Implementation of Lean Manufacturing in a Remote Manufacturing Facility

by

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B.S. Mechanical Engineering, Rutgers University, 1987

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

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ABSTRACT

Flexible manufacturing and lean manufacturing are important strategies for companies to succeed in increasingly competitive markets. Flexible manufacturing systems increase the company's ability to respond to customer demands more rapidly and lower finished good inventory levels at the distribution center. This thesis examines the difficulties involved in implementing a flexible manufacturing strategy in a remote location.

Implementing flexible manufacturing in a remote location requires a complete examination of the different manufacturing processes required to deliver a product to the consumer. Each piece of the manufacturing chain must be flexible in order to realize the advantages of a flexible manufacturing system.

A remote manufacturing location has different constraints than a local facility. The objective of this thesis is to analyze the limits of manufacturing flexibility at a remote location.

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1. Introduction

Flexible manufacturing and lean manufacturing are important strategies for companies to succeed in increasingly competitive markets. Flexible manufacturing systems allow companies to respond to customer demands more rapidly and hold lower finished good inventory levels at their distribution centers. This thesis examines the difficulties involved in implementing a flexible manufacturing strategy in a remote location and builds a model to analyze the effects of an increase in the transportation flexibility.

A remote manufacturing location is faced with different constraints than a local facility. The objective of this thesis is to describe the limits of transportation flexibility at a remote location. A model is developed to determine how this decision impacts the finished good inventory levels at the distribution centers and the finished good production requirements at the plant.

1.1. Thesis Overview

Implementing flexible manufacturing in a remote location requires a complete examination of the different manufacturing processes required to deliver finished good products to the consumer. Each piece of the manufacturing chain must be flexible in order to take full advantage of a flexible manufacturing system. This includes flexibility in the transportation system used to deliver raw materials to the plant and finished good inventory to the distribution centers. In the case of a remote location, the transportation system may be the activity preventing the remote location from attaining the benefits of flexible manufacturing.

Transportation flexibility is measured by the shipping frequency of finished good inventory from the plant to the distribution centers. Finished good inventory at the
distribution centers, production requirements at the plant and the resulting finished good inventory held at the plant between shipments are calculated for different shipping frequencies. These quantities are converted into finished good opportunity costs, resulting in a tradeoff between operational costs and shipping frequencies. The model will also assist in defining how the decision to create a flexible manufacturing strategy can affect the various levels in the organization.

Manufacturing locations wishing to compete in the global market are faced with the difficult task of attaining flexibility throughout their manufacturing processes. The purchase of flexible equipment is a start, but other parts of the manufacturing process require the remote manufacturing location to extend their efforts to make the entire manufacturing system flexible. Given flexible production lines, the model presented here, indicates that the benefits of lean manufacturing are constrained by the transportation system. The results conclude that an opportunity for lower finished good inventory requirements exist with an increase in the shipping frequency.

This thesis is the result of a seven month internship at Johnson & Johnson Consumer Products Incorporated. The remote manufacturing facility studied is a plant located in Puerto Rico.

1.2. Thesis Format

Chapter 2 describes the company background and a brief history of the remote manufacturing location analyzed. Chapter 3 is a description of the remote manufacturing location and its transition towards lean manufacturing. Chapter 4 presents a model designed to examine the effects of transportation flexibility on the company. Chapter 5 is a brief discussion of the effects of these decisions on the organization and Chapter 6 summarizes the conclusions.
2. **Company Background**

2.1. **Background on Johnson & Johnson**

In order to better understand the factors affecting the implementation of lean manufacturing in a Johnson & Johnson decentralized culture, we must first examine how Johnson & Johnson is organized. The Johnson & Johnson family of companies employs approximately 82,000 people worldwide and manufactures and sells a wide range of health care products. The company is organized on the principles of decentralized management under three sectors.

2.1.1. **Three Sectors**

The business is structured around three sectors, each focusing on a customer or product market. The three sectors are professional and diagnostic equipment, pharmaceutical products, and consumer products. The professional and diagnostic sector concentrates on products whose customers are mostly surgeons or specialty doctors. The pharmaceutical sector is the most profitable as shown in Figure 1 and includes products prescribed by health care professionals in such areas as dermatology and immunobiology. The consumer sector is the company's largest segment by sales as shown in Figure 2. This sector concentrates on toiletries and hygienic products marketed directly to the general public (Johnson & Johnson, 1991).
2.1.2. Decentralization Philosophy and Credo

The decentralized nature of Johnson & Johnson enables the individual companies to concentrate on their local operations while maintaining intrinsic core values of Johnson & Johnson embodied in the company's Credo. The Johnson & Johnson Credo serves as the backbone of values by which all operating companies shape their future. The Credo which categorized the company's social responsibility is shown in Appendix A.

