workers and machines, jidoka (automation), inventory reduction, decrease in set-up time, production control (kanban method), and self inspection that that collectively became known as TPS.[21]

2.6.2 The Toyota Production System

The main goal of TPS is profit creation by cost reduction. Costs sink by eliminating waste.[22] Taiichi Ohno, the father of TPS, identifies 7 types of waste in his book, Toyota Production System:

1. overproduction
2. waiting
3. transportation
4. processing

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[20] Kenneth N. McKay, "The Evolution of Manufacturing Control – What Has Been, What Will Be", (working paper 03-200), 9-10.

[21] Taiichi Ohno, "The Origin of Toyota Production System and Kanban System", Proceedings of the International Conference on Productivity and Quality Improvement, Tokyo, 1982, reprinted in Applying Just In Time, ed. Yasuhiro Monden, (Atlanta: Industrial Engineering and Management Press, 1986), 3-8.

[22] Monden, Yashiro, Toyota Production System 3rd edition, (Norcross, GA: Engineering and Management Press, 1998), 2.

5. inventory
6. movement
7. defects[23]

Overproduction is the worst type of waste because it leads to excessive inventory and unnecessary capital investment. For example, it is necessary to build or lease a warehouse for extra inventory, to hire extra workers to manage it, to purchase forklifts to move it around, and to repair any inventory that becomes damaged in storage. The inventory then runs the risk of obsolescence, resulting in further waste.[22]

In addition to waste minimization, TPS has other minor goals: quality control, quality assurance, and respect for individuals.[24] Two main concepts guide TPS in attaining the goals:

1. Just In Time is the production of ordered units at the right time.
2. Autonamation, or *jidoka*, is a tenet of quality control that says products should not flow downstream if they are defective.

TPS employs several tools to implement these guiding concepts:

- kanban system – dispatches production as needed to ensure JIT, encourages flow
- production smoothing – manages demand changes
- set-up time reduction – enables flexibility
- standardization of operations – permits workforce flexibility
- manufacturing cells – allows flexibility
- worker involvement – encourages creativity and boosts morale
- trained workforce – allows efficient labor allocation; rotation minimizes boredom
- visual control system – promotes quality control by using andons
- continuous improvement – encourages creativity to streamline operations[25]
- "Five Whys" analysis – ask "Why?" repeatedly to get to the root of problems[26]

Toyota's product portfolio of small vehicles helped them weather the OPEC crisis in 1973, as did the operational advantages conferred by TPS. In 1975, 1976, and 1977, Toyota led the pack in profitability, and other companies took note.[27] The lean style of manufacturing developed at Toyota changed the nature of work, customer choice, and ultimately the success of companies far removed from the automobile industry.[28]

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[23] Ohno, Taiichi, Toyota Production System, (Cambridge, MA: Productivity Press, 1988), 19-20.
[24] Monden, Yashiro, Toyota Production System 3rd edition, (Norcross, GA: Engineering and Management Press, 1998), 3.
[25] Ibid., 5.
[26] Ohno, Taiichi, Toyota Production System, (Cambridge, MA: Productivity Press, 1988), 17.
[27] Ibid., 1.
[28] James P. Womack, Daniel T. Jones, and Daniel Roos, The Machine That Changed the World, (New York: Harper Perennial, 1991), 12.

2.6.3 Lean Machine

Among the people to take notice of TPS is the MIT International Motor Vehicle Program. Its members James Womack, Daniel Jones, and Daniel Roos authored an influential book on lean manufacturing: The Machine That Changed the World. In fact, one member of their group even coined the term "lean". Womack and Jones went on after MIT to write a follow-up book, Lean Thinking.

Womack, Jones, and Roos define *lean manufacturing* as increasing output while simultaneously decreasing labor input, factory space, time, tools, rework and product development expenses.[29] Lean empowers workers to get things done. It encourages workers to develop a broad skill base to keep workers challenged and so that they can better deal with problems as they arise.[30] It features teamwork, Just-In-Time deliveries and close collaboration with suppliers.

2.6.3.1 Transition to Lean

Following the OPEC crisis of the 1970's, the mature automobile markets in the US and Europe knew that they had to change their business practices, but had difficulty doing so. The efficiency gains under lean manufacturing techniques would make a great number of workers simply unneeded, resulting in the loss of many jobs.[31] As a result, lean efforts were politically unpopular. Additionally, any initiative that drastically changes every manager's and hourly worker's job breeds resistance.[32] This resistance sometimes comes in the form of withholding knowledge or outright sabotage. Even when Eiji Toyoda first implemented lean concepts in his own factory resulting in job losses, upset workers shamed him into resignation. If lean efforts are to succeed, Western companies need to focus on personnel systems, career paths, and ways to elicit cooperation.[33]

Over the course of time, Womack's group observed that shedding labor is inevitable.[34] The best practice is to cut headcount at the beginning of a lean transition to a sustainable level, and to replace managers who are set in their wasteful ways.[35] Then management can confidently tell workers that no further reductions are expected, which encourages cooperation between workers and management.

To get the lean transition started, it is helpful if a mass producer has a lean competitor right across the street. First, it serves as a model to emulate. Second, it creates a sense of urgency resulting in a survival mentality.[36] This urgency puts people into crisis mode,

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[29] Ibid., 13.
[30] Ibid., 14.
[31] Ibid. 235.
[32] Ibid. 238.
[33] Ibid. 251.
[34] Ibid. 259.
[35] James P. Womack and Daniel T. Jones, Lean Thinking, (New York: Simon & Schuster, 1996), 180.
[36] James P. Womack, Daniel T. Jones, and Daniel Roos, The Machine That Changed the World, (New York: Harper Perennial, 1991), 257.

spawning revolutionary thinking and encouraging teamwork. Also, it is useful to restrict access to capital. The rationale here is the less money that is available, the less money can be wasted, and the more efficiently is must be used. Product development cycles need to be shorter, machines need to be more flexible, and operations must be streamlined to survive with access to a mere trickle of capital.[37] Last of all, experienced professionals should manage the introduction of lean production techniques. Managers without experience cannot hope to compete and will resort to non-lean ways.[38]

2.6.3.2 Elements of Lean

In the follow-up book, Lean Thinking, Womack's group reveals the secrets of lean manufacturing. They identify the following five lean principles:

1. Value – listen to the customer to discover what they want
2. Value Stream – share information to eliminate wasteful steps from production
3. Flow – set-up the value creating steps so that work flows through them
4. Pull – produce only what the customer orders
5. Perfection – continuously refine and improve the process[39]

Lean Thinking examines lean implementation efforts at companies large and small, foreign and domestic, in several different industries. No matter which company implements lean methods, if done properly, the benefits are always the same: increased production, less inventory, and maintained wage levels even as prices to consumers decline.[40] In each case, it takes someone years to learn lean production techniques well enough to drive change.[41] The common themes of standardizing work and addressing quality issues consistently re-emerge.[42] So does the fact that lean efforts take a long time to become engrained into daily work habits. It takes 5 years to institutionalize new practices in an organization to the point where the change leader can get hit by a bus, and the new, lean methods will stick.[43]

In retrospect, "the machine that changed the world" consisted of the way Toyota integrated product development, production, supply chain management, and customer relations.[44] Toyota perfected a higher form of skill: the ability to consistently re-invent an organization that proactively preempts problems thereby creating value.[45]

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[37] Ibid., 258.
[38] Ibid., 243.
[39] James P. Womack and Daniel T. Jones, Lean Thinking, (New York: Simon & Schuster, 1996), 16-26.
[40] James P. Womack, Daniel T. Jones, and Daniel Roos, The Machine That Changed the World, (New York: Harper Perennial, 1991), 218.
[41] Ibid., 243.
[42] James P. Womack and Daniel T. Jones, Lean Thinking, (New York: Simon & Schuster, 1996), 180.
[43] James P. Womack, Daniel T. Jones, and Daniel Roos, The Machine That Changed the World, (New York: Harper Perennial, 1991), 214.
[44] Ibid., 239.
[45] Ibid., 207.

2.6.4 World Class Manufacturing

Another author, Richard Schonberger, wrote accounts of lean manufacturing in parallel to Womack's group. In his book, Japanese Manufacturing Techniques: nine hidden lessons in simplicity, he espouses the virtues of TPS, including fewer suppliers, reduced part counts, fewer racks, shorter distances, less reporting, fewer inspectors, less buffer stock and fewer job classifications. Toyota was able to accomplish these results by scheduling to a rate of demand, making more frequent deliveries, and by building smaller plants focused on a narrow line of products or technologies.[46] In his next book, World Class Manufacturing, he outlines the fundamentals of lean manufacturing with several useful, real-world stories.[47] The follow-up book, World Class Manufacturing: The Next Decade, shares anecdotes about individual companies' trials and tribulations while implementing lean manufacturing principles.[48]

2.6.5 Review of Prior LFM Theses on Lean Manufacturing

In order to examine the most recent innovations in lean manufacturing implementation at LFM partner companies, this section discusses LFM theses written on lean manufacturing within the past decade that are relevant to the project at Hamilton Sundstrand. The most recent theses appear first.

Victoria Gastelum focuses on the value stream mapping and line balancing, the first two of the nine tactics that Boeing uses to improve operational efficiency in her thesis, "Application of Lean Manufacturing Techniques for the Design of the Aircraft Assembly Line", written in 2002. Boeing's nine tactics in entirety are:

1. Map the value stream
2. Balance the line
3. Standardize work procedures
4. Put visual controls in place
5. Put everything at point of use
6. Establish feeder lines
7. Redesign products and business products
8. Pulse flow
9. Convert to a moving line[49]

Gastelum developed a methodology to implement the first two tactics in the Boeing 717

[46] Richard Schonberger, Japanese Manufacturing Techniques: nine hidden lessons in simplicity, (New York: Free Press, 1982).
[47] Richard Schonberger, World Class Manufacturing, (New York: The Free Press, 1986).
[48] Richard Schonberger, World Class Manufacturing: The Next Decade, (New York: The Free Press, 1996).
[49] "Tactics to Improve Operational Efficiency", Boeing brochure, 2002.

aircraft final assembly line in a way that maximizes economic profit given production rate uncertainty.[50]

Garret Caterino performed a lean manufacturing project at Instron Corporation in 2000. His thesis, "Implementation of Lean Manufacturing in a Low-Volume Production Environment", describes how he revised the layout of assembly areas, standardized work procedures, implemented point of use inventory, cross-trained workers, and organized a kanban card driven inventory management system.[51]

Richard Welnick's thesis examines flow and material scheduling at the Ford's Wayne Stamping plant. In "Applying Lean Manufacturing in an Automotive Stamping Plant", Welnick maps the value stream and discusses dye changeovers. With a large blanking press, single piece flow is not possible, so Welnick analyzes batch sizes and makes recommendations.[52]

Julie Wilhelmi investigated the implementation of a standardized JIT process to pull interior components such as stowbins of Boeing 777 jets. She also benchmark's Boeing's progress against the MIT Lean Aerospace Initiative's Transition to Lean Roadmap in her thesis, "Analyzing the Boeing 777 Link the Flow Process for Value Stream Flow Reduction Against the Lean Aerospace Initiative's Enterprise Level Roadmap".[53]

Mark Lulgjuraj's thesis written in 2001 explores a failed lean implementation effort at Intrigue Corp., a tier 1 automotive supplier. In "Lean Manufacturing At A Tier-1 Automotive Supplier", he offers hypotheses as to why the lean efforts failed and develops a systems dynamics model to help better understand the dynamics of change. From this model, he makes both short term and long term recommendations on how to proceed.[54]

Rafael O. de Jesús spent his LFM internship in Chihuahua, Mexico, at an electronics supplier for Visteon and Ford Motor Co. His thesis, "Implementation of Lean Manufacturing Practices to Improve Production Performance at Altec Electrónica Chihuahua", specifically looks at cellular design, pull systems and production control, and he offers suggestions as to how to do so nimbly within the Ford Production System environment.[55]

[50] Victoria Gastelum, "Application of Lean Manufacturing Techniques for the Design of the Aircraft Assembly Line", (Masters Thesis, Massachusetts Institute of Technology, 2002).
[51] Garret J. Caterino, "Implementation of Lean Manufacturing in a Low-Volume Production Environment", (Masters Thesis, Massachusetts Institute of Technology, 2001).
[52] Richard Welnick, "Applying Lean Manufacturing in an Automotive Stamping Plant", (Masters Thesis, Massachusetts Institute of Technology, 2001).
[53] Julie L. Wilhelmi, "Analyzing the Boeing 777 Link the Flow Process for Value Stream Flow Reduction Against the Lean Aerospace Initiative's Enterprise Level Roadmap", (Masters Thesis, Massachusetts Institute of Technology, 2001).
[54] Mark Lulgjuraj, "Lean Manufacturing At A Tier-1 Automotive Supplier", (Masters Thesis, Massachusetts Institute of Technology, 2001).
[55] Rafael O. de Jesús, "Implementation of Lean Manufacturing Practices to Improve Production Performance at Altec Electrónica Chihuahua", (Masters Thesis, Massachusetts Institute of Technology, 2000).

Daniel H. Wheeler helped to reduce inventory and increase inventory turns during his time at Instron Corp in 1999 in part by examining the shadow labor rate for a facility operating under maximum capacity. The shadow price is the marginal cost for the use of an additional input in the production process. Its is not the market price of the input, but rather the opportunity cost inherent in using the input in the activity under consideration instead of in an alternative activity. Essentially it is the maximum price that one is willing to pay for one extra unit of a constraint (labor). The shadow price helped him to optimize lot sizes. Wheeler also assisted in the consolidation of redundant supply chains, in the changeover from a make-to-stock to a make-to-order production system, and in the implementation of a pull production regime. In 2000, he wrote his thesis: "Pulling a Job Shop into Supply Chain Management".[56]

Michael Kimber planned the implementation of a pull production system in the cast shop and rolling area at the Alcoa (Shanghai) Aluminum Products Co., Ltd. The result of this implementation is a 20% decrease in WIP and a 24% decrease in lead time. Key to the implementation is a visual inventory management system. The title of his thesis is: "Definition and Implementation of a Visual Inventory Management System".[57]

C. Harrison Smith, III, focused on the implementation of lean manufacturing techniques at the Ford assembly plant in Cologne, Germany, in 1998. In specific, his thesis addresses three major points of the internal supply chain. These points are flow, inventory control, and material receipt and storage. By focusing on these points, Smith established optimal inventory levels, decreased part delays, and reduced the non-value added steps in the replenishment process. In his thesis, "Implementation of Lean Manufacturing Techniques to the Internal Supply Chain of an Automotive Assembly Plant", he claims that the result of his inventory policy is an annual savings of around $200,000 and a one-time savings from inventory liquidation amounting to approximately $1,000,000.[58]

Derek Trimble wrote "Implementation of Lean Manufacturing Techniques for the Replenishment of Purchased Parts Used at a Tier One Automobile Supplier" as he worked on a lean manufacturing implementation in one of Ford's assembly plants. In particular, this thesis, written in 1999, details the design and implementation of a pull system and inventory management via a card and call part marketplace. Trimble warns not to follow a cookbook implementation approach, as it is necessary for the underlying theory of lean to be understood by the change agent.[59]

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[56] Daniel H. Wheeler, "Pulling a Job Shop into Supply Chain Management", (Masters Thesis, Massachusetts Institute of Technology, 2000).

[57] Michael A. Kimber, "Definition and Implementation of a Visual Inventory Management System", (Masters Thesis, Massachusetts Institute of Technology, 1999).

[58] C. Harrison Smith, III, "Implementation of Lean Manufacturing Techniques to the Internal Supply Chain of an Automotive Assembly Plant", (Masters Thesis, Massachusetts Institute of Technology, 1999).

[59] Derek L. Trimble, "Implementation of Lean Manufacturing Techniques for the Replenishment of Purchased Parts Used at a Tier One Automobile Supplier", (Masters Thesis, Massachusetts Institute of Technology, 1999).

Sean Hilbert's thesis, "Effective Coordination of Technical and Social Components During the Design and Launch of a New Lean Manufacturing Work System", examines some of the socio-dynamic aspects of implementing lean manufacturing systems. He states that careful monitoring of both technical and social aspects is necessary to ensure success. For example, a complete shutdown of the plant will greatly increase the chances of a successful implementation of lean manufacturing principles.[60]

Steven Harman's thesis entitled "Implementation of Lean Manufacturing and One-Piece Flow At AlliedSignal Aerospace" focuses on a flexible sheet metal production cell in which he examines material flow, waste reduction, and production scheduling. The results of his efforts are reductions in inventory, lead time, and cost. Harman also highlights organizational changes that are necessary to ensure successful implementation of lean practices.[61]

Barrett Crane implemented a kanban system tailored to low-volume manufacturing in the Optical Products division of Eastman Kodak in his thesis, "Cycle Time and Cost Reduction in a Low Volume Manufacturing Environment" in 1996. He tracks production process cycle time as well as models procurement policies in light of risk over various time horizons.[62]

Mark MacLean spent his LFM internship at an automobile manufacturer in 1995. His thesis, "Implementing Lean Manufacturing in an Automobile Plant Pilot Project", offers an intermediate methodology that can be applied to existing plants as they transition to lean manufacturing. His suggestions include redesigning assembly lines, re-examining material handling, and eliminating waste in the form of errors. His methodology yields productivity and quality improvements as well as a reduction in inventory. MacLean identifies organizational changes as the largest impediment to the implementation of a lean production system.[63]

Paul Dul's thesis, "Application of Cellular Manufacturing to Low-Volume Industries", deals with the layout of manufacturing space in Boeing Commercial Airplane Group's Renton Division where doors for the 737 and 757 are manufactured. Dul endorses the standardization of parts as well as the standardization of manufacturing processes to streamline production. He projects cost holding and labor cost reductions of 50% of current practices upon implementation of cellular manufacturing. He also highlights

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[60] Sean H. Hilbert, "Effective Coordination of Technical and Social Components During the Design and Launch of a New Lean Manufacturing Work System", (Masters Thesis, Massachusetts Institute of Technology, 1998).

[61] Steven R. Harman, "Implementation of Lean Manufacturing and One-Piece Flow At AlliedSignal Aerospace", (Masters Thesis, Massachusetts Institute of Technology, 1997).

[62] Barrett Crane, "Cycle Time and Cost Reduction in a Low Volume Manufacturing Environment", (Masters Thesis, Massachusetts Institute of Technology, 1996).

[63] Mark D. MacLean, "Implementing Lean Manufacturing in an Automobile Plant Pilot Project", (Masters Thesis, Massachusetts Institute of Technology, 1996).

opportunities to extend the cellular manufacturing detail fabrication to further harvest additional cost reductions.[64]

Arthur Raymond examined whether or not lean manufacturing principles apply to a low-volume production facility at Boeing in 1991. His thesis, "Applicability of Toyota Production System to Commercial Airplane Manufacturing", investigates the applicability to product type, manufacturing processes, culture, and specific parts. He concludes that while some concepts such as standardization are maxims, lean implementation must be custom designed for each individual processes and products. TPS is more easily implemented in fabrication operations than in assembly operations in the short term. His specific examination of the application of lean techniques to wing skin panels resulted in inventory and flow time reductions of 60 to 80%.[65]

In summary, this chapter presents the challenges facing Hamilton Sundstrand and shows that lean transformations are already well documented. The above problem statement and literature review set the stage for the lean transformation at Hamilton Sundstrand's Windsor Locks facility. The next chapter discusses two frameworks for lean transitions.

[64] Paul Dul, "Application of Cellular Manufacturing to Low-Volume Industries", (Masters Thesis, Massachusetts Institute of Technology, 1994).

[65] Arthur Raymond, "Applicability of Toyota Production System to Commercial Airplane Manufacturing", (Masters Thesis, Massachusetts Institute of Technology, 1992).

Chapter 3: Lean Transition Methods

Several methods exist that serve as guides to implement lean production methods. For example, MIT student Vincente Reynal wrote a thesis entitled "Production System Design and Its Implementation in the Automotive and Aircraft Industry" in 1998. He presents an excellent description of a lean manufacturing implementation methodology in Chapter 8 of his thesis.[66] Other methods for transition to lean exist as well. Hamilton Sundstrand empirically developed its own lean conversion method, as did MIT's Lean Aerospace Initiative. This chapter presents both methods and explains how Hamilton Sundstrand's method is a subset of the Lean Aerospace Initiative's.

