Improving On-Time Delivery Performance
Through the Implementation of Lean Supply Chain Management
by
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Bachelor of Science in Civil Engineering, Tufts University, 1999

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

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Abstract

Instron Corporation, a manufacturer of material testing equipment in Canton, Massachusetts, has recognized a need to improve its on-time delivery performance and to reduce costs in order to meet the increasing expectations of customers and to maintain its position as market leader. Among many potential approaches, supply chain improvement has been considered one of the most promising solutions. This thesis describes the efforts of a project team led by the author to analyze the root causes of the delivery problems and examine the effectiveness of a lean approach to supply chain management to improve the competitive advantage of the company.

The project team conducted a thorough root cause analysis for the production and supply chain problems using various management tools such as personal interviews, the Language Processing (LP) method, and the Ishikawa approach. The team also performed a complete value chain analysis and identified several opportunities for improvement. These findings were then translated into a set of recommendations for inventory policy and supplier policy.

This thesis presents the concepts and methodology of a lean approach to supply chain management, assesses Instron performance using lean perspectives, and suggests a roadmap for lean transformation. While time constraints prevented a full implementation of this lean solution, current business literature shows many companies have made significant improvements in performance and profitability when implementing it.

The practical contribution of the internship project is the development of a material replenishment model that helps the company pull parts effectively from its suppliers. The implementation of this pilot model at the company's machine shop in Binghamton, New York has been expected to increase part availability and machine utilization significantly, while reducing inventory level. However, this pilot model represents only the first step in using lean supply chain management to improve the service level and reduce waste. More importantly, the thesis delivers a documented framework to achieve similar improvements for other Instron's product lines.

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1. INTRODUCTION

1.1 Introduction

In the fierce competition of today's global market, many companies are facing numerous challenges in meeting the heightened expectations of customers and maintaining a profitable operation. Inspired by the great success of Japanese manufacturers in the 80's, strategies such as lean manufacturing, just-in-time strategy, total quality management, and "kanban" have become very popular in many companies in the United States and other parts of the world. However, in the last few years, these companies have made almost all possible reductions in manufacturing costs using these approaches. Looking for further opportunities to reduce costs while still maintaining satisfactory service levels, they have discovered that effective supply chain management is the source of additional improvements.

Instron Corporation in Canton, Massachusetts is one of those companies. It recognized the need to improve its on-time delivery performance and reduce costs in order to maintain its position as market leader. Among many potential approaches, supply chain improvement was considered the most promising solution. The research supporting this thesis was conducted at Instron Corporation in 2001, from June through December, to explore the effectiveness of lean supply chain management for improving the competitive advantage of a manufacturing business.

1.2 An Overview of the Company

In 1946, two researchers from MIT, Mr. Harold Hindman and Mr. George Burr, founded Instron Corporation in response to a growing demand for their materials testing systems, which were developed from the technology of their original experimental product, a tensile tester for the textile industry. Instron quickly grew and became the world's leading manufacturer and supplier of materials testing equipment, software, and accessories[1] that are used to evaluate the mechanical properties and performance of various materials, components, and structures. Instron systems are used to test materials such as metals, plastics, composites, textiles, ceramics, rubber, biomedical products, foods, fruits, and adhesives in research laboratories and on production lines, in quality control and also in education. The company's mission is "to lead in advancing material and component testing techniques by supplying instrumentation, support services and expertise for testing products, structures and materials."[2]

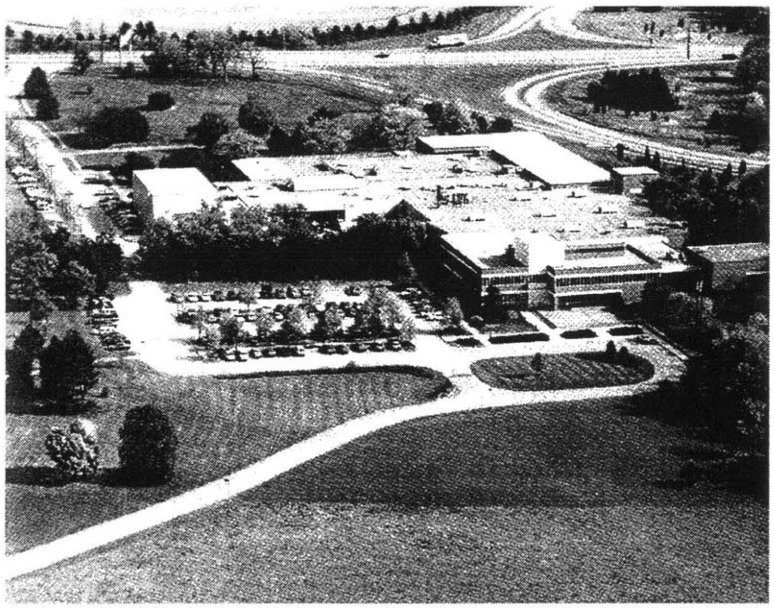

Figure 1.1. View of Instron's headquarters in Canton, MA

Instron Corporation has been a stable and profitable company with annual sales in excess of $150 million. Since 1999, it has been a private company after the retirement of its founder, Mr. Harold Hindman. Currently, Instron has sales and service offices in more than 17 countries and has over 1000 employees worldwide. Instron has two major manufacturing sites, one in Canton, Massachusetts, and one in High Wycombe, England. With more than 50 years of evolution, Instron has further expanded its product lines from the primary Electro-Mechanical

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[1] Alvarez, Maria J., "Analysis of the Accessory Business: Focus on EletroMechanical Grips," Master's Degree Thesis, MIT Leaders for Manufacturing Program, May 1999.
[2] Excerpt from Instron's Website: <http://www.instron.com/world/profile.asp>

(EM) tensile testing machines to a complete line of testing systems and support services. It has achieved this growth through both R&D and the acquisition of smaller testing equipment companies. Some of these acquisitions were direct competitors; others produced equipment that complemented Instron's core product offerings. The nature of Instron's business is that of low-volume, broad product line, and highly customer-driven configurations. These are very critical factors that must be taken into consideration for any intended analysis or implementation.

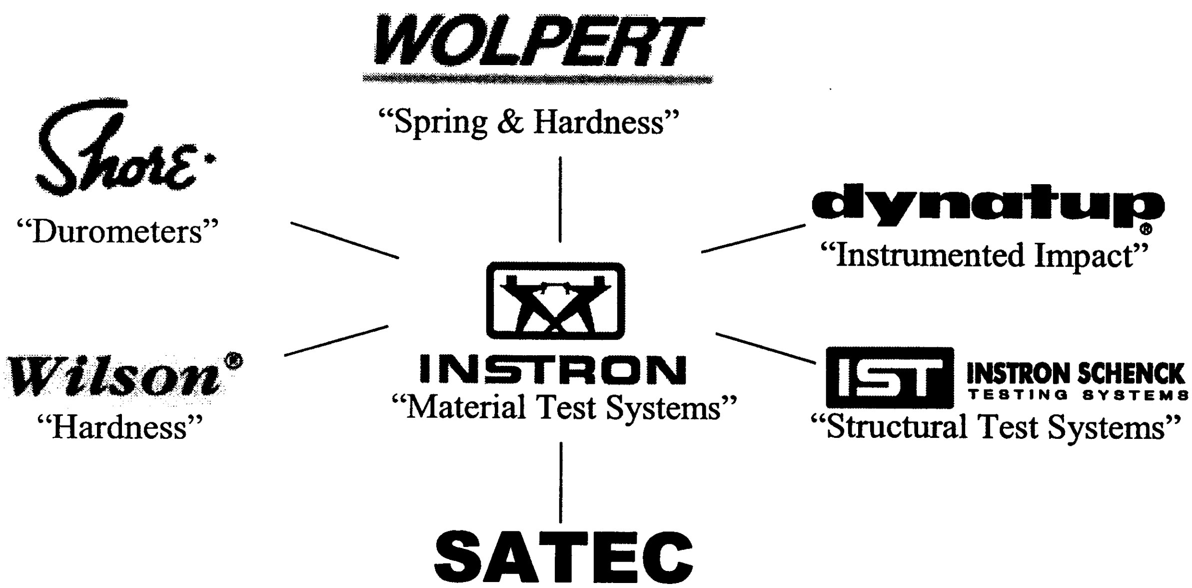

Figure 1.2. Today Instron is home for many testing systems

To maintain its competitive advantage, Instron's management has recently created Centers of Excellence[1] (COE) to improve its responsiveness to market demand. The goal of COE is to consolidate the assembly of each product family to one of Instron's worldwide locations. Hence, if a product is produced in a COE, that center is responsible for supplying the respective demand worldwide. Instron's plant in Canton, Massachusetts, has been designated as the COE for EM and Hardness testing systems, and reengineered to be able to provide quick and accurate responses to the respective product orders from all over the world.

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[1] Caterino, Garret J., "Implementation of Lean Manufacturing in a Low-Volume Production Environment," Master's Degree Thesis, MIT Leaders for Manufacturing Program, June 2001.

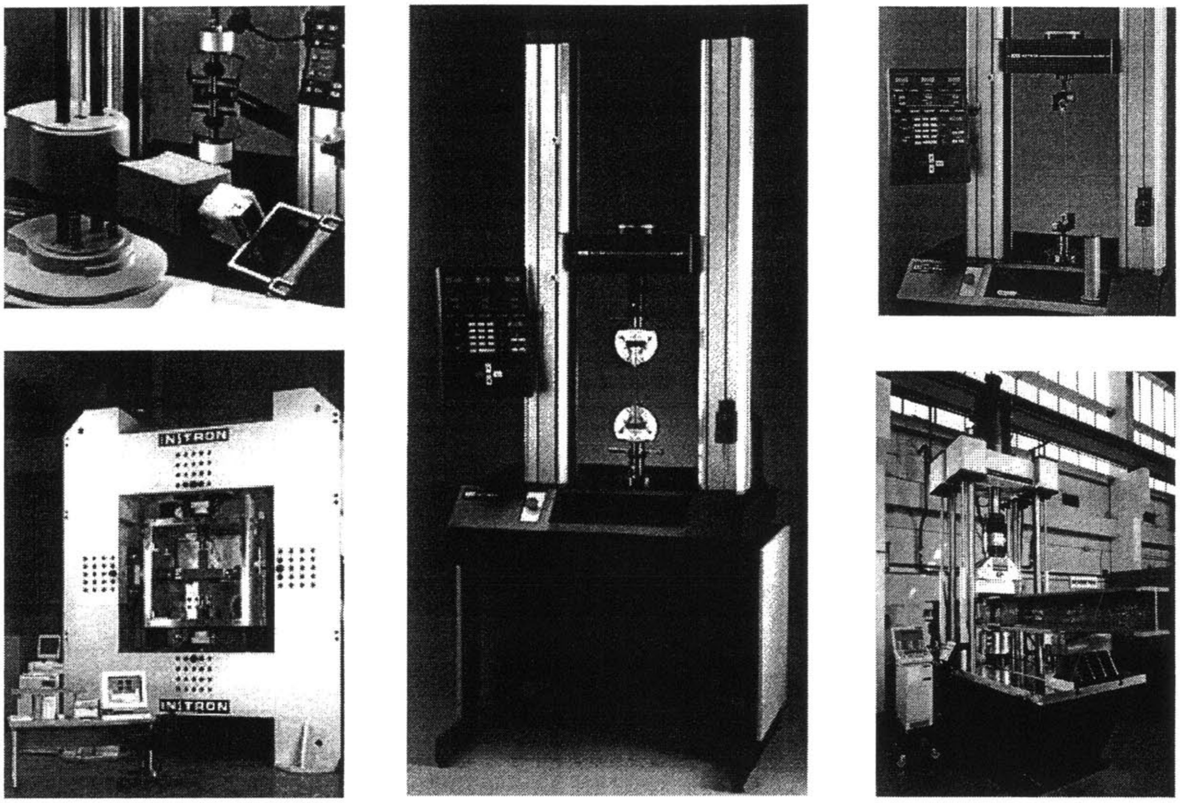

Figure 1.3. Instron's typical products

1.3 Thesis Scope and Objectives:

Instron has had difficulty in maintaining a satisfactory on-time delivery performance for years. Measured against its promised dates, the average fill rate at the EM Business Unit was just about 80 percent. Due to the emergence of fierce competition, this problem has become one of the major obstacles that the company needs to overcome to protect its leading position in the materials testing equipment market.

The internship project focused on one of Instron's core product categories: the EM frames (single-column and dual-column) that are used for tensile and compression testing. These frames form the foundation for complete testing systems, to which material gripping devices and accessories are added to create total system solutions for the material testing needs of customers.

These frames are the company's highest profit-generating items, which, with efficient and timely manufacturing output, can contribute positively to the company's revenue and profit.

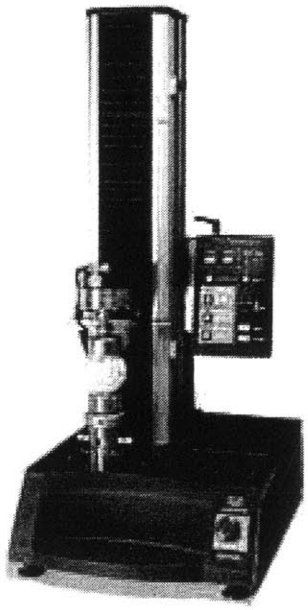

Figure 1.4. EM Single Column Model

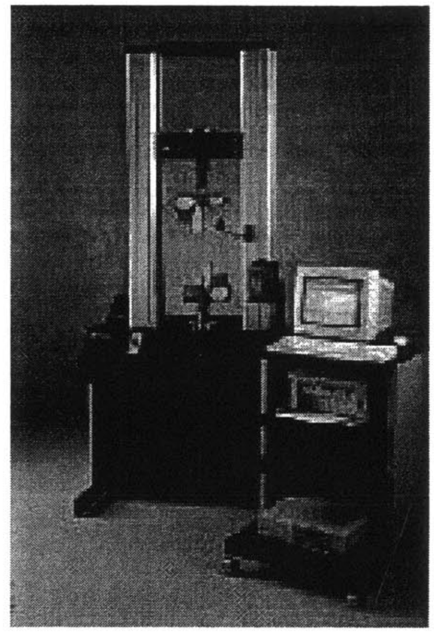

Figure 1.5. EM Double Column Model

The research project and this thesis provide an extensive root cause analysis for the problem and the development of sustainable solutions using lean supply chain approaches. The focus of the project was to develop a set of recommendations on lean supply chain strategy and a flexible material replenishment model that can help Instron work more effectively with its suppliers to improve the delivery performance of Instron's EM core products. The pilot model, which has been implemented for Instron's machine shop at Binghamton, New York, was expected to significantly eliminate the potential stock-out of parts while reducing inventory levels, which would result in better responsiveness and lower costs for final products. The application of similar implementations at most, if not all, critical suppliers was recommended.

1.4 Project Approach

The project was conducted following the procedure shown in Figure 1.6. below:

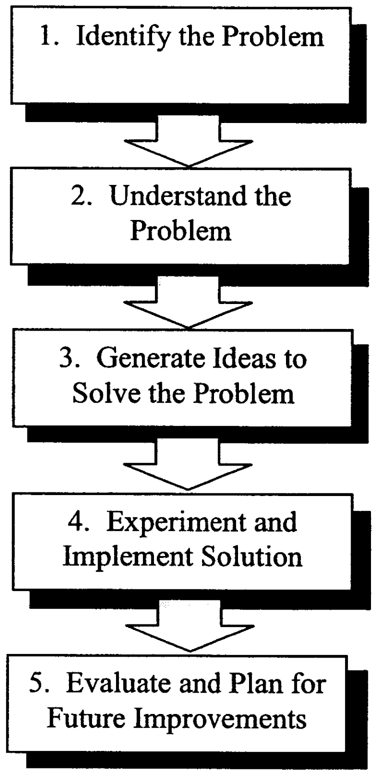

Figure 1.6. Project Approach

Many management and planning tools such as interviews, the language processing (LP) method, the Ishikawa (cause-and-effect) analysis, and process flow diagram were also used in this project in order to fully understand the investigated problem and explore most applicable solutions. A more detailed procedure is described as follows:

1. Identify the problem: Conduct the root cause analysis for current production and supply chain problems using personal interviews, language processing (LP) method, and Ishikawa analysis. Define project scope and specify detailed goals and metrics.
2. Understand the problem: Collect and analyze data. Review and evaluate the current supply chain process focusing on standardization, visibility, timeliness, and control. Identify opportunities for improvement using process flow diagram, and other tools.

3. Generate Ideas to Solve the Problem: Research supply chain models and develop strategic supply chain solutions using a lean approach.
4. Experiment and Implement Solution: Develop and implement a pilot replenishment model for supplying parts between the machine shop in Binghamton and the final assembly line in Canton through a systematic approach based on the principles of the Deming wheel: plan, do, check, act.
5. Evaluate and Plan for Future Improvements: Evaluate results, adjust model, and expand the implementation to other product lines. Make recommendations for future improvements.

1.5 Thesis Overview

The thesis consists of seven chapters and three appendices with the contents summarized as follows:

- **Chapter 1** provides an overview of the company, the thesis scope and objectives, and project approach. Instron and its products are then briefly described to familiarize readers with a basic background for better understanding discussions in following chapters.
- **Chapter 2** provides a brief knowledge review of the concepts and principles of lean thinking, supply chain management, and some related issues.
- **Chapter 3** presents the tools, processes, and results of problem identification. Various management tools are described including interviewing, the LP method, and the Ishikawa analysis. Discussions on the obtained results are also provided.
- **Chapter 4** analyzes Instron's value system that includes customers, products, and suppliers. Several recommendations are also made along with the analysis.
- **Chapter 5** outlines the process of implementing lean approach in supply chain improvements. This chapter includes the assessment of Instron operations in lean perspectives and a lean roadmap for future improvement.
- **Chapter 6** presents the development and implementation of a pilot materials replenishment model at the machine shop in Binghamton, New York. The capacity model is briefly described and the formula to calculate the reorder point and order-up-to-level quantities are also presented.

- **Chapter 7** summarizes the results of the project for both academia as well as for the company. Further recommendations are also included.
- **Appendix A** presents the detailed LP diagram.
- **Appendix B** displays the complete fishbone diagram.

All volume data in this thesis is disguised to protect Instron's competitive information.

2. KNOWLEDGE REVIEW

This chapter provides a review of some necessary knowledge that was used in the internship project, as well as in this thesis, and presents a summary of lean production systems, a brief history of lean thinking evolution, the five lean principles, and the definition of the seven wastes. The chapter then provides a brief summary of value stream management and value stream mapping tools. The rest focuses on supply chain management issues and their interactions with a manufacturing strategy.

2.1 Lean Concepts

2.1.1 Overview of Lean Production Systems

The term "lean production system" was used in the well-known books The Machine That Changed the World (Womack et al., 1990) and Lean Thinking (Womack and Jones, 1996) to describe the production approach of the Toyota Corporation, a world-class automotive manufacturer. By using the term "lean" (a term coined by the researcher John Krafcik) in "lean production systems," Womack and Jones wanted to make a clear distinction between the approach of the Toyota Production System (TPS) from that of the mass production systems of European or American companies. Many people today have to agree that TPS is an outstanding, proven production system that efficiently uses far fewer resources to produce faster, better, and more flexible products than the Western mass production systems.

The lean production system was created in Japan in response to its depleted resources after the country's surrender in World War II. The financial and economic hardship at that time did not allow Japanese automotive manufacturers to pursue the same path as Western automakers. Taiichi Ohno (1912-1990), Toyota's then-chief process engineer, patiently designed and developed a production system that most efficiently utilized its limited resources, yet fulfilled market demand with quality products. He demonstrated that "a systematic attack on waste would also provide a systemic attack on poor performance within manufacturing and supply systems."[1] Ohno's lean production system not only helped Toyota survive during that tough time, but also brought the company up to the level of one of the most respectable world-class manufacturers. Today, the Toyota lean production system has become one of the ideal production systems that numerous manufacturers have contemplated and tried to replicate.

2.1.2 The Five Lean Principles

Most simply, the core concepts of lean manufacturing are about adding value and removing waste. In the widely acclaimed book, Lean Thinking, Womack and Jones crystallized the essence of the lean revolution into the five principles fundamental to the elimination of waste:

- VALUE: Specify what does and does not create value from the customer's perspective.
- VALUE STREAM: Identify and line up all value-creating actions in the best sequence.
- FLOW: Make these value-creating actions flow without interruption, detours, backflows, waiting or scrap.
- PULL: Only make what is ordered or requested by the customer.
- PERFECTION: Strive for perfection by continuing to remove discovered wastes[2].

2.1.3 The Seven Wastes

Taiichi Ohno listed seven types of wastes that should be removed to make production systems lean:

1. OVERPRODUCTION – is the making of too much too early, or just in case, which is regarded as the most serious waste, as it disrupts the smooth flow of goods and services and reduces productivity and quality.
2. WAITING – occurs when time is not being used effectively, when goods are not moving or having value added; or when workers have to spend time waiting for available machines or parts.

[1] Taylor, David and David Brunt, Manufacturing Operations and Supply Chain Management, London, England: Thomson Learning, 2001, page 227.
[2] Ibid, page 226.

3. TRANSPORT – involves goods being moved within or outside of the factory. Movements in the factory should be minimized as non-value addition.
4. INAPPROPRIATE PROCESSING – involves when overly complex equipment or solutions, resulting in unnecessary steps, excessive transport, poor communication, or low quality products.
5. UNNECESSARY INVENTORY – ties up capital and space, increases costs, and prevents identification of problems.
6. UNNECESSARY MOTIONS – include unnecessary robotic machines' and workers' movements, which lead to low productivity and poor quality.
7. DEFECTS – affect the bottom line of the company as they are direct costs. Preventing defects by making quality products is more cost-effective than fixing or discarding defective products.

Although Ohno originally developed this work within a manufacturing context, the wastes are equally relevant across other activities in the supply chain.

2.2 Value Stream Management

2.2.1 What is the Value Stream Management?

A group of researchers in the United Kingdom defines Value Stream Management as follows: "Value Stream Management is a strategic and operational approach to the data capture, analysis, planning and implementation of effective change within the core cross-functional or cross-company processes required to achieve a truly lean enterprise."[1] This method basically applies lean principles within the value stream in a systematic approach that utilizes education, policies, and selected mapping tools to diagnose, identify, and eliminate wastes within the company or the supply chain.

[1] Taylor, David and David Brunt, Manufacturing Operations and Supply Chain Management, London, England: Thomson Learning, 2001, page 44.

2.2.2 Value Stream Mapping Tools

There are many ways to map a value stream in order to capture the process and identify the potential problems or hidden wastes. Seven such mapping tools are widely used to achieve the indicated purposes. In general, value stream managers employed from three to six mapping tools to map a value stream. In order to achieve better results, one should understand the nature of particular wastes targeted as well as the usefulness of each mapping tool before any mapping activities take place. Table 2.1. below will show readers the effectiveness of the seven mapping tools in correlation with Ohno's seven wastes.[1]

	MAPPING TOOLS						
Wastes	Process Activity Mapping	Supply Chain Response Matrix	Production Variety Funnel	Quality Filter Mapping	Demand Amplification Mapping	Decision Point Analysis	Physical Structure Mapping
Overproduction	L	M		L	M	M	
Waiting	H	H	L		M	M	
Transport	H			L			L
Inappropriate Processing	M		M			L	
Inappropriate Inventory		H	M		H	M	L
Unnecessary Motion	H	L					
Defects	L			H			
Overall Structures	L	L	M	L	H	M	H

Table 2.1. The Seven Value Stream Mapping Tools

[1] Taylor, David and David Brunt, Manufacturing Operations and Supply Chain Management, London, England: Thomson Learning, 2001, page 31.