The credo states that the company's first responsibility is to the customers who use its products; the second responsibility is to the employees of the company; the third
responsibility is to its community and environment; and the fourth is to the stockholders. The concept of the credo is, if the first three responsibilities are met then the stockholders will also be satisfied. The credo is a tool used by Johnson & Johnson to tie together the decentralized company (Johnson & Johnson, 1989).

At every Johnson & Johnson location, whether the company is a new start up or an older, well established company, visitors immediately confront the Johnson & Johnson Credo at the main entrance. Even though the company is decentralized, the Credo is the constant reminder to the individual autonomous site of what the values for the facility should be. Employees are aware of the impact in placing the Johnson & Johnson brand name on a product. One such example was during the Tylenol™ crisis. During this event, Johnson & Johnson maintained their positive brand name through television advertisements and removed every Tylenol™ bottle from the market. They followed by eliminating the capsule from their product line and introduced tamper-evident seals on every product. The Johnson & Johnson brand name was maintained by focusing on the commitment to the customer as expressed in the credo.

2.2. Background Johnson & Johnson Consumer Products Incorporated

Johnson & Johnson Consumer Products Incorporated (CPI) is a newly formed company of Johnson & Johnson with headquarters in Skillman, New Jersey. Plants are located in North Brunswick, New Jersey, Royston, Georgia, and Las Piedras, Puerto Rico. This company was formed as a combination of the Johnson & Johnson Dental Care, Johnson & Johnson Baby Products and Johnson & Johnson Health Care companies. Competitive pressures in sales, marketing and operations stimulated the formation of a single company from three separate operating companies.
2.2.1. *Three Companies into One*

The joining of the three consumer companies into one was different from Johnson & Johnson's past practices. The decentralization practices of Johnson & Johnson have been the foundation for the company's success. As new technologies are developed, new companies are formed and chartered with the autonomy and opportunity to create their own futures. However, the increasing competitive pressures in the consumer market have directed the formation of Johnson & Johnson CPI. Focusing on the customer and being responsive to their needs is an important competitive advantage for Johnson & Johnson companies.

The company has seldom joined separate operating companies into one. This is against the decentralized nature of the corporation. However, there are certain advantages in joining similarly based companies such as some of the consumer sector companies in order to reduce costs and be more competitive in the marketplace. Operating profit as a percent of sales by sector for the years 1989, 1990 and 1991 as shown in Figure 3, displays how the consumer sector has had the lowest operating profit as a percent of sales and remains a very competitive market for Johnson & Johnson CPI (Johnson & Johnson, 1991).

![Operating Profit as a Percent of Sales](image)

1991 Stockholders Report
The consumer sector within Johnson & Johnson is the largest in sales but the lowest in operating profit. The increased competitiveness in the consumer market has forced Johnson & Johnson to reevaluate their consumer business strategy. The companies had all focused on consumer markets with functional overlaps in distribution, purchasing and marketing. The newly formed Johnson & Johnson CPI concentrates the efforts of the consumer companies and better leverages the consumer products at both the customer and wholesale level.

2.2.2. Operations Vision

Johnson & Johnson CPI's centralization of consumer companies and the joining of these companies requires a common vision. The Operations Vision of the newly formed CPI is stated by four simple objectives.

- **24 Hour Conversion.** To successfully compete on time, Operations must be able to convert raw materials into finished goods within 24 hours. Our manufacturing plants are being transformed into state of the art production facilities employing computer integrated manufacturing technology. In addition, World Class manufacturing practices will enable CPI to drastically reduce costs, decrease throughput time, and virtually eliminate inventory.

- **Zero Non conformance to Requirements.** Zero non conformance to requirements demands that Operations personnel understand their jobs and have the procedures required to accomplish them in the best possible way. Tools such as Quality Improvement Process and Statistical Process Control encourage Operations employees to ask tough questions and make the necessary improvements.