3.1 Lean Aerospace Initiative's Transition-to-Lean Roadmap

The following subsections introduce the Lean Aerospace Initiative, discuss its history and goals, and present a template for lean transition developed specifically for aerospace companies.

3.1.1 Background of LAI

The Lean Aerospace Initiative is a consortium of aerospace concerns that cooperates to facilitate enterprise transformation throughout the entire value chain. This organization was originally created to reduce overhead costs in production and support of military aerospace defense programs. Lean methods confer a competitive advantage to its proponents in the marketplace as well as above the battlefield. Founded at MIT in 1993, the LAI consists of members representing academia, unionized labor, industry, and the government.

From Sep. 1993 to Sep. 1996, the LAI consortium performed several benchmarking studies of aerospace companies in all aspects of their operations. They incorporated this information into a "Lean Enterprise Model", which highlights the importance of waste minimization and responsiveness to change. The LAI consortium then broadened their attention over the next three years to an entire system perspective, the result of which is a comprehensive plan to implement lean practices in an organization.

The LAI defined *lean thinking* in their book, Lean Enterprise Value, as "the dynamic, knowledge-driven and customer-focused process through which all people in a defined enterprise continuously eliminate waste with the goal of creating value."[67]

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[66] Vincente Reynal, "Production System Design and Its Implementation in the Automotive and Aircraft Industry", (Masters Thesis, Massachusetts Institute of Technology, 1998).

[67] Earll Murman, Thomas Allen, Kirkor Bozdogan, Joel Cutcher-Gershenfeld, Hugh McManus, Deborah Nightingale, Eric Rebentisch, Tom Shields, Fred Stahl, Myles Walton, Joyce Warmkessel,

3.1.2 The Transition-to-Lean Roadmap

Figuring out how to change an established, large aerospace manufacturing company into a paradigm for lean manufacturing occupied the LAI from Sep. 1996 to Sep. 1999. The focus on an entire system resulted in a transformation plan: the Production Operations Transition-to-Lean Roadmap.[68]

The road to lean comprises eight implementation phases that span the supply chain and the production environment. Figure 5 below on page 32 neatly summarizes LAI's lean transition method. Each phase consists of specific actions. Phase 0 lists some action items prerequisite to the implementation of any change: management support, vision, commitment, etc. The order of the phases reflects the recommended order of precedence. An exception is Phase 7, "Strive for Perfection", which may take place concurrently with any of the preceding Phases 2 through 6.

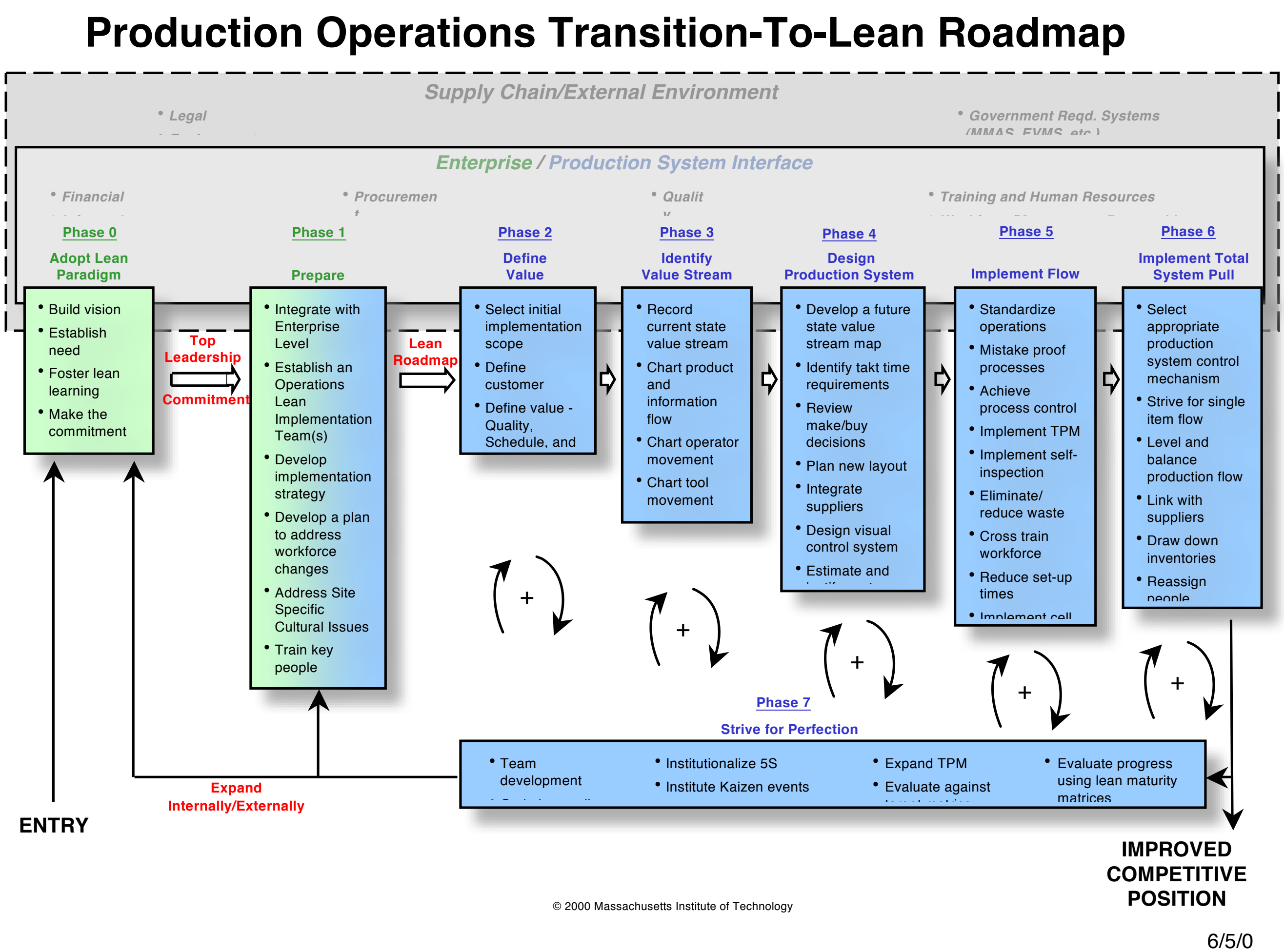
There are many routes to take to a destination, and this roadmap reflects just one of them. The Roadmap merely serves as a guide, and every company needs to find its own way.[69]

Stanley Weiss, and Sheila Widnall, Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative, (New York: Palgrave, 2002), 90.

[68] John Crabill, Ed Harmon, Don Meadows, Ron Milauskas, Craig Miller, Deborah Nightingale, Brian Schwartz, Tom Shields, Bob Torrani, "Production Operations Level Transition-To-Lean Roadmap", (Version 1.0, Massachusetts Institute of Technology 6/5/2000), 3.

[69] Ibid., 5.

Figure 5. Lean Aerospace Initiative's Transition-to-Lean Roadmap[70]



[70] John Crabill, Ed Harmon, Don Meadows, Ron Milauskas, Craig Miller, Deborah Nightingale, Brian Schwartz, Tom Shields, Bob Torrani, "Production

3.2 Hamilton Sundstrand's MRD Transition Method

Hamilton Sundstrand's method to affect lean change arose from years of experience in implementing lean manufacturing techniques under the Market Rate of Demand progra
The 10-step method is as follows:

1. Kick-off of cross functional team / overview training
2. Initial Data Collection
   - 80/20 Volume Breakdown
   - Bill of Material Analysis
   - Demand Pattern
   - Baseline Metrics
3. Process Analysis
   - Process Flow Maps
   - RBWA's (Routing By Walk Around)
   - Part/Process matrix
   - Design, Quality, Supplier, Material issues
   - OEE (Overall Equipment Effectiveness)
4. To-Be Process Definition
   - Part Families
   - Standard Processes
   - MRP Cell
5. Resource Requirement Calculations
6. Kanban Design Analysis
7. Define Cell Layout / Simulation
   - MRD Cells
   - MRP Cell
8. Final Presentation
9. Equipment Procurement / Transition Plan
10. Implementation[12]

The HS MRD method uses kanbans and work/wait boards to execute production. Chapter 4 delves into more detail about each individual step in the HS method, and provides specific examples of implementation in the Heat Exchanger Core Area. The next section compares the two methods.

3.3 Comparison of HS vs. LAI Lean Transition Methods

Regardless of which method one considers, the concept of pull has three requirements:

1. a signal to trigger production on the basis of consumption
2. a way to limit work in process
3. visual control of system [71]

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[71] Eric Rohrbacher, Hamilton Sundstrand Lean Manufacturing Facilitator, conversation on June 24, 2002

Both the LAI and HS methods meet these minimum requirements. The LAI Roadmap covers all steps in the MRD transition method, as Table A below shows. In the table, an "x" indicates overlap of the two methods. The HS MRD method tacitly assumes that senior management supports lean implementation and provides vision, but the LAI Roadmap explicitly states these as Phase 0.

Table A. Hamilton Sundstrand's Market Rate of Demand Method vs. Lean Aerospace Initiative's Production Operations Transition-to-Lean Roadmap

Group	Step	Lean Aerospace Initiative Production Operations Transition-to-Lean Roadmap Phases							
		0. Adopt Lean Paradigm	1. Prepare	2. Define Value	3. Identify Value Stream	4. Design Production System	5. Implement Flow	6. Implement Tot Sys Pull	7. Strive for Perfection
Hamilton Sundstrand MRD Method Steps	1. Kickoff/Overview Training		x						
	2. Initial Data Collection		x	x	x				
	3. Process Analysis				x	x	x		
	4. To-Be Process Definition					x			
	5. Resource Requirement Calcs					x			
	6. Kanban Design Analysis					x			
	7. Define Cell Layout/Simulation					x			
	8. Final Presentation	x							
	9. Procurement/Transition Plan					x	x	x	
	10. Implementation						x	x	
UTC ACE Elements	5S								x
	TPM					x	x		
	Quality								x
	Productivity						x		
	Design	(not accounted for by LAI method)							

The MRD method introduced in Windsor Locks does not appear as far reaching as the LAI method because some points specified by LAI already exist at HS under the ACE program. For example, one foundational pillar of both the ACE and MRD programs is 5S. Because ACE existed in Windsor Locks prior to MRD, 5S was not promoted as part of MRD in Windsor Locks. In LAI's Roadmap, 5S is covered in Phase 7 (Strive for Perfection).

Similarly, the quality elements of ACE also exist in MRD, but are not presented in the methodology in Windsor Locks because they would be redundant. These quality elements are covered by LAI's Phase 7.

TPM falls under Phases 4 and 5 of the LAI method (Design Production System and Implement Flow), whose analog in MRD is Overall Equipment Effectiveness in Step 3 (Process Analysis).

Productivity elements of ACE are accounted for by LAI's Phase 5 (Implement Flow); only ACE's design element does not have a counterpart in LAI's transition method.

In conclusion, the combination of Hamilton Sundstrand's MRD lean transformation method with UTC's ACE program is the equivalent of LAI's Transition-to-Lean Roadmap. UTC companies apply ACE to all aspects of doing business, not just manufacturing processes. The application of MRD to a production process rounds out the lean transformation process to the analog of LAI's Roadmap.

This chapter evaluates models for change; the next chapter discusses the Hamilton Sundstrand's MRD method with specific examples from the Heat Exchanger Area.

Chapter 4: Implementation of Pull in Heat Exchanger Core Area

"Lean is a way of thinking, not a list of things to do." –Hajime Ohba[72, 73]

In order to transition people to a lean way of thinking, they need leadership to provide them with direction. Womack and Jones offer direction in Lean Thinking, stating that implementing lean manufacturing practices requires a change agent, a lean knowledge base, a crisis to get initiated and to facilitate the transformation, a map of value streams, and the determination to revolutionize value-creating activities.[74]

The Hamilton Sundstrand MRD group has perfected its own set of directions for lean transformation. This chapter describes the planning and the implementation of lean manufacturing principles in the core area for high-volume parts. Pull is achieved for high-volume parts by making only what is ordered when it is needed. Low-volume parts continue to be manufactured via traditional push methods. The result is a hybrid push and pull system on the factory floor. The factory retains its MRP software and used kanbans to execute the pull in the factory.

The structure of this chapter reflects the optimal sequence for implementation of lean manufacturing principles learned from experience at Hamilton Sundstrand.[75]

4.1 Kick-off of Cross Functional Team

A team composed of stakeholders, including hourly employees, supervisors, operation center manager, and a lean manufacturing facilitator convene for overview training. This team performs the tasks explained below.

4.2 Initial Data Collection

This step is a first look at current processes. It involves identifying candidate parts for pull production and benchmarking of existing methods in order to improve them. In specific, the individual steps are called 80/20 Volume Breakdown, Bill of Material Analysis, Demand Pattern Analysis, and Baseline Metrics.

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[72] Earll Murman, Thomas Allen, Kirkor Bozdogan, Joel Cutcher-Gershenfeld, Hugh McManus, Deborah Nightingale, Eric Rebentisch, Tom Shields, Fred Stahl, Myles Walton, Joyce Warmkessel, Stanley Weiss, and Sheila Widnall, Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative, (New York: Palgrave, 2002), 87.

[73] Mr. Ohba was the General Manager of the Toyota Supplier Support Center.

[74] James P. Womack and Daniel T. Jones, Lean Thinking, (New York: Simon & Schuster, 1996), 247-271.

[75] "MRD Supervisor Training", (United Technologies Corp. Hamilton Sundstrand presentation, 2002).

4.2.1 80/20 Volume Breakdown

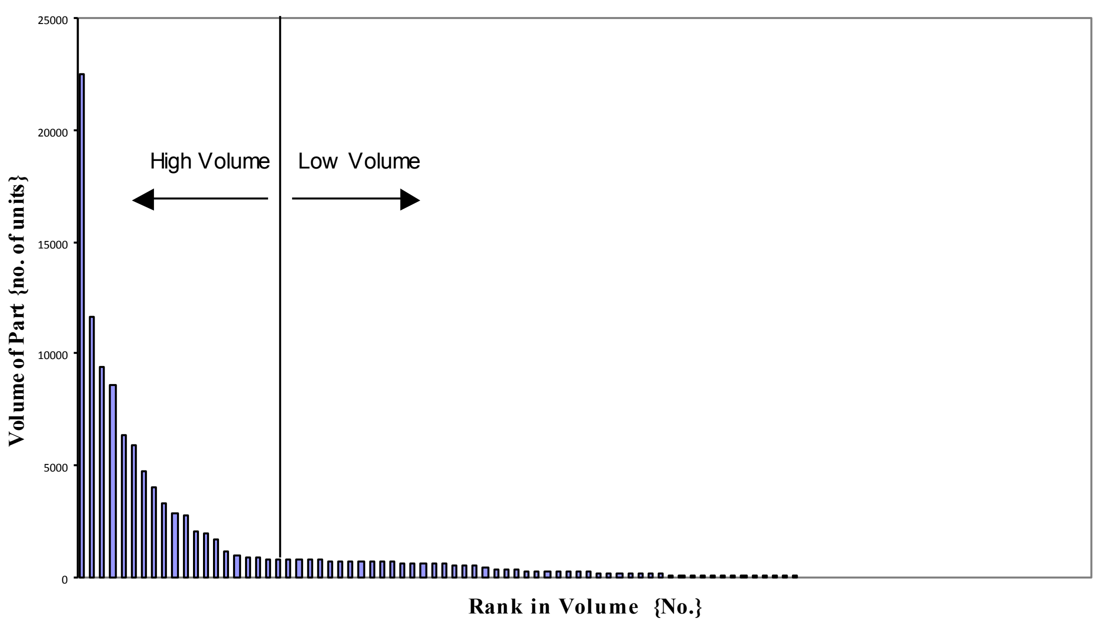
In a Pareto Analysis, priority ratings are assigned to parts in order to better focus on the more important ones. This method is often called an ABC Analysis or a Distribution by Value Analysis. Typically the following classifications are used:

Class A: the approximately 20% of items that account for 80% of the total stock value.
Class B: the next 30% of items that account for 10% of the total stock value.
Class C: the balance of approximately 50% of the stocked items that comprise the remaining 10% of stock value.[76]

The lean manufacturing team performed a modified Pareto analysis to determine which parts deserve the most attention. They grouped parts into two categories: high volume or low volume. High-volume parts are manufactured via pull techniques, whereas low-volume parts continue to be pushed through the system.

Figure 6 below shows the distribution of various fins by annual unit production. Both the part numbers and quantities are intentionally omitted from this figure. One part accounts for 20% of volume, as measured by number of pieces. Twenty percent of the part numbers represents 83% of the piece volume. Using this data, the lean team designed manufacturing cells to accommodate the high-volume parts. Low-volume parts made

Figure 6. Pareto Classification of Fins by Volume (Forecast until EOY 2003).



[76] Edward Silver and Rein Peterson, Decision Systems for Inventory Management and Production Planning, (New York: John Wiley & Sons, 1985), 67-68.

by similar processes can also be manufactured in these cells if desired. Otherwise low-volume parts continue to be scheduled according to the traditional MRP (manufacturing resource planning) push methods upon necessity. The sheer quantity of low-volume parts coupled with the infrequency of their production make it impractical to manage the large number of usually inactive kanbans required for each part. It makes more sense to use non-replenishable kanbans for low-volume items, which like most production in the factory, are build to order. We comment more on this later in Section 4.6. Pareto analyses were also performed on a dollarized basis, which are not shown here.

4.2.2 Bill of Material Analysis

The goal of this step is to determine what lower level parts require kanbans. This step consists of obtaining bills of materials for all parts under consideration for cellular manufacturing. It is the first step towards grouping parts consisting of the same constituents together in order to be manufactured in a common manufacturing cell. This step may also include decisions about outsourcing parts and products.

4.2.3 Demand Pattern

The lean implementation team investigated the demand pattern of parts. The goal is to identify irregular demand patterns and to smooth them out if possible. Knowledge of the demand pattern allows the design of manufacturing cells sized properly for volume.

4.2.4 Baseline Metrics

Several metrics are used to analyze production efficiency and factory operation. In MRD implementation, these metrics are:

- inventory: turns and dollars (level)
- order cycle time
- quality: scrap, rework, repair, defects per million
- on-time delivery
- safety: recordable incidents
- productivity: measure total hours required to make product

The goal of the lean transformation is to improve performance as gauged by all of these metrics. Note that productivity is difficult to measure in contracting economic climate.

4.3 Process Analysis

This step consists of a detailed analysis of the flow of materials through the factory. It also sets the stage for the design of manufacturing cells.

4.3.1 Process Flow Maps

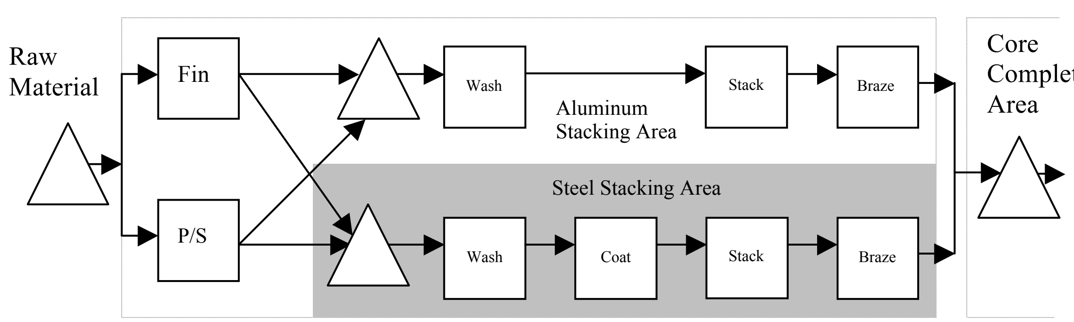
The goal of creating process flow maps is get a high-level view of the current process. In doing so, one recognizes where value is added to the process, allowing the removal of waste from operations. One follows a product's path of production from beginning to end and draws a diagram to understand how the shop floor currently operates.

During this process, there is an opportunity to get rid of unnecessary steps that do not add value and to identify opportunities to improve value-adding steps. Improvement occurs by designing a process such that value added standard work sequence occurs within the takt time.