Notes: H = High correlation and usefulness

M = Medium correlation and usefulness

L = Low correlation and usefulness

Below are brief descriptions of what these mapping tools can achieve, based on the paper "The Seven Value Stream Mapping Tools" of Peter Hines and Nick Rich[1]. More details about these tools may be found in the reference.[2]

- **Process Activity Mapping:** Process activity mapping, originated in industrial engineering, consists of five stages: study the process flow, identify waste, consider alternative arrangement for more efficient process sequence, consider changes for a better flow pattern, consider each stage for necessity and improvement. This mapping method involves simple steps such as detailing all process steps, categorizing their activity type, and recording distance moved, time taken, and number of people involved in each step. Next steps are further analyzing and improving by eliminating unnecessary activities, simplifying steps, rearranging processes that reduce waste.
- **Supply Chain Response Matrix:** This mapping approach provides a visual image of the time compression and logistics movement for a particular process. Parameters are usually mapped are critical cumulative lead time, cumulative days of inventory, and/or total process time.
- **Production Variety Funnel:** The production variety funnel provides an overview of how the company or the supply chain operates. This method helps mapper make decision on process changes to inventory reduction.
- **Quality Filter Mapping:** This tool helps to identify where quality problems (product defects, service defects, or internal scraps) are occurring, thus provide opportunity for subsequent improvement actions.
- **Demand Amplication Mapping:** This approach originates in Forrester's work on systems dynamics. It can be used to show how delay of information and materials flows affects demand variation.

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[1] Taylor, David and David Brunt, Manufacturing Operations and Supply Chain Management, London, England: Thomson Learning, 2001, page 27-43.

[2] Ibid.

- **Decision Point Analysis:** This approach helps to identify the decision points in the supply chain for push-pull decisions.
- **Physical Structure Mapping:** This new mapping tool is useful in providing an visual overview of a particular supply chain at an industry level. This approach may help to redesign supply chain structure in order to reduce waste and create value.

2.3 Supply Chain Management

Supply chain and supply chain management have become "buzzwords" in today's business environment. However, many executives and managers have different definitions of their true meaning and benefits. These unaligned perceptions have caused numerous misunderstandings and have resulted in a lack of commitment from management for supply chain improvement projects. There is an urgent need for many companies to educate executives and employees alike about the scope of supply chain management, its objectives, and the values that it can add to the company and other supply chain partners.

2.3.1 What is Supply Chain Management?

The supply chain encompasses "the set of facilities, equipment, people, and operating policies that make possible the flow of goods from acquisition of raw material through production and distribution into the hand of the customer."[1] Simply put, the supply chain involves the flow of moving things from raw materials to end-users; supply chain management is the management of the flow.

Dr. David Simchi-Levi, an MIT professor in logistics and supply chain, defines supply chain management as follows:

> Supply chain management is a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements[2].

[1] Shapiro, Roy D. and James L. Heskett, Logistics Strategy, South-Western College Publishing, Cincinnati, Ohio, 1998, page 1.
[2] Simchi-Levi, David et al., Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies, New York, NY: The McGraw-Hill, Inc., 2000, page 1.

Simchi-Levi emphasizes the utilization of a system approach, which "encompasses the firm's activities at many levels, from the strategic level through tactical to operational level," to "minimize systemwide costs"[1] while ensuring time, place, and quantity utility.

Figure 2.1. provides readers with a good overview of the supply chain flow and its components.

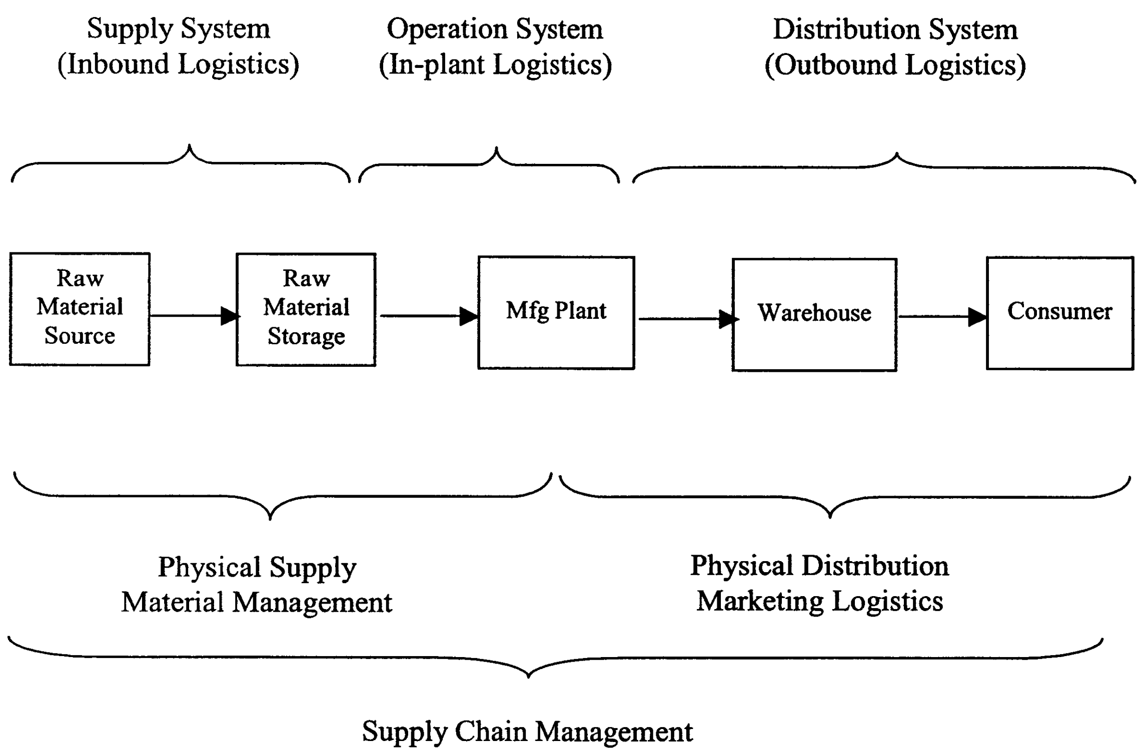

Figure 2.1. The Supply Chain System.
Source: Roy, Shapiro and James Heskett, Logistics Strategy, page 3.

2.3.2 Why Supply Chain Management?

The objective of supply chain management is to maximize the total value generated by efficiently managing flows between and among stages in a supply chain in order to optimize

[1] Simchi-Levi, David et al., Designing and Managing the Supply Chain, New York, NY: The McGraw-Hill, Inc., 2000, page 2.

customer service, to minimize the systemwide cost of supply chain operations, and to maximize the flexibility of the supply chain.

According to Roy Shapiro and James Heskett in Logistics Strategy (1998), the ultimate goal of a supply chain manager is to guarantee the availability:

- of the right product,
- in the right quantity,
- and the right condition,
- at the right place,
- at the right time,
- for the right customer,
- at the right cost.

Studies show that in the 90's, American companies spent more than $700 billion annually on supply-related activities, which unfortunately included many unnecessary expenses due to inefficient management or bad practices in the supply chain[1]. Many companies have been discovering that effective supply chain management would help them to improve their competitive advantages and profitability.

2.3.3 Flows within the Supply Chain

As I mentioned in its definition, a supply chain can be considered as a system of flows: information, material, product, and financial. The information and financial flows will move from upstream to downstream, whereas the material and product flows will go the opposite direction. The design and management of flows within the supply chain is very important, as they will dictate the failure or success of the firm. A stop or problem that occurs in any flow would definitely make other flows impossible and eventually cause havoc and damage to the firm. Figure 2.2. below gives readers an overview of the four main flows that need to be handled properly in the supply chain context.

[1] Simchi-Levi, David et al., page 5.

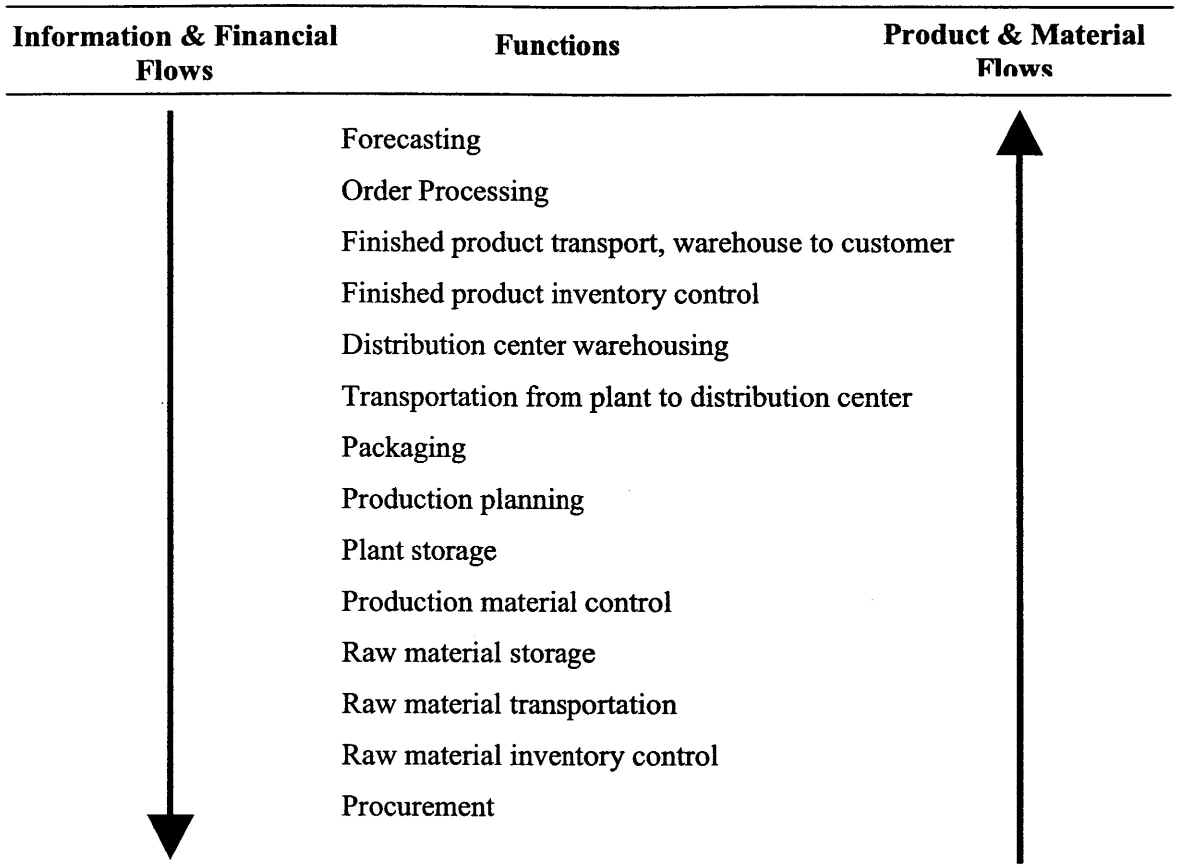

Figure 2.2. Flows within Supply Chain
Source: Roy, Shapiro and James Heskett, Logistics Strategy, page7.

2.3.4 The Supply Chain Challenges

Many companies know that effective supply chain management will significantly boost their performance, and thus increase their bottom line and market share. However, there are also many challenges in supply chain management. Below are listed the most commonly perceived ones:

1. The supply chain network is usually very complex. Supply chain partners most often have different goals and incentives; therefore, it is difficult to find the best supply chain solution for a company that can also satisfy all other partners' interests.

2. It is always a big challenge to match supply with demand, as "demand forecast is always wrong" as people say. Companies cannot avoid the risk of either investing in inventory or losing sales due to stock-outs.
3. Business parameters change over time; therefore, it is a big challenge to establish a supply chain management that can be effective and agile all the time.
4. New supply chain problems emerge every day with new products, new industries, and new customers. Without historical data or experience for all these recent parameters, it is significantly difficult for supply chain managers to predict and solve these problems effectively.[1]

2.3.5 Key Issues in Supply Chain Management

In order to develop and sustain effective supply chain systems, today's executives and managers need to think over and find suitable solutions for some key issues on the strategic, tactical, and operational levels :

- Customer Value
- Product Design
- Inventory Control
- Supply Chain Integration and Strategic Partnering
- Distribution Network Configuration
- Distribution Strategies
- Information Technology and Decision-Support Systems[2]

2.4 Manufacturing Strategy and Delivery Lead Time

Suppliers and customers may define delivery lead time differently. "From the supplier's perspective," delivery lead time is "the time from the receipt of an order to the delivery of the product. From the customer's perspective, it may also include time for the order preparation and transmittal."[3] Usually, most customers want to receive their orders in the shortest possible

[1] Simchi-Levi, David et al., Designing and Managing the Supply Chain, New York, NY: The McGraw-Hill, Inc., 2000, page 7-8.
[2] Ibid, page 9.
[3] Arnold, J. R. Tony, Introduction to Materials Management, 3rd ed., Upper Saddle River, NJ: Prentice-Hall, Inc., 1998, page 3.

delivery lead time; thus, order winners are those who design a good manufacturing strategy that can meet or exceed customers' expectations.

Figure 2.3. below shows the four basic strategies, which include engineer-to-order, make-to-order, assemble-to-order, and make-to-stock strategy, and their influence on the delivery lead time[1]:

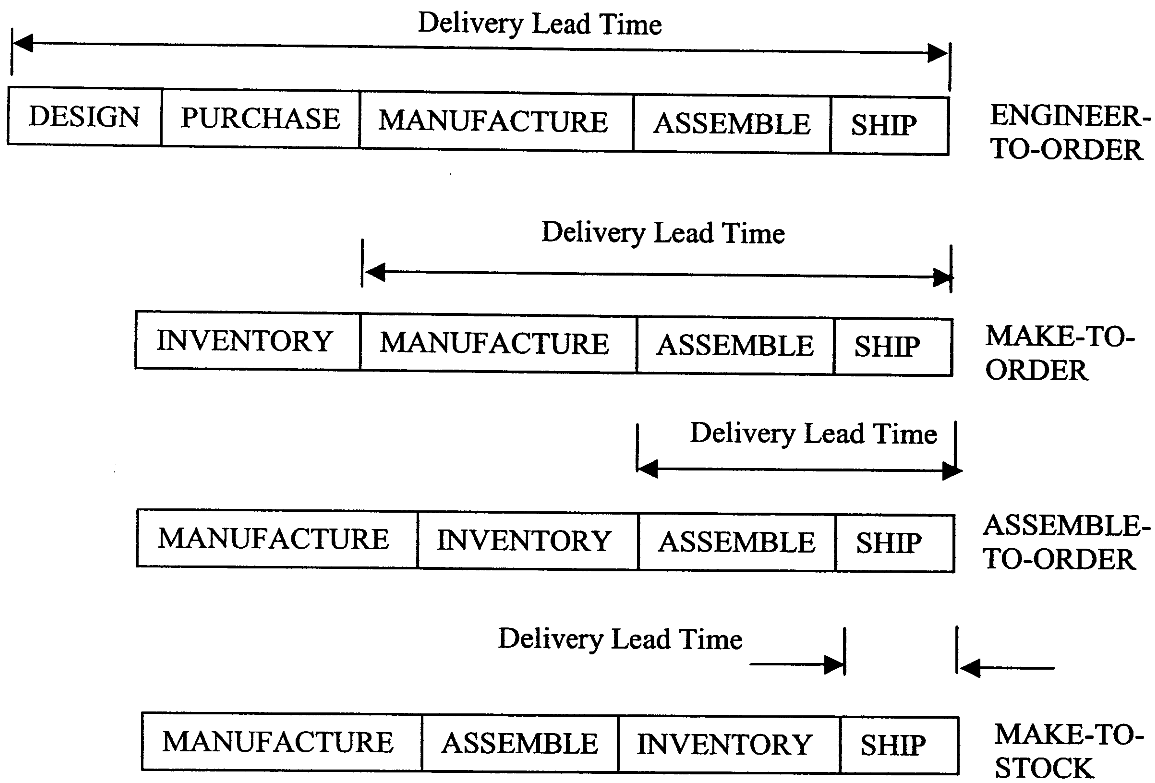

Figure 2.3. Manufacturing Strategy and Lead Time

Among these four strategies, make-to-stock has the shortest delivery lead time, but inventory levels may be high with finished goods. On the contrary, engineer-to-order has the longest delivery lead time due to time spent on unique product design, inventory long lead time, and custom manufacturing. Instron's current manufacturing strategies can be identified as engineer-to-order (commonly named as "one shot" in the company) and assemble-to-order production processes.

[1] Arnold, J. R. Tony, Introduction to Materials Management, 3rd ed., Upper Saddle River, NJ: Prentice-Hall, Inc., 1998, page 4.

2.5 Manufacturing Strategy and Inventory Policy

A chosen manufacturing strategy strongly influences the inventory policy that a company needs to pursue. Within the company, the manufacturing process (engineer-to-order, make-to-order, assemble-to-order, and make-to-stock), the assembly methods (manual or automated processes), and process metrics are critical factors for inventory policy selection decisions. Moreover, an inventory policy also has an effect beyond internal company boundaries.[1] How a company controls its inventory has a significant impact on the customer service level, vendor relationships, and supply chain systemwide cost.

As mentioned above, Instron has traditionally been an assemble-to-order manufacturer. It carries purchased parts and internally machined parts in inventory. Because demand for Instron products is cyclical, the control of inventory levels to provide adequate amounts with no excess is a dynamic issue that requires active control.

Usually, inventory turns are an important metric in inventory policy, as increasing inventory turns generate larger cash flow. However, there is always a trade-off in this incentive. Striving for higher inventory turns by keeping low inventory, managers have to ensure that the set minimum inventory level is adequate for manufacturing demand, otherwise this effort may lead to production problems. Besides, coordination with suppliers is a "must," as they have their own limitation of capacities and commitments that they need to adjust to comply with demand changes. Problems usually arise when the desired metric is not well aligned with other company metrics nor with the cyclical nature of the inventory demands. Consequently, materials or parts do not come as desired. Then, material stock-outs occur since the safety stock may be inadequate to cover a longer lead time, forcing panic orders, costly actions, and resultant chaos. These stock-outs then lead to missed shipments and lost revenues.

[1] Caterino, Garret J., "Implementation of Lean Manufacturing in a Low-Volume Production Environment," Master's Degree Thesis, MIT Leaders for Manufacturing Program, June 2001.

3. IDENTIFY THE PROBLEM

My internship project began with a focused effort to identify the core problem for EM supply chain management. This chapter summarizes the actions taken to unveil the root cause of the investigated delivery performance problem for Instron's Electro-Mechanical Business Units. The project team used various managing and planning tools to uncover this underlying issue. The findings of these analyses are included and discussed in this chapter.

3.1 Personal Interviews

When I started the project at Instron in June, 2001, I conducted a 360-degree interview[1] to familiarize myself with the organization and also obtain some initial information on the delivery problem in the Electro-Mechanical Business Unit. I believed that this would be the fastest way to capture the essence of the problem by mapping and finding the similarities in the perceptions of different people or departments on the same issue. I conducted numerous interviews with executives and managers responsible for sales, quality, procurement, manufacturing, marketing, forecasting, machine shop, and planning. In addition, I interviewed engineers, technicians, workers, and team leaders working in various functions of the EM business unit, such as assembly, stock room, packing, and testing units.

While the comapny met its financial goal in 2000, there were a few negative themes that emerged from the interviews. The first theme was the concern about the repeated capacity gap created by the "hockey stick" phenomenon that was driven by the financial policies of the company. Business unit performance has been measured based on the achievement of the quarterly financial target. Thus, toward the end of every quarter or year, every business unit tries to surpass the financial goal. However, due to the difficulty in adjusting planned capacity and long lead times of supplied parts, which are usually weeks or months, the manufacturing business unit has had a difficult time keeping up with the quarter-end or year-end demand generated by the sales department.

Another theme was the efficiency of the current supply chain management at Instron. Some managers brought up concerns about the obsolescence and rigidity of some management policies and procedures that no longer matched the current conditions of the constantly changing market demand. A manager pointed out, "Lot sizing was defined several years ago in a different market and needs to be reviewed and adjusted for today's sales forecasts." Another manager commented, "Improper lot sizes and reorder points lead to stock out conditions," and "Reorder points do not incorporate proper supplier lead times." Another manager added, "We have low inventory turns. Another aspect of the inventory problem is the mismatch between inventory and demand." Therefore, these managers thought that the company must quickly review, evaluate, and improve the current supply chain management in order to better respond to market demand.

Coordination across business units or sites was also a problem. "We have a bad reputation for lacking urgency.The problem is particularly acute when needing to operate cross-site," another manager admitted. "We lack consistency of process across business units, especially when dealing with internal and external suppliers," a manager observed. An aligned vision and commitment were critical across business units, as the unbalanced effort might jeopardize the expected outcomes. More commitment, responsibility, and discipline were considered as important aspects of the solution.

The last major theme was the need for attention and support from the executives. A manager said, "When we make on-time delivery a top priority, we always see an improvement. Once we begin paying less attention to it, performance always drops." With limits on financial and supervisory resources, managers have been too busy to manage every necessary aspect of the production and supply chain. They had to pick the "first things first" approach, which was what the "boss" chose to focus on at the moment.

In addition, the recent restructuring created organizational changes in which people did not know whom to address for help with problems. Workers and staff had to wait long hours

[1] What I imply by a "360-dergree interview" is that I interviewed not only the department directly involved in the investigated problem, but also other departments in the company to get their opinions or comments on the same issue. This method usually provides a more complete picture of the problem and reduces subjectivity.

before emerging needs were satisfied, which consequently caused chains of delay and jeopardized delivery performance. Also, a manager mentioned that there were some "material shortages due to quality issues...or due to unexpected incoming order product mix."

3.2 The Language Processing® (LP™) Method

To obtain some initial insight into the key variables of this investigation, I chose to use the Language Processing® (LP™) Method. The LP method is best known as a powerful tool for analyzing a complex situation.[1] Professor Shoji Shiba has been teaching this method in his Total Quality Management (15. 766) and Breakthrough Management (15.097) courses at the MIT Sloan School of Management for many years.

Following the method, I conducted this analysis with my project team, a cross-functional team of six people, which was formed to ensure that the project would achieve targeted objectives and benefit the company. I served as a team facilitator, while the other members came from different business units in the company, such as planning, manufacturing, purchasing, quality, and machine shop. Based on the ideas that I filtered from the 360-degree interviews, the theme was posed as a question: "What were the most critical factors that have prevented the company from achieving 95 percent of on-time delivery performance for Electro-Mechanical products?" I then asked all the team members to provide at least five of the most relevant and concise answers when responding to the question. With the received feedback from the project team members and verbatim quotes related to the theme selected from the 360-degree interviews, I conducted the analysis process by going step-by-step through the 19 steps of the LP method. First, I wrote all quotes on index cards, then "scrubbed" them (i.e., the quotes were semantically reviewed, edited, and rewritten until their meanings were clear symbolic facts). Next, I grouped them in first-level groups of two or three quotes based on similar "images"[2] and created a new headtitle that summarized the meaning content of each group. I then iterated the process to form second-level and third-level groups until there were five or fewer groups that represented the most important factors of the analyzed problem. After that, I ranked these groups based on the

[1] Shiba, Shoji and David Walden, Four Practical Revolutions in management. Cambridge, MA: Center for Quality Management, 2001, page 215-219.

[2] Grouping fact based on similar "image" is one of the most interesting and unique features of the LP method. Participant intuitively creates a mental image for each card conveying the the essence of the meaning rather than from the words themselves. Then, they group two or three cards that have similar image.

level of importance of those factors to the theme. I then constructed the concluding statement based on the resulting final diagram.[1]

See Appendix C for the complete LP diagram. A simplified version is presented below to show the outcome. There were four main factors identified: "Management's Limits," "Work Condition Issues," "Financial Drive," and "Material Handling Issues." Contrary to the common perception in the company, the "Material Handling Issues" are not viewed as the root cause for the late delivery performance, but they are viewed as the effect of the other three factors. Every factor was the effect of some related reasons which are also included in the diagram. For example, the "Managenent's Limits" factor represented the group of "Process Inconsistency," "Insufficient Executive Attention," "Limited Resources," and so on.

The concluding statement did not result in a desirable finding, but it at least pointed out where the true problems were. It states: "The current financial policies and management resource limits have worsened the work conditions and material handling issues, eventually driving down the EM on-time delivery performance." The key reflection from this conclusion is that a sustainable improvement in delivery performance can hardly be made without a well-suited financial policy and more focused management.

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[1] Shiba, Shoji, The Language Processing Method, Document ML0060, Cambridge, MA: Center for Quality of Management, 1997.