Often the layout of machines and location of inventory changes as a result of this step. By making manufacturing cells in which equipment is arranged in sequence of use, material can easily flow along easily (eliminate spaghetti). Also, location of materials at the point of use eliminates operators wasting time looking for parts.

In the core area, an overview map that indicates the flow of parts through the core area appears in Figure 7 below. This map shows the addition of value. This area takes raw materials in the form of coils of aluminum and steel sheet stock and makes them into fin and parting sheets. Note that some purchased details such as closure bars are not depicted in the figure. Parts made of steel (shaded area of diagram) need to be washed, and coated with braze alloy prior to stacking, whereas aluminum (area above shading) comes pre-coated. All cores get brazed in material dedicated ovens. The cores then travel to an area, core complete, for further work.

Figure 7. Heat Exchanger Core Assembly Area Process Overview



4.3.2 RBWA's (Routing By Walk Around)

RBWA is an in-depth look of the entire process to make a part. The lean team found that parts were traveling miles throughout the factory because equipment was not co-located in sequence, and parts were not stored at their point of use. As a result, all equipment was relocated to one consolidated area. One monument that cannot be moved exists (coating machine), which is due to be replaced and located at the point of use in 2003. Overall, the coating process was not significantly changed.

This step also consists of witnessing set-ups, and identifying opportunities for improvement to cycle time. During this step, value-added steps are identified so that non-value added activities can be removed.

4.3.3 Part/Process Matrix

The Part/Process matrix is a tool to identify common production methods. It is the first step in part family identification, which allows manufacturing cells to be sized for families of parts. In such a matrix, operations are written across the top and part numbers along the left side. An "x" identifies which operations each part undergoes.

4.3.4 Design, Quality, Supplier, Material Issues

The purpose of this step is to identify problems with existing processes in order to institute changes. A two-step process is used:

1. *Gather info*: In the process analysis phase, ask the operators to share information with the lean team about issues in design, quality, etc.
2. *Quantify problems using a pareto chart*. Problems turn up in the form of scrap, rework, and repair (SRR) as well as the total number of defects. SRR tells the lean team the loss in dollars whereas the number of defects identifies problems with low cost parts.

4.3.5 OEE (Overall Equipment Effectiveness)

The MRD team examines the current processes to try to identify if there any equipment issues that could prevent flow of material. For example, is the machine unreliable? Does it take an excessive time to set-up? This step is also known as Total Productive Maintenance (TPM).[77]

4.4 To-Be Process Definition

The design of new processes involves identifying part families to be made according to standard processes in a manufacturing cell.

[77] Rohrbacher, Eric, Hamilton Sundstrand Lean Manufacturing Facilitator, conversation on December 18, 2002.

4.4.1 Part Families

The lean implementation team analyzes exclusively high-volume parts to identify common processes. They group these parts into part families.

In the core area, stacking cells are divided according to the material of which they are made: aluminum or steel. Steel cores need additional processing steps. Further part family grouping can occur for core details such as fin that share tooling to be manufactured.

4.4.2 Standard Processes

Standard processes allow several different parts to be built in the same manufacturing cell as long as they share common processes. High-volume parts receive their own dedicated cells. Low-volume parts can also pass through these cells as long as they share the same processes. An important aspect of standard processes is that designers who develop new products are locked into these standard processes in the future. All new designs and products must be able to be manufactured according to standard processes.

In order for a process to be truly flexible, the machines involved must be able to quickly change from production of one part to another. Flexible production enables small and frequent lot sizes, which enables low average inventory levels.

To do so, set-up processes should be standardized. Any and all steps that can be performed off-line should be done so. Sometimes machines need to be modified or replaced to achieve set-up times that take only minutes.

Part of process analysis involves a determination of how long it takes to set up a machine or to prepare for an operation.

Traditional set-up approach:

- Individual operators have their own preferred methods to set up machines.
- Sometimes workers on different shifts re-do set-ups the way they prefer.
- Managers do not question the work of veteran operators.[78]

The traditional set-up approach is rife with variation. As a result, a standard set-up is necessary. Of course any activities that can be performed off-line (externally) should be done so.

In Hamilton Sundstrand's Windsor Locks Fin Forming Area, three waves of set-up reduction activities have dramatically improved the set-up times of fin machines over the years. Even so, set-ups are still significantly longer than the goal of mere minutes. Further reduction in time using existing equipment will not yield a large enough

[78] William Mazza, "Kaizen Preparation Value Stream Improvement", (United Technologies Corp. Hamilton Sundstrand presentation, 2002), 147.

improvement to justify its expense. As a result, new equipment with shorter set-up time was identified and will be acquired at a future date. Until then, sequencing parts in an optimal fashion will yield cost reductions using existing machines. This method is the subject of the next chapter.

4.4.3 MRP Cell

The remaining low-volume items that cannot be manufactured via a standard process get manufactured via traditional push methods (MRP) in their own manufacturing area. The low volume of these parts is not high enough or frequent enough to merit pull. Managing the high quantity of kanbans necessary to pull these parts would take longer than the part fabrication process itself. As a result, low-volume production of parts that follow standard processes is executed via traditional MRP triggers (work order).

4.5 Resource Requirement Calculations

The goal of this step is the determination of the proper amount of labor and capital resources necessary in the newly designed manufacturing cells in order for them to run properly.

In the core area, some labor reductions occurred during implementation, but they were attributed to the economic downturn in the aerospace sector.

After performing this step, the lean team concluded that some capital items need replacement. For example, the replacement of a braze alloy coating machine for steel details is in order; alternately, the existing machine could be moved to a new location at a large expense. Capital availability postponed its procurement until 2003, temporarily requiring waste of movement for all steel details until the replacement.

Also, the fin forming machines in the heat exchanger core area were identified as incompatible with flow production. They have a standard set-up time of several hours for each part, whereas the goal for lean manufacturing is minutes or even seconds. The standard set-up time of several hours is the best possible after three independent waves of set-up activity over the past few years. When capital becomes available at a future date, new machines that require reduced set-up time may be purchased. Note that pull production is possible even with equipment that features long set-up times because the kanban sizes will accommodate the high order cost. (See Section 5.2 Optimization of Lot Sizes.) This internship involved the identification of manufacturers of equipment featuring reduced set-up time, solicitation of bids, and a capital budgeting analysis. Capital budgeting was performed, and recommendations were made. The results were communicated to management, but they are not presented in this work.

4.6 Kanban Design Analysis

This section provides an introduction to the concept of kanbans as well as specific examples from implementation in the Heat Exchanger Area in Windsor Locks.

4.6.1 Introduction to Kanbans

The kanban system originated at Toyota under Taiichi Ohno. The goal is to produce and consume only what is needed when it is needed. In order to achieve this Just-In-Time goal, Ohno came up with kanban cards. These are tools that help to produce in a Just-In-Time manner. Using kanbans can help a manufacturing entity regulate production, provide visual control, and reduce costs.[79] The kanban system has been so effective at reducing inventory and responding to fluctuations in demand that all of Toyota's factories implemented the kanban system by 1962. By 1982, 98% of Toyota's vendors had implemented the kanban system.[80]

A pull system using kanbans is an excellent solution in situations that involve a fairly steady material flow along a fixed path through repetitive processes. Variations in volume and/or product mix undermine the benefits of a pull system because they change the amount of WIP, wreak havoc with scheduling, and make engineering changes difficult. One should address the following questions when assessing the feasibility of a pull system:

- How often do changes in design, engineering, and schedule occur?
- Will the costs of converting to a pull system outweigh the benefits?
- Will a pull system result in a reduction in lead time (compared with push)?
- Can suppliers be relied upon to support Just-In-Time delivery of materials?
- Is the production system reliable, or does it frequently break down?
- Are both labor and management aligned to improve the production processes?
- How frequently and to what degree does the mix of products change?[81]

These questions above help identify if a production process is a strong candidate for pull production. In order for the kanban system to work, the following rules apply:

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[79] Monden, Yashiro, Toyota Production System 3rd edition, (Norcross, GA: Engineering and Management Press, 1998), 313.
[80] Ibid., 37.
[81] Richard P. Marek, Debra A. Elkins, and Donald R. Smith, "Understanding the Fundamentals of Kanban and CONWIP Pull systems using Simulation", Proceedings of the 2001 Winter Simulation Conference, eds. B. A. Peters, J. S. Smith, D. J. Medeiros, and M. W. Rohrer, pp. 921-929, (accessed Oct. 10, 2002); available from http://www.informs-cs.org/wsc01papers/122.PDF, 923.

Rule 1. The downstream process withdraws the minimum necessary amount of product at the necessary time from the upstream process.
Rule 2. The upstream process produces only the quantity that is specified by downstream process' production kanban.
Rule 3. Defective products do not move downstream.
Rule 4. The total number of each kanban should be kept to a minimum.
Rule 5. Kanbans are used to adapt production to minor demand fluctuations by varying the number of cards or the lot quantities on the cards, resulting in production of only what is required at the appropriate time.[82]

These rules will yield results only if several criteria for success exist. First of all, production must be smoothed in order to reap the most benefit from inventory reduction. Without smoothing of production, high inventory levels are required to deal with fluctuations in demand. High inventory stocks may not be cost effective. Second, workers must embrace productivity enhancing measures. Third, manufacturers must train their suppliers, and likewise suppliers must accept guidance.[83]

Yoshuhiro Monden and Yoshimitsu Iizuka wrote a landmark publication outlining fundamental kanban concepts and equations. These equations yield the proper number of kanbans to have active in the system as a function of demand profile, cycle time, etc.[84]

There two most common types of kanbans are:

1. *Withdrawal* -- specifies the kind and quantity of product to send to the downstream process
2. *Production* -- indicates the kind and quantity of product to pull from upstream process[85]

Other types of kanbans exist. The only other type that concerns us is the distinction between a replenishable and a non-replenishable kanban. A replenishable kanban stays in circulation, as opposed to a non-replenishable kanban, which gets thrown away after the production run. In practice, all high-volume parts have replenishable kanbans, and production planners issue non-replenishable kanbans to trigger production of low-volume items.

4.6.2 Kanban System Implementation

The most important factor to ensure success in kanban implementation is getting the support of operators, production planning and management. More information on organizational factors appears in Chapter 7: Organizational Change.

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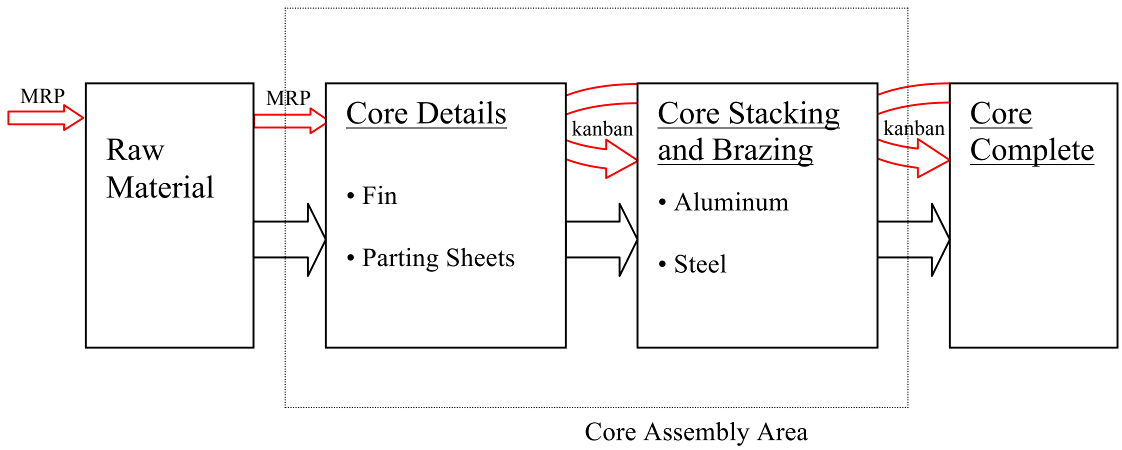
[82] Ibid., (Monden), 24-27.
[83] Monden, Yashiro, Toyota Production System 3rd edition, (Norcross, GA: Engineering and Management Press, 1998), 24-27.
[84] Yashuhiro Monden and Yoshimitsu Iizuka, "Mechanism of Supplier's Response to the Kanban System", reprinted in Applying Just In Time, ed. Yasuhiro Monden, (Atlanta: Industrial Engineering and Management Press, 1986), 69-78.
[85] Ibid., 16.

Figure 8 depicts the usage of kanbans to pull material through the core area of Hamilton Sundstrand's Windsor Locks factory. In particular, it describes the use of replenishable kanbans to trigger production of high-volume parts. Note that purchased parts are omitted from this figure.

Figure 8. Use of Kanban Cards for Material Flow through the Core Area.



The Core Complete area of the factory pulls a core from one of the Core Stacking and Brazing areas. These areas, in turn, pull their fins and parting sheets from the Core Detail areas, which consume raw materials. The signals used to trigger production are kanban cards. Raw materials may in the future be pulled via kanbans, but the MRP system will be used temporarily in order to track inventory and consumption of raw materials using the existing computer system. An operator in the Fin or Parting Sheet Areas will issue a work order using the MRP system when they receive a kanban from upstream. This work order can be thought of as a kanban to pull raw materials.

Kanbans in this area contain at minimum the following information: part number, description, lot size, replenishable or non-replenishable, and trigger level. The color of card indicates whether it is replenishable or not.

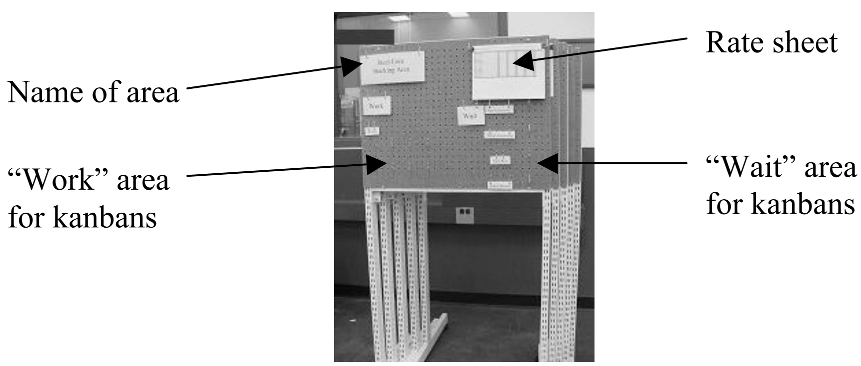
The core area has a unique, one-card kanban system. For high-volume parts, each kanban is strategically placed at the trigger level of the fin and parting sheet inventory. In practice, operators pull parts until they get to the trigger level, at which point the kanban triggers production to happen within a specified lead time. The kanban system allows operators cut their own work orders instead of a production planner, resulting in a shorter time that the work order is open, which improves the apparent cycle time. Upon replenishment, the kanban gets replaced at the appropriate trigger level.

High-volume parts get replenished using these cards because their demand for profile is predictable and stable. All other parts, especially spare parts with sporadic demand, have production scheduled by the MRP system. In the case of low-volume items made according to standard processes, production control issues a non-replenishable kanban card of different color to an individual areas that triggers production that gets pushed through the system.

One of the challenges of the project is to marry scheduling by kanban and by MRP together into one system. Yashiro Monden recognized that kanban systems are compatible with MRP. He states that kanban systems could be used to dispatch production that is planned via MRP.[86] Indeed that is exactly what we did. The HS system is essentially an MRP system that utilizes kanbans for execution. HS retained the MRP system to track raw material usage, thereby facilitating the reordering process. No work is performed without a work order, which gets issued using the MRP software whenever a kanban appears on a work/wait board.

Work/wait and boards are tools to assist visual scheduling and to track production. Kanban cards get hung on the "work" side of a work/wait board. In the case where details are missing or a part cannot be made, the kanban hangs on the "wait" side of the board. Operators process jobs on the work side of the board on a FIFO (first in, first out) basis. When an operator takes a kanban off the board, they immediately issue a work order. After production, the finished goods get delivered with the kanban (assuming that it is a replenishable card), and the operator tracks the production on a rate sheet. In the case of fin, the kanbans get placed at a trigger level corresponding to the reorder point. In the case of non-replenishable kanban, the kanban is discarded following production. A central MRP program tracks all work so that raw materials get purchased accordingly.

Figure 9. Photograph of Work-Wait Board



Low-volume items use the kanban system for execution. Production of low-volume items gets scheduled by a production planner who issues non-replenishable kanban cards to the various areas. All kanban cards get hung on the work wait board, and are attended to sequentially (see Figure 9).

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[86] Yashiro Monden, "Notes and Communications: A Simulation Analysis of the Japanese Just-In-Time Technique (with Kanbans) for a Multilane, Multistage Production System: A Comment", reprinted in Applying Just In Time, ed. Yasuhiro Monden, (Atlanta: Industrial Engineering and Management Press, 1986), 147-149.

Operators received training to issue work orders, which a production planner used to do. They also received formal instruction on how the kanban system works. The best training is hands-on.

By having operators issue work orders when they are ready to make them, the lead time for production of each part decreases dramatically. Lead time is defined as the total time elapsed from release of raw materials to shipment of finished product.[87] Under the push system, 10 jobs await work at any one time. The metrics used to evaluate performance of the area improve.

During the implementation phase, a backlog of orders threatened to derail the lean implementation efforts. Working down the backlog is perceived as necessary, however, experience has shown that much of the backlog disappears upon implementation of a pull based system. In an ideal situation, one would work off the backlog of orders prior to implementing pull, but in the case where that is not possible, it is worthwhile anyway to implement the kanban system, since the pull system itself offers improvements over the status quo. A backlog should not be allowed to delay lean implementation indefinitely.

During implementation, an "issues" board proves extremely helpful. The purpose of this visual tool is to highlight problems as they arise during the implementation process. The supporting engineers and supervisor should tend to the issues written on it as soon as possible. This issues board is used throughout all phases of the pull implementation. Note that it only works well if a supervisor or area support engineer pays attention to the issues listed on it.

4.7 Define Cell Layout / Simulation

The goal of this step is to design manufacturing cells to handle the part families defined in Section 4.4 To-Be Process Definition. In the Heat Exchanger Core Area, we used two criteria to design the manufacturing stations: material type and volume. The first criteria is division by material type (aluminum or steel). Steel parts require additional processing. (See Figure 7 on page 39.) Within each material type, production volume defined manufacturing cells. Two types of cells exist:

1. MRD Cells: high volume
2. MRP Cells: low volume

Volume is determined in the Pareto Analysis in Section 4.2.1 80/20 Volume Breakdown.

[87] William Mazza, "Kaizen Preparation Value Stream Improvement", (United Technologies Corp. Hamilton Sundstrand presentation, 2002), 55.

4.8 Final Presentation

The purpose of the presentation is to achieve the following:

1. communicate budget requirements
2. relay changes in direct labor requirements
3. obtain approval from senior management
4. set goals for new processes

Note that this presentation is not the only opportunity for communication with management, but rather a culmination of regularly scheduled meetings.

4.9 Equipment Procurement / Transition Plan

During this step, any new equipment that is necessary is identified, ordered and procured. This step can be quite lengthy depending on the lead time of individual pieces of equipment. Exterior vendors may not always be able to deliver in accordance to the lean implementation schedule.

It is wise to stagger the lean transition throughout the factory so that each lean implementation is funded by savings in the previous one.

4.10 Implementation

The most difficult aspect of the implementation of lean is the Material Conversion Plan, which is a transfer from a push to a pull method. Experience of members of the MRD Team has yielded the following plan:

1. Rearrange equipment
2. Burn off all old work orders
3. Make produce kanbans
4. Sequence the line
5. Set up finished goods kanban
6. Place tools at POU
7. Size material kanbans
8. Material holding
9. Move material into cell[88]

After these steps have been achieved, the only thing that remains is to turn the cell on. It is advisable to run a few test parts through the cell in order to work out kinks. One can expect issues to crop up. A period of time is necessary for operators to get comfortable with new ways of doing things. An issues board is a good way to handle any problems as

[88] Scott Horner, Hamilton Sundstrand Lean Manufacturing Coordinator, conversation on Aug. 28, 2002.

they arise. Operators write problems on the board and a supervisor or support engineer address the problems. This step may take longer than initially anticipated.

The Heat Exchanger Core Area was amid implementation at the time that the internship ended. The various sub-areas had already implemented some of the above steps to varying degrees. The work performed as a part of this thesis facilitates the completion of the implementation.

In summary, this chapter describes the advances achieved in the Heat Exchanger Core Area through the application of the MRD method. Further contributions were made outside the framework of MRD such as production scheduling. The next chapter discusses a newly-designed process featuring optimal lot sizes produced under coordinated replenishment that is consistent with the lean transformation.

Chapter 5: Select Aspects of Inventory Management

> *"Ordinarily, money put into raw materials or into finished stock is thought of as live money. It is money in the business, it is true, but having a stock of raw material or finished goods in excess of requirements is waste — which, like every other waste, turns up in high prices and low wages."* —Henry Ford [89]

Calculating the proper amount of inventory to handle is a big challenge for most companies. Too much inventory ties up capital and contributes to Ohno's 7 wastes. (See Section 2.6.2 The Toyota Production System above.) On the other hand, too little inventory can result in a stockout. In addition to avoiding stockouts, several reasons exist for carrying inventory:

1. To balance ordering or setup costs and carrying costs.
2. To satisfy customer demand.
3. To avoid shutting down manufacturing facilities because of machine failure, defective parts, unavailable parts, or late delivery of parts.
4. To buffer against unreliable production processes.
5. To take advantage of discounts.
6. To hedge against future price increases.[90]

Decreases in inventory and WIP is possible with a pull-system, whereby the proper quantity of parts get ordered only when they are needed. Lean pull systems utilizing kanbans are described above in Section 4.6 Kanban Design Analysis. In order to maximize their utility, it is wise to optimize the amount of inventory as well as the reorder point.

5.1 Calculation of Reorder Points (Trigger Levels)

The number of units demanded over the lead time is the trigger level. This is the quantity that triggers a production or procurement of additional resources.[91] It consists of two components: the calculated average demand over the lead time as well as a statistical component that represents safety stocks. Safety stocks cover the uncertainty of future demand to ensure that no stock outs occur.

$$D = \lambda L + SS$$

[89] Henry Ford , Today and Tomorrow, (New York: Productivity Press, 1926), 103.
[90] Jozsi, Celina, Chapter 19 Inventory Management, (accessed June 27, 2002), available from http://www.coba.usf.edu/departments/accounting/faculty/jozsi/slides/ch191.PDF.
[91] Zipkin, Paul, Foundations of Inventory Management, (Boston: McGraw Hill, 2000), 32.

where:
D = demand during lead time {units}
λ = demand rate {units/day}
L = lead time {days}
SS = safety stocks {units}

The statistical term is normally calculated according to the following formula:

$$SS = z * \sigma * \sqrt{lead\,time}$$

where
z = number of standard deviations from the mean corresponding to confidence interval; z = 1.96 refers to the 95% confidence interval.
σ = standard deviation of demand variance during a single replenishment period (assumes no serial correlation or lead time variation)[92]

Note that in the case of the brazed core assembly area, a dearth of data representing past order patterns prevented the calculation of the statistical component: safety stocks. Our simplified calculation equates the trigger level with the units demanded over the lead time. We are confidently able to do this since demand is regular for high-volume parts in the core area. In the absence of past data, we calculated a generous lead time in order to avoid stock outs. Experience over the course of time will allow this lead time to be gradually reduced.

5.2 Optimization of Lot Sizes

> *"Clearly, the most important calculation a business can make regarding inventory is lot size."* —Dennis Butt [93]

In order to minimize the total costs of production, it is important to produce the appropriate amount of goods at the appropriate time. Several lot-sizing techniques exist. This thesis examines two techniques: shadow price analysis and economic order quantity. Both are based on Wilson's lot size formula.

A shadow price method using a Lagrange multiplier is appropriate when production runs under capacity. It essentially reduces lot size to the point where a machine is being set up or run all or nearly all of the time.

[92] Garret J. Caterino, "Implementation of Lean Manufacturing in a Low-Volume Production Environment", (Masters Thesis, Massachusetts Institute of Technology, 2001), 63.
[93] Dennis Butt, "Just In Time in Lincoln, Nebraska: Why and How", presented at seminar "Three Practical Approaches: Quality Control Circles, Measurement, and Kanban", February, 1981, reprinted in Applying Just In Time, ed. Yasuhiro Monden, (Atlanta: Industrial Engineering and Management Press, 1986), 81-86.

If production is not subject to a hard constraint but by a soft constraint such as labor, then the economic order quantity (EOQ) method may be more appropriate. Soft constraints refer to resources that are readily available and can be purchased at a higher price (overtime labor hours). In the case of the Fin Forming Area of Hamilton Sundstrand's Windsor Locks facility, a coordinated replenishment technique based on EOQ evinces optimal results by reducing the number of overtime labor hours.

5.2.1 Lagrange Multiplier Method

Determining the shadow price of time is a useful tool when scheduling production in a shop operating under capacity. An analysis of the shadow price of time is appropriate when running under capacity, because the shadow price of time allows the calculation of lot sizes to be decreased until all of the available capacity is taken up by set-up time and run time.

Shadow price is the marginal cost for the use of an additional input in the production process. Its is not the market price of the input, but rather the opportunity cost inherent in using the input in the activity under consideration instead of in an alternative activity. Essentially it is the maximum price that one is willing to pay for one extra unit of a constraint (labor).

Daniel Wheeler (LFM 2000) wrote a thesis dealing with this topic. A detailed explanation of this method appears in his thesis on pages 57-59.[56]

In the case of the Fin Forming Area at Hamilton Sundstrand, capacity is limited by labor. This area of the factory logs significant overtime hours. In this case, the EOQ method is more appropriate than the Lagrange multiplier method since the overtime labor price establishes the cost of time rather than a shadow price.

5.2.2 The Economic Order Quantity

One method to determine lot sizes is the economic order quantity (EOQ). F. W. Harris of the Westinghouse Corporation originally developed the EOQ method, but R. H. Wilson, a consultant, widely popularized it. It therefore became known as Wilson's Lot Size Formula.[94] This formula evinces the following assumptions:

Assumptions of EOQ:
1. Demand rate known and constant over time
2. No minimum or maximum restrictions on order quantity
3. No discounts for large quantity purchase or for transportation costs
4. Low inflation

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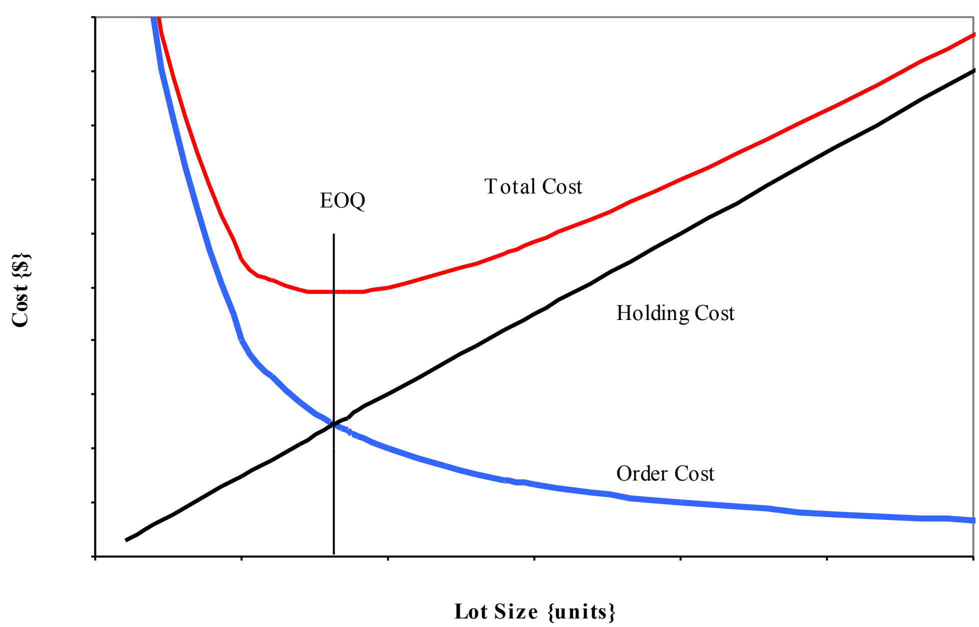
[94] Ferreira, P. M., "Handout #4-1: Inventory Management", IE 373 : Production Planning and Control, (accessed July 16, 2002); available from http://www.cen.uiuc.edu/courses/ie261/ie262/notes/invm/h1/IE373-Inventory-1.html.

5. No joint replenishment
6. Replenishment lead time is zero
7. No shortages allowed
8. Entire order delivered at same time[95]
9. Inventory does not become obsolete
10. Sufficient storage space for full lot size exists[96]

The two inputs into total costs are order costs (also called set-up or replenishment costs) and inventory holding costs. The order costs decrease inversely with increasing quantity produced, whereas holding costs increase linearly with increasing quantity. The minimum total cost is at the lot size where the order cost and the holding cost intersect, as shown below in Figure 10. Mathematically, the optimum lot size can be found by taking the first derivative of the total cost function with respect to cost, setting it equal to zero, and solving for the lot size quantity. The result is the EOQ formula: [97]

$$EOQ = \sqrt{\frac{2(annual \;\; units)(order \;\; cost)}{annual \;\; carrying \;\; cost \;\; per \;\; unit}}$$

Figure 10. Economic Order Quantity Graphical Depiction



[95] Edward Silver and Rein Peterson, Decision Systems for Inventory Management and Production Planning, (New York: John Wiley & Sons, 1985), 174.
[96] Garret J. Caterino, "Implementation of Lean Manufacturing in a Low-Volume Production Environment", (Masters Thesis, Massachusetts Institute of Technology, 2001), 65.
[97] Edward A. Silver and Rein Peterson, Decision Systems for Inventory Management and Production Planning 2nd ed., (New York: John Wiley & Sons, 1985), 178.

5.2.2.1 Calculation of Order Cost

Calculation of the order, or replenishment, cost is straightforward. One adds up all of the costs involved with a discrete transaction (such as set-up labor cost, material procurement labor cost, etc.) and divides it by the number of units being produced. In a manufacturing environment such as at HS, order cost is the cost of time. Often the set-up time of a machine is used. Note that it is important to use actual set-up times, and not target set-up times in order for the EOQ calculation to be meaningful. The cost decreases inversely with increasing units.

5.2.2.2 Determination of Holding Cost

The determination of holding costs has very wide-reaching implications for inventory management, potentially affecting millions of dollars of inventory in a large factory. Inventory consignment as well as lot sizing using EOQ are strongly dependent on the value that one assesses for holding costs. This topic thus bears significant importance.

Holding costs are often calculated as a rate applied to a unit cost. In this sense, it represents an internal annual tax on each unit that does not come due, but that is used to determine lot sizes and the value of off-loading inventory as consignment. In lot sizing, the use of a low (conservative) rate encourages larger lot sizes, more inventory and good customer service and low replenishment costs. On the other hand, a high figure results in less inventories, higher order costs due to more frequent lots, and potentially a decreased customer service level.[98]

Holding Cost Rate

The holding cost rate consists of those costs that are variable with inventory. These costs do not vary with each transaction. Fixed costs such as overhead expenses (lights, heat, rent, property tax, property insurance, environmental remediation) do not factor in. Costs that vary with inventory include:

- Cost of capital
- Insurance on inventory
- Tax on inventory
- Personnel to manage inventory
- Obsolete inventory
- Scrap, rework, and repair of inventory damaged while in storage
- Inventory handling equipment (fork truck, racks, bins, etc.)

There is no single correct value for the holding cost rate in the accounting sense due to the complexity in estimating capital costs and in assessing which costs are variable. Rather, a holding cost value is correct as long as senior management approves of the

[98] Edward Silver and Rein Peterson, Decision Systems for Inventory Management and Production Planning, (New York: John Wiley & Sons, 1985), 76.

resulting inventory level, customer service level, and order costs associated with a given holding cost rate.[99] There are trade-offs to be made here between inventory and customer service levels. The exact holding cost rate is site specific and it can even change from one work area to another within a factory depending on scrap rework, repair, and obsolescence of a certain product mix. A good rule of thumb for holding costs is 25%. One MIT thesis lists holding costs at 30% in 1999 at Instron, a company near Boston that makes equipment to evaluate mechanical properties of materials. The holding cost for Instron breaks down as 15% as capital costs, 10% taxes, insurance, and storage, and 5% disposition costs.[100]

5.2.3 Optimal Coordinated Replenishment Based on EOQ

Sometimes one cannot simply plug numbers into the EOQ formula. This is precisely the case when several parts in a production run can share the set-up costs, spreading them out among all parts that are run. This is called "joint", or "coordinated" replenishment, and the lot sizes are calculated according to a more general version of the EOQ. In the case of the Fin Forming Area of the Windsor Locks factory, resizing the lots and sequencing their production results in savings that are easily calculated by quantifying the reduction in inventory and holding costs as well as the reduction in overtime labor hours.

Sometimes it is advantageous to share replenishment costs. Silver and Peterson identify pros and cons of coordinating replenishment below in Table B.[101]

Table B. Pros and Cons of Coordinated Replenishment

Advantages:	Disadvantages:
1. Quantity discounts sometimes possible	1. Average inventory level may increase
2. Transportation cost savings	2. Control costs higher
3. Order costs savings	3. Reduced flexibility (run all together)
4. Ease of scheduling	

According to Table B, more advantages for coordinated replenishment exist than disadvantages.

One disadvantage of coordinated replenishment is a decrease in flexibility due to the necessity to always run several parts together. If the parts can share the same set-up, then this disadvantage can be converted into an order cost savings. If demand patterns are regular or if all parts in a part family belong to the same parent assembly, then the

[99] Ibid.

[100] Daniel H. Wheeler, "Pulling a Job Shop into Supply Chain Management", (Masters Thesis, Massachusetts Institute of Technology, 2000), 28.

[101] Edward Silver and Rein Peterson, Decision Systems for Inventory Management and Production Planning, (New York: John Wiley & Sons, 1985), 431-432.

consumption of inventory over time is synchronized, facilitating coordinated replenishment.

The most flexibility is possible with machines with low set-up times, allowing frequent set-ups which results in lower inventory carry costs. One issue that arises during the implementation of lean practices is that the set-up times of some equipment cannot be drastically improved to make them flexible. Equally possible is a lack of resources to perform a set-up reduction activity. Replacement equipment that allows shorter set-up time may be too expensive to purchase right away; alternately, the lead time of new equipment may be long. In the meantime, some measures can be taken for parts that share set-up costs that will yield an immediate improvement in the number of set-ups and the amount of inventory on hand. The trick is to break the parts into part families, sequence production, and optimize lot sizes using a modified version of the Wilson formula. This method has no capital expenditures and can greatly reduce the costs of production.

For a machine with a long set-up time, it makes sense to group parts that share the same tooling into part families, and to run all parts in this part family sequentially. In this case, the set-up costs are shared over the family of parts, which reduces the overall number of set-ups necessary. Analogously, for items with high replenishment costs, it makes sense to order several parts in one order.

One cannot use the classic Wilson formula for a whole family of parts because it assumes that each part has its own discrete set-up cost. Parts grouped into part families share set-up costs. It would be incorrect to merely divide the set-up cost by the number of parts in the part family, since the EOQ equation would yield small lot sizes, require frequent set-ups and the part family order cycle would be out of sync. Rather, the optimal solution is to sum the initial and incremental set-up costs and to calculate a composite unit cost and a total part family demand. By doing so, one can use the EOQ formula, and the part family shares set-up costs. The result of this method is that the total number of set-ups decreases, the inventory holding costs decrease, and production runs are automatically synchronized across the whole part family, resulting in savings. Upon implementation, there will be a one-time inventory reduction savings as well as recurring savings in inventory holding costs and fewer set-ups.

Note that several prior academics, including Silver and Goyal, worked on deterministic models of joint replenishment in the 1970's, and they present their elaborate solutions in the literature.[102, 103, 104] Silver and Peterson's textbook presents a solution in terms of time supply that is free of the constraint that all parts in a part family are replenished

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[102] S. K., Goyal, "Determination of Optimum Packaging Frequency of Items Jointly Replenished", Management Sciences, 21, no. 4, (1974), 436-443.

[103] S. K., Goyal, and A. S. Belton, "On a Simple Method of Determining Order Quantities in Joint Replenishments Under Deterministic Demand", Management Science, 25, no. 6, (June 1979), 604.

[104] Edward A. Silver, "A Simple Method of Determining Order Quantities in Joint Replenishments Under Deterministic Demand", Management Science, 22, no. 12, (1976), 1351-1361.

every time a set-up occurs.[105] The earlier work of Silver therefore serves as an general method, into which the method presented below can be classified as a subset. The method presented here was derived independent of knowledge of prior art and is in a non-time supply format, which may make it easier to comprehend. Silver himself reviewed this method and verified that it does indeed yield the optimal solution for the condition imposed: all parts in the part family are replenished every time a set-up occurs. Silver commented that this method is "intuitive and easy to understand".[106]

In summary, the conditions for coordinated replenishment via the EOQ-based method presented here are:

- Several parts can share set-up costs.
- The set-up time is long.
- No further reduction in set-up time is possible.
- The replacement of capital equipment is not imminently possible.
- Production is constrained by labor.
- All assumptions of EOQ hold. (See 5.2.2 The Economic Order Quantity above.)

5.2.3.1 Three-Step Method to Calculate Lot Sizes for Part Families

1. First of all, group parts that share set-ups into part families.

   These parts must be able to share a major set-up cost. Minor, incremental set-ups are also permissible; they can be aggregated into the total set-up cost, thereby pushing the curve outwards. Additionally, all of the criteria for use of EOQ apply. (See above.) For example, all parts must have a constant and deterministic demand.

2. Calculate total part family production quantity using EOQ formula with modified inputs.

   Recall the classical, deterministic EOQ equation is given by:[97]

$$EOQ = \sqrt{\frac{2(annual\ \ units)(order\ \ cost)}{annual\ \ carrying\ \ cost\ \ per\ \ unit}}$$

   The modified EOQ formula looks very similar and is given by:

$$Q = \sqrt{\frac{2A_a C_o}{iC_c}}$$

[105] Silver, Edward A. and Rein Peterson, Decision Systems for Inventory Management and Production Planning 2nd ed., (New York: John Wiley & Sons, 1985), 432-438.
[106] Edward A. Silver, <edward.silver@haskayne.ucalgary.ca>, "EOQ Heuristic for Joint Replenishment w/ Coordinated Order Cycle", private e-mail message to Jonathan Rheaume, Sep. 28, 2002.

where

Q = aggregate economic order quantity; the total number of all parts in the part family to make or order

A_a = aggregate annual demand of all parts in the same part family

C_o = total order cost (total set-up cost or replenishment costs; sum of initial and incremental set-up costs)

i = holding cost rate

C_c = composite unit cost of product mix

Note that the aggregate annual demand, A_i, is merely the sum of the individual demands for each part number:

$$A_a = \sum_{1}^{n} A_i$$

where

A_i = annual demand of the i^{th} part in a part family consisting of n parts.

The total order cost consists of the initial set-up costs plus any incremental set-up costs incurred while switching between parts in the part family.

The composite unit cost is the annual demand-weighted cost of all n parts in the part family:

$$C_c = \frac{1}{A_a} \sum_{1}^{n} C_i A_i$$

where

C_i = unit cost of the i^{th} part in a part family consisting of n parts.