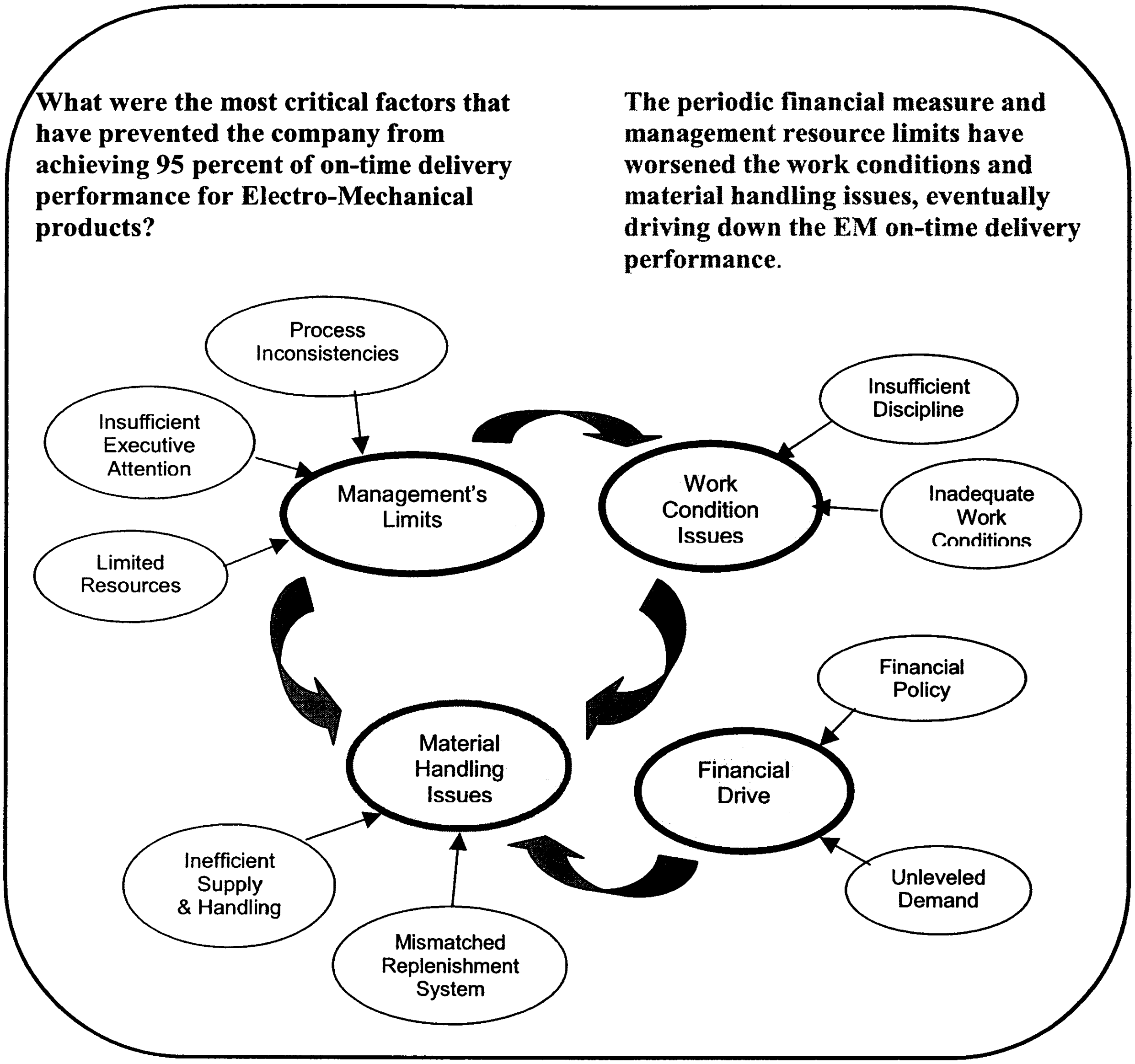

Figure 3.1. LP View of EM Late Delivery Problem

3.3 Ishikawa Analysis (Cause-and-Effect or Fishbone Diagram)

To explore all possible causes related to the investigated problem, I decided to conduct a cause-and-effect analysis based on the method introduced by Dr. Ishikawa a couple years ago. It is a highly visual technique which assists the process of defining the elements of a problem or event.[1] The benefits of this method are that it can help to focus the team on causes, not symptoms, and graphically display a snapshot of the collective knowledge and consensus of the team around the problem. Without such a diagram, it would be very difficult to know how well or poorly the team considered the possible causes of the problem. Five main categories were selected to form the structure of the fishbone: Work Force (Man), Equipment (Machine), Process (Method), Materials (Material), and Product Development. The next step was to uncover all the potential causes by answering "5 Whys" down five levels as shown in the example below:[2]

	Why	Answer
1st level:	Why late?	Process
2nd level:	Why process?	A
3rd level:	Why A?	B
4th level:	Why B?	C
5th level:	Why C?	D

The thoroughness of the analysis can be diagnosed by seeing how many levels of branches there are. A fishbone diagram with only one or two levels of branches might be considered a superficial analysis. The complete fishbone diagram for this analysis is included in Appendix C. However, for the reader's convenience, a simplified version of the fishbone is presented below to show major potential sources of the delivery problem.

[1] Wilson, Paul F. et al., Root Cause Analysis: A Tool for Total Quality Managemnent. Milwaukee, WI: ASQ Quality Press, 1993, page 195.
[2] Shiba, Shoji and David Walden, Four Practical Revolutions in management. Cambridge, MA: Center for Quality Management, 2001, page 158.

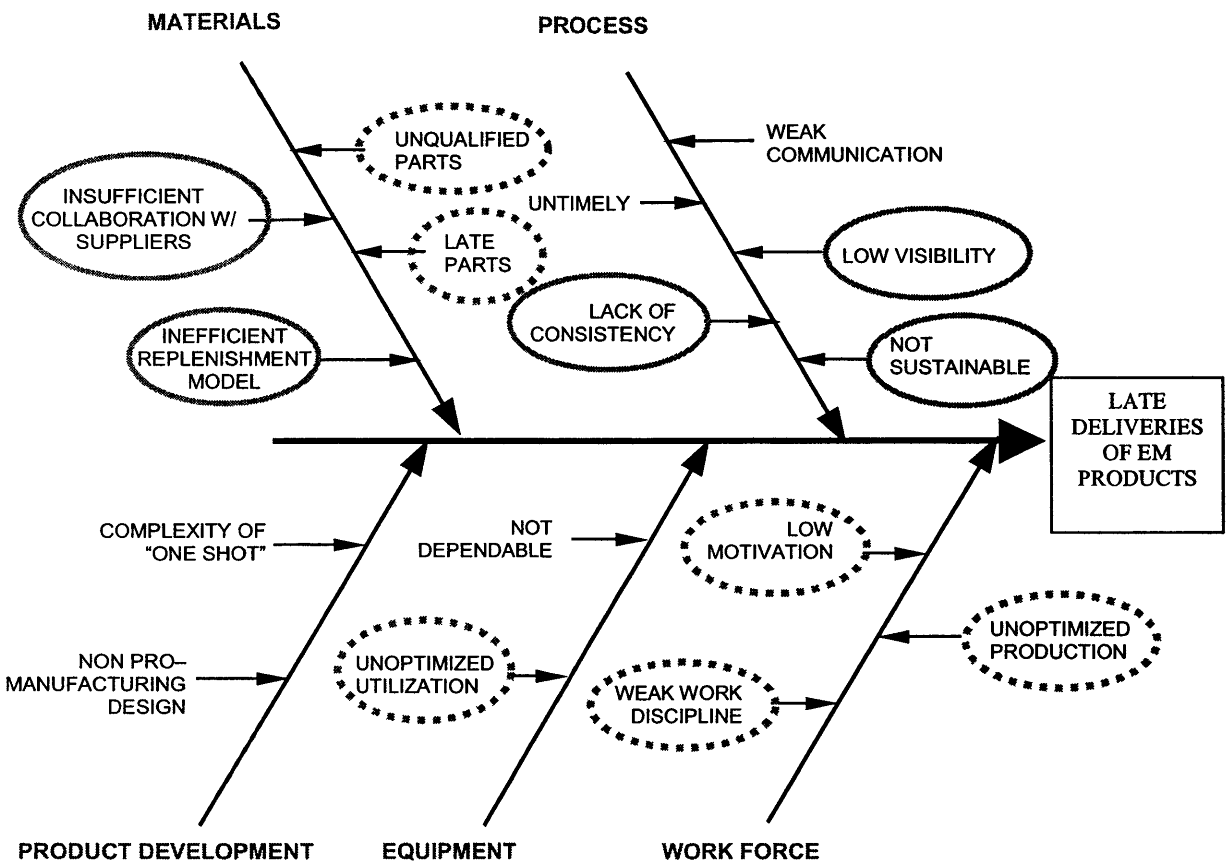

Figure 3.2. Fishbone Diagram of Late Delivery Problem

Due to the time constraints of the internship, the project team foresaw that it could not explore all potential causes but must focus on a few critical ones. The factors circled by a solid line were the areas that the team would like to investigate. The causes circled by a dotted line would be reviewed and improved by the managers who are in charge in those areas.

4. THE VALUE SYSTEM ANALYSIS

This chapter describes the analysis of the value system of the Instron Electro-Mechanical Business Unit to help readers understand the current state of demand, products, and supply forces related to the operation of this business unit. The analysis examines all the core activities of the company in the relationship with a larger stream of activities of buyers, suppliers, or distributors. It helps to bring to the surface strengths and weaknesses in the current supply chain management of the company, which would serve as opportunities for improvements. This chapter also includes recommendations and guidelines for Instron's inventory and supplier policies.

4.1. Overview of Instron EM Supply Chain Model

Conceptually, Instron has pursued a simple, direct, and powerful build-to-order supply chain model since the company was founded. Instron does not have a retailer, wholesaler, or a distributor in its supply chain. It fills customer orders directly. Instron receives customer orders through its own sales force and recently via the Internet, buys materials, manufactures, and ships products to customers.

Figure 4.1. below shows a diagram of the Instron Elctro-Mechanical supply chain. The whole supply chain includes only three phases: customer, manufacturer, and supplier. The retailer and distributor phases are taken out of the supply chain. The Instron's sales and marketing department is the company's contact point with customers. It performs all processes included in the typical customer order cycle with customers and those of the replenishment cycle with the manufacturing business unit. Therefore, the sales and marketing representatives, who generate customer orders and control the information and finance in-flows, have a very important role in Instron's supply chain management. The engineering department provides design and technical support for manufacturing and engineering services for customers. Instron has a

captive machine shop in Binghamton, New York. This machine shop plays the role of an internal supplier. It makes and supplies the majority of needed machined parts and some other accessories to the Canton plant.

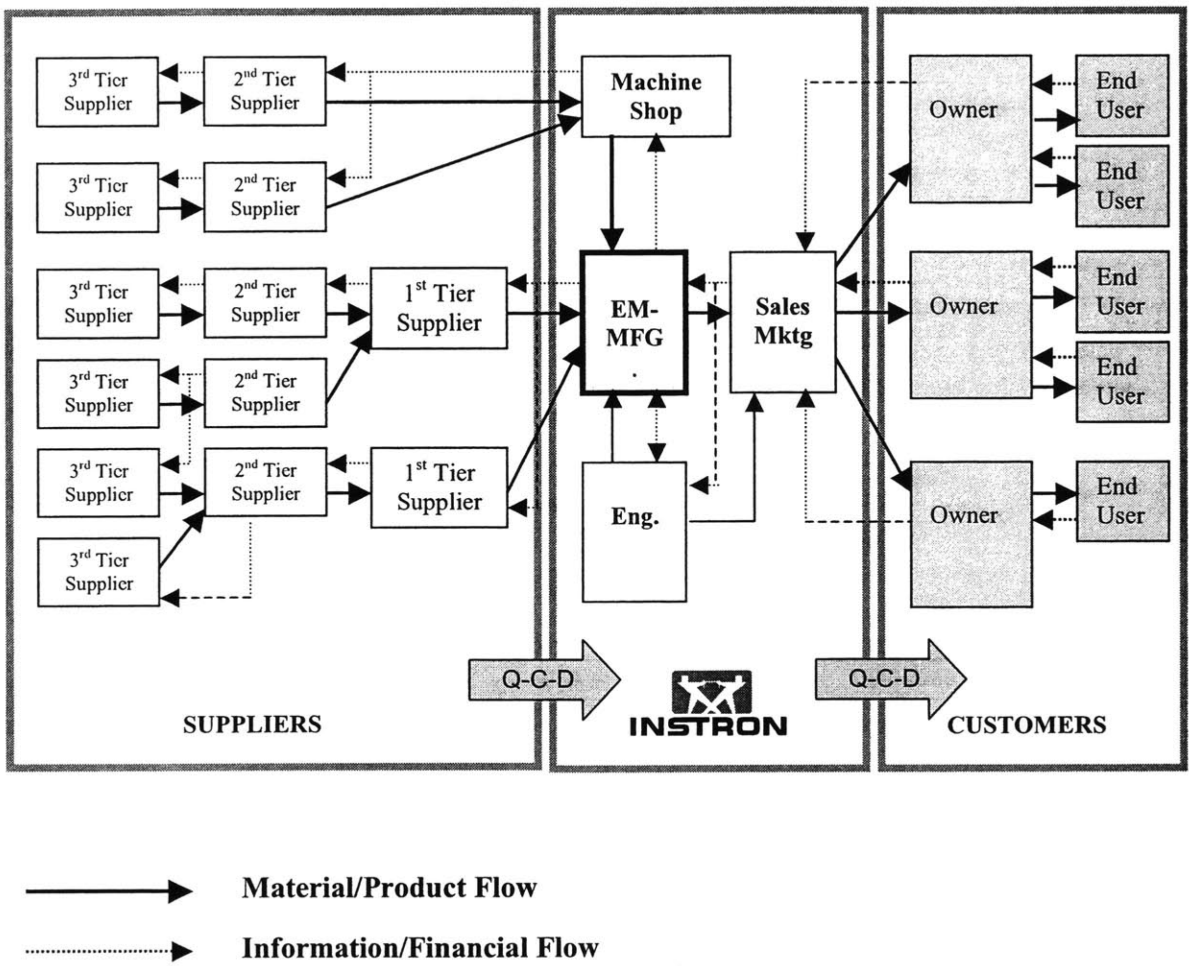

Figure 4.1. Instron EM Value System Diagram

Based on historical data, every year, the Electro-Mechanical Business Unit made and shipped thousands of EM testing systems to a large customer base around the world, in which many were repeat customers. On the supply side, the Electro-Mechanical Business Unit currently has 74 active first-tier suppliers, of which the 18 percent of top suppliers have supplied 80 percent of total material cost volume.

4.2. Process Analysis

It is generally agreed that "supply chain is a sequence of processes and flows that take place within and between different supply chain stages and combine to fill a customer need for a product."[1] It is useful to look at the cycle view of the supply chain because "it clearly specifies the roles and responsibilities of each member of the supply chain."[2] Figure 4.2. shows the cycle view of Instron's Electro-Mechanical supply chain compared with the typical supply chain process cycles. As Instron builds to orders and sells its products directly to customers, it bypasses the retailer and distributor phases and reduces the four typical supply chain process cycles down to two, as seen in the diagram. This definitely reduces costs and lead times that Instron would have experienced if it followed the full supply chain process cycles.

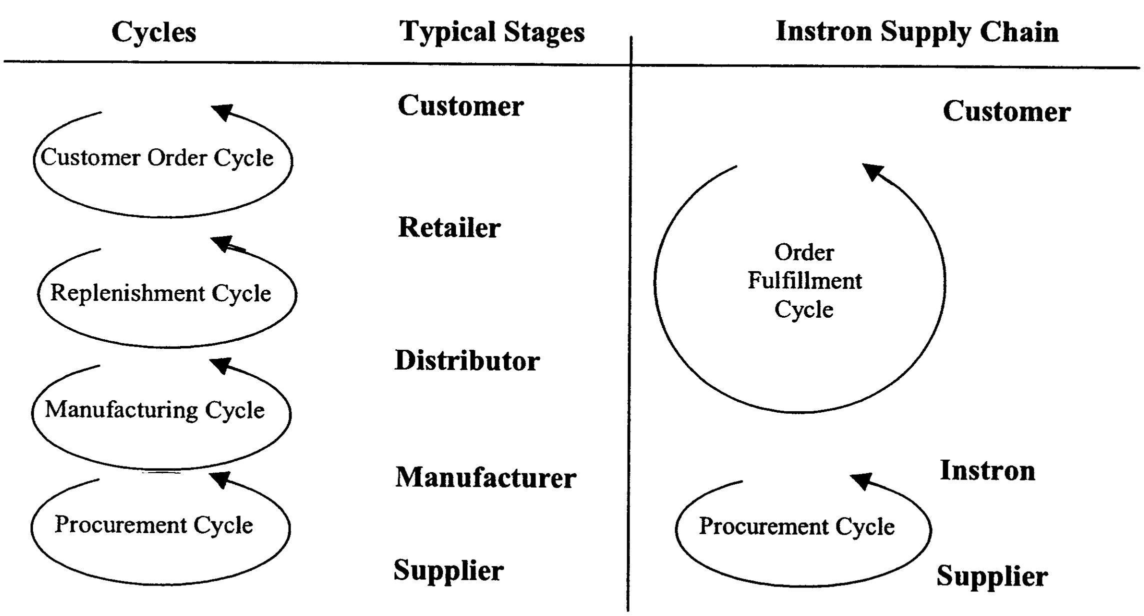

Figure 4.2. Instron EM Supply Chain Process Cycles

[1] Chopra, Sunil and Peter Meindl, Supply Chain Management: Strategy, Planning, and Operation, Upper Saddle River, NJ: Prentice-Hall, Inc., 2001, page 7.
[2] Ibid, page 8.

- **Order Fulfillment Cycle:**

  The order fulfillment cycle occurs at the customer/company interface and includes all the processes as shown in Figure 4.3.

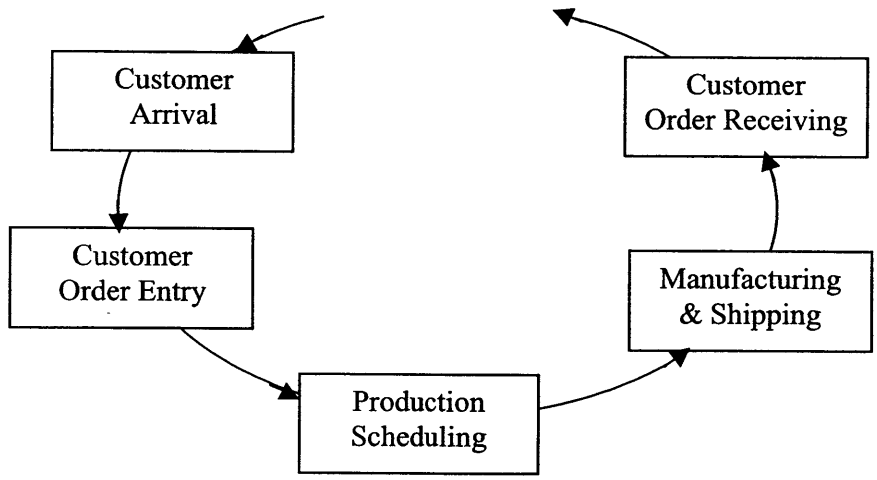

Figure 4.3. Order Fulfillment Cycle

- **Procurement Cycle:**

The procurement cycle occurs at the manufacturer/supplier interface and includes all processes as shown in Figure 4.4.[1]

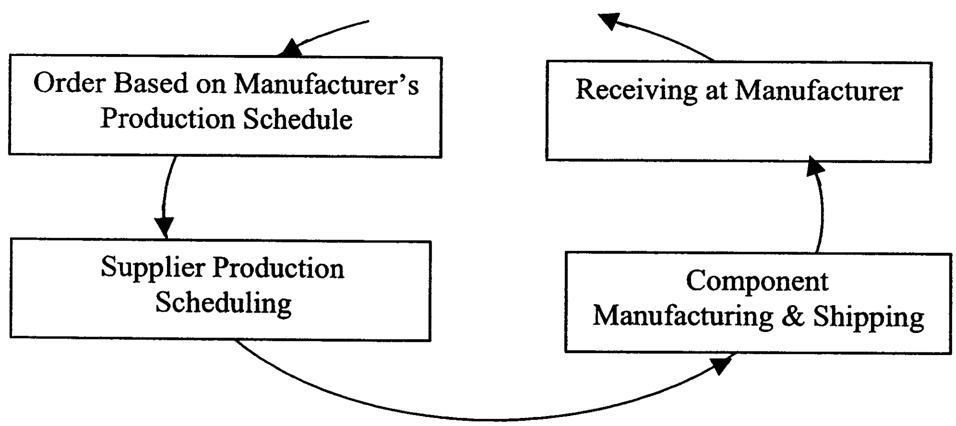

Figure 4.4. Procurement Cycle

[1] Chopra, Sunil and Peter Meindl, Supply Chain Management: Strategy, Planning, and Operation, Upper Saddle River, NJ: Prentice-Hall, Inc., 2001, page13.

Figure 4.5. shows a generalized process view of a supply chain, based on the suggestion of R.C. Camp in Business Process Benchmarking: Finding & Implementing Best Practice (1995). Generally, from the process perspective, every supply chain includes inputs, process steps, outputs, feedback, and results as shown in the diagram. The beauty of this generalized process is that it not only illustrates the big picture of the supply chain of an organization with all key processes, but also highlights the overall performance of each of these processes. Thus, by making strengths and weaknesses obvious, it is possible to indicate where future improvement potential exists.[1]

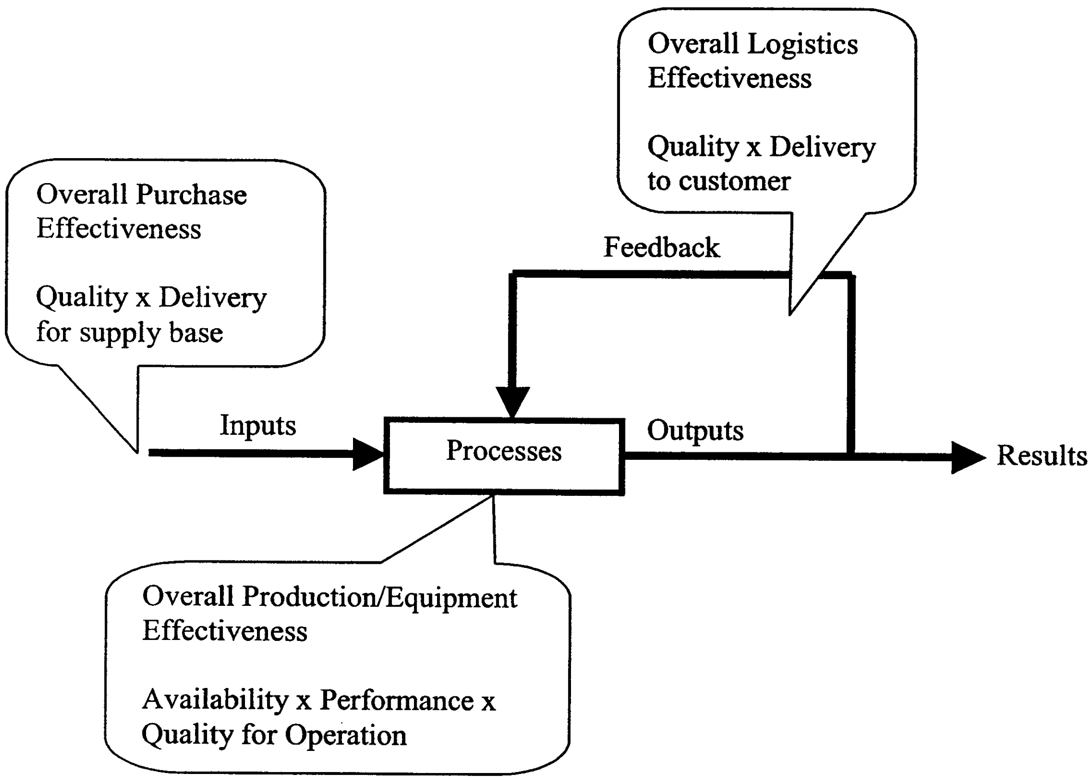

Figure 4.5. Generalized Process View of an Organization

Using Cam's "big picture" concept in the Instron EM situation, we can see in Figure 4.6. how other process performances affected the overall effectiveness of the supply chain. With the 98 percent quality and 80 percent on-time delivery performance, the effectiveness of the internal manufacturing business unit appeared stable at 78.4 percent. However, if combined with the

[1] Brunt, David, "Creating big picture maps of key processes: company activities viewed as part of the value stream," Manufacturing Operation and Supply Chain Management, London, England:Thopson Learning, 2001, page 88-96.

performance of other processes, the overall effectiveness of the supply chain management was just over 40 percent! [1]

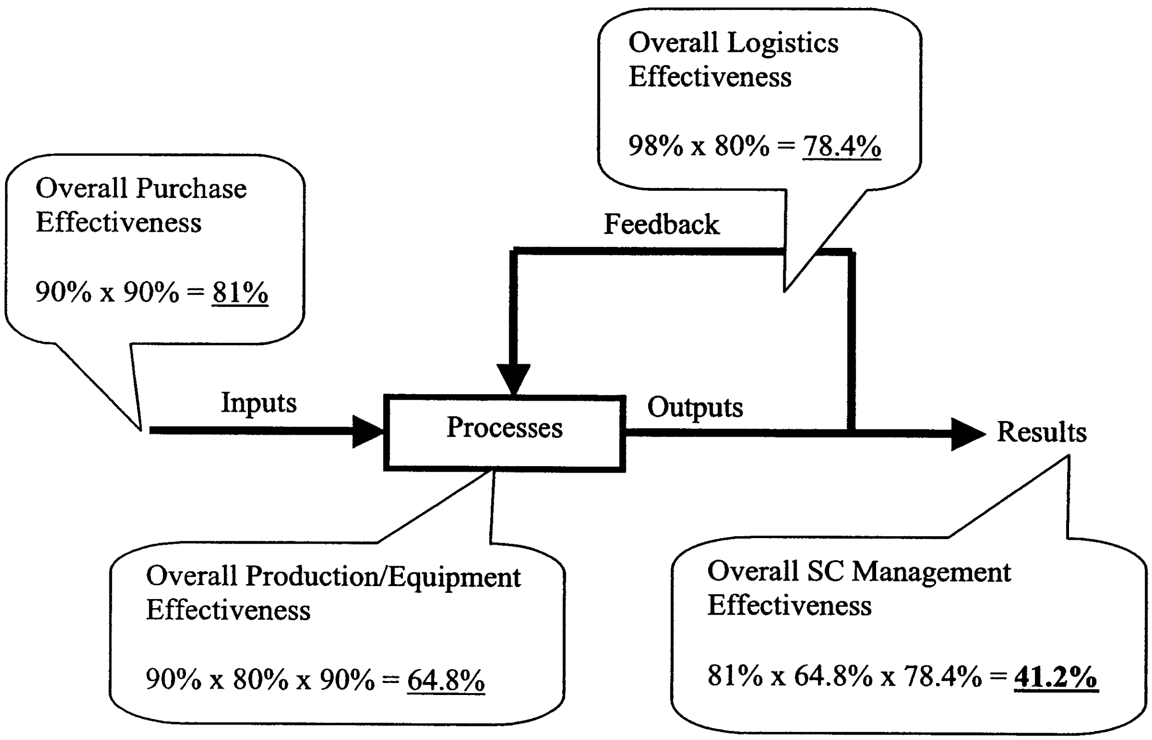

Figure 4.6. Overall evaluation of SCM effectiveness

Therefore, to achieve a systemwide improvement, the company should realize "the importance of synergy between different improvement efforts and the need for commitment at all levels of the company."[2]

4.3. Understanding Demand and Customers

4.3.1. Demand Analysis Approach

To understand the demand patterns for Electro-Mechanical products and its customers, I analyzed the data of the last four years extracted from the database of the Instron Business

[1] These actual performance figures are for illustrative purposes only.
[2] Kobayashi, I., Twenty Keys to Workplace Improvement. Portland: Productivity Press, 1994.

System (IBS). Figure 4.7. shows the approach by which I used data to analyze the past demand and recommend for future improvements.

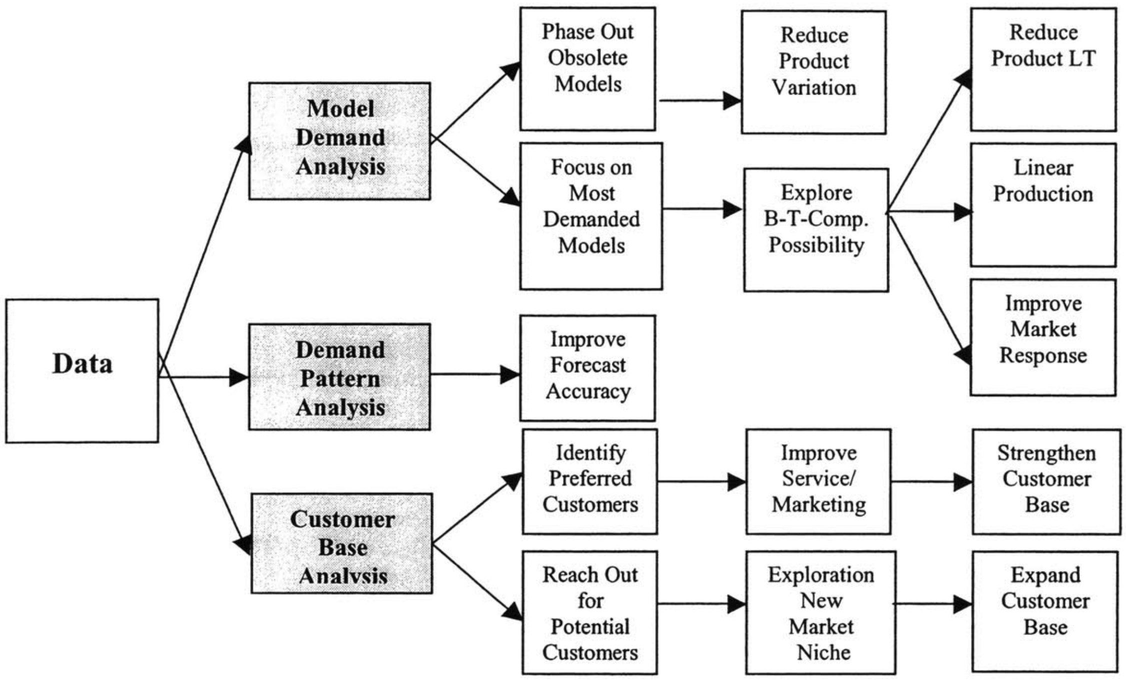

Figure 4.7. Demand Analysis Approach

4.3.2. Understanding Demand Patterns

The historical booking data of the last four years shows that the customer demand varied for different EM and over time for one year. In terms of models, the data shows strong and stable demand for all EM single-column testers, whereas for EM dual-column testers, high demand concentrates on model 4411, 4465, and 5565, average and low-demand spread on the rest (see Figure 4.8. below). This observation would suggest a continuing and careful follow-up to such a demand pattern in order to make strategic moves on phasing out less popular models in order to reduce product variation, and explore the possibility of the assemble-to-order strategy (see the section 2.4) for preferred models, which can reduce product lead time, linearize production, and improve market response.

The monthly booking data for each model gives a sense of customers' demand patterns over the period of one year. We can see the typical "hockey stick" phenomenon at almost every quarter-end and year end. However, the demand patterns are quite different from model to model, and throughout one year. Acquiring an accurate demand forecast for every month or quarter is rather difficult; therefore, the demand forecasting has been a challenging task at Instron. Consequently, an agile, short-lead time manufacturing strategy with a lean supply chain management would be best for this environment.

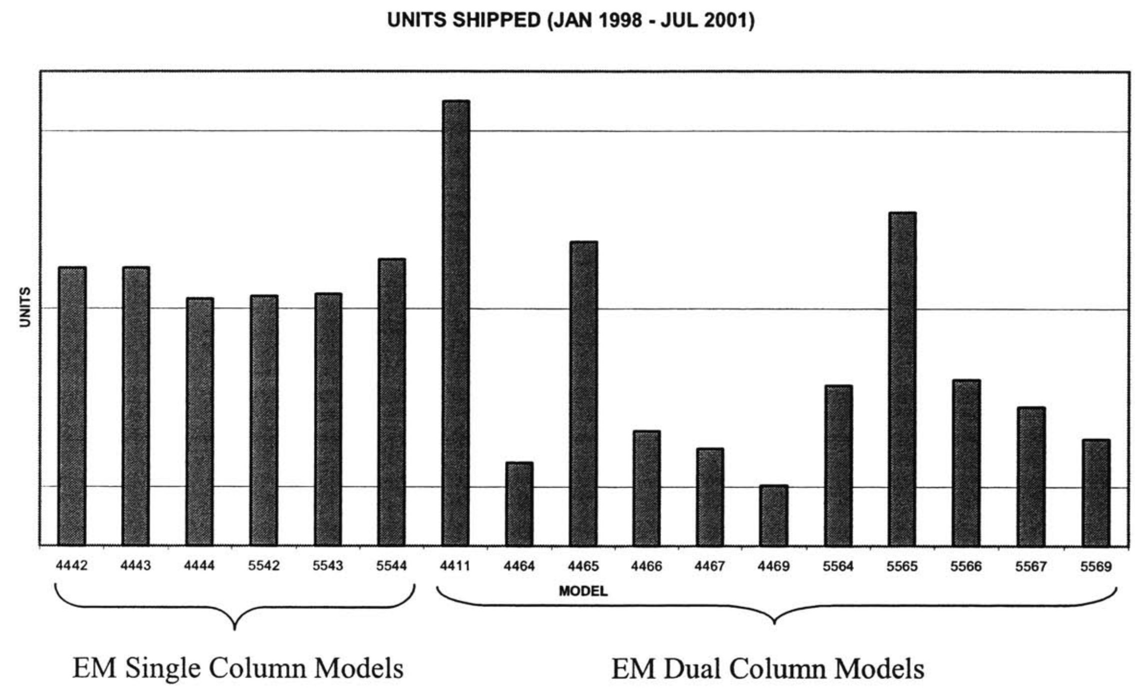

Figure 4.8. Aggregate demand for EM testing models

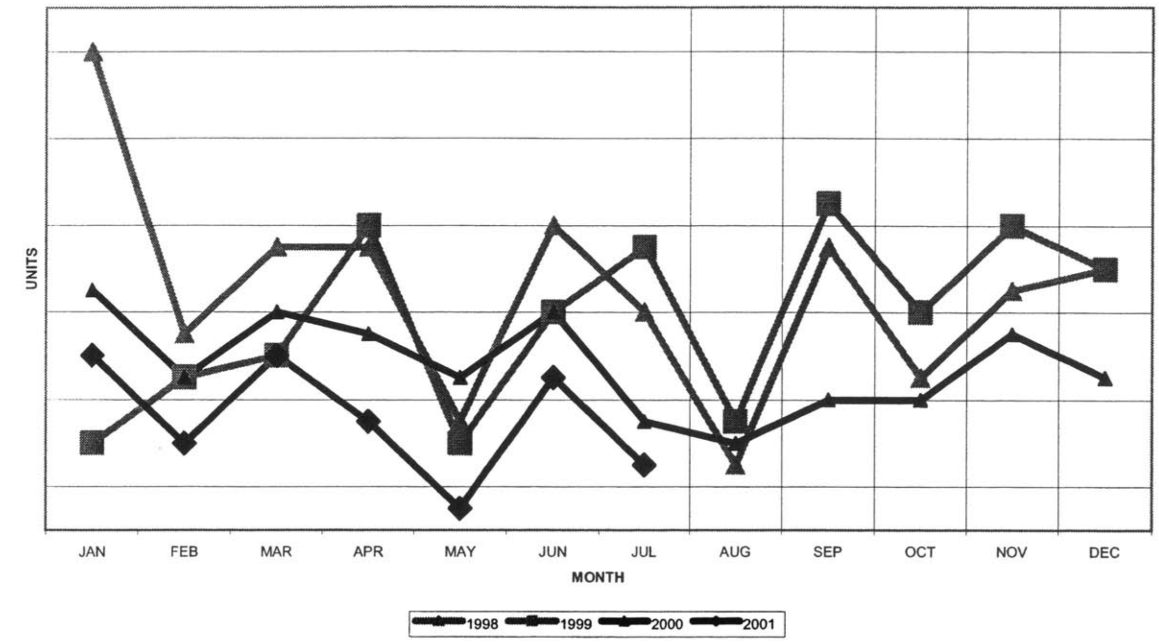

Figure 4.9. An example of the monthly demand pattern for an EM model

4.3.3. Understanding Customers

Instron has had a large customer base for EM testers. Many of them have placed repeated orders. End users of these testing systems are engineers, research scientists, professors, college students, technicians, and production operators.

Instron's major customers have included many research laboratories and numerous big companies in materials, manufacturing, or biotech industries. Their orders add up to 70 percent of sales volume. Universities and other educational institutions currently account for about 20 percent of sales volume, but, with the rapid growth of material science, they appear as both an expanding market segment now and promising leads in the future. Today, many students who have been using these testing systems in their studies or research will likely order the familiar testers in the future when they hold positions as researchers, quality controllers, or lab managers in companies or R&D laboratories.

A customer-focused policy with the ability to listen to customers and the willingness to satisfy their needs will definitely bring in substantial rewards for the company. Customers are loyal only to the companies that understand and address their issues. At Instron, the salespersons who have good communication and close relationships with customers always create the most successful leads for the company. Therefore, good marketing and customer service are vital factors for the company's bottom line and growth.

4.4. Understanding Products and BOMs

4.4.1. Products Analysis Approach

Instron has developed a very broad product catalog for EM testers. If we count every possible combination with different frame capacity, voltage options, controller options, load cells, display options, language options, accessories, etc, we can come up with a list of tens of thousands EM testing systems, regardless of custom design and build features for some special needs that can often happen. Luckily, since the inception of the company, engineers at Instron have wisely pursued the modular innovation design approach. When they invent new testing systems, they try to use the same design structures and the highest number of common parts in old systems. Therefore, every system seems to have a very long and complex bill of materials (BOM) with many layers of sub-assembly components, but there is a large overlap with other BOMs. However, due to the complex structure of these BOMs, there had been no complete analysis done before on the advantage of part commonality.

Thinking that there is a great benefit in capturing that engineering value, I conducted a complete analysis of the BOM of 55 EM single-column and dual-column frame models. Figure 4.8. below presents my approach in this analysis:

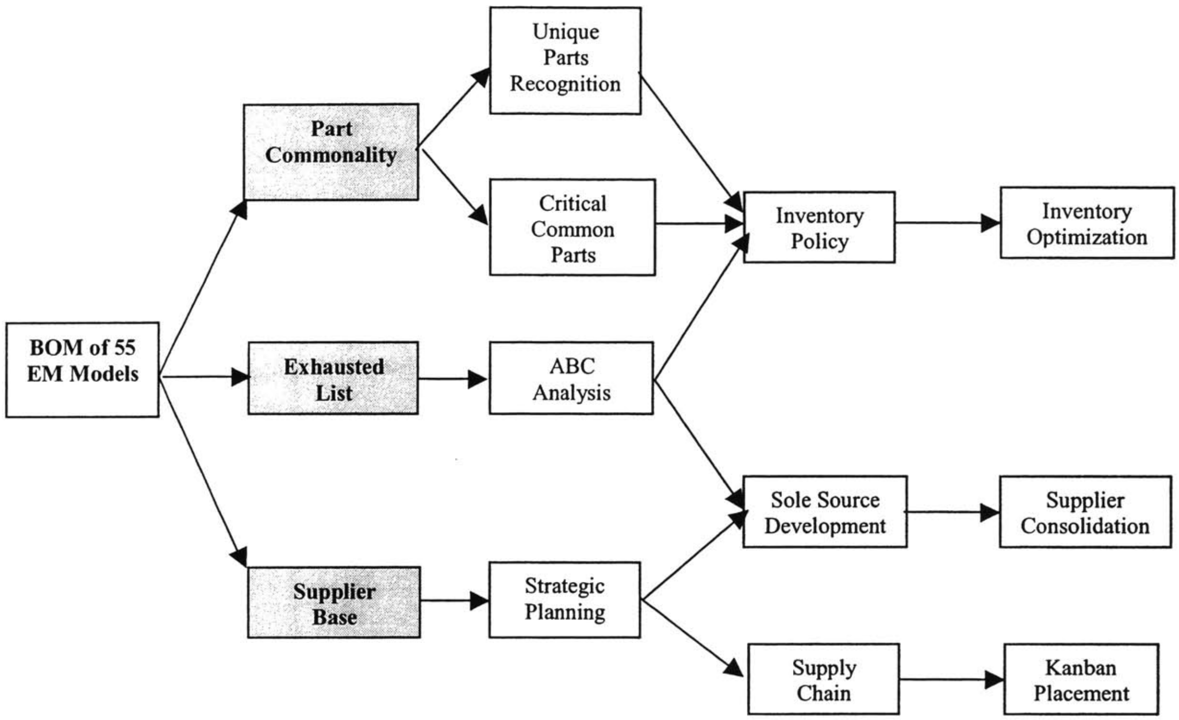

Figure 4.10. Approach for BOM Analysis

4.4.2. BOM Analysis

The result of the BOM analysis was very interesting. The Venn diagram in Figure 4.9. shows the commonality among these frame models. In total, there are 422 parts used in the 55 EM frame models, in which 42 parts are common to all three groups including single-column models (series 4400 and 5500), dual-column models series 4400, and dual-column models series 5500; 209 parts are shared between the two dual-column models series 4400 and 5500, 55 parts are shared between single-column models and dual-column models series 4400, and 58 parts are common between single-column models and dual-column models series 5500.

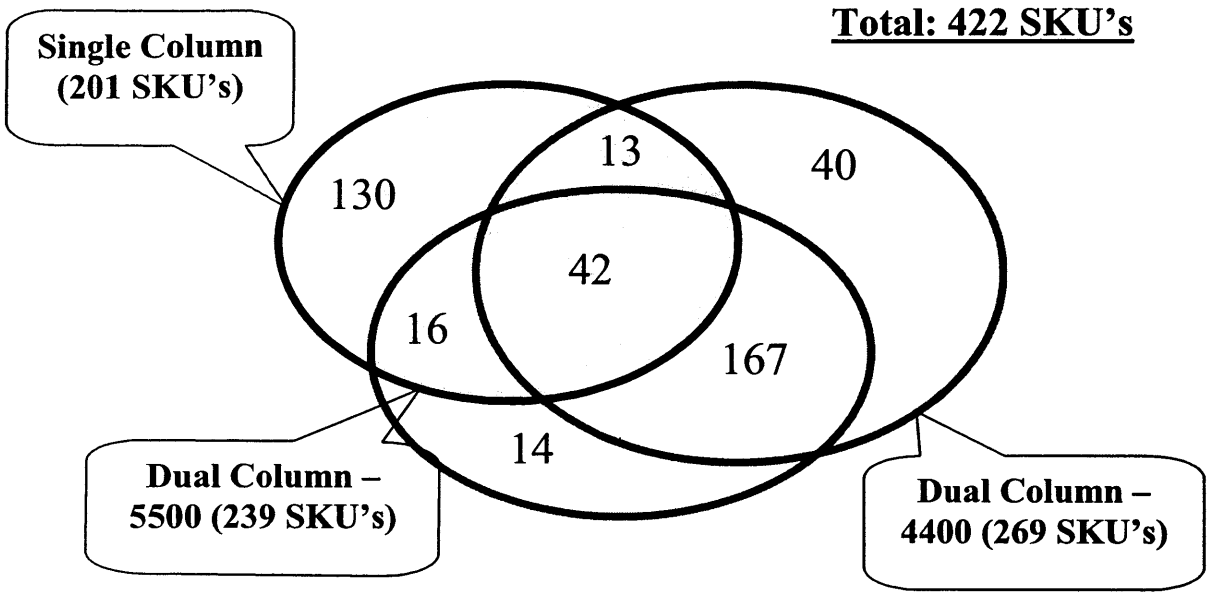

Figure 4.11. Results of BOM Analysis for EM testing systems

4.4.3. Distribution by Value Analysis (ABC Analysis)

To help the company focus its control efforts on the most significant items, I analyzed the value distribution of these parts using an ABC analysis. The result shows the 80/20 rule is obvious here: top 20 percent of parts is worth more than 80 percent of total cost volume.

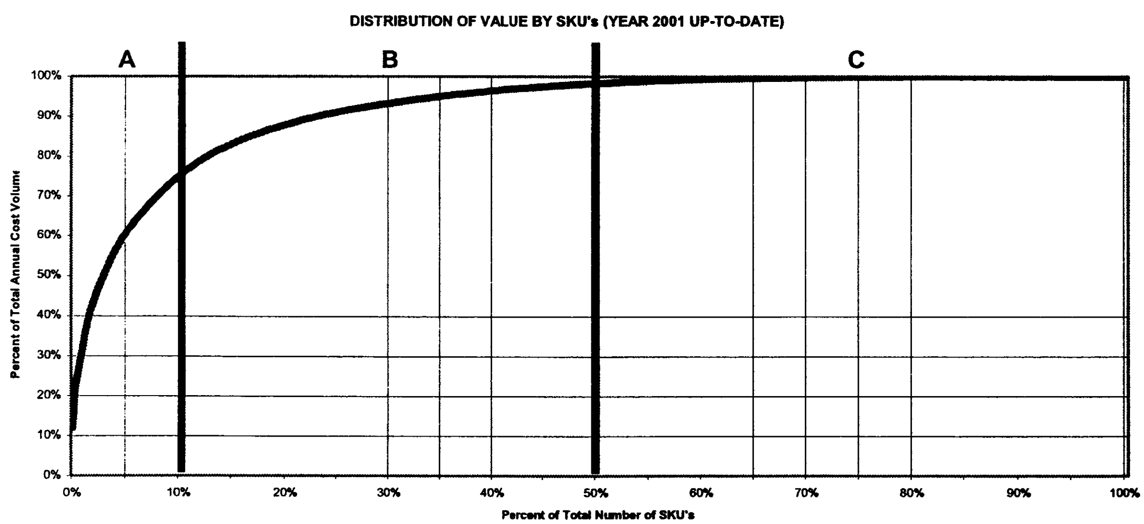

Figure 4.12. Distribution of Value by SKUs for EM testing systems

In this ABC analysis, items are classified into three categories: Class A items include all high-value components that typically account for 75 percent of the total annual cost volume and represent about 10 to 20 percent numbers of inventory SKUs; class B items account for about 20 percent of the total annual cost volume, and class C items are the remaining components of the list whose value is no more than 5 percent of the total annual cost volume. The value distribution categories may influence the company's inventory policy. For example, Class A items account for the major part of the cost volume, and it requires a high-frequency periodic review policy. Similarly, Class B items also receive a periodic review policy although the frequency of review is not as high as that for Class A products. Depending on the product value and lead times, the company may decide to keep low inventory of expensive Class A items and a blanket policy for Class C items.

Table 4.1. below presents the combined result matrix of the two analyses. The numbers 1,2, 3 in commonality columns indicate parts shared among one, two, or three groups of EM models as indicated in Figure 4.11. above. Class A items with 44 parts account for 76 percent of the total annual inventory cost volume, class B items with 169 parts account for 23 percent more of the total annual inventory cost volume, class C items with 209 parts contribute only 2 percent of the total annual inventory cost volume:

		COMMONALITY			TOTAL	PERCENT
		3	2	1		
A	# PARTS	4	26	14	44	10%
	COST	7%	52%	17%	76%	76%
B	# PARTS	27	85	57	169	40%
	COST	3%	12%	7%	23%	23%
C	# PARTS	11	85	113	209	50%
	COST	0%	1%	1%	2%	0%
TOTAL PARTS		42	196	184	422	100%
% OF TOTAL OF PARTS		10%	46%	44%	100%	100%
% OF TOTAL OF COST		10%	65%	25%	100%	100%

Table 4.1. Result Matrix of BOM Analysis

4.4.4. Guidelines for the Control of Class A Items

The Class A inventory items should receive special attention from managers. The top five strategies are:

- Frequently review Class A inventory by top management. In this strategy, class A inventory is reviewed at a high frequency basis (e.g., a weekly review) and every time it is reviewed, a decision is made on the order quantity. The frequent inventory review policy helps management maintain a low Class A inventory level but adequate enough to avoid stock-out situations.
- Pay close attention to usage rates, lead times, and safety stock. Review the order quantity and reorder point volumes frequently. Besides, the company should influence supply partners to cooperate in establishing the flexible kanban replenishment plan for Class A items. This allows the firm to keep inventory at an appropriate level.
- Make constant efforts to reduce safety stock by influencing both customers and suppliers to decrease demand variations and supply lead times.
- Precisely determine control-quantity values.
- Focus on maintaining the right balance between ordering and holding costs (EOQ approach).[1]

4.4.5. Guidelines for the Control of Class B Items

The Class B inventory items should receive a similar control guidelines applied to the Class A items, but with a more relaxed periodic review policy (e.g., a monthly review). Order quantities and reorder points should be checked at least on a quarterly basis. A kanban system should be established also for the Class B items.