3. Size individual part lots as fraction of total annual demand.

The modified EOQ equation yields an aggregate economic order quantity for all parts in the part family that must be decomposed in order to determine the optimal production mix. To find the quantity of each individual part, one only has to multiply the aggregate quantity by each part's fractional demand. The fraction consists of each part's annual demand over the aggregate annual demand.

$$q_i = Q * \frac{A_i}{A_a}$$

where

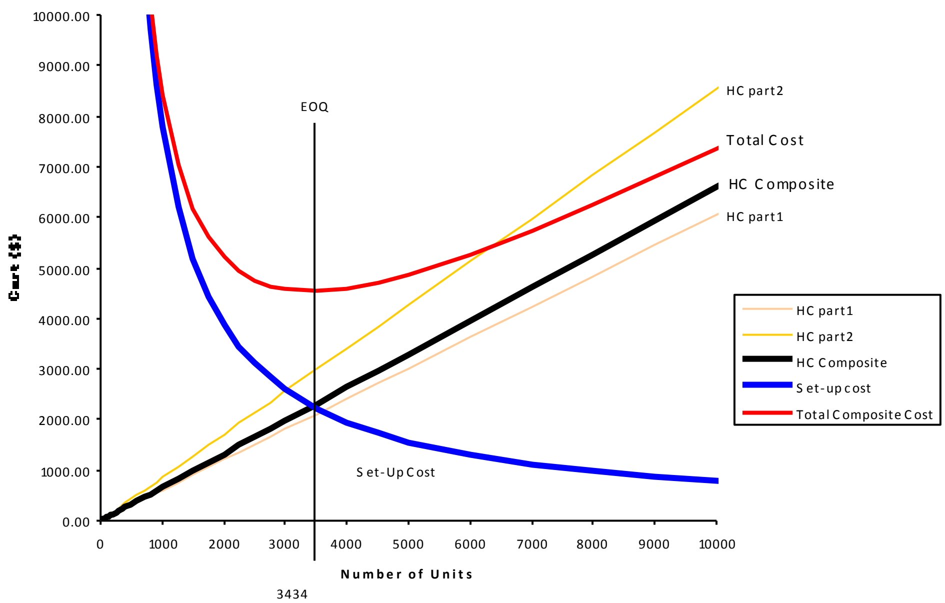
q_i = quantity of part i to produce or order in each lot.

5.2.3.2 Graphic Representation of EOQ Coordinated Replenishment

A graphic representation of the EOQ concept portrays the set-up costs and holding costs intersecting at the optimum lot size, which corresponds to the minimum point of the total cost curve. The method makes a composite holding cost from the various individual holding costs. The composite holding cost comes from the composite unit cost, and is calculated as described earlier. In Figure 11 below, the composite holding cost has a slope that is closer to part 1's, whose volume is higher than part 2's. Even though part 2 costs 22% more than part 1, the annual demand of part 1 is 4 times higher, causing the composite holding cost slope to lean towards part 1's holding cost. In this example, the following assumption exists: no incremental set-up costs are incurred by switching between parts in the part family. If there were incremental set-up costs, then they would be added to the total set-up cost, effectively shifting the set-up cost curve to the right.

The economic order quantity for both parts in the part family is in this case at the intersection of the composite holding cost and the set-up cost.

Figure 11. Economic Order Quantity under Coordinated Replenishment



Example of Coordinated Replenishment Using EOQ

The concept of sharing set-up costs can be extended to any number of parts in a part family. The below Table C compares the production of three high-volume parts in a part family with a combined annual demand of 9,400 pieces according to the way they are scheduled: (1) set up each part separately using EOQ vs. (2) grouping parts into part families and using the EOQ joint replenishment method.

The salient features of the method are a decrease in lot sizes, set-up costs, inventory, and inventory holding costs. Checking the method by multiplying the lot size by the set-ups does indeed agree with the annual demand of the individual parts. (Note that values for A_1, A_2, A_a, C_o, I, C_1 ,C_2, and C_c used in the calculations for this example are omitted.)

Table C. Traditional EOQ vs. Coordinated Replenishment Methods

	Traditional EOQ Method	EOQ Joint Replen-ishment	Traditional EOQ Method	EOQ Joint Replen-ishment	Traditional EOQ Method	EOQ Joint Replen-ishment	Traditional EOQ Method	EOQ Joint Replen-ishment
	Lot Sizes		**Set-Up Costs**		**Weeks Inventory**		**Set-Ups/Yr**	
Part A	778	588	$168	$168	8.5	6.5	6	8
Part B	645	362	$168		11.5		5	
Part C	561	226	$168		16.0		3	

5.2.3.3 Coordinated Order Cycle

One benefit of this method is that it not only optimizes the lot sizes for the whole part family, but also it computes them in levels that are proportional to their annual demand pattern. In other words, this method calculates lot sizes that will be consumed in a perfectly synchronized manner, assuming that the depletion rate of all parts is linear over time. In the case of the core area, virtually all parts in part families belong to the same core, so the synchronization of depletion and replenishment is possible.

When a part in a part family triggers its replenishment, ideally the remaining parts would be produced until their bins are full. That is, their order-up-to levels are reached. However, accounting issues led to resistance during implementation. In practice, to avoid complications, lot sizes are fixed in size.

During the implementation period, it takes some time to coordinate the utilization of parts within part families. During this time period, some lots should be run that are smaller than optimal until synchronization of coordination is achieved.

5.2.3.4 Cost Accounting for Shared Set-Ups

"This is a noble cause. How do you make it work?" —Alan Deprospero [107]

Allocating set-up costs to a family of parts that shares a set-up is a challenge in a standard cost system. The Sundstrand Corporation used an average actual cost system prior to the merger with Hamilton Standard in 1999. Under that cost system, sharing set-up costs would not have been an issue. Under a standard cost system, some issues arise.

This modified EOQ method does not allow for lost parts, defective parts, etc. As a result, the lot sizes should be interpreted as the maximum bin level for a given part. Ideally, the part that runs out first triggers a new set-up, and all bins are filled to an amount corresponding to the levels as calculated using the modified EOQ method above. This

[107] Alan Deprospero, Manufacturing Engineering Manager, conversation on November 6, 2002.

method allows the automatic synchronization of the order cycle. In practice, this method presents some issues when working in the framework of a standard cost accounting system.

Reconciling shared set-up costs within the framework of the existing accounting system poses some interesting challenges. Under the current standard cost accounting system, a standard cost for each part is calculated on an annual basis according to a fixed lot size. This method boasts simplicity at the expense of flexibility in response to changes in market conditions. For example, if amidst a market downturn, demand falls, and the optimum lot sizes decrease. In this case, a set-up cost is spread out over fewer parts, resulting in negative variation, making each individual unit more expensive. This "loss" must be made up by the shop.

Implementing the new lot-sizing scheme for part families is possible under existing accounting practices by charging a full set-up cost to the part that triggers the set-up. Then all other parts in the part family have no charge when set-up, resulting in a credit to the shop. While this method is consistent with acceptable accounting practices, it creates some other issues.[108] For example, the triggering part may appear to get overcharged.

Note that this method works best for part families whose parts all belong in the same core, otherwise one customer may object to paying for the set-up of another. Some legal issues present themselves when sharing set-ups for commercial and military production.

5.2.3.5 Impact of Coordinated Replenishment in Fin Forming Area

Modeling the high-volume inventory before and after coordinated replenishment forecasts the following improvements:

- One-time inventory reduction in excess of $100k
- Annually recurring labor set-up savings $25k
- Annually recurring holding costs savings of over $20k
- Net present value of above savings over 10 years over $450k
- ROI of internship due to coordinated replenishment of over 700%

Note that a very conservative holding cost rate was used, so that the actual savings may be understated. Labor savings consist of savings due to avoided overtime hours, and the marginal cost of overtime was used in those calculations. NPV and ROI projections occur over a period of 10 years (with terminal values included).

In addition, the effectiveness of this method is predicated upon utilization of accurate figures for set-up costs. If target set-up times are used instead of actual times, then this method understates the lot sizes, requiring more frequent set-ups than optimal. It is thus important to use actual figures for order costs.

[108] Raj Barman and Arthur Allaire, Hamilton Sundstrand Finance Department, conversation on Nov. 6, 2002.

In summary, this chapter delves deeply into a lot-sizing method that promotes lean principles. The discussion of the mechanics of the lean transformation concludes here. The next chapters discuss less tangible, yet highly important topics such as operations strategy, change implementation, and labor relations.

Chapter 6: Operations Strategy

At HS, operations strategy focuses on operational excellence. This results from a three-pronged effort that calls for improving factory execution, reconsidering the scope of manufacturing, and linking together all entities in the value chain.[109] ACE and MRD are programs that help to improve factory execution. A strategy team regularly addresses the scope of manufacturing by reviewing core competencies in order to make the decision to produce or procure parts. A common MRP program is currently being introduced company-wide in order to better link the value chain. All of these initiatives have a common goal: reduce costs.

This chapter highlights some aspects of operations strategy, especially those that involve identifying what to make, and outsourcing or finding the highest productivity, lowest cost manufacturing center. Often the places that offer the most potential for low cost, high quality productivity are in emerging markets, which this chapter examines from the perspective of discussion with macroeconomists at the MIT Sloan School of Management. A discussion of James Womack's findings sheds new light on foreign sourcing decisions. Lastly, this chapter re-examines a possible strategic merger or acquisition.

6.1 Core Competency Identification

Henry Ford was well ahead of his time when he commented in his autobiography on supply chain design:

> *"The most economical manufacturing of the future will be that in which the whole of an article is not made under one roof – unless, of course, it be a very simple article. The modern –or better, the future– method is to have each part made where it may best be made and then assemble the parts into a complete unit at the points of consumption."* –Henry Ford[110]

The Hamilton Sundstrand Strategy Group has a process to determine whether a product or part is made in-house. The method involves reviewing every part and screening for proprietary or critical technology, operational capability, cost advantages, and improvement potential. HS continues to manufacture a part or product in-house if they determine that it represents a core competency or a cost advantage. Otherwise the part or product is a candidate for out-sourcing. Note that some other criteria for outsourcing work exist, and may be considered in the outsourcing decision. For example, off-loading work is sometimes unpopular with workers, poor for morale, and it presents political

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[109] John Boyd, "Operations at Hamilton Sundstrand", (United Technologies Corp. Hamilton Sundstrand Presentation), Oct., 2002.

[110] Henry Ford, My Life and Work, (Garden City, New York: Doubleday, Page & Co., 1922), 52.

issues-involving state governments. Also, suppliers are more vulnerable to the vicissitudes of the business cycle, a phenomenon known as the bullwhip effect. Suppliers have less access to capital markets and are consequently less likely to make long-term, productivity-enhancing investments.[111] In conclusion, outsourcing is not a panacea to improve productivity and profitability. For this reason, a complete review of every part and product should be repeated every few years as market conditions change.

6.2 Emerging Markets

In order to evaluate the present and future business climates in three emerging labor markets, interviews were conducted with leading macroeconomists at the Sloan School of Management, Roberto Rigobon and Lester Thurow. In addition, a macroeconomist from the World Bank Group, Arthur Kraay, provided his perspectives. They were all asked the same questions, reprinted below.

6.2.1 Mexico

> *Why has the Mexican peso been falling against the dollar since the promulgation of NAFTA?*

MIT Professor Roberto Rigobon asserts that Mexico joining NAFTA has nothing to do with their currency's depreciation. Rather, he attributes the loss of value of the peso to:

1. higher inflation in Mexico
2. lower productivity gains in Mexico vs. in US
3. high interest rates at the end of the 90's in the US[112]

World Bank economist Arthur Kraay's professional opinion supports the points made by Rigobon. In addition, Kraay adds that the nominal exchange rate of the peso has varied widely, whereas the real exchange rate (which measures the relative costs of similar goods in different countries) has barely moved versus the US dollar during 1990's. Low labor costs are not what matters; productivity does. Increased productivity in Mexico by companies that relocate operations to Mexico would normally result in an appreciation of the peso, according to the BB-NN model. This model determines the real exchange rate at the equilibrium of an economy's balance of payments and labor market.[113] But in reality, appreciation of the peso against the dollar has not materialized. Productivity gains in Mexico lag those in the US, contributing to the depreciation of the peso's

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[111] Earll Murman, Thomas Allen, Kirkor Bozdogan, Joel Cutcher-Gershenfeld, Hugh McManus, Deborah Nightingale, Eric Rebentisch, Tom Shields, Fred Stahl, Myles Walton, Joyce Warmkessel, Stanley Weiss, and Sheila Widnall, Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative, (New York: Palgrave, 2002), 68.

[112] Roberto Rigobon, <rigobon@mit.edu>, "Re: Questions about Emerging Markets by LFM Student", private e-mail message to Jonathan Rheaume, Jan. 7, 2003.

[113] Roberto Rigobon, "The BB-NN Model", (Handout in Macroeconomics Course 15.021, MITSloan School of Management, Spring Semester 2002), 1.

nominal exchange rate. Depreciation of the peso has offset inflation, resulting in a relatively unchanged real exchange rate.[114]

MIT Sloan Professor Lester Thurow said that the biggest problem in Mexico is skills. Mexico lacks human capital. Thurow would locate a business in Eastern Europe before he'd consider Mexico.[115]

The Mexican economy has grown 28% between and 1995 and 2001, largely due to NAFTA. In this time, exports have tripled, to $166.4 billion.[116] As a consequence, the peso strengthened 25% in value between 1999 and 2002 before plunging precipitously in the latter half of 2002.[117] The strong peso from 1999 until 2002 injured Mexico's export-driven economy, driving 350 factories and 240,000 jobs out of the country. In response, the Central Bank of Mexico eased its monetary policy, encouraging a weaker peso at the expense of inflation. A cheaper peso encourages foreign investment at a time when factories are shuttering in Mexico and re-opening in China.[118] Table D below illustrates some important aspects of doing business in Mexico.[116]

Table D. Pros and Cons of Production in Mexico

Pros:	Cons:
Location (same day flight from US)	Poor quality suppliers
NAFTA	Rampant corruption
Lower overhead costs	Crumbling infrastructure
Low cost of labor (but steadily rising)	Currency fluctuations
Available labor force	Education - average worker 7th grade
No Worker's Compensation	Bureaucracy - 90 days to est. corp.
Remain competitive with other firms	Political instability

Since 1999, rising wages and the volatile peso have made Mexico less attractive. Doing business in Mexico today is more expensive than in 1999.

Professor Rigobon recommends that aerospace companies skip Mexico and head straight to Brazil. Mexico lacks an aerospace company whereas Brazil is home to air-framer

[114] Arthur Kraay, Senior Economist in the Development Research Group at the World Bank Group, telephone conversation on Jan 24, 2003.

[115] Lester Thurow, Professor Of Mgmt & Econ at MIT Sloan, conversation on Feb. 3, 2003.

[116] Geri Smith, "Is the Magic Starting to Fade for Manufacturing in Mexico?", BusinessWeek, Aug. 6, 2001, (accessed July 10, 2002); available from http://www.businessweek.com/%40%40DkuU5IQQnBZq9gIA/magazine/content/01_32/b3744085.htm.

[117] Geri Smith, "The Decline of the Maquiladora", BusinessWeek, April 29, 2002, (accessed July 10, 2002); available from http://www.businessweek.com/magazine/content/02_17/b3780078.htm.

[118] James C. Cooper, Kathleen Madigan, and Geri Smith, "Mexico: Say Adios to the Super Peso", BusinessWeek, June 17, 2002, (accessed July 10, 2002); available from http://www.businessweek.com/%40%401aHIFIQQmhZq9gIA/magazine/content/02_24/b3787041.htm.

Embraer. He suggests a joint venture with Embraer in Brazil because of a trained workforce, lower labor rates, government subsidies, and a small political risk. Thurow mentioned that Brazil's sizeable German influx last century altered the culture of production in some regions, boosting efficiency and skill levels.[115]

6.2.2 Eastern Europe

> *What will the short term and long term local economic effects of the induction of Poland, Czech Republic, etc. in the EU? Is the relationship between Mexico and the US under NAFTA a valid comparison?*

Poland, the Czech Republic, Hungary, and Russia are all excellent candidates for locating manufacturing operations, according to MIT Professor Roberto Rigobon. He thinks that Poland and the Czech Republic will join the EU, which will have more political ramifications than economic ones. NAFTA has been far more beneficial for Mexico than what he expects the EU will be for Poland. In this case, a comparison with Mexico should be considered an upper bound.[112]

Art Kraay of the World Bank agrees with Rigobon, and further urges caution about drawing analogies between NAFTA and the EU. NAFTA is just a free trade agreement, whereas the EU entails political integration, economic integration, a monetary union, and freely mobile labor markets within the borders of the EU. Kraay foresees many large hurdles associated with the integration of the EU given its scope; the EU consists of very different economies at various points in the economic cycle.[114]

Kraay noted that agricultural subsidies account for approximately 50% of the EU budget.[119] Kraay does not believe that all farmers in Eastern Europe can be offered equal treatment. Mexico and the US have largely protected their agricultural markets, with tariffs to be phased out over years.

Professor Lester Thurow of MIT Sloan pointed out another key difference between NAFTA and the EU. A free trade agreement such as NAFTA encourages production at the lowest possible environmental and safety standards, whereas a wider-reaching agreement such as the EU will bring all countries up to certain standards. Some transfer payments will be made to new member states to help them. As a result, Thurow expects wages to rise faster in Eastern European Countries than in Mexico. Some social legislation will also be introduced, which may significantly impact the economy.

Thurow further commented that Eastern Europe boasts an excellent education system, and consequently is very rich in human capital. Unfortunately, the culture of production under the former communist regime was slow. He remarked: "Cultural effects are not to be underestimated." As an example, he told the story of GE's lighting plant in Hungary. In this case, a very high number of workers and management alike needed to be replaced

[119] European Union Website, Activities of the European Union: Summaries of Agricultural Legislation, (accessed Jan. 23, 2003), available from http://europa.eu.int/scadplus/leg/en/lvb/l04000.htm.

in order to overcome the "command and control" culture inherited from the communists. Before doing business there, he urges learning from past mistakes as well as investigating the proposed changes in legislation and regulations due to occur over the next 10-15 years.[115]

Although far removed from talks of EU integration, Russia is an attractive location for locating production due to its highly skilled workforce. Already Hamilton Sundstrand has sourced some of its production to Nauka, a leader in cabin environmental conditioning.[120] Boeing Co. has outsourced some of its design work there, and now employs 350 aerospace engineers in Russia. Boeing thinks that this strategy will help them win orders from Russia's Aeroflot. So far, Boeing's Russian strategy has only caused them difficulty with the union representing Boeing's American engineers, the Professional Engineering Employees in Aerospace. Boeing has laid off 5,000 engineers since 2001 in the US.[121]

6.2.3 China

> *How will production in China be affected if the Chinese Yuan floats against the dollar?*

Roberto Rigobon asserts that the effect of a change in valuation of the yuan on production has to be minimal. The wage in dollars of China is tiny. It will 25 years for China's economy to be relevant on the global stage.[112] China is awash in cheap labor, but has little human capital, which is defined as the intangible skills, capabilities, and experiences of an individual. Despite the opening of chip fabs in Pudong, it is not likely that strategically important industries such as defense will get relocated there.[112, 122]

Kraay of the World Bank says that predicting nominal exchange rates movements is difficult. Economists have established poor track records attempting to do this. No accurate models exist for the long term. Regardless of which direction the nominal exchange rate of the yuan would hypothetically move, it's good for some, but bad for others.[114] A stronger yuan would make imports of materials and machinery cheaper, further driving down consumer goods prices. An appreciation of 25% would be necessary to reduce exports. On the other hand, floating the yuan may weaken the currency due to bad loans.[123]

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[120] Hamilton Sundstrand Space Systems International Website, "Russian Efforts", (accessed Jan. 27, 2003), available from http://www.hsssi.com/WhoWeAre/History/russian_efforts.html.

[121] Stanley Holmes and Simon Ostrovsky, "The New Cold War at Boeing", BusinessWeek, Feb. 3, 2003, 58-59.

[122] Dexter Roberts, Mark L. Clifford, Bruce Einhorn, Pete Engardio, "Greater China", BusinessWeek, Dec. 9, 2002, (accessed March 5, 2003); available from http://www.businessweek.com/%40%40PQj3W4YQHzNq9gIA/magazine/content/02_49/b3811007.htm.

[123] Mark Clifford, "China's Exports: How Low Can Prices Go?", BusinessWeek, Dec. 2, 2002, (accessed Dec. 3, 2002), available from http://www.businessweek.com/@@1WjR0oYQr0Rq9gIA/magazine/content/02_48/b3810081.htm.