4.4.6. Guidelines for the Control of Class C Items

As Class C items have very low value but they are required for assembly; therefore, it is fine to keep them at a relatively high level of inventory and with long reorder intervals (6-12

[1] Simchi-Levi, David et al., Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies, New York, NY: The McGraw-Hill, Inc., 2000, page 63-64.

months). Further recommendations include reducing the number of items stocked, disposing slow-moving inventory, and increasing component sourcing.

4.5. Understanding Suppliers

4.5.1. Supply Base Analysis

Using the same approach for the BOM analysis, I mapped the supply base for EM single-column and dual-column product lines in the Venn diagram in Figure 4.13. as follows:

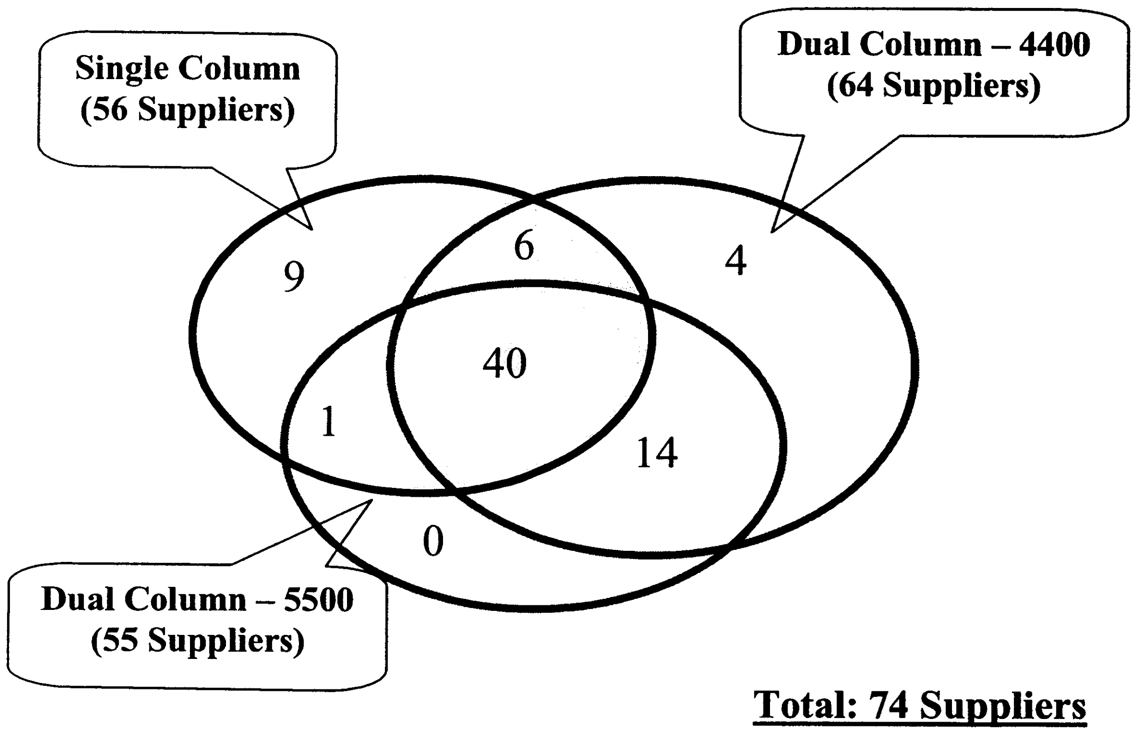

Figure 4.13. Instron EM Supply Base Analysis

Currently, Instron EM has a total of 74 suppliers that supply materials to the EM single-column and dual-column product lines, in which 40 suppliers provide parts for all three groups of EM tester models, six more suppliers provide parts for both dual-column models series 4400 and single-column models, and one more supplier has parts for dual-column models series 5500 and single-column models. The dual-column lines for series 4400 and 5500 have shared 54 suppliers. Last year, 42 suppliers from Massachusetts supplied 63 percent of total annual volume in costs, 29 suppliers from 14 other U.S. states supplied 36 percent of total annual volume in costs, and three foreign suppliers supplied the remaining 1 percent of the annual volume (see Figure 4.14.).

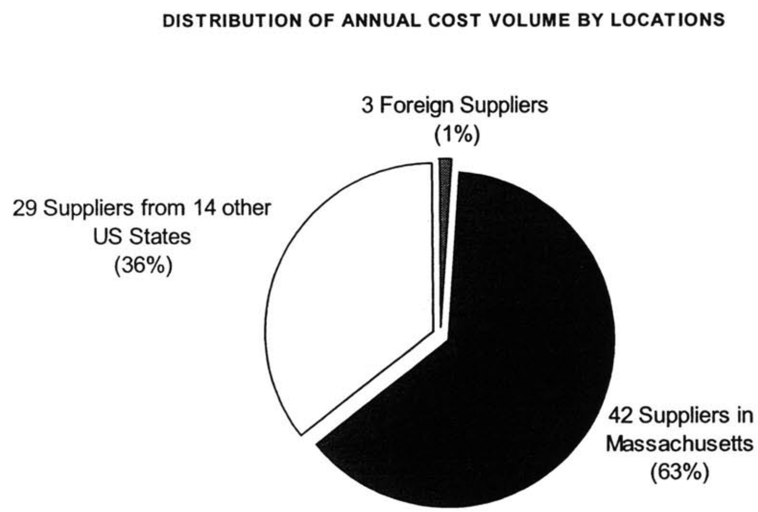

Figure 4.14. Distribution of Cost Volume by Geographical Regions

To help the company recognize and focus on the major vendors, I used the same approach of the value distribution analysis to categorize suppliers in three groups based on their volume supplied to Instron EM single-column and dual-column tester lines. Again, the 80/20 rule exists here. Thirteen top suppliers, which represent about 18 percent of the total number of suppliers, supplied 81% percent of the total annual cost volume last year. The volume supplied by 37 the top suppliers, which represent the top half of the total number of suppliers, was 98 percent. The other half of suppliers contributed less than 2 percent of the total annual cost volume. In current status, if Instron currently has strong commitments from the top 20 suppliers, then up to 90 percent of the required materials for EM single-column and dual-column frames can be guaranteed.

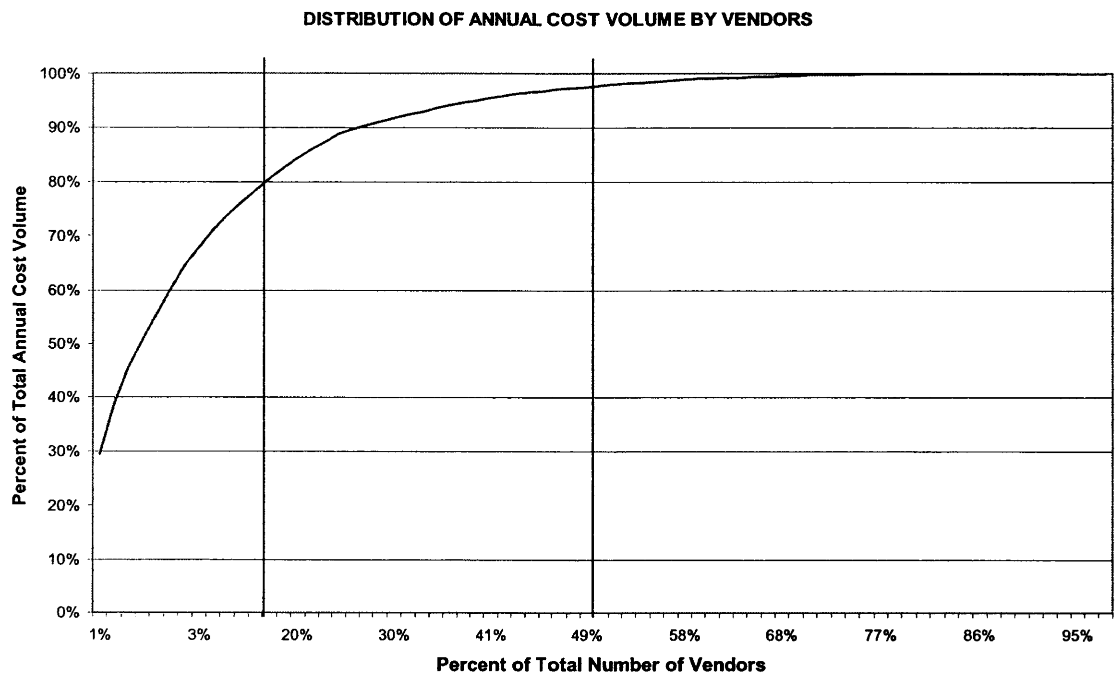

Figure 4.15. Distribution of Annual Cost Volume by Suppliers

4.5.2. Guidelines for Supplier Policy

To improve the materials replenishment for EM single-column and dual-column product lines, there are some guidelines that I would suggest Instron consider for its supplier policy:

- Focus on finding local suppliers for Class A and B items. It is much easier for the company to communicate, visit, and develop strong relationships with local suppliers, which may lead to reduced lead times and improve collaboration, especially for just-in-time efforts.
- Influence suppliers to participate in Pull or Kanban systems for materials or parts replenishment. A Kanban system will help both suppliers and the company to significantly reduce inventory level, to simplify the inventory control, and to increase flexibility.

- Manage strategic issues concerning suppliers with commodity teams staffed with purchasing, engineering, manufacturing, and quality personnel. It needs to be emphasized that the strategic issues with key suppliers are very important to several functions of the company and that the system-wide cost is more important than the immediate price in stand-alone purchasing decisions. The benefits of this collaboration will outweigh the complexity of the team's work because, with the various expertise of the team members, many problems and/or value-adding ideas can be identified earlier in the process, leading to a great deal of savings and gains for the company. This strategy truly provides a forum for engineering, manufacturing, quality, and purchasing personnel to influence the criteria for selecting and managing strategic suppliers.
- Create and use a certification process that challenges suppliers and makes them proud to be certified suppliers. This lets the supplier know what your standards are and ensures that the certification process contains exactly the criteria that are important to the company. Recognize and reward certified suppliers publicly. Make the suppliers strive to become better partners and to eliminate mistakes and confusion to create leaner operations.
- Continue the effort of consolidating the supply base. The company should reduce the number of suppliers for each part or component to a few or only one. With a smaller number of suppliers, the company can share more business volume with them, make itself their major customer, and thus can influence quality, price, delivery schedules, and capacity decisions. Moreover, the company can improve its development and fulfillment operations because fewer and more dependable suppliers will reduce the number of variables and make fewer mistakes and interruptions.[1]

[1] Source: <www.leanstrategies.com>.

5. LEAN APPROACH TO SUPPLY CHAIN IMPROVEMENT

This chapter presents in detail a lean approach to supply chain improvement that I would strongly recommend Instron to pursue for future development. This method suggests a new process using lean principles and value stream management to systematically transform Instron's supply chain into a lean supply chain. This lean approach was initiated in my internship at Instron, but has not been completed due to time constraints. This chapter includes a brief overview of the lean supply chain concept, a short outline for a lean solution, and an introduction of a proposed lean methodology. Also presented is a self-assessment of Instron's key operations based on lean perspectives and a roadmap for further lean improvement efforts.

5.1. Overview

Since 1990s, the term "lean manufacturing" has become very popular in many industries and organizations, but the word "manufacturing" is misleading and has often created false perceptions of the original concept. Many people still think this term indicates that the opportunities for improvement using lean principles lies within the manufacturing department. This narrow thinking has substantially overlooked the potential value and impacts of a lean approach in a larger context. It is important to realize that the name "Toyota Production System," the original source of lean thinking, does not express a focus on manufacturing but includes all of the business elements and support systems necessary to achieve the production goals. Taiichi Ohno literally defined "Lean Manufacturing" as follows:

> This is the manufacturing system developed by Toyota which pursues optimum streamlining throughout the entire system through the thorough elimination of Muda (waste), and aims to build quality in at the manufacturing process while recognizing the

principle of cost reduction. It also includes all the accompanying technology necessary to accomplish those aims.[1]

Apparently, the perfection of only the manufacturing process would not have brought Toyota Company the outstanding successes that it has enjoyed for decades. Therefore, by understanding the breadth and depth of the Toyota Production System, we can see that lean concepts can and should be extended beyond manufacturing into many different functions of a company including marketing and sales, product development, and supply chain.

In this extended perspective, the lean supply chain can be defined as a system-wide change program implementing lean principles to identify and eliminate waste from the supply chain step-by-step. The ultimate goal of the lean supply chain is to develop a system that provides perfect value to the customer through a perfect value creation process with zero waste, and, thereby creates opportunities for the company to improve its competitive advantages.[2]

5.2. Lean Methodology

The transformation of supply chains from the current status to lean is a time-consuming and complicated task. Many companies have invested a substantial amount of resources in developing a lean supply chain, but few have succeeded. There are many hurdles that have been considered as barriers to supply chain improvement. The four greatest obstacles are: (1) the time lags of the improvement process, (2) the functional silos within and between the organizations, (3) the lack of a hierarchical structure that can gather all involved parties within the organization, and (4) the unaligned knowledge and appreciation of senior and operational managers toward lean principles and supply chain management.

To overcome these issues, David Taylor suggests an approach that applies the techniques of value stream management to create a "supply chain improvement program in such a way as to educate, involve and enthuse personnel from all levels and parts of the supply chain via

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[1] Ohno, Taiichi. The Toyota Production System: Beyond Large-Scale Production. Portland, Oregon: Productivity Press, 1988.
[2] Womack, James B., PowerPoint presentation "Lean Thinking for the Canadian Auto Industry: The Next Leap," in Ontario, Canada, on 04/12/2000.

numerous, self-generating and self-sustaining incremental improvement initiatives."[1] This proposed method consists of the six following initiatives that proceed in parallel to develop a lean supply chain:[2]

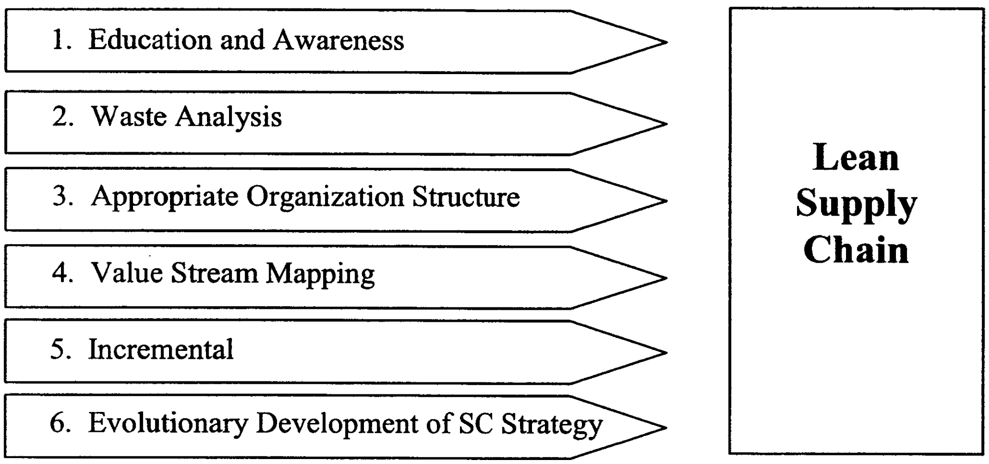


Figure 5.1. Lean Approach to Supply Chain Improvement

- **Initiative One: Education and awareness.** The objective of this initiative is to ensure that all involved people, including managers and employees, have a clear understanding of the scope and objectives of supply chain management, the principles of lean thinking and value stream management. It also aims to make those concepts familiar and applicable in the organization.
- **Initiative Two: Waste analysis.** This initiative aims to help managers identify and know how to reduce waste in individual value streams. Structured interviews to evaluate the "seven wastes" and other perceived wastes should be conducted with every participant. They may reveal surprising results.
- **Initiative Three: Creating an appropriate organizational structure.** The development of a lean supply chain is impossible without the involvement and

[1] Taylor, David and David Brunt, "Parallel Incremental Transformation Strategy: An Approach to the Development of Lean Supply Chains," Manufacturing Operations and Supply Chain Management: The Lean Approach, London, England: Thompson Learning, 2001, page 222.
[2] Ibid, page 222-235.

support of the senior management, lean supply chain champions, and management and operation staff involved in supply chain processes. The "three-tier structure"[1] for lean transformation can be seen in Figure 5.2.

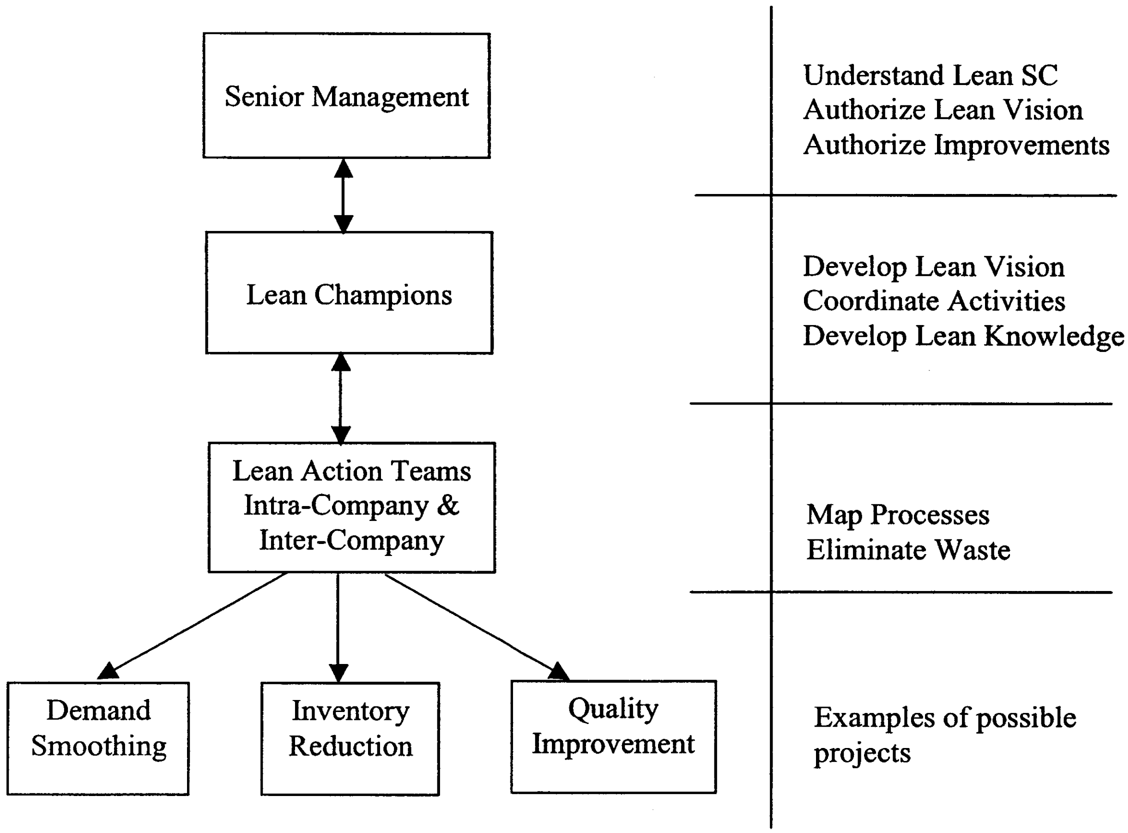


Figure 5.2. Organization Structure for Lean Transformation (Applicable to each company and for the whole supply chain)

- **Initiative Four: Value stream mapping.** In these activities, the lean operational teams will assess and select the most effective methods of mapping tools (see section 2.2.2.) to create a multidimensional assessment of the supply chain performance. This is a time-consuming process, but it is critical for identifying waste and opportunities for improvements. The role of Lean Champions is also very important in these activities as those who assume it are initial mentors and project coordinators.

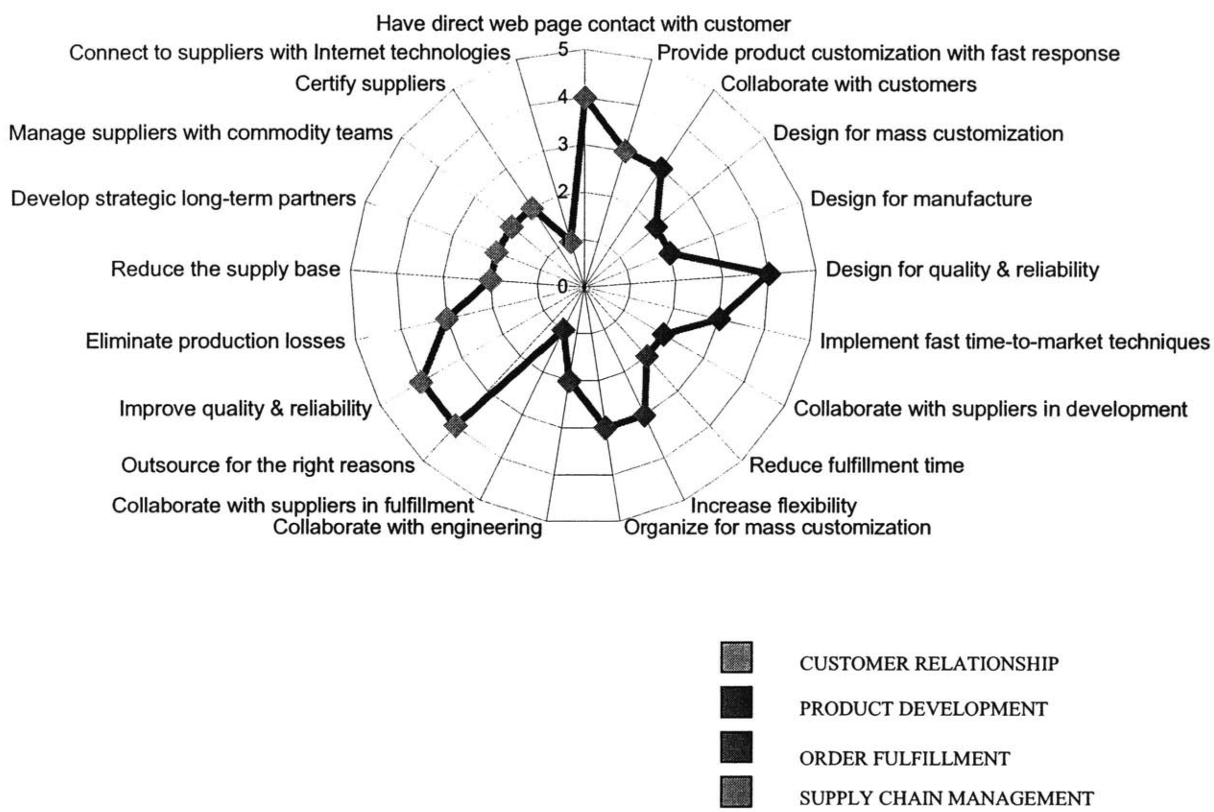
[1] Ibid, page 231.

- **Initiative Five: Incremental improvement.** Once all necessary maps for a targeted value stream are mapped out, the Lean Champions and other operational groups will review the maps to identify critical areas of waste, its root causes, and develop an action plan to eliminate the discovered waste for the value stream. It then becomes a working model that can be used to make other value streams leaner.
- **Initiative Six: Evolutionary development of supply chain strategy.** Once the lean approach is shown to work for a product flow to a key customer, it can be rolled out to other product families and other customers. However, as different product families and /or customer segments may have different characteristics and service requirements, the lean initiative teams should proceed with the strategy through incremental steps, value stream by value stream, to ensure the approach complies with new requirements.

Each of the six initiatives aims to create three effects: (1) to educate involved staff and prepare them for future self-generating improvement activities, (2) to achieve immediate beneficial results, and (3) to spread out the success to a wider supply chain.

5.3. Assessment in Lean Perspective

Figure 5.2. below shows the lean assessment result in the form of a spider chart that I did for Instron using the self assessment page of the website <www.leanstrategies.com>. As the Web site suggested, I used a 1-to-5 scale, which respectively represents poor to very lean status, to rate the 21 important aspects of the four critical categories that should be transformed to leaner operations. These focused categories are customer relationships, product design and development, order fulfillment, and supply chain management. As I conducted the assessment just based on my own observation, sense making, and qualitative evaluation, the rating might be somewhat subjective; however, I hope it could still provide an insightful view on the company operations for future lean initiatives.



Source: www.leanstrategies.com

Figure 5.3. Instron EM Lean Assessment Graph

The assessment chart shows Instron is strong in customer relationships, design for quality and reliability, product quality, and outsourcing for the right reasons. As a matter of fact, Instron has achieved a high customer satisfaction rate for the last five decades. Customers have highly praised the company for good engineering designs, product quality, and customer service. Instron has guaranteed its customers that it will provide technical support and spare parts for every machine that it has installed for the last five decades. On outsourcing, since the '70s, Instron has pursued a strategy to outsource the majority of its supply demand and has kept inhouse only the core competencies such as product design and development, operating system software, and final assembly and testing. Today, from 90 percent to 95 percent of the total number of needed parts or components come from external suppliers. This effective strategy has freed up a great amount of resources and investment for Instron.

The areas that are considered as having an average lean performance are the responsiveness to custom orders and markets, the increasing of flexibility in order fulfillment, the preparation for mass customization, and the elimination of production losses. In the Ishikawa analysis, the interviewed engineers admitted that their modular design focuses more on product quality and the convenience for future design rather than on the ease of manufacturing. The solely pro-engineering mindset might overlook value opportunities it could have offered to the company through collaborations with manufacturing and suppliers. The flexibility in order fulfillment and mass customization preparation should also be initiated by the collaboration of engineering, manufacturing, and supply forces. The breaking of functional silos will open up more opportunities for becoming a leaner operation.

The lean improvement effort should be focused on the areas with the rating of 1 or 2. In the product development area, the weak areas are designing for manufacture, designing for mass customization, and collaborating with suppliers in product development. In order fulfillment, a new focus should be placed on reducing lead times and increasing the collaboration with suppliers and engineers in the order fulfillment processes. In supply chain management, the lean effort should be used to improve the strategic management of the supply base, such as consolidating the supply base, developing strategic long-term partners, managing suppliers with a commodity team, promoting certified suppliers, and implementing advanced information technology to speed up and improve supply chain processes. These issues will be further discussed in the following section.

5.4. Lean roadmap

Based on the lean assessment of Instron described in the previous section, I recommend that a strategic plan for future supply chain improvement at Instron be implemented. Together with the lean solution and methodology presented earlier in this chapter, this plan is designed to serve as a roadmap for a lean transforming process at Instron.

A supply chain involves many functions in its processes. In order to successfully transform a traditional business system into a lean supply chain, changes must take place across all key functions. Figure 5.4. shows the big picture of the necessary changes in the four important areas: (1) customer relationships, (2) product development, (3) supply chain management, and (4) order fulfillment. The improvement in some of these functions will have a positive impact on the success of other areas and eventually the whole company.

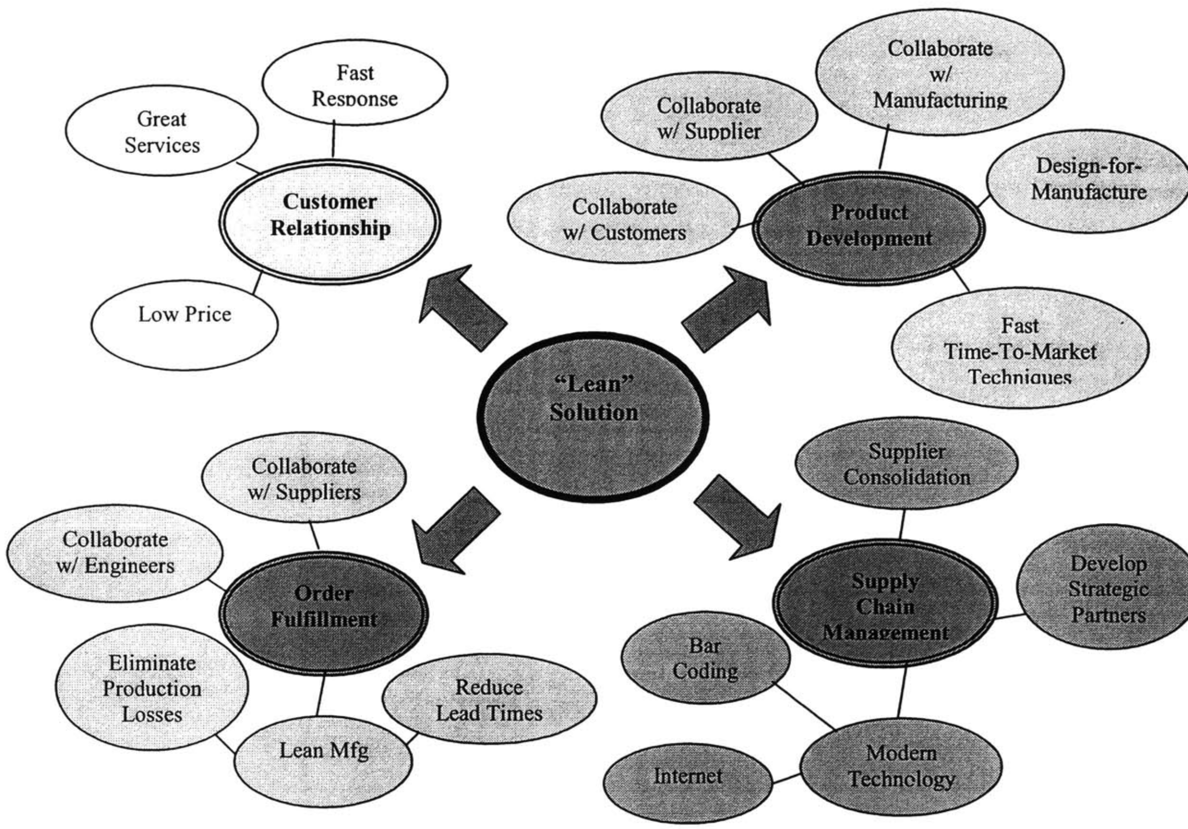


Figure 5.4. Lean Roadmap for Instron
(Source: www.leanstrategies.com)

5.4.1. Lean Approach to Customer Relationships

As Instron has had a large and loyal customer base, the company should continue to focus on providing its customers with greater value at lower prices. It should listen seriously to customers' feedback and satisfy them in the most appropriate way. In addition, Instron should look for opportunities for improvement in product development, supply chain management, and manufacturing in order to reduce the response time and price for customer orders while continuing to increase product and service quality. We always need to keep in mind the importance of specifying the value of our product and service from the standpoint of the end customer.

5.4.2. Lean Approach to Product Development

The big improvement in this function should focus on increasing collaboration with customers, manufacturers, and suppliers. There is so much value that can be obtained from these collaborative processes. By engaging customers in them, designers can satisfy their requirements for the product the first time, and thus eliminate design changes late in the design process when they can be very expensive. Designers also can recognize market's trends early, which helps to refocus technology and innovation on issues that are important in the marketplace and to accelerate time-to-market.

By including manufacturing people in the product development team, the designers will have a great resource in manufacturability issues; thus, their product designs can be manufactured easily and can meet targeted quality, reliability, cost, and schedule goals. They can also reduce costly late engineering change orders, facilitate ramp-up to production, and increase the speed of the entire product development process. In addition, the collaboration will provide opportunities for improved modular assembly, cellular manufacturing, mass customization, or introduction of new technologies.

5.4.3. Lean Approach to Supply Chain Management

Instron has developed a large supply base over the years along with its volume growth and product proliferation. The problem with having so many suppliers is that the business volume shared among them is so small that very few good working relationships have been established. The company's buying power and influence are low with all of them. Purchasing decisions then have been made based primarily on price. The synergistic benefit of collaboration has rarely been obtained.

To improve supply chain management, Instron needs to consolidate its supply base, develop strategic partners, and implement more advanced technology in supply chain processes. By consolidating the supply base, Instron will have fewer and more dependable suppliers to deal with while, as their major customer, the company will have increasingly influential power on quality, price, and delivery schedule. The development of strategic long-term partners will allow Instron to fully understand its supplying partners' capabilities and to have frank discussions at all levels about technical, quality, cost, and capacity-planning issues. That smooth and open communication will permit better solutions for both sides, speed development and fulfillment operations, and produce savings to be shared.

Along with having a website for customers, Instron should continue to implement Internet technology to connect to its suppliers with each other and to incorporate bar coding in inventory control. The Internet and other supply chain advanced technologies will make it much easier and more effective to share information, exchange transactions, and accelerate business processes with suppliers. Great savings and process effectiveness are just some of the numerous benefits that can be received from these new technologies.

5.4.4. Lean Approach to Order Fulfillment

As a core component of Instron's supply chain, the order fulfillment/manufacturing business unit plays the very critical role of a driving force in the value creation process. To produce increasingly greater value at lower cost, Instron's manufacturing arm should focus more on lean manufacturing and better collaboration with engineers and suppliers in the order fulfillment cycle. The lean solution and approach presented in sections 5.2 and 5.3 are an excellent lean transforming process that can help the company quickly become leaner, and thus, more efficient. The application of five lean principles and value stream management in this approach would help the company to pursue a perfect continuous improvement cycle while eliminating more waste and inefficiencies. It would also permit lead times, setup times, and inventory levels to be significantly and steadily reduced. In addition, the effective collaboration with engineers will add value to the supply chain through better product designs that are easy to manufacture, test, and inspect, making them more compatible with existing equipment. Good collaborations with suppliers will help the company to lower costs by receiving high quality parts or materials on-time and utilizing suppliers' resources and expertise in product development and order fulfilment. The delivery of product to market will happen sooner, at lower cost, with more savings for all process partners, including manufacturer, supplier, and customer.

6. PILOT REPLENISHMENT MODEL

This chapter focuses on the materials replenishment model for the machine shop in Binghamton, New York. The first task is to determine the most economic lot sizes for each of the parts that the machine shop has been supplying to the EM final assembly line at the Canton plant. The current lot sizes of many parts supplied from Binghamton have been considered to be improperly calculated for the current demand level, and thus have not supported the desired build plan. The stock-out potential as well as the excess inventory situations have created unexpected rush orders and/or undesirable inventory levels. Besides, havoc demand has caused problems for production planning and productivity optimization. The capacity model was developed to provide answers to the lot-sizing issues.

In addition, the chapter will address three other basic inventory management questions:

1. How often should inventory levels be reviewed?
2. When should an order be placed?
3. What quantity should be ordered?

The inventory review frequency and the reorder point answer the first two questions. The last question is solved by the economic order quantity (EOQ) theory.

6.1. Capacity Model for Lot Sizes

Simply put, a lot size is the quantity that is either produced or purchased at a given time. In a lot-sizing decision, supply chain managers need to consider at least three kinds of costs:

- Unit cost or material cost is the average price paid per unit purchased. Buyers may increase lot size if there is a volume discount. However, in this pilot material replenishment model, the unit cost is the fixed standard cost of producing a unit at the machine shop in Binghamton.

- Ordering cost: Ordering cost for products purchased from an outside supplier typically include the cost of transmitting the order, the cost of receiving the product, the cost of placing it in storage, and the cost of processing the payment. Ordering cost for products made inside the company typically include the costs of processing the transfer request, the cost of setting up production to produce it, the cost of receiving it, and the cost of documentation. In the pilot project the ordering cost is the cost of setup times.
- Holding cost is the cost of keeping one unit in inventory for a specified period of time. It is the combination of the cost of capital, the cost of physically storing the inventory, and the cost that results from the product becoming obsolete. At Instron, the annual holding cost is estimated at 30 percent of product cost, which includes 15 percent of capital cost, 10 percent of storing cost, and 5 percent of disposition cost.[1]

To reduce only the holding cost, managers would decrease lot sizes and cycle inventory. However, in many cases managers have to increase lot sizes and cycle inventory to reap the benefit of economies of scale in purchasing or to reduce ordering cost. Therefore, when making a lot-sizing decision, a manager must make a trade-off between ordering cost and holding cost to minimize the total cost[2]. Figure 6.1. below illustrates the concept of cost trade-offs and the position of the economic order quantity.

[1] Wheeler, Daniel H., " Pulling a Job Shop into Supply Chain Management," Master's Degree Thesis, MIT Leaders for Manufacturing Program, June 2000.
[2] Chopra, Sunil and Peter Meindl, Supply Chain Management: Strategy, Planning, and Operation, Upper Saddle River, New Jersey: Prentice-Hall Inc., 2001, page 138-141.

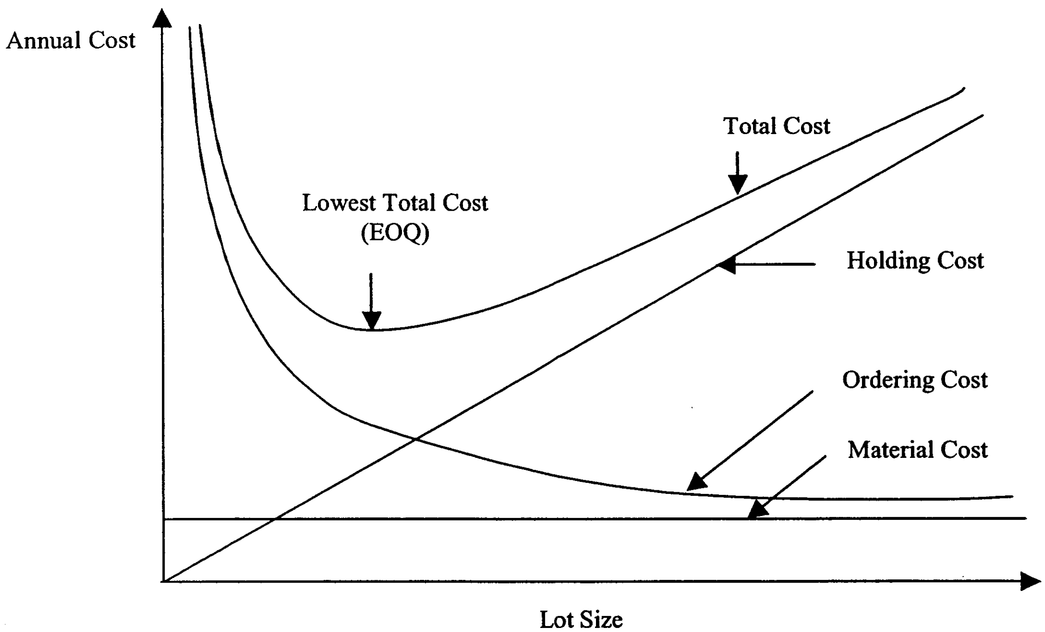


Figure 6.1. Cost Trade-offs in Economic Order Quantity

For any single part, the optimum lot size can be derived from the economic order quantity (EOQ) model as shown below.[1] The optimum lot size (Q^*) balances setup or ordering costs (K) with holding costs (hC) based on demand (D).

$$Q^* = \sqrt{(2 * K * D / hC)} \qquad [1]$$

For multiple parts, we can extend the model by evaluating demands and holding costs for different items, and the total machine time available. In addition, since we are in a production environment, we use setup times (A_i) rather than a ordering costs. The value of the setup time is the parameter λ. In optimization theory, the variable λ is known as the Lagrangian multiplier or the shadow price representing implicit cost of setup time.[2] The extended model is shown as follows with subscript i denoting the individual parts being considered :

[1] Simchi-Levi, David et al., Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies, NewYork, NY: The McGraw-Hill Companies, Inc., 2000, page 45.
[2] Wheeler, Daniel H., " Pulling a Job Shop into Supply Chain Management," Master Thesis, MIT Leaders for Manufacturing Program, June 2000.

$$Q_i = \sqrt{(2 * \lambda * A_i * D_i) / (h_i * C_i)} \qquad [2]$$

Our goal is to find all the lot sizes Q_i for every part that we are investigating. On the right side of the above equation we know all but λ. Thus, we need to find λ to calculate Q_i. To do this, we need some more known factors that relate to either λ or Q_i. Therefore, we name W as total machine hours available and set it equal to the sum of total setup times and total run times. This creates the third equation[1]:

$$\underbrace{W}_{\text{Total machine time available}} = \underbrace{\sum (A_i * D_i / Q_i)}_{\text{Total setup times}} + \underbrace{\sum (R_i * D_i)}_{\text{Total run times}} \qquad [3]$$

In the above equation, R_i is the machine run time for a specific part denoted by subscript i, and D_i / Q_i gives the number of lots built each year. We substitute Q_i in equation (3) by its value in expression (2) and solve for λ:

$$W = \sum (A_i * D_i) * \sqrt{h_i C_i / (2 * \lambda * A_i * D_i)} + \sum (R_i * D_i)$$

$$W = \sum (A_i * D_i) * \sqrt{h_i C_i / (2 * A_i * D_i)} * 1/\sqrt{\lambda} + \sum (R_i * D_i)$$

$$W - \sum (R_i * D_i) = \sum (A_i * D_i) * \sqrt{h_i C_i / (2 * A_i * D_i)} * 1/\sqrt{\lambda}$$

$$[W - \sum (R_i * D_i)] * \sqrt{\lambda} = \sum (A_i * D_i) * \sqrt{h_i C_i / (2 * A_i * D_i)}$$

[1] Wheeler, Daniel H., " Pulling a Job Shop into Supply Chain Management," Master Thesis, MIT Leaders for Manufacturing Program, June 2000.

$$[W - \sum (R_i * D_i)] * \sqrt{\lambda} = \sum \sqrt{h_i C_i * A_i * D_i / 2}$$

We obtain the result shown below:

$$\lambda = \left(\frac{\sum \sqrt{h_i C_i * A_i * D_i / 2}}{W - \sum (R_i * D_i)} \right)^2 \qquad [4]$$

When we know λ, we can calculate all of the lot sizes[1]. In the following examples, we define the efficiency as the ratio of the total setup times and run times needed for the calculated lot sizes over the total available machine time. In solving for λ, to deal with unexpected conditions, one may want to target an efficiency lower than 100%. For the Yam machine cell used in the analysis, the targeted efficiency, based on operator's experience, was about 85%.

Figure 6.2. shows the results of the analysis of 13 parts produced at Instron's machine shop in Binghamton, New York.[2] These lot sizes were calculated based on the extended EOQ model described above and the assumptions listed on the upper left corner of the figure:

- Holding cost is 30 percent of product cost
- Hours Machine/Year: 4,160 hours, resulted from the product of two shifts per day and 40 hours per week per shift and 52 weeks a year.
- The machine was assumed to run at 95 percent of total time during the year. The other 5 percent of time was reserved for machine maintenance or unexpected breakdowns.

The Lagrangian multiplier (λ) value in this analysis is 0.33. The efficiency is 84.3%. This value is fairly good considering the existing status of the Yam cell at the machine shop in Binghamton, New York.

[1] Rosenfield, Don B., advisor to the internship, June-December 2001.
[2] Actual figures in Table 6.1. and 6.2. are made-up for illustrative purposes only.

Holding Cost	30%
Hours/Month	347
Hours/Year	4,160
Available	0.95
Avail hours, W	3,952

Lagrange Multiplier	Avg. Lot Size	Total Lots	Total Units	Efficiency
0.33	1.63	621	1,010	84.3%

Item	Annual Demand	Setup Time	Run Time	Std Cost	Holding Cost	Tot Run Time	Lot Size Factor	Assy Lot Size	Lots / year	Tot Setup	Tot Time
i	Di	Ai	Ri	Ci	hiCi	DiRi		Qi			
	units	hrs/lot	hrs/unit	$	$	hrs		units		hrs	hrs
1	200	2.00	1.90	288	86	380	131	2	100	200	580
2	50	2.00	3.50	435	130	175	81	1	50	100	275
3	55	2.00	3.00	1,166	350	165	139	1	55	110	275
4	30	2.00	1.50	1,220	366	45	105	1	30	60	105
5	150	2.00	0.40	48	14	60	46	4	38	75	135
6	220	2.00	1.70	233	70	374	124	2	110	220	594
7	30	5.00	4.40	464	139	132	102	1	30	150	282
8	60	1.00	1.50	1,244	373	90	106	1	60	60	150
9	30	1.00	1.50	1,244	373	45	75	1	30	30	75
10	10	1.00	7.00	1,337	401	70	45	1	10	10	80
11	55	5.00	4.40	466	140	242	139	1	55	275	517
12	100	3.00	0.70	71	21	70	57	3	33	100	170
13	20	3.00	1.60	182	55	32	40	1	20	60	92
Total	1,010					1,880	1,189	20	621	1,450	3,330

Table 6.1. Part Lot Sizes based on Capacity Model

The capacity model is useful as what-if analyses to estimate the effect of certain factors on the lot sizes of these parts or the utilization of the machine's capacity. For example, we can also see the effect of setup time reduction on lot sizing by replacing the original setup times with the reduced ones. If we can reduce setup time by one-half, then the number of lots per year increases from 621 lots per year in the base case to 860 lots per year. Then the lot sizes become smaller, representing a leaner, more flexible production flow.

Holding Cost	30%
Hours/Month	347
Hours/Year	4,160
Available	0.95
Avail hours, W	3,952

Lagrange Multiplier	Avg. Lot Size	Total Lots	Total Units	Efficiency
0.16	1.17	860	1,010	72.2%

Item	Annual Demand	Setup Time	Run Time	Std Cost	Holding Cost	Tot Run Time	Lot Size Factor	Assy Lot Size	Lots / year	Tot Setup Time	Tot Time
i	Di	Ai	Ri	Ci	hiCi	DiRi		Qi			
	units	hrs/lot	hrs/unit	$	$	hrs		units		hrs	hrs
1	200	1.00	1.90	288	86	380	93	1	200	200	580
2	50	1.00	3.50	435	130	175	57	1	50	50	225
3	55	1.00	3.00	1,166	350	165	98	1	55	55	220
4	30	1.00	1.50	1,220	366	45	74	1	30	30	75
5	150	1.00	0.40	48	14	60	33	3	50	50	110
6	220	1.00	1.70	233	70	374	88	1	220	220	594
7	30	2.50	4.40	464	139	132	72	1	30	75	207
8	60	0.50	1.50	1,244	373	90	75	1	60	30	120
9	30	0.50	1.50	1,244	373	45	53	1	30	15	60
10	10	0.50	7.00	1,337	401	70	32	1	10	5	75
11	55	2.50	4.40	466	140	242	98	1	55	138	380
12	100	1.50	0.70	71	21	70	40	2	50	75	145
13	20	1.50	1.60	182	55	32	29	1	20	30	62
	1,010					1,880	841	16	860	973	2,853

Table 6.2. Part Lot Sizes with Reduced Setup Times

6.2. Inventory Review Frequency

Instead of a periodic review system, the Electro-Mechanical Business Unit has been choosing a continuous inventory review policy because it significantly reduces potential inventory stock outs while requiring less safety stock and thus lowering inventory carrying costs. Manufacturing operators and materials handling personnel have the responsibility of carrying out the review on a continuous basis. In the currently implemented Kanban system at both sites, Canton and Binghamton, each stocked part has been placed at a specifically designated location or in bins with a Kanban card on which the minimum quantity (which is the reorder point) for that part is written. Whenever the operators or materials handlers see the minimum quantity of any stocked part is reached, they pull the card from the stock location and place it in an order bin, which will trigger the purchasing department or planners to order another lot of that part on the same day.

6.3. Determining the Reorder Point (ROP)

Since we can characterize Instron's manufacturing strategy was assemble-to-order and the ordering process between Canton plant and Binghamton machine shop as one with multiple order opportunities and fixed order costs, the inventory policy that should be used is a (s, S) policy, in which the reorder point (s) is different from the order quantity, or more correctly speaking, the order-up-to-level quantity (S)[1].