China is keeping their nominal exchange rate low in order to sell Chinese produced products more competitively on the world market, says Lester Thurow. He suspects that the Chinese will continue to do so as long as they can. He does not foresee that China will undergo the same problems that Argentina had with fixing their currency to the dollar. Argentina had a currency board that printed pesos depending on their supply of dollars.[115]

With low labor rates and tax incentives, China offers an attractive production environment to the many price-sensitive, low-margin businesses that have opened operations in China in recent years.[116] Some firms have relocated operations to China from Mexico. In China, "The supply of $100-a-month Chinese labor is virtually inexhaustible."[123] China currently sees $50 billion in annual foreign investment. In 2002, China evinced 4% annual productivity improvement, 20% increase in exports, and 8% economic growth. Overproduction flooded global markets and drove prices down.[123]

Investing in China is not without risks. Human capital tends to be behind the West. The legal system including intellectual property rights needs shoring up. Cases in which a strategic partner turns competitor exist.[124]

6.2.4 Discussion of Emerging Markets and Lean Math

> *"The triumph of lean production has created a new threshold for product quality that no producer can hope to offset merely through low prices based on low wages. As a result, producers in the next tier of developing countries must become lean producers as well."*
>
> – The Machine That Changed the World [125]

MIT Professor Charles Fine asserts that supply chain design is the ultimate core competency in Part II of his book, Clockspeed.[126] Thus it is the goal of every manufacturing company to design the delivery of value as reliably and as low-cost as possible while providing high quality products. Discretion must be used in outsourcing work and/or relocating manufacturing, because these decisions are the most important ones that a business faces.

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[124] Gabriel Kahn, "For New Balance, a Surprise: China Partner Became Rival", Wall Street Journal Online, Dec. 9, 2002 (accessed April 1, 2003) from http://www.wfsgi.org/_wfsgi/new_site/news/days/new-balance_china.pdf.

[125] James P. Womack, Daniel T. Jones, and Daniel Roos, The Machine That Changed the World, (New York: Harper Perennial, 1991), 252.

[126] Charles Fine, Clockspeed: Winning Control in the Age of Temporary Advantage, (Reading, MA: Perseus Books, 1998), 69-124.

When thinking about relocating, Professor Rigobon urges investigating a host of questions:

- Is the human capital present?
- What are the wages?
- Are there possibilities for joint ventures?
- Is there macroeconomic stability? Corporate governance? Property rights?

In addition to these questions, Womack and his associates at the Lean Enterprise Institute have devoted considerable thought to the economics of relocating production. Womack says that it is not enough to focus only on savings from lower wages and transportation costs, but rather one must make a more comprehensive evaluation using "lean math". In an email newsletter, he writes that lean math consists of the following additional costs:

- "The overhead costs allocated to production in the high-wage location, which usually don't disappear when production in transferred. Instead they are re-allocated to remaining products, raising their apparent cost.
- The cost of the additional inventory of goods in transit over long distances from the low-wage location to the customer.
- The cost of additional safety stocks to ensure uninterrupted supply.
- The cost of expensive expedited shipments. (A bit of casual empiricism will show that they always exist.)
- The cost of warranty claims if the new facility or supplier has a long learning curve.
- The cost of engineer visits or resident engineers to get the process right so the product is made to the correct specification with acceptable quality.
- The cost of senior executive visits to set-up the operation or to straighten out relationships with managers and suppliers operating in a different business environment. (Note this may include all manner of payments and considerations, depending on local business practices.)
- The cost of out-of-stocks and lost sales caused by long lead times to obtain the part.
- The cost of remaindered goods or of scrapped stocks, ordered to a long-range forecast and never actually needed.
- The potential cost, if you are using a contract manufacturer in the low-cost location, of your supplier soon becoming your competitor." [127]
- Connectivity costs associated with remotely managing complex supply chains, production and information flows.
- Currency costs, which strike when the currency of the production and consuming markets shift relative to one another.
- Political costs, which consist of risk of expropriation, perception of corporate imperialism, and reaction to trade deficits, tariffs, unemployment, etc.[128]

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[127] James Womack, <jwomack@lean.org>, "Move your operations to China? Do some lean math first.", e-mail newsletter, Jan. 10, 2003.
[128] Ibid.

Performing lean math does not lead to the de-facto conclusion that relocation to China is the best business strategy. If, you are, however, trying to sell products in the Chinese market, then relocation may be necessary. The costs of transportation, inventory, and connectivity are lower within the product market, and the risk of currency fluctuation decreases.[127] Some foreign governments will offer a tax incentive and/or subsidies to source production there.[114] It may be a result of these reasons that Rolls-Royce and Pratt & Whitney plan on doubling output of jet engines in China to fortify their presence in the Chinese aerospace industry.[129]

According to Womack, management's first reaction to a lower cost labor market should not be relocation, but rather lean implementation in existing facilities. Indeed this is precisely the strategy that HS is pursuing by implementing lean manufacturing in its Windsor Locks plant and at other plants. If transfer of work is necessary according to lean math, then Womack advocates relocation of all steps of the value chain in a low-wage country near the end market. He suggests Mexico for the North American market, Eastern Europe for the European market, and China for the Asian (Japanese) market.[127]

MIT Professor Lester Thurow said the capital mobility is an important factor to consider as well. Some operations can be picked up and moved within 6 weeks if currency fluctuations instantaneously make one location "economically unviable". That depends, of course, on human capital, and how long it takes to train workers in a new location.[115]

Environmental factors such as soil contamination may prevent the complete transfer of work and a plant's shut-down. For example, in the case of Hamilton Sundstrand's Windsor Locks plant, site contamination was discovered in 1980. Since then soil has been excavated and a groundwater purification project is underway. Shutting down the facility would require a thorough site remediation, making shut-down costs prohibitively expensive. As a result, it is likely that at least some assembly work will remain in the factory.[130]

To examine some of the risks of locating centers of production in foreign sites, the consulting branch of PriceWaterhouseCoopers has developed an index of metrics that yields an assessment of a country's business climate. The PWC Opacity metric ranks 35 countries on the business environment. (The term "opacity" comes from taking the first letter of each category of evaluation, which collectively spells "clear".) The Opacity Index equally weighs:

1. corruption
2. legal system
3. economic and fiscal policy
4. accounting standards and practices
5. regulatory regime.

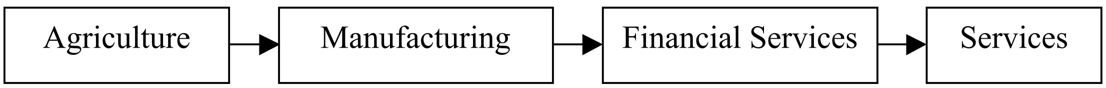
[129] United Technologies Morning News Summary, Bloomberg, (accessed Nov. 19, 2002); available from http://www.corphq.utc.com/innews/mns/archive/mns_11_19_02.1.html.

[130] "Remediation Activities Status", (Hamilton Sundstrand-Windsor Locks Environmental Health & Safety internal communiqué, Sep. 9, 2002).

A turbulent business climate introduces additional costs of doing business. For this reason, it is beneficial to have an index that compares various markets.[131] Rigobon notes: “The better the country, the higher the wages.” [132]

According to Professor Rigobon, the life cycle of economic development within a country occurs involves several transitions. The natural evolution of an economy follows a pattern that reflects development over a long period of time:

Figure 12. Steps in the Natural Evolution of an Economy



It is a natural course of events that manufacturing loses its predominance in an economy. This transition should not be feared because living standards increase with every step, according to MIT Professor Rigobon.[132] Globalization will keep the prices of services in check. Economist Robert E. Lipsey of the City University of New York says that globalization will cause American comparative advantage to shift to other fields. As long as productivity remains high, Americans will enjoy a high standard of living. Spurring economic development abroad expands foreign markets for American goods and services.[133]

In addition to high domestic labor costs, a strong dollar has been driving manufacturing jobs overseas for the past decade. A strong dollar makes it difficult to compete with competition from foreign low cost producers, resulting in a transfer of 2 million jobs outside of the US manufacturing sector overseas since 2000. The decline of the dollar in the second half of 2002 will likely benefit domestic manufacturers, allowing them to be more competitive on US soil against imports as well as in foreign markets. The dollar’s decrease in value effectively lowers prices of American goods abroad.[134] Professor Rigobon believes that the US dollar will continue to depreciate against other currencies of the world for about three years. [112]

6.3 Strategic Merger/Acquisition

A possible way to cut costs and increase product offerings is to find a strategic partner and either merge with or outright acquire them. Overhead of common parts gets spread out over a larger production base, and air framers find it easier to deal with fewer suppliers.

[131] PriceWaterhouseCoopers Endowment for the Study of Transparency and Sustainability, “The Opacity Index”, (Jan. 2001).
[132] Roberto Rigobon, Asst. Professor of Applied Economics at MITSloan, conversation on Jan. 22, 2003.
[133] Pete Engardio, Aaron Bernstien, Manjeet Kripalani, “Is Your Job Next?”, BusinessWeek, Feb. 3, 2003, 56.
[134] Peter Coy, Jack Ewing, Laura Cohn, “Soggy and Still Sliding”, BusinessWeek, Jan. 13, 2003, 33.

This section briefly revisits an acquisition of Honeywell Aerospace. Honeywell Aerospace manufactures a product line that is more complementary to Hamilton Sundstrand's than competitive. For example, Hamilton Sundstrand makes air management systems, electric systems, and flight control systems whereas Honeywell Aerospace makes avionics, landing gear, and airport radar systems. Some overlap exists, notably in auxiliary power units, engines, and Air Management Systems. A merger of the two businesses would create a one-stop shop for aerospace OEM products and allow the consolidation of global aftermarket service centers. Note that the same synergy could possibly exist with other aerospace OEMs such as Parker Hannifin and Goodrich.

A deal by United Technologies to acquire Honeywell International almost went through in 2000, but a last minute intervention by General Electric thwarted the attempt. The European Union blocked GE's attempted takeover worth $41 billion in 2001.[135] Honeywell shareholders can be happy that the European regulators prevented the deal, because GE stock has tumbled by more than 50% since the time of the original offer to November of 2002.[136] Unfortunately, Honeywell International's stock has also dropped in value by 50% since 2000, when it was trading in the $50's. In November 2002, the stock price hovers about $25.[137] Whereas both GE and Honeywell's stock have dropped by 50% since 2000, UTC shares have remained resilient, leaving the door open for an acquisition.

A cursory analysis of Honeywell Aerospace indicates that strategically, this business unit would be a good fit, but the time is not right for a deal. Honeywell's P/E is approximately 29, leaving UTC with a P/E of 15 in a poor position to take advantage of the situation. UTC's currency for an acquisition is weak, making 2002 a poor time to construct a deal.

Honeywell's Aerospace accounts for approximately 40% of Honeywell's total revenues, but self-disclosed, pro forma projections by their aerospace division claim that 70% of Honeywell stock value is justifiable by the Honeywell Aerospace's own revenue projections from the aerospace unit alone. This analysis indicates that Honeywell stock is undervalued, and/or that their projections are optimistic. In any case, the current mayhem in the aerospace sector makes for a challenging time for an acquisition.

In the future, further consolidation can be expected in the aerospace industry following the model set forth by James Utterback in his book, Mastering the Dynamics of Innovation. Members of the Lean Aerospace Initiative at MIT examine the phases of innovation in the aerospace sector according to Utterback's model in their book, Lean

[135] Steve de Bonvoisin, "European Commission Approves GE Purchase of ABB's Structured Finance Unit", Dow Jones Newswires, Nov. 5, 2001, (accessed Nov. 5, 2002); available from http://story.news.yahoo.com/news?tmpl=story&u=/dowjones/20021105/bs_dowjones/200211051120000579.

[136] United Technologies Morning News Summary, Barron's, (accessed Nov. 18, 2002); available from http://www.corphq.utc.com/innews/mns/archive/mns_11_18_02.1.html.

[137] Yahoo Finance, Honeywell Intl, (accessed Nov. 25, 2002); available from http://finance.yahoo.com/q?s=HON&d=c&k=c1&a=v&p=s&t=5y&l=on&z=m&q=l

Enterprise Value: Insights from MIT's Lean Aerospace Initiative . The shakeout period is well underway and will likely continue until only a small number of firms is left.[138]

6.4 Conclusion

In summary, operations strategy addresses the most important issues facing a company. The questions addressing what to make, where to make it, and with or by whom form the basis of a company's value proposition. This chapter focuses in on these elements as they relate to HS.

This next chapter examines how the changes that the Strategy Group advocates get translated into reality on the shop floor.

[138] Earll Murman, Thomas Allen, Kirkor Bozdogan, Joel Cutcher-Gershenfeld, Hugh McManus, Deborah Nightingale, Eric Rebentisch, Tom Shields, Fred Stahl, Myles Walton, Joyce Warmkessel, Stanley Weiss, and Sheila Widnall, Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative, (New York: Palgrave, 2002), 56-58.

Chapter 7: Organizational Change

Methods of manufacturing never stand still. –Henry Ford[139]

This chapter analyzes the change process in several ways. First of all, it examines change through the lenses of strategy, politics, and culture, providing specific examples from Hamilton Sundstrand's Core Assembly Area. Then the Sloan Leadership Model provides a framework for analysis of the dynamics of change, which according to the model, consists of sensemaking, relating, visioning, and inventing.[140]

7.1 Three Perspective Analysis of the Change Process

Introducing new ways of doing things in the Core Assembly Area of the Hamilton Sundstrand Windsor Locks plant yielded rich results suitable for analysis according to strategic, political, and cultural challenges. The changes that this section describes all deal with implementing lean manufacturing methods on the shop floor in many manifestations. Goals aligned with the lean effort include developing and getting support for a new coordinated replenishment method; specifying a new fin forming machine; and making some improvements on a braze alloy coating machine to improve its reliability.

7.1.1 Strategic Perspective

Lean manufacturing methods are necessary to remain competitive in today's aerospace marketplace. The goal of MRD is to make the Windsor Locks factory more competitive. During tough times in the aerospace industry, work is more likely to remain in a competitive and efficiency factory. True to Darwinian fashion, a competitive factory is more likely to retain jobs.

Lean production methods promise to slash inventory, reduce cycle time, improve productivity and increase quality. The project of lean implementation in the Heat Exchanger Core Assembly Area therefore fits perfectly with the needs of the organization. Coordinated replenishment in this area goes hand-in-hand with lean because it too reduces inventory levels and increases production efficiency.

Figure 13 below presents a modified version of the formal structure of the organization within Hamilton Sundstrand. The formal design of the organization facilitates project efforts because of a centralized, top-down push from senior management to implement lean manufacturing processes. No changes in the organizational structure are necessary

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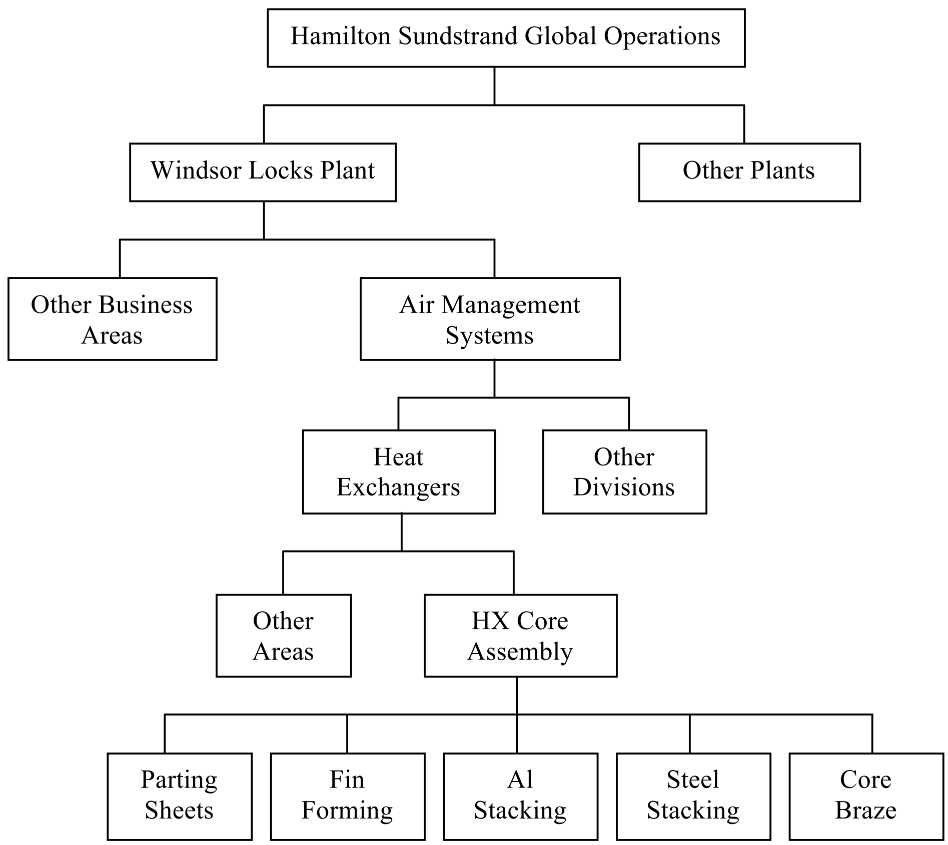
[139] Henry Ford, My Life and Work, (Garden City, New York: Doubleday, Page & Co., 1922), 41.
[140] Deborah Ancona, Thomas Malone, Peter Senge, and Wanda Orlikowski, "The Sloan Leadership Model," Draft manuscript, Sloan School of Management, 2003.

to implement the lean transformation. The Vice President of Operations, John Boyd, participated in Sundstrand's Supply Chain Initiative in the 1990's. As a result, he is fully behind lean manufacturing methods, and is overseeing lean implementation throughout the organization. Support from senior executives is crucial in such a wide-reaching program for change, and this support extends to all layers of management.

Figure 13. Organizational Structure of Heat Exchanger Core Assembly Area



The way in which jobs are designed bear influence on the project. Staffing levels for management and engineering are centrally determined by formulas that allow certain staffing for every hourly labor unit. Throughout the course of the project, salaried staff felt challenged by the additional lean implementation tasks above and beyond their regular duties. As a result, additional engineering support was generally well received.

What's more, a somewhat strained relationship between management and the labor union had existed, and cannot be changed overnight. Extreme diplomacy and patience were required.

In order to coordinate implementation efforts, cross-functional teams composed of both salaried and hourly workers tackled items in the lean transformation plan together. Sometimes a lack of volunteers from the hourly workforce slowed efforts. All employees received training in lean manufacturing. In practice, some employees chose not to attend training, and supervisors sometimes forgot to remind employees of the training. Quarterly "all-hands" meetings further contributed to coordinate lean transformation efforts.

Having discussed the strategic aspects of the project, the next section examines its political aspects. Strategy was rather straightforward in comparison to the political nature.

7.1.2 Political Aspects

A lean transformation is rife with political considerations. In the wake of layoffs in a slow economy, any further changes that could cause further reductions are very unpopular. Eliminating overtime is unpopular as well, since some workers have grown accustomed to extra pay. A lean transformation will only succeed as long as employees blame the economy for staff reductions, and not the new manufacturing method.

Coming into a new organization as an outsider has pros and cons. One advantage is that nobody feels threatened by a student present for only 6 months. Being neither labor nor management allows one to bridge the two. On the other hand, despite student status, hourly employees perceive an intern as a member of management, and not as one of them.

In order to be effective, it is important to understand the various stakeholders and their interests. Table E. Stakeholders in Lean Transformation and Their Interests below lists the most immediate priorities of the various constituent parties affected by the lean implementation.

Table E. Stakeholders in Lean Transformation and Their Interests

Stakeholders	Interests
Senior Management	maximize shareholder value
Division and Plant Management	satisfy production metrics, safety, be cost competitive
Area Supervisor	satisfy production metrics, respect, credit for improvement
Hourly Associates	job security, seniority, respect, overtime, freedom
Purchasing	low cost, high quality, ability to deliver according to pull
Engineering	meet technical specifications at lowest cost , quality
Suppliers	profits, ability to produce and deliver at required times
Facilities	operation of plant and machinery, staffing levels
Production Control	prevent stockouts
Customers	value, on-time delivery, quality
Union	job security, high number of members, union dues

Virtually all stakeholders are concerned about job security, so this interest appears only for those parties whose primary interest is keeping their job. Also, everybody is interested in having control over the way they perform their job. Everyone is suspicious of "outsiders" who wish to change the way one's job is performed.

Almost all parties favor the lean transition. It is not entirely clear whether or not suppliers supported the lean transformation. Undoubtedly some did and others did not. This is an area that deserves future attention and exploration.