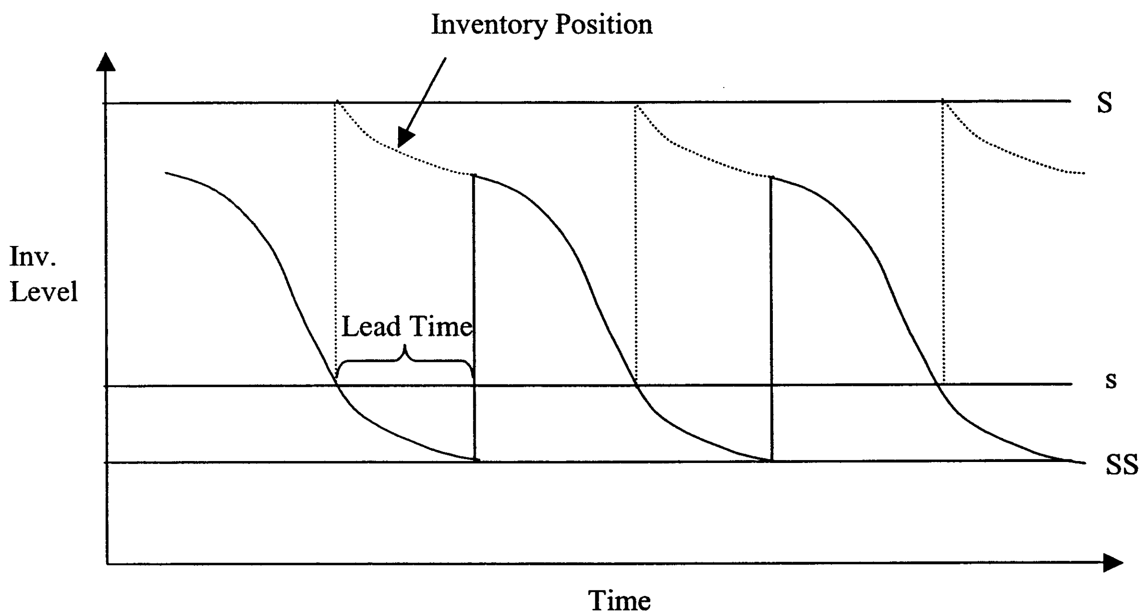


Figure 6.2. (s, S) policy with multiple order opportunities

The reorder point (s) is the sum of the average demand over the lead time (DOLT) and a level of safety stock (SS).

$$\text{ROP} = \text{DOLT} + \text{SS} \qquad [5]$$

The average demand over lead time (DOLT) is the average manufacturing demand over the vendor's supply lead time. DOLT is simply acquired by multiplying the average demand per a given time unit (m) with the lead time (LT):

[1] Simchi-Levi, David et al., Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies, NewYork, NY: The McGraw-Hill Companies, Inc., 2000, page 51-55.

$$DOLT = (m) * (LT) \quad [6]$$

Demand per given time (m) can be either the average forecasted demand or the average historical demand. The lead time (LT) is the time it takes a vendor to supply the manufacturer with a new lot of materials. If a vendor has the requested inventory stocked in his or her warehouse, then this is simply the time to order and ship product to the manufacturer. If a vendor has to build the lot before he or she can ship to fulfill the order, then the lead time is defined as the time it takes the vendor to manufacture the parts and the time for ordering and shipping.

To provide a buffer against the variability of demand, which frequently happens, a safety stock (SS) must be added to the reorder point equation. Safety stock is calculated based on the statistical probability that demand could be higher than average. It includes the standard deviation of demand (σ) over a chosen time period and a desired service level representing the probability that the parts are available for demand. Instron management agrees that service levels between 95 percent and 97.5 percent are reasonable; with stock-outs happening once for every 20 to 40 orders on average. This probability is then translated into a z-statistic value corresponding to a normal distribution at the given probability level. The safety stock (SS) is then calculated as follows:

$$SS = \sigma * z * \sqrt{LT} \quad [7]$$

6.4. Determine the Order Quantity

The value of the order-up-to-level, S, is calculated based on the Economic Order Quantity (EOQ). As presented above, the economic order quantity Q is determined as follows:

$$Q = \sqrt{(2 * A * D / hC)}$$

In which:

- A is the ordering cost, estimated $20 at Instron
- D is annual average demand for a specific part

- h is the holding cost expressed as a percentage, estimated at 30 percent annually for Instron
- C is material or part cost

Then, the order-up-to-level[1] is:

$$S = \max\{Q, m^*LT\} + SS \qquad [8]$$

Or:

$$S = \max\{Q, m^*LT\} + (\sigma * z * \sqrt{LT})$$

where max means to take the maximum of order quantity Q or (m*LT).

6.5. Examples of Calculation

I provide an example in this section to illustrate how to calculate the reorder point (s), the order quantity (Q), and the order-up-to-level (S) using the provided equations. In practice, we can create an Excel template to obtain these values conveniently.

Table 6.4. and Table 6.5 shows the monthly usage and some necessary inventory parameters of a part X:[2]

MONTH	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
DEMAND	9	21	33	12	17	27	16	8	35	13	19	30

Table 6.4. Monthly Demand of Part X

[1] Simchi-Levi, David et al., Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies, NewYork, NY: The McGraw-Hill Companies, Inc., 2000, page 51-55.

[2] Actual figures in Table 6.4. and 6.5. are made-up for illustrative purposes only.

INVENTORY PARAMETERS	VALUE
Standard Unit Cost (C)	$300.00
Ordering Cost (A)	$45.00
Holding Cost (h)	30%
Total Demand in Year 2000 (D)	240
Monthly Demand Average (m)	20
Monthly Demand St Dev. (σ)	9.30
Supply Lead Time (LT)	30 days
Desired Service Level	97.5 %
z-value (z)	1.96

Table 6.5. Inventory Parameters for Part X

With provided information, we can find all the values as follows:

DOLT = (m) * (LT) = (20 units/mo.*12mo./365days) * 30 days = 19.80 units

SS = $\sigma * z * \sqrt{LT}$ = $9.3 * 1.96 * \sqrt{30/30}$ = 18.20 units

s = ROP = DOLT + SS = 19.80 + 18.20 = 38.00 units

Q = $\sqrt{(2 * A * D / hC)}$ = $\sqrt{(2 * 45 * 240 / (.30*300))}$ = 15.50 units

As DOLT = 19.80 units > Q = 15.50 units, then:

S = DOLT + SS = 19.80 + 18.20 = 38.00 units

From these calculations, we see that there are four factors that directly affect the reorder point (s), which is considered as the minimum inventory level. These are the demand average, the demand variability, suppliers' lead times, and targeted service level. Usually, we don't want to reduce the desired service level and cannot control the demand average. However, if we can somehow reduce the suppliers' lead times as well as streamline the demand, then we can significantly reduce the level of the reorder point, then also the overall inventory level, which will lead to increased inventory turns and cost savings. For example, if we have another part with almost similar parameters, except the lead time and demand variation are about 50 percent of the former, say, the lead time now is 15 days, and the demand standard deviation is 4.65, then we have the results as follows:

$$DOLT = (m) * (LT) = (20 \text{ units/mo.}*12\text{mo.}/365\text{days}) * 15 \text{ days} = 9.90 \text{ units}$$

$$SS = \sigma * z * \sqrt{LT} = 9.3 * 1.96 * \sqrt{15/30} = 6.40 \text{ units}$$

$$s = ROP = DOLT + SS = 9.90 + 6.40 = 16.30 \text{ units}$$

$$Q = \sqrt{(2 * A * D / hC)} = \sqrt{(2 * 45 * 240 / (.30*300.00))} = 15.50 \text{ units}$$

As $DOLT = 9.90$ units $< Q = 15.50$ units, then:

$$S = Q + SS = 15.50 + 6.40 = 21.90 = 22.00 \text{ units}$$

With the 50 percent reduction in demand variation and supply lead time, the reorder point level is reduced more than 57 percent, and the order-up-to-level is also cut down by 42 percent. By implementing the lean supply chain approach introduced in Chapter 5, Instron can gradually streamline its production - which would level its demand, and increase collaboration with its suppliers to influence the lead time reduction.

7. RESULTS AND RECOMMENDATIONS

This internship project provided great opportunities for academic research and business improvement practice. This chapter presents the results in both areas. The academic results include the successful application of various management tools for problem identification, value chain analysis, and solution implementation. The business results consist of a thorough root-cause analysis, a set of recommendations on lean supply chain management, and a pilot replenishment project for Instron's machine shop in Binghamton, New York. The thesis concludes with important recommendations for future improvements.

7.1. Academic Results

Instron's manufacturing and business environment provided an ideal setting for utilizing advanced academic knowledge in the real manufacturing world. By comparing the management theory and on-site practice, I gained a great deal of valuable learning and made insightful discoveries during the internship process. These value-adding lessons could not be better learned in any other setting.

The successful application of many management tools including the LP method, Ishikawa analysis, and process mapping, established a sound approach for a thorough root- cause analysis and concurrently helped me to develop a better understanding of the logic and purpose of these tools. The interviews with managers and executives as well as group discussions helped me to learn how a business strategy or process was considered, developed, and implemented in a real business environment. The internship project also gave me a good chance to observe the dynamic interactions within an organization using the three-lens approach introduced in the Organizational Process class at the Sloan School of Management: (1) strategic design lens, (2) political lens, and (3) cultural lens.[1] The value chain analysis and the supply chain application reinforced my understanding of capacity management, inventory management, and the interactions and tradeoffs between determining factors such as order costs, holding costs, setup costs, lot sizes, etc.

The most valuable discovery was the possibility of extending the lean principles into Instron's non-manufacturing areas, including product development, customer relationships, order fulfillment, and supply chain management. This new approach has provided a more feasible and sustainable process to lean transformation, which would significantly improve the company's competitive advantages. However, it's important to understand that this process requires a substantial amount of learning, commitment, and involvement by the executives, managers, and employees, as well as from outside partners.

7.2. Results at Instron

This internship project involved multiple potential improvements to the operation performance and supply chain practices at Instron ElectroMechanical Business Unit. First of all, the 360-degree interview combined with the LP and Ishikawa analyses provided Instron management with a complete root-cause analysis and a big-picture perspective for improvement initiatives. In addition to an exhaustive list of all related problems, the analysis also showed the interactions and cause-and-effect relationship of these factors. This led to the development of a logical action plan that could help the management to prioritize improvement efforts and, step-by-step, to conduct these initiatives effectively. For example, responding to the issue of insufficient supervisory resources, the management quickly promoted a product manager who has streamlined many production problems.

The value chain analysis revealed many simple truths in Instron's supply chain. It provided the company with a clear, simple, and useful understanding of the three most critical components of its supply chain: products, customers, and suppliers. For example, the product structure analysis showed the great engineering strength in modular design. Instron management should take more advantage of the substantial commonality of parts among many different Electro-Mechanical testing models in order to reduce inventory levels and create more

[1] Ancona, Deborah et al., Organizational Behavior & Processes, Cincinnati, Ohio: South-Western College Publishing, 1999, M2, page 1-97.

flexibility for its manufacturing strategy. Concurrently, the analysis also showed that the collaboration between engineering and manufacturing was rather insignificant. Both sides rarely used the expertise of the other group to enhance their own performance or to create more value for Instron's products and processes. The supply base analysis combined with supply value distribution studies revealed insightful paths and focal points for future cooperation with supply partners.

The set of recommendations on lean supply chain management presented Instron management with a more radical option for lean transformation, which has been considered as one of the most effective and sustainable processes to strengthen a company's leading position and competitive advantages. In addition, the assessment and suggested roadmap on lean perspectives provided Instron with a more structured way to accelerate the desired improvement.

The practical contribution of the project was the development of a simple yet effective material replenishment model that will allow the company to compute the right lot sizes, reorder points, and order quantities. The model provides the appropriate economic lot sizes by balancing the setup costs and holding costs. Consequently, this will improve the overall on-time delivery performance, the bottom-line, and customer satisfaction. Regrettably, the length of the internship prevented me from fully implementing the pilot model and observing the end results. However, based on calculations, the implementation of this pilot replenishment model is expected to increase significantly parts availability and machine utilization, while reducing inventory levels from five to ten percent (see Table 7.1. below[1]).

[1] Proprietary data is disguised to protect Instron's competitive information. These actual figures in Table 7.1 are for illustrative purposes only.

Potential Stock outs

				CURRENT			RECOMMENDED		
PARTS	Annual Demand	STD COST	Monthly Demand	Order Quantity	COST	ROP	OQ	COST (S)	ROP
A563-110	49	1018	4	8	8244.99	4	5	4890.72	4
A563-118	319	289	27	16	4676.454	8	30	8583.65	30
A563-119	73	438	6	8	3549.177	4	8	3453.69	7
T563-2	319	240	27	16	3885.57	8	30	7149.29	30
T563-11	328	48	27	16	771.444	8	42	1981.53	31
T563-60	73	473	6	8	3834.459	4	7	3177.43	7
T563-66	142	72	12	16	1168.992	8	21	1524.57	13
T563-282	49	471	4	8	3816.234	4	6	2899.73	4
A581-15	494	332	41	65	21494.16	32	46	15297.47	46
T581-41	347	31	29	65	1995.192	32	51	1581.55	32
				Total	**53436.672**		Total	**50539.61**	
							Reduction	**2897.06**	
							% Reduction	**5.42%**	

Oversupplied

Inventory Reduction

Table 7.1. Some Benefits of the Pilot Project for Instron's Machine Shop

Last but not least, the project delivered a documented frame-work for achieving similar improvements in Instron's other product lines.

7.3. Recommendations

The benefits of being lean are sustainable and significant in helping a company to improve its competitive advantages. The lean supply chain approach introduced in this thesis is a combined strategic and operational method that can help the company successfully transform into a lean enterprise and also expand the lean status to the whole supply chain. To accelerate the current improvement process and ensure long-term success, Instron Corporation should definitely follow this evolutionary path. A three-point plan has been recommended as follows:

- Strengthen the current business by removing all non-value adding waste.

- Redefine the value proposition to provide customers with better values.
- Collaborate with customers and suppliers to optimize the entire value stream[1].

The recommended process is to focus on each product family and its value stream, then eliminate activities that do not add value and streamline the remaining ones. The most crucial issue is the notion of value and waste. In the lean approach, we need to specify value through the eyes of customers, not from the perspective of the company, departments, or functions. Value is truly what the end-customer is willing to pay for, whereas waste is an element of the supply chain that adds time, effort, and cost, but no value.

The next important step is to clearly design and build a long-term strategy to provide customers with increasingly cost-effective, hassle-free, and improved quality solutions. In the competitive market, customers will only stay with the company that understands and better addresses their needs.

As collaboration is the current trend in today's business, people have stopped thinking of business deals as zero-sum games. They have started to see win-win solutions in collaboration, "to expand the pie," as people usually say and hope in their supply chain integration. The last point reminds the management of the synergy of early collaboration with customers and suppliers that will accelerate the lean transforming process and optimize the whole value stream, leading to the savings being shared among all supply chain partners.

7.4. Conclusion

In summary, the internship project and this thesis made me realize that an isolated improvement effort can achieve very limited effects, especially in the complex and competitive environment of today's business world. To improve the on-time delivery performance of the Electro-Mechanical Business Unit, Instron's management should pursue a more radical and broader approach that can ensure the correction of a problem from its root causes and be able to sustain the improvement for future successes. Lean supply chain management is one of the best answers.

[1] Womack, James B., PowerPoint presentation "Lean Thinking for the Canadian Auto Industry: The Next Leap," in Ontario, Canada, on 04/12/2000.

APPENDICES

A The Complete LP Analysis

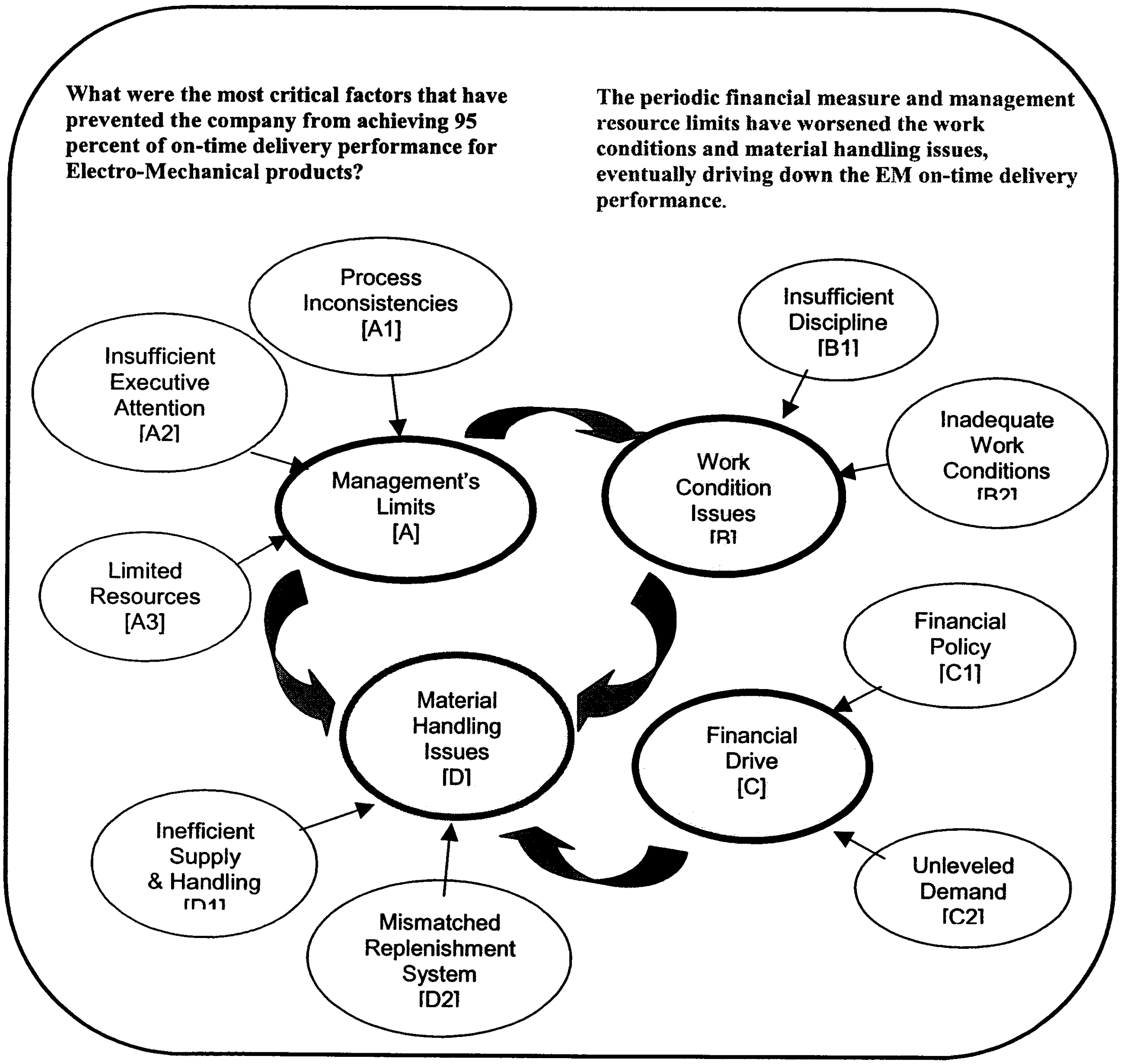


Figure A.1. Simplified LP Analysis of EM Late Delivery Problem

[A]. EM HAS LIMITATIONS IN HANDLING ITS OPERATION ISSUES

[A1]. EM HAS NOT FULLY SUCCEEDED IN IMPLEMENTING AND SUSTAINING PROGRESSIVE MANUFACTURING PROCESSES		
a) INSTRON MANAGEMENT (LOW & MIDDLE LEVELS) DOES NOT HAVE ALIGNED VISION ON MANUFACTURING PROCESSES	b) NEW PROCESSES ARE USUALLY NOT SUSTAINABLE	c) EM IS NOT SUCCESSFUL IN IMPLEMENTING AND MAINTAINING DEMAND FLOW PROCESS
The EM pull system is working very well as volume is way down. However, any shift upward in production will magnify problems	Workers prefer old work methods due to insufficient trust or knowledge for new manufacturing processes	Linear process is not followed
There is a lack of proper education in management of kanban process	Due to time constraint, the knowledge transfer was not done efficiently in many previous internship projects	We continue to batch machines, which only extends our lead time
		Workers do batch production because they think it works better

[A2]. TOP MANAGEMENT HAS NOT PROVIDED SUFFICIENT NEEDED ATTENTION AND SUPPORT FOR MANUFACTURING ISSUES		
a) MANAGEMENT HAS NOT PAID SUFFICIENT SUPERVISION TO IMPROVE PRODUCTION PERFORMANCE	b) MANAGEMENT HAS NOT IMPLEMENTED AN EFFECTIVE CONTROL SYSTEM FOR PRODUCTION	c) MANAGEMENT HAS NOT DONE ADEQUATE STUDIES ON LATE DELIVERIES
On time performance is improved when management pays attention, but it drops when it's not the top priority	Instron has been lacking the right metrics which facilitate and anticipate when processes go astray	Order progress or status is not adequately tracked
There has not been sufficient supervisory resources to provide needed supervision and support to production	Instron has been lacking proactive measures/reports to give early warning messages to out-of-balance conditions	There has been no historical record on late deliveries
Supervisors do not always notify emerging problems early		Tracking order status daily is a difficult job

[A3]. EM CANNOT HANDLE EFFECTIVELY UNPLANNED SITUATION DUE TO ITS LIMITED RESOURCES		
a) EM CURRENTLY HAS MINIMUM WORK FORCE THAT CAN HARDLY DEAL EFFECTIVELY WITH THE UNEXPECTED	b) EM HAS NOT PREPARED SOME GOOD PLANS FOR UNEXPECTED SITUATIONS	c) IT'S HARD FOR EM TO MANAGE ONE-SHOTS OR CUSTOM ORDERS ON TIME
Current low employment has caused labor constraint when dealing with unexpected needs	Unexpected problems often cause deviations from work	Custom designs are usually late, which causes chain delay in production processes
There has been capacity constraint due to unexpected labor shortages	Order are often changed at the last minute, negatively impacting delivery performance due to lack of materials or accessories we don't plan for	One-shots regularly run late
It may take 2 or 3 weeks to catch up with 1 week delay due to labor shortages		

[B]. EM HAS ISSUES IN WORK CONDITIONS AND DISCIPLINE

[B1]. INSTRON HAS A SOFT HAND ON WORK DISCIPLINE		
a) INSTRON HAS LACKED A CONSISTENCY OF PROCESS ACROSS BUSINESS UNITS	b) PEOPLE DON'T ALWAYS HAVE A CONSISTENT CONCERN FOR GETTING THING DONE IN A TIMELY MANNER	c) INSTRON'S MANAGEMENT DOES NOT STRICTLY REQUIRE WORKER TO FOLLOW NEW IMPLEMENTED PROCESSES
Planners do not always look into parts that show both in stock and on shortage	Stock room people do not always draw jobs from stock room on time	Workers tend to do things the way they like to do because there is no penalty for doing so
Buyers/Planners have their own forms or ways to communicate with suppliers	Buyers/Planners do not always send parts out for finishing in a timely manner	Workers can freely arrange their work as long as they meet deadline
Both planners and workers don't like to change their own way of doing things	Planners do not always complete MRP jobs on time	

[B2]. **INSTRON HAS A LIMITATION ON WORK CONDITIONS**		
a) INSTRON HASN'T HAD AN EFFECTIVE INCENTIVE SYSTEM	b) INSTRON HAS BORE RISKS USING OBSOLETE AND INEFFICIENT EQUIPMENT	Workers don't have enough proper tools
Bonus cutoff has lowered workers' morale and their motivation for work	Inadequate preventive maintenance may cause unexpected capacity constraint at Binghamton machine shop	
There is now no incentive system in place except overtime	The equipment that we depend upon is old and was poorly maintained for many years	
	It takes longer than it should to run a test because the testing computers are slow	

[C]. TO ACHIEVE ITS PERIODIC FINANCIAL GOALS, INSTRON HAS SUFFERRED FROM ITS SELF-CREATED UNLEVEL DEMAND FLOWS

[C1]. **EM HAS BEEN STRUGGLING WITH UNLEVEL DEMAND**		
a) DEMAND FLUCTUATION CAUSES DIFFICULTY FOR BOTH MANUFACTURING AND MATERIAL HANDLING	Lack of order causes problems in fully utilizing and allocating production capacity	Incoming order product mix is different from quarterly forecasted product mix
Spikes and shifts in product mix severely affect machining capacity within the cell		
Non-linear pulls create havoc in machining cell with define capacity and maintenance issues		
Some raw materials require long lead times and consistent demand. Both non-linear pulls and the build spikes affect the availability of these materials		

[C2].		
a) DEMAND FLUCTUATION CAUSES DIFFICULTY FOR BOTH MANUFACTURING AND MATERIAL HANDLING	Instron has offered large variation of testing models to meet most of customers' needs	
We don't focus on daily output. Our emphasis tends to be weekly, monthly, or quarterly goals		
Quarterly financial goals drive EM management to ship as much as it can by quarter ends		
Booking is highly inflated by the end of quarters due to sales effort to achieve or exceed quarterly financial goals		

[D]. EM HAS BEEN STRUGGLING WITH ITS MATERIAL REPLENISHMENT ISSUES

[D1]. EM HAS HAD SERIOUS PROBLEMS IN METERIAL SUPPLYING AND HANDLING		
a) LATE PARTS HAVE CAUSED THE MAJORITY OF PRODUCTION AND SHIPMENT DELAYS	b) UNQUALIFIED PARTS HAVE CAUSED DELAYS FOR PRODUCTION AND SHIPMENT	c) EMPLOYEES DO NOT ALWAYS HANDLE MATERIAL ISSUES IN A TIMELY ISSUES
Purchased parts don't come in on time	Material shortages due to quality issues	Stock room or material handler does not proceed rejects in a timely manner
Quite often a frame is ready to ship, but we have to wait for an accessory from LTD or another supplier	Tooling Units parts get rejected regularly	Stock room or material handler does not make stock adjustment in a timely manner
Part stock-outs delay production and on-time shipment		Rejected parts don't get repaired quickly enough

[D2]. CURRENT INSTRON'S REPLENISHMENT SYSTEM DOES NOT WORK EFFECTIVELY IN CURRENT MARKET CONDITION		
a) CURRENT LOT SIZES ARE NOT APPROPRIATE FOR CURRENT DEMAND CONDITION	b) CURRENT REPLENISHMENT SYSTEM DOES NOT INCORPORATE PART LEAD TIMES VERY WELL	Low inventory level can't support production efficiently when there are material problems
Lot sizes do not support build plan	Current reorder points do not incorporate proper supplier lead times	
Improper lot sizes and reorder points lead to stock out conditions	Low inventory level and long lead time parts lead to frequent stock outs when demand suddenly goes up	
Lot sizing needs to be reviewed and adjusted for today's sales forecasts		

B The Complete Ishikawa Analysis

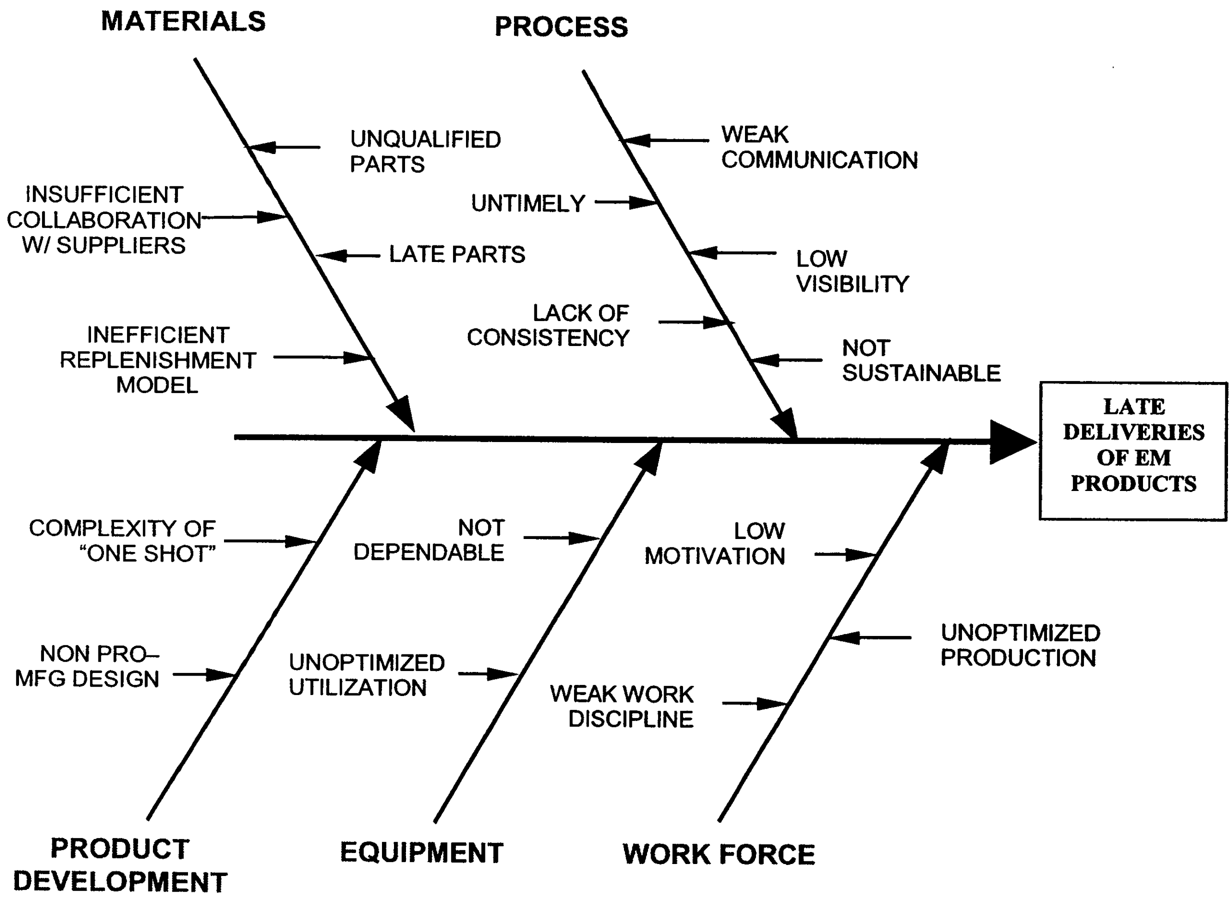


Figure B.1. Simplified Fishbone Diagram

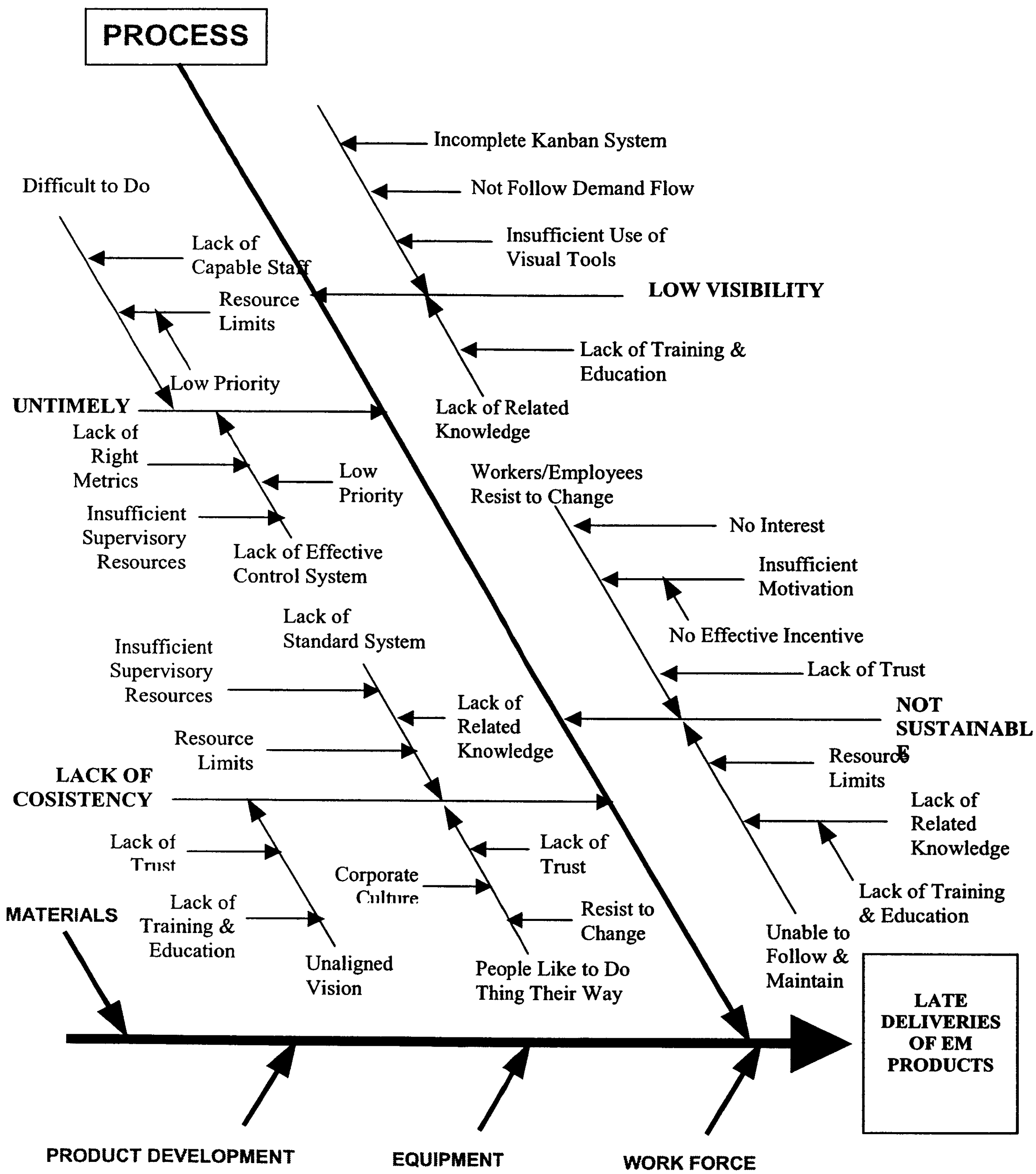


Figure B.2. Details of Process Analysis

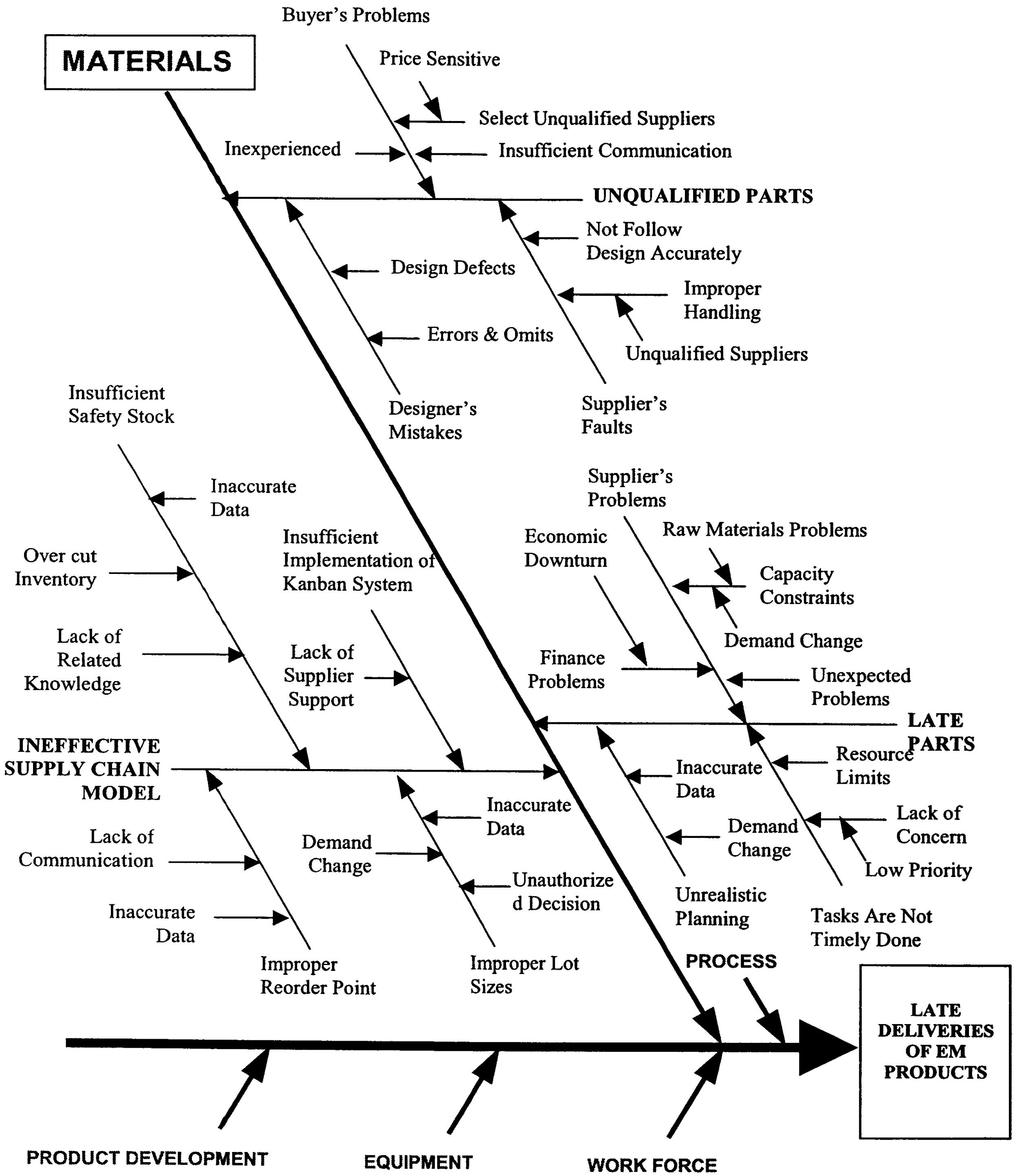


Figure B.3. Details of Materials Analysis

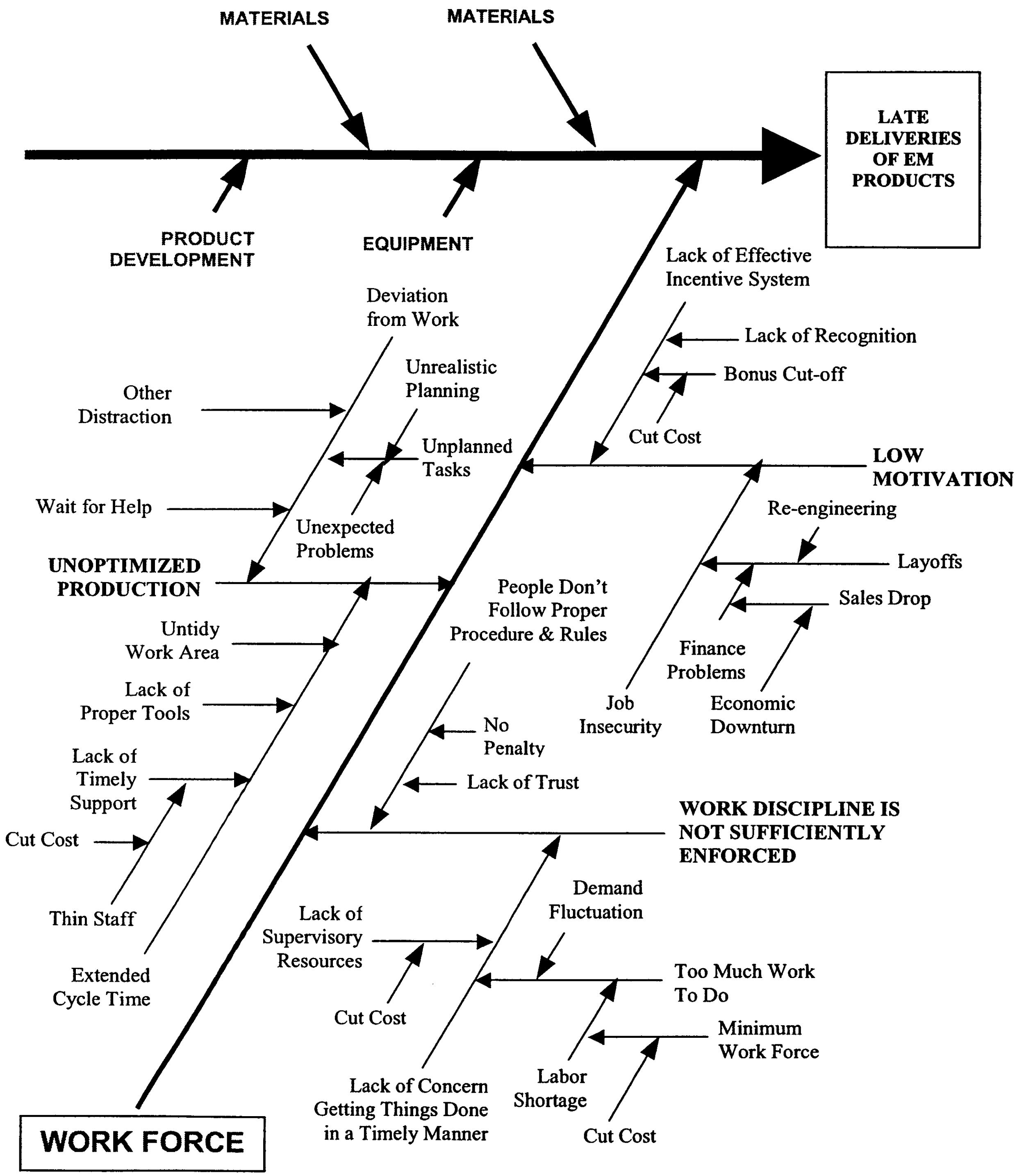


Figure B.4. Details of Work Force Analysis

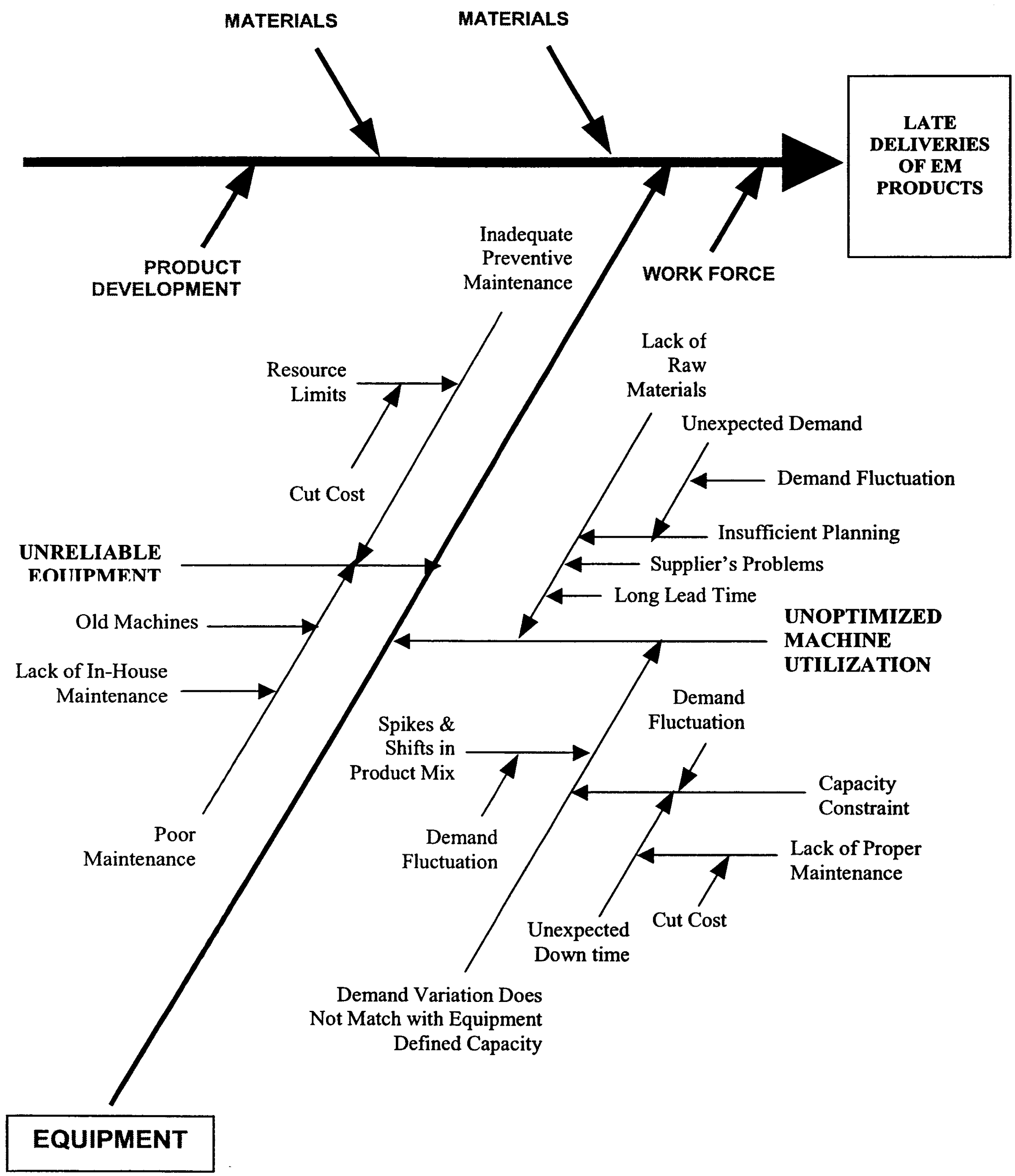


Figure B.5. Details of Equipment Analysis

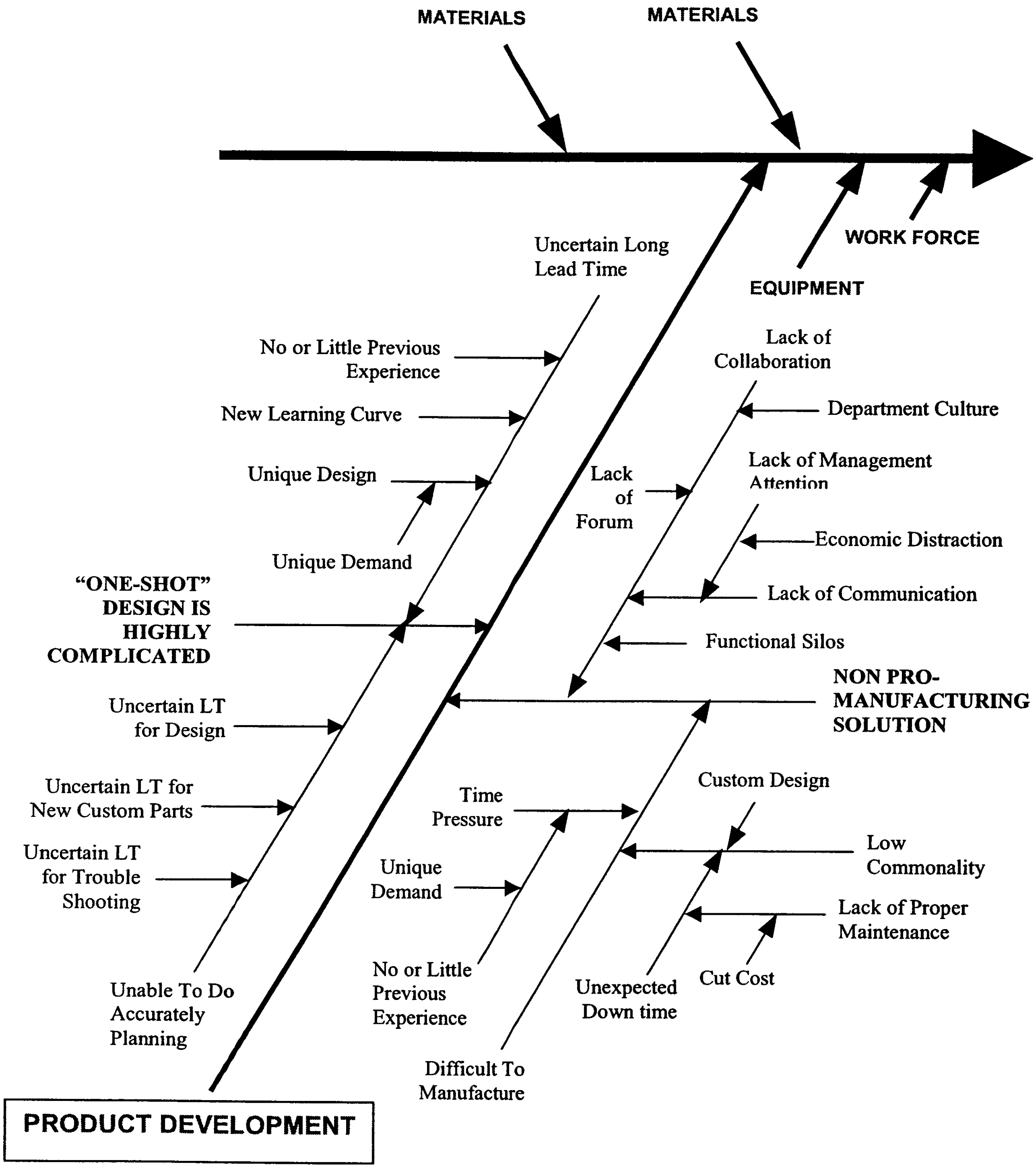


Figure B.6. Details of Product Development Analysis

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