The hourly workers and the union showed the most resistance outwardly against lean manufacturing methods. They were skeptical for several reasons: first of all, they feared that workforce reductions would occur as a result of the change. They perceived productivity improvements as a threat to job security. To bolster their fears, a recent article in BusinessWeek proclaimed: "Rising productivity without rising demand is a recipe for disappearing jobs."[141] Second, they perceived this initiative as management's "flavor of the month", a new program subject to the vagaries of current management that is destined to fail. On the factory floor, three prior waves of lean manufacturing have failed over the past decade. Previous initiatives lacked support of senior management, and the supply chain was not linked to the production process. Last of all, lean methods were perceived as reducing worker autonomy. Skilled workers did not appreciate the tacit implication that their work in the past has been unsatisfactory and needed improvement. For these reasons, some employees were wary of the changes and yet others dedicated themselves to hindering lean manufacturing initiatives.

In order to build support, workers are invited to join lean planning teams. By having input, they can put their own mark on the transformation, and take ownership of the new methods. Nevertheless, some hourly employees showed resistance to joining lean teams in some areas of the factory. Social pressure from their co-workers prevented some from participating. The International Association of Machinists and Aerospace saw to it that no workers would be forced to participate in any change initiatives without their consent. Some workers attempted to erect roadblocks to the process in ways such as complaining about material moved to the point of use performed by non-union personnel. Other workers refused to take part in activities that would involve them in designing their new work areas. They often did not see the connection between lean manufacturing and preservation of their jobs. On the other hand, a minority of workers embraced the changes, cooperated with management, and appreciated the new freedoms offered to them under lean methods.

Hourly workers in the Heat Exchanger Core Assembly Area became much more receptive to lean methods after explanation that the firm's considerable investment in the lean program signaled management's intention to keep jobs in the factory. A large capital investment accompanied the implementation of lean practices. Most of the employees in other areas of the factory did not arrive at the same conclusion.

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[141] Michael Mandel, Emily Thornton, Stephanie Anderson Forest, Andrew Park, Ben Elgin, Charles Haddad, "The Educated Unemployed", BusinessWeek, Sept. 30, 2002, 36.

This relationship between the union and management has historically been strained. Joint problem solving was largely unknown at the site. Lean represents an entirely new mentality and business model, one that requires time to get used to. The next section shows that cultural changes require patience.

7.1.3 Cultural Changes

> *"The biggest challenge in the factory is changing the status quo."*
>
> —Eric Rohrbacher[142]

The mechanics of a lean transformation are rather straightforward. Step-by-step roadmaps exist that detail the proper sequence of steps.[143] There is no recipe, however, for changing the culture of an organization. Cultural change is the biggest challenge an organization faces in implementing lean practices.

People tend to resist change because of the insecurity involved with the fear of the unknown. Even Taiichi Ohno and Eiji Toyoda, founders of the Toyota Production System, experienced resistance to their efforts to implement change. It took a long time to convince some workers of the merits of a new production method.[144] They found that winning people to their way of thinking could be facilitated by including elements into the Toyota Production System to encourage the acceptance of new manufacturing methods leading to cultural change:

- Give the workers valuable jobs.
- Keep communication between workers and management wide open.
- Implement a suggestion system, and react quickly to suggestions.[145]

These suggestions represent a new paradigm of doing business that Hamilton Sundstrand embraces. At its heart lies cooperation between management and labor. Perhaps the biggest cultural change of all is for labor and management to work together. An adversarial stance reaches back to an engrained conflict between labor and management, which hampered efforts at lean implementation.

The Senior Foreman of the Heat Exchanger Area outlined specific cultural changes affecting hourly workers:

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[142] Eric Rohrbacher, Hamilton Sundstrand Lean Manufacturing Facilitator, conversation on June 5, 2002.

[143] For an excellent resource, see the Lean Aerospace Initiative's following work: John Crabill, Ed Harmon, Don Meadows, Ron Milauskas, Craig Miller, Deborah Nightingale, Brian Schwartz, Tom Shields, Bob Torrani, "Production Operations Level Transition-To-Lean Roadmap", (Version 1.0, Massachusetts Institute of Technology 6/5/2000), 38.

[144] Taiichi Ohno, "The Origin of Toyota Production System and Kanban System", Proceedings of the International Conference on Productivity and Quality Improvement, Tokyo, 1982, reprinted in Applying Just In Time, ed. Yasuhiro Monden, (Atlanta: Industrial Engineering and Management Press, 1986), 3-8.

[145] Monden, Yashiro, Toyota Production System 3rd edition, (Norcross, GA: Engineering and Management Press, 1998), 185-186.

- Technician moves to the work
- Promote team ownership of cell performance by using ACE tools
- POU inventory and hand tools
- Manufacture parts based on pull, not MRP
- All new processes to be reviewed with cell to assure fit
- Incorporate MRD rules in new product and process designs[146]

These changes implied that the workers had conventionally performed their jobs in an unsatisfactory way. The average age in this area of the factory was over 50. After 20-30 years of work experience, the workers argued that no one knows their job better than they do, and that management should mind their own business. They did not recognize lean manufacturing as an investment in keeping work in the factory and retaining jobs. They felt that lean was yet another management fad, and that they were being singled out.

One area of the factory, the Fin Forming Area, was generally autonomous. The workers in that area are so talented that they succeeded in running the area for years without a supervisor who understood their jobs or knew how to operate the equipment. These individuals were particularly resistant to outsiders coming in and telling them what to do. Treating these talented experts with the respect that they deserve was the only way to gain their cooperation. They were more than willing to use their years of experience to help specify new capital equipment purchases. They appreciated small favors that had a big impact on their daily jobs, such as getting voicemail installed and the acquisition of stock reel decoilers.

To get the support of everyone in the plant, everybody's job must change, both management and labor alike.[147] A worker with decades of experience who has gathered a treasure chest of tools is not likely to willingly abandon his trophy box for POU (point of use) tools unless others make sacrifices as well.[142] Cost Engineering must drastically change their traditional techniques to evaluate standard work times for production operations. The introduction of single piece flow changes the accuracy of the existing standard work times. The people in Purchasing need to develop new ways to buy supplies just-in-time. Everybody's job is affected by the lean transformation.

Communication from Management and from the MRD team about lean changes came frequently. A weekly newsletter updated progress in lean implementation, and it featured articles from stakeholders from several different areas (quality control, purchasing, etc.). In addition, both the plant manager and the Vice President of Operations held regular "all hands" meetings to discuss the business and its changes. All layers of management spent a considerable amount of time interacting with employees to discuss the nature and impact of lean changes. Sometimes the message was framed as the ability to take on more work in the factory, which was a tough sell in the down economy.

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[146] Gary Keene, "Design Review Heat Exchanger Business", United Technologies Corp. Hamilton Sundstrand Presentation, May 21, 2002.
[147] Richard Schonberger, World Class Manufacturing, (New York: The Free Press, 1986), 18.

Despite frequent communication, some workers still felt left in the dark. They had no idea whether they were able to meet their schedule, or what parts they would be making next. They felt powerless as a result of not knowing what changes to expect, and they often feel excluded which can breed resentment. Whenever possible, I searched for valid concerns amidst sometimes hostile behavior, and attempted to address them. A deep-seated adversarial relationship between labor and management does not change overnight.

Despite the fact that lean manufacturing techniques will make the factory more competitive in the marketplace and thereby increase job security, some workers were not interested in helping. A few individuals thwarted efforts by refusing to cooperate, forgetting to come to meetings, and by claiming that lean methods won't work in their area of the factory. A strong personality can severely disrupt the change process. Often these individuals are ex-foremen who got downsized into a fabrication role during a round of layoffs. They are natural leaders, and they choose to use their leadership skills to oppose lean implementation. One could spend half one's time trying to win them over to no avail.[148] An effective response would be to transfer or remove naysayers, but in the case of hourly workers, the union regulations did not always render this option possible.

To deal with resistance and skepticism on the factory floor, one effective response was adopting the indifferent attitude that their jobs can very well move overseas and it won't matter to me. This reaction generally evoked an increased level of cooperation. Another tactic would have been to simply hire new people to work in the newly designed manufacturing cells because new employees are more open to change, but the union's seniority rules prevent new blood from entering the factory. Yet another strategy to increase the acceptance of changes is to have workers participate in the lean efforts in their area. For example, instead of having inventory and tooling moved to the point of use by someone else, they should do it themselves and have a say about how their workspace is arranged.

Resistance does not always stem from hourly employees. One supervisor did not actively resist lean change, but he was always too busy to allocate workers to help with the lean implementation. He feared changes in the area might have upset his workers and decreased his power. Eventually he was removed from his position. In another case, a mid-level manager found it easier to stall efforts than to help with a proposed lean change. It took several weeks of meetings and going over his head to achieve cooperation.

Creating a feeling of shared responsibility and employee empowerment is a difficult task since it reflects a new culture within the organization. Changing a culture takes a long time—often years—to achieve a desired effect, if the change ever happens at all. The lean implementation represents a huge investment in the factory, and that it shows management's desire to keep jobs there. I urged the workers in the Heat Exchanger Core Assembly Area to support all lean efforts after the internship.

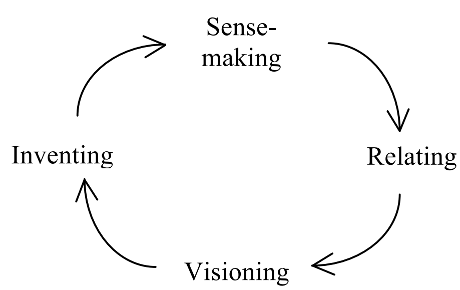
[148] Gary Keene, Hamilton Sundstrand Windsor Locks Senior Supervisor, conversation on Dec. 12, 2002

The next section examines the dynamics of change from the point of view of a leadership model developed at the MIT Sloan School of Management.

7.2 Leading the Change Process: The Sloan Leadership Model

The Sloan Leadership Model is a four-step recipe for catalyzing action. The four steps are: (1) *Sensemaking* consists of learning about the business, its climate, and challenges. (2) *Relating* involves building relationships in order to promote change. (3) *Visioning* is conceptualizing improvement and garnering support. (4) The last step, *inventing*, entails implementing change and innovation. Figure 14 illustrates the Sloan Leadership Model.[140]

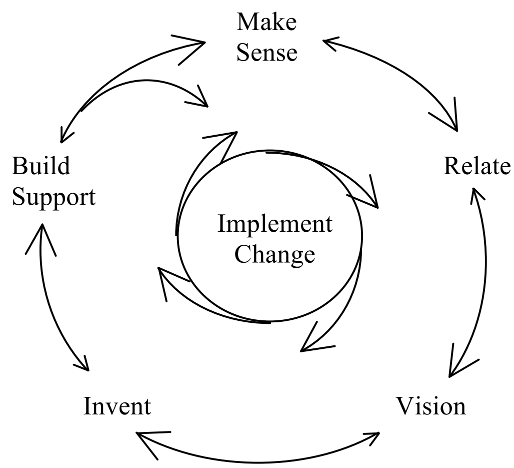
Figure 14. The Sloan Leadership Model



The Sloan Leadership Model is not a specific course of behavior guaranteed to ensure success. Rather, this model is a framework in which change tends to occur. The Sloan Leadership Model is a very powerful model, spanning change in all disciplines.

In terms of this project, inventing new lean methods was not enough to ensure a successful outcome. Rather, the most difficult task is building support for the change and then implementing it. For example, after developing an optimization method for lot sizing, it took 10 weeks to gain acceptance for this method and even longer (several months) for implementation. The Sloan Leadership Model pays short shrift to the importance and difficulty of garnering support and implementing change. For these reasons, a modified version of the model appears below in Figure 15. This new model includes *build support* as a part of the change process. At the heart of the modified leadership model is "*implement change*", which takes place after at least one cycle through the model. For successful change to occur, the invention/change must *make sense*, and people must *relate* to the change as well as the change agent. The change must align with the *vision*, and one must *build support* for it since one is likely to encounter resistance to the proposed change. Finally, during *implementation*, there will be opportunities to refine and re-*invent*. A second cycle through all of these processes can take place concurrent with the *implementation* phase, as depicted by the arrows emanating from the center.

Figure 15. The Modified Sloan Leadership Model



Additional innovative features of the Modified Sloan Leadership Model include prescriptive instead of descriptive word choices (uses action verbs instead of nouns), which promotes this method as a tool for leadership instead of a description. Furthermore, the arrows of the outer circle go in both directions, allowing one to revert to an earlier step. For example, often when *relating* to people, one finds out new information that one must process so that it *makes sense*. The favored direction evinces larger arrows. Finally, this method is iterative; over several cycles, the invention or change may improve.

The sections below describe the various steps of the Modified Sloan Leadership Model as they pertain to the work performed at HS.

7.2.1 Make Sense

My first steps on the job were to learn about the business, its culture and the challenges that it faces. From the media and from my colleagues, I quickly discovered that a lean focus was desperately needed in the Windsor Locks plant. The economic downturn made production there less competitive and more expensive than other locations. All employees feared downsizing. In particular, workers on the shop floor were skeptical of management, and especially of newcomers who have been sent to help.

7.2.2 Relate

The purpose of relating is to build relationships with others to help figure out what is wrong and what needs to be done. Upon arrival at Hamilton Sundstrand, my supervisor took me around to shake everybody's hand. Over the next few weeks, I made time to get to know everyone (management and hourly) in order to learn about their concerns and to determine what needed to be done. Doing so built allies for change.

I found it to my advantage not to advertise my background from MIT. Most workers did not have similar credentials in common, and many felt threatened by the name.

One way to relate with some operators was to advocate the acquisition of several stock reel decoilers. For years they had wanted these devices to run with their machines. Specifying these machines and bringing in representatives provided an excuse for regular contact. During this time, I also learned much about the way they ran their area, and started conceptualizing ideas for improvement. While relating, one employee told me about the need for a coordinated replenishment system, which is the topic of Chapter 5. In adjacent areas, I had better lighting installed according to the requests of operators and some signs made. Specifying the equipment was an opportunity to get to know fellow co-workers.

The first few interactions with one particular hourly operator were strained. He perceived me as someone from management coming to tell him how to run his job. Cursing was not uncommon. He obviously felt threatened by my presence. By listening carefully to concerns (complaints) to the end, by asking questions, by soliciting him for ideas, and by undertaking small projects that will directly help him at work, a marked change in behavior occurred over time. He became cooperative. He was glad to see me whenever I came by. His cooperation was earned by respecting him, his abilities, and his professional opinion

It was not until the end of the internship project that I discovered how well I had done in relating with some members. When I left, one operator complained: "You just got here and now you're leaving us."[149] He was unhappy that I would no longer be around to advocate his ideas and to carry through improvements to his area of the factory.

On the other hand, despite numerous attempts to relate to some people, my efforts failed. An adversarial attitude is engrained in some. These people were in the minority, but they delayed lean efforts.

In summary, there is no one method that works for relating in all situations to all people. Everybody is different. Nonetheless, respect for others and frequent communication are necessary ingredients in any successful recipe for relating with others.

Often while relating, information comes available that allows one to form a vision, as the next section shows.

7.2.3 Vision

In the vision phase, one conceptualizes improvement. In the case of the Fin Forming Area, the solution to the inventory problem had to be some method to optimize production of fin. Such a plan would have to evince the following characteristics:

[149] Bob Keating, Hamilton Sundstrand Fin Forming Operator, conversation on Dec. 12, 2002.

- short set-up times
- small lot sizes
- standardized fin configurations
- pull production and flow

This method would likely involve neatly organized working areas with tools and materials organized at point of use. Material would flow through the area by pull production using a kanban system. In order to make this work, some inventing needed to be done.

7.2.4 Invent

The goal of the inventing step is to create innovation. To make the Fin Forming Area more competitive, it needed a production management plan to meet the goals envisioned above. To meet these goals, I invented a scheduling and lot-sizing method to optimize production and minimize inventory in the Fin Forming Area. (Unfortunately a literature search yielded that someone else had derived this method 25 years ago. In any case, this method was new to the factory.) Doing so required the grouping of parts into part families that could share set-ups as well as sequencing production of parts in these part families. To reduce the overall set-up time, I identified new capital equipment that could be set up for production much faster than existing equipment. I then designed and made work-wait boards for pull production.

Despite my efforts, not everyone was eager to implement the coordinated replenishment and pull production immediately. I needed to spend well over two months building support.

7.2.5 Build Support

The goal of this phase is to align stakeholders to agree to implement change. The biggest hurdle to implementation of lean manufacturing principles is winning people over to new ways of doing things. Sometimes a strained labor-management relationship must be overcome. Soliciting cooperation can require much time. But an adverse stance should not unnecessarily delay the implementation of lean manufacturing. One must, however, budget significant time to convince others to cooperate. In the end, not everyone will choose to cooperate.

A detailed pro forma projection of cost savings for every proposed change proved to be a very powerful tool with management. Merely stating that a machine will save time and money is not enough to justify its purchase. Rather showing in detail the cost savings over several years worked effectively.

Cost projections had its limitations, though. For one project, I found out that the heavily positive NPV analysis was not enough in order to begin implementing change. Rather the area foreman and area manager wanted to see and discuss a detailed Gannt chart prior to implementation. Preparing this chart took less than an hour and ended weeks of stagnant progress.

Building support for a new lot-sizing technique with its innovative production sequence required several meetings with the various stakeholders in order to gain acceptance. It was necessary to actively sell changes by pointing out reduction in set-ups, lower inventory holding costs, ease of use, etc. With one particular group, it took regular meetings over a couple months to gain acceptance. These meetings provided a forum to get to know the members of that group. They had several ideas about how to implement the change, but a question about the legality of innovative cost allocation methods arose, which delayed implementation. In the end, it was necessary to gain approval from senior management to win the support of all parties.

Another way to win support is by training workers in the merits of the new. Sometimes workers would not pay attention during training, though, or their supervisor would forget to remind the workers that they have a training session.

Building support often consists of overcoming resistance. Hammer and Stanton wrote in The Reengineering Revolution that reasons for resisting change are not always rational.

> *"If you go into an organization and bring the people who work there the glad tidings that you are going to change what they do, how they do it, who they do it with, how they are measured, how they are paid, how they are organized, and even what goes on inside their heads, their response is likely to be utter panic."*[150]

If a person feels frightened, threatened, or uncertain about a change then their reaction will be negative.[151] Hammer and Stanton further outline principles of resistance to change:

Table F. Principles of Resistance to Change [152]

Expect resistance; it is natural and inevitable.
Seek resistance out, since it does not always show its face.
Understand the motivations of resistance.
Confront resistance by addressing people's concerns, not their arguments.
Resistance comes in many forms; adapt your strategy accordingly.

Since resistance is ubiquitous, one must expect it. Luckily, techniques exist to overcome resistance. Hammer and Stanton have developed the "5 I's" of overcoming resistance as shown in Table G below.

[150] Michael Hammer and Steven Stanton, The Reengineering Revolution, (New York: HarperBusiness, 1995), 122.
[151] Ibid., p 127.
[152] Ibid., p. 128.

Table G. Strategies for Overcoming Resistance: The 5 I's [153]

Incentives:	Offer both positive and negative reinforcement.
Information:	Communicate frequently to dispel fear and uncertainty.
Intervention:	Connect with people one-on-one to build support.
Indoctrination:	Convince people that change is ineluctable.
Involvement:	Co-opt people into the change initiative.

People inevitably come up with arguments about why a change initiative will not work. Some of the arguments against sweeping organizational change reappear with such frequency that Hammer and Stanton consolidated them into a list and drafted responses.

Table H. Dealing with the Arguments of Naysayers [154]

Argument	Response
It doesn't work.	Tell that to the winners.
It's nothing new.	Then you won't mind helping.
It's not enough change.	Everybody's job will change.
It's too much change.	Compared to what?
We're different.	Everyone else is different too.
We can't afford it.	We can't afford not to.
We're already doing it.	Keep up the good work.
It's another name for downsizing.	No, the premise is faulty.
It's cost cutting when we need growth.	It promotes both.
It's just common sense.	Good; thanks for your support.

Hammer and Stanton say that despite your most valiant attempts, sometimes, naysayers cannot be won over. Keeping them around doesn't do any good, and in the end you'll have to get rid of them anyway. Experience has shown the advantages of removing them sooner than later.[155]

In summary, it takes considerable salesmanship to win people over to new ways of thinking. To implement change, one must move slowly and let people get used to the idea that change is coming. Greasing wheels facilitates implementing change.

7.2.6 Implement Change

The implementation of change is at the heart of the Sloan Leadership Model. If one has dutifully performed all the requisite tasks, then the change implementation should go smoothly. If, however, not everyone is on board, then one can expect resistance. In this

[153] Ibid., p. 131.
[154] Ibid., pp. 170-182.
[155] Ibid., p. 133.

case, one must back-track and build support for the change, or even re-invent a new solution amenable to all parties.

During the implementation of change, one must continue to make sense of the situation, relate to others, share vision, (re-)invent, and above all build support. These processes happen concurrently during the implementation. The implementation of change is not a destination, but rather a path. Ways of doing things continue to change as a natural result of continuous improvement.

Having examined the change process, the next chapter explores the relationships between two primary stakeholders: labor and management.

Chapter 8: Observations on Labor Relations

> *"A strike which brings higher wages or shorter hours and passes on the burden to the community is really unsuccessful. It only makes the industry less able to serve—and decreases the number of jobs that it can support. This is not to say that no strike is justified."* —Henry Ford[156]

Cooperation between management and the labor union is critical in order to effect organizational change. This chapter examines the historical aspects of this relationship and provides examples of labor relations at other firms.

The International Association of Machinists and Aerospace Workers has a long-standing tradition of representing hourly workers at Hamilton Sundstrand's Windsor Locks plant. In the past, the strong union at HS has worked hard to negotiate on behalf of the hourly workforce for the best possible working conditions, wages, benefits, and hiring/reduction practices. The union presence has greatly benefited the workforce. For over a decade, the hourly workforce has been in decline. In summer 2002, the bargaining pool consisted of 1,050 hourly workers at the Windsor Locks site, which is down from 4,000 in the union bargaining unit in 1990. Although in decline, the union still boasts a strong presence. This chapter conveys the results of a discussion with the Manager of Labor Relations at HS and first-hand observations from the factory floor.

A career spanning over 30 years has taught Tom Cryer, Manager of Labor Relations, the secrets to successful labor relations:

1. Respect your hourly people.
2. Communicate—keep everybody informed.
3. Show integrity; it's the working capital in labor relations.

In the on-going struggle for power between labor and management, Cryer sees the union as having a disadvantage. After all, the current labor pool is only 25% of what it was a decade ago. Producing in Windsor Locks, CT has become expensive over the past decade, and most hourly jobs have already left this location.

Cryer harbored concerns about the union's practice of seniority. Due to union seniority policies, no workers are being developed to replace the currently aging workforce. As a result, when the current workforce retires in 10-20 years, work requiring a high level of skill may get transferred out of the Windsor Locks plant. Seniority may be the heart of the union, but this practice is slowly putting the union out of business, and gradually restricting competitiveness. Cryer said: "Competitiveness saves jobs, not seniority."[157]

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[156] Henry Ford, My Life and Work, (Garden City, New York: Doubleday, Page & Co., 1922), 259.
[157] Tom Cryer, Manager of Labor Relations, conversation on Aug. 1, 2002.

The seniority policy introduces inefficiency to the production process. The retraining of workers in new jobs after a layoff requires time for an operator to learn a new job. In the Fin Forming Area, 6 months are required to develop an adequate skill level working on the machines. Bob Keating, the most senior individual in the area with 35 years of experience at HS, revealed that he's trained over 10 guys in recent years who have all been laid off.[158] In an effort to minimize waste in training of personnel, management should consider giving senior hourly workers the jobs involving core competencies.

Specialized job descriptions expose the company to risk, especially with an aging workforce. For example, if one highly skilled individual gets a heart attack and is out for 6 weeks, then some shipments may incur delay.

Unions have become so powerful that they are pricing themselves out of the manufacturing market, oddly enough. High domestic wages make foreign factories with lower wages attractive. Workers with over 20 years of seniority do not perceive how wage and benefit levels at HS compare with competitors domestically and abroad. Although labor costs are relatively high in Connecticut in comparison to other regions of the country and the world, the Windsor Locks site will likely always remain open despite high labor costs because this site houses the HS world headquarters.

As an incentive to participate in lean manufacturing activities, it would be advantageous for management to be able to provide status or higher wages or increased job security to workers who participate in lean efforts. In that way the goals of the companies and workers could be aligned. Unfortunately, none of these incentives appeared to be an immediate option. As a result, the lean-related groundwork that must be performed by hourly workers relies on their voluntary cooperation, and participation levels were not high in all areas of the factory.

Workforce reductions due to the downturn in the aerospace industry threaten the success of the lean manufacturing effort underway at HS. If the hourly workforce equates lean manufacturing with culling the workforce, then the hourly workforce may attempt to derail lean manufacturing efforts.[159] Layoffs generate tensions within the remaining ranks if workers perceive them as unjustified, unfair, or inhumane (without severance), making it difficult to win employee commitment for widespread changes that improve operations.[160]

Yashiro Monden wrote: "It is quite obvious that the Toyota Production System cannot be implemented in a company or organization where a labor union opposes productivity increases."[161] The International Association of Machinists and Aerospace Workers

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[158] Bob Keating, Hourly Associate in Fin Forming Area, conversation on Oct. 8, 2002.
[159] James P. Womack and Daniel T. Jones, Lean Thinking, (New York: Simon & Schuster, 1996), 258.
[160] Earll Murman, Thomas Allen, Kirkor Bozdogan, Joel Cutcher-Gershenfeld, Hugh McManus, Deborah Nightingale, Eric Rebentisch, Tom Shields, Fred Stahl, Myles Walton, Joyce Warmkessel, Stanley Weiss, and Sheila Widnall, Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative, (New York: Palgrave, 2002), 67.
[161] Monden, Yashiro, Toyota Production System 3rd edition, (Norcross, GA: Engineering and Management Press, 1998), 53.

(IAM) recognizes the inherent conflict between lean procedures and the interests of the union. After all, the goal of the union is to create and preserve high-paying jobs. The union has addressed lean by developing the "high performance work organization" (HPWO) at Boeing Co. The union partners with management to develop a HPWO in exchange for a guarantee of continued investment in an operation for three to five years. This framework allows for the implementation of many lean principles and practices, but is not yet in practice at the HS Windsor Locks plant.[162]

Don Kennedy, Director of the International Association of Machinists' HPWO Department gave a talk at a conference entitled "Enhancing the Effectiveness of Our National Workforce," held in Washington, D.C. on January 19-20, 2000. The Lean Aerospace Initiative co-sponsored this conference, and members of the LAI Transition to Lean Team summarize the points made by Mr. Kennedy in "Transitioning to a Lean Enterprise: A Guide for Leaders Executive Overview". The principles of a HPWO lay the foundation for win-win working agreements between labor and management. They are quoted below.

HPWO Principles and Processes

- "Underlying the High Performance Work Organization (HPWO) model developed by the IAM is a commitment to an overall workplace change strategy centered on:
    - Grow the business
    - Cost the activities (activity-based costing)
    - Improve the work
- We now have a global marketplace — different than we've ever faced before. In this context, "it is a never-ending change process. To be effective, we have to have a process and an approach."
- The necessary components for an HPWO include:
    - Full partnership
    - Shared decision-making
    - Continuous learning and skill-building. Every employee is a knowledge worker.
    - Technology integration — labor and management identify the technology needed and the strategy needed.
    - Co-determine the definition of quality
    - Share technical and financial information. Make information available to a far greater extent than we did before.
    - Joint determination of costs — traditional costing system doesn't give us good information about the way people do work. ABC gives more accurate information, and powerful non-financial information as well.
    - A collective bargaining agreement

[162] Earll Murman, Thomas Allen, Kirkor Bozdogan, Joel Cutcher-Gershenfeld, Hugh McManus, Deborah Nightingale, Eric Rebentisch, Tom Shields, Fred Stahl, Myles Walton, Joyce Warmkessel, Stanley Weiss, and Sheila Widnall, Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative, (New York: Palgrave, 2002), 113.

- Leadership (both labor and management) motivates employees to accept partnership.
- A jointly developed strategic business plan: What business are we in? How can we grow? How can we keep the good jobs here?"[163]

Mr. Kennedy further presents key factors to the success of HPWOs:

- "Compelling business reason for change to survive and grow. Communicate to all employees.
- Commitment to change by management and labor
- Labor-management role changes
- Readiness of workplace culture
- Time to accomplish the plan — long-term view and one step at a time"[164]

Ideally HS will partner with the International Association of Machinists and Aerospace Workers to adopt the above principles and to develop their own HPWO. Doing so may help them to avoid the fate of the United Steelworkers of America (USWA). Recognizing that inaction could result in the loss of the US steel industry, the USWA made historic concessions by encouraging mergers and allowing newly merged companies to dump their pension and retiree health care costs. In an industry with declining payrolls, such drastic actions were necessary to restore competitiveness.[165]

In conclusion, the relationship between management and labor represents a decisive factor in the competitiveness of operations, which helps to determine where work is performed. A cooperative relationship can be beneficial for both parties.

The next and final chapter summarizes the highlights of this thesis, presents recommendations, and relays key lessons learned.

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[163] Kirk Bozdogan, Ronald Milauskas, Joe Mize, Deborah Nightingale, Abhinav Taneja, David Tonaszuck, Transitioning to a Lean Enterprise: A Guide for Leaders Executive Overview vol. 1, Massachusetts Institute of Technology, 2000, 49-50, (accessed Mar. 31, 2003); available from http://lean.mit.edu/Products/TTL/TTL-vol1.pdf.

[164] Ibid., 50.

[165] Michael Arndt, "Salvation from the Shop Floor", BusinessWeek, Feb. 3, 2003, 100-101.

Chapter 9: Results, Recommendations and Conclusions

> *Experience has shown that meaningful change usually does not come to an organization without a crisis occurring first.*[166]

In the wake of the 9/11/01 terrorist attack on the World Trade Center, the aerospace industry finds itself amidst its largest downturn ever. The looming war with Iraq will offer no relief for the commercial aviation sector, where sales of commercial jetliners are forecast to drop by 33% in 2003. One forecast predicts "no prospect of net gains for aircraft builders and their myriad suppliers" in 2003. The Aerospace Industries Assn. foresees a 6.8% decline in total military and civilian revenues in 2003. Surplus aircraft account for 13% of the world's fleet of jetliners, the highest percentage ever, and even more are apt to get parked in the desert.[167] One might question whether or not the aerospace market is large enough to support the existing infrastructure and installed capacity.[168]

In such austere times, drastic measures that streamline operations are called for. Virtually all large manufacturing concerns in the United States have implemented lean manufacturing methods to some degree or have plans to do so. For some companies, increasing shareholder value is the driver, whereas for others, it is a response to competition and even a matter of survival. By incorporating lean manufacturing techniques, we expect to reduce inventory, improve material flow, and be more responsive to customer needs in efforts to increase competitiveness and profitability.

The following sections review the results of the internship, provide recommendations about continued work, draw conclusions and presents key lessons learned.

9.1 Results

To quantify the impact of the internship project, an NPV (net present value) analysis was performed on the projects undertaken in the Core Assembly Area. My HS supervisor and I calculated that the internship had a NPV = $558k and ROI = 744%. The largest benefit resulted from the coordinated replenishment method, which was responsible for most of the value generated during my internship. The net present value of that project alone

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[166] James G. Ling, Christina J. Houlahan, Renata A. Pomponi, J. Thomas Shields, Todd M. Stout, Stacey Cowap, "Summary of Inventory Pilot Project", Working Paper Lean 94-05, Massachusetts Institute of Technology, Dec. 1994, 39.

[167] Stanley Holmes and Stan Crock, "Defense & Aerospace: Woes Not Even War Will Ease", BusinessWeek, Jan. 13, 2003, 105-106.

[168] Earll Murman, Thomas Allen, Kirkor Bozdogan, Joel Cutcher-Gershenfeld, Hugh McManus, Deborah Nightingale, Eric Rebentisch, Tom Shields, Fred Stahl, Myles Walton, Joyce Warmkessel, Stanley Weiss, and Sheila Widnall, Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative, (New York: Palgrave, 2002), 247.

exceeds half a million dollars over 10 years, including terminal values. It will result in a one-time inventory reduction of over $100,000 as well as recurring savings of $25,000 per year in avoided set-up costs per year and over $20,000 per year in avoided holding costs in the Fin Forming Area. Coordinated replenishment is readily transferable to other areas in the factory and to other factories.

The results of the lean implementation consist of locating materials at their point of use, making work/wait boards, and training operators. Implementation throughout the Heat Exchanger Core Assembly Area was not complete at the termination of the project due to resource constraints, but the path was clear. For example, some inventory and tools were arranged at the point of use; work-wait boards were made; and high-volume items were identified and their lot sizes recalculated. Most important of all, the workers in this area were aware of the changes, how they would affect their daily tasks, and how factory competitiveness and job security would increase as a result of the lean changes.

9.2 Recommendations

Upon completion of the internship, a memo with extensive recommendations was presented to the management of Hamilton Sundstrand. This section presents highlights of that memo for each project.

Coordinated Replenishment Recommendations

- Look for opportunities elsewhere in the factory to implement coordinated replenishment.
- Monitor the implementation of joint replenishment in the Fin Forming Area closely, since it will take some time to coordinate the depletion and replenishment of stocks.

Heat Exchanger Core Assembly Area Lean Implementation Recommendations

- Begin implementation when management can pay full attention to process.
- Implement pull in two phases:
  (1) Core Complete pulls from Stacking Areas
  (2) Stacking Areas pull from Fin and P/S Areas
- Work down backlog of orders in fin forming area. More labor may be needed. If not possible, implement anyway.
- Inflate trigger levels initially and temporarily to avoid stock-outs.
- Synchronize consumption of parts in families by producing non-optimal lot sizes during first replenishment round to get all inventories in sync.
- After MRD implementation, conduct a 5S activity/kaizen event. Possible improvements include: tape floor outline of storage areas, store details in kit quantities , order racks for inventory
- Increase the engineering support staffing in the Heat Exchanger Core Assembly Area.

Recommendations for Organizational Change

- Communicate regularly with all stakeholders.
- Address the concerns of affected parties .
- Deal with headcount reductions at the start; do not fire anybody because of operational efficiency gains lest they disappear.
- Do not underestimate the necessity or time commitment to build support for change. Be patient.
- Accept that not everyone will accept changes.
- Reassign and/or remove naysayers.
- Tie compensation to performance.
- Forge a High Performance Work Organization agreement between management and the union.

Implementing change is a complex and lengthy process. The next section presents conclusions.

9.3 Conclusions and Key Lessons Learned

This section presents a list of key results as well as a discussion of the future of manufacturing in the US. On a very high level, the key lessons learned are:

- Altering culture and implementing change are the largest challenges an organization faces. Determining what to do is easy; getting people to go along is hard. Any change initiative requires the support of top management. Step-by-step plans to change organizations exist, but they do not provide clear direction for changes in culture.
- A lean transformation can have very positive results on the way a business is run, but patience is required.
- The transformation from a manufacturing to a service economy is a natural part of economic evolution. Manufacturing in the United States has become expensive in relation to other markets. The high costs of doing business domestically do not mean that jobs will migrate overseas.
- Lean transformation is often a better alternative to shipping work overseas.

The largest challenge in introducing change into an organization is getting people to go along with new ways of doing things. Implementing change consumes time beyond which initial forecasts suggest.

The recent downturn in economy has forced managers not only in the aviation industry but also in the entire manufacturing sector to find innovative ways to cut costs. The industry trend is for manufacturing concerns to move overseas and/or South of the Border in a search for high productivity at lower costs. Labor rates are but one factor to keep in mind when making the decision to transfer production overseas. Productivity, political risk, and movements of nominal exchange rates all demand consideration. A prime example in the current news is the layoff of 30,000 workers at Boeing Co. in August, 2002. When the economy picks up again, Boeing will not hire these workers but rather will shift production overseas.[169] Note that job migration abroad might eventually occur anyway even if the economy were booming if union seniority policies prevent firms from training the next generation of skilled workers to take over current positions.

Some industries are likely to always remain in the US. These industries predominantly belong to one of the following categories:

1. strategically important (defense industry)
2. craft/specialty/luxury products for which customers are willing to pay a premium
3. products that are significantly cheaper to manufacture close to the customer
4. high skill or technical expertise required
5. low labor content or highly automated

With the implementation of lean techniques, traditional manufacturing industries become more competitive, encouraging more jobs to stay in the US. In any case, manufacturing is tending towards globalization, and future managers would be wise to verse themselves in both lean techniques and in global business and cultural issues, including foreign languages.

In summary, Hamilton Sundstrand's lean manufacturing efforts are helping them to compete in the global aviation industry. These efforts are effective at increasing key metrics such as cycle time, inventory levels, and quality. Affecting organizational change can be difficult and time-consuming, but the rewards justify the efforts.

[169] Stanley Holmes, "Boeing's High Speed Flight", BusinessWeek, August 12, 2002, pp. 74-75.

Disclaimer

All conclusions made in this document represent the author's personal views, and not necessarily those of the Massachusetts Institute of Technology, the Sloan School of Management, the Lean Aerospace Initiative, the Leaders For Manufacturing program, United Technologies Corporation, Hamilton Sundstrand, or of any individuals associated with these organizations. None of these entities expresses or implies any warranty or assumes any legal liability or responsibility for the accuracy, utility, or completeness of any information disclosed. The mention of commercially available products, services, trademarks, or business entities should not be interpreted as an endorsement.

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Appendix A: Electronic Mail Message from Edward Silver

-----Original Message-----
From: Edward Silver [mailto:edward.silver@haskayne.ucalgary.ca]
Sent: Monday, September 23, 2002 6:53 PM
To: jonathan.rheaume@sloan.mit.edu; David Pyke; Rein Peterson
Subject: Re: EOQ Heuristic for Joint Replenishment w/ Coordinated Order Cycle

Jonathan,

Sorry for the delay in responding. Interesting about the demise of ADL - kind of sad!

Your heuristic is intuitive and easy to understand. However, it is really a direct consequence of a special case of coordinated replenishment in Chapter 11 of the 3rd edition of our book. Specifically, if in section 11.2 one sets all of the m's to 1 (i.e. all items are replenished every family setup) and all the a's = 0 (i.e. there is only a major setup cost), then you can show analytically that the time supply result of equation 11.2 leads directly to your heuristic and the calculations are a little simpler. In other words, for the special situation where there are no extra costs for minor setups in switching from one item to another and it is decided to include all items in each replenishment, then your heuristic actually gives the optimal solution. So I guess I've provided good and bad news. If you submit your paper to a journal I believe that you should also mention what I've indicated above about your result being a direct consequence of using the logic in our book under special parameter values.

Hope this feedback helps. I wish you a successful completion of your internship and your studies.

Sincerely yours,

Edward A. Silver

Jonathan Rheaume wrote:

> Hello,
>
> I am a student working on internship. Today I am writing to you because of
> your reputation in the field of Inventory Management and Production
> Planning, and I am interested in your opinion.
>
> At my internship at Hamilton Sundstrand, I have come up with a deterministic
> method to use the EOQ equation for machines that share set-up costs
> across a whole part family. I do this by calculating the total annual part family

> demand and a composite (annual demand weighted) unit cost. Putting these
> values into the EOQ formula yields an optimal order quantity for the whole
> part family, which can be disaggregated in proportion to each parts'
> fractional annual demand. Another feature of this method is that the whole
> part family is on the same order cycle. A more extensive description is
> attached.
>
> Are you aware of anyone doing this before?
> I would be greatly interested in your thoughts and opinions. Depending how
> you respond, maybe I'll try to write a paper on this method.
>
> By the way, I also worked at Arthur D. Little. I was an RA over in their
> headquarters in Acorn Park, Cambridge, MA a few years ago. The original
> Arthur D. Little building on the Charles River is slated for demolition to
> make way for the expansion of the Sloan Business School.
>
> I really hope you will respond, as I value your opinion highly.
> Thank-you for your help,
>
> Jonathan Rheaume
>
> Jonathan Rheaume
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> UTC-Hamilton Sundstrand
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