- **Elimination of Non-Value Added Cost.** Operations personnel aspire to eliminate all costs and activities which do not add value to our products. Whether this occurs in the manufacturing process itself, or in any other aspect of our day-to-day work, we strive to evaluate procedures and challenge conventional thinking.
• *Trained, Developed, and Empowered People.* World Class manufacturing requires more than machinery. It takes a team of trained, developed, and empowered people with the enthusiasm to adapt to new technologies, and the imagination to think things through from a different perspective.

(Johnson & Johnson CPI Human Resources Division, 1992)

All of the sites are empowered with decision making responsibility to improve the competitiveness of the company. The objectives of the Operations Vision help align the CPI manufacturing plants toward a common strategy. The 24 hour conversion goal requires plants to decrease their lead times. This, along with the other objectives, moves the different manufacturing sites toward lean manufacturing principles of reduced inventories and increased responsiveness to the customer. The four areas express lean manufacturing in terms which are easily transferable to day to day activities. With the increasing competitive pressures in a consumer products company, the speed at which these companies attain lean manufacturing is critical. Reducing costs and rapidly responding to the customer demand are key success factors in the consumer market.

The Operations Vision is being broadcast throughout the company. CPI manufactures product at three production sites and some contract manufacturing companies. Each facility supplies products to distribution centers. These distribution centers supply the retail stores and major chain outlet stores. These customers are becoming more demanding and are driving CPI and other finished good suppliers to be more responsive to their demands or risk losing business.

2.2.3. *Move Toward Lean Manufacturing*

On the one hand, lean manufacturing is based on the recognition that refers to the attempts to reduce inventory by quickly responding to customer demand. On the other
hand, lean manufacturing means reducing the vertical layers in an organization while improving the functional integration.

Another element of lean manufacturing includes an increase in manufacturing flexibility. This requires that the production process be made more responsive to changes in customer demands. Manufacturing machinery must be able to produce more than one type of product and quickly switch from one product to another. This flexibility reduces the investment in dedicated machinery by having one piece of machinery produce many different products.

Finally, lean manufacturing refers to the process of reducing the overall cycle time of the product. The overall cycle time of the product includes raw material lead time in addition to the manufacturing lead time at the plant and the delivery transit time to the customer. Reducing this cycle time allows companies to quickly respond to the demand variations from the various market segments and their requirements. This is another feature of flexible manufacturing systems. Staying close to the customer requires firms to look internally and improve their manufacturing technology to create flexible manufacturing processes that have short cycle times and minimum changeover times. The technology alone will not respond to the demand changes. There must be systems implemented to provide the proper information on what product and how much should be produced. The coordination of these activities is the key to using the resources of the firm effectively.

2.2.4. *Common System Implementation*

In order to achieve the Operations Vision and implement lean manufacturing principles, CPI introduced a new Manufacturing Resource Planning (MRP II) or Enterprises Resource Planning (ERP ) system. This system has two main purposes.
First, the new MRP system was designed to provide a common planning system across the three previously independent companies. Different hardware and software were used at these sites making any consolidation of existing systems very difficult.

The second purpose of the new system serves to integrate the various sites into one common database. The system provides real time information on many aspects of the business, from actual sales demand to the production levels of products at the plants. The employees across the company make business decisions by accessing the information from the various sites.

The new MRP system was introduced across all of the manufacturing locations. However, each site was responsible for its own system implementation. The distributed database approach encouraged each of the sites to take ownership of the data at their local level. The introduction of the system in the Las Piedras, Puerto Rico facility will be examined to understand how the implementation of lean manufacturing principles is performed in a remote environment. The history and cultural environment of the plant will assist in analyzing the strategy of lean manufacturing at the remote plant location.

2.3. History of Puerto Rico Industrialization

2.3.1. Operation Bootstrap Groundwork

In order to understand the history of the plant in Puerto Rico it is important to understand the evolution of the United States based companies that are located in Puerto Rico. Puerto Rico was acquired by the United States after the Spanish American War in 1898. The island was primarily used for agricultural purposes. Sugar, coffee, and tobacco were the main products. Following the United States takeover, there was rapid development in these commercial crops and large sums of capital flowed into the island to expand the commercial crop industry. This activity of implementing the agricultural economy continued on the island until about 1927. The period from about 1928 to 1940
was a time of economic stagnation in Puerto Rico with massive unemployment. There was little if any economic growth and with an increasing population on the confined island, the economic future for Puerto Rico was uncertain (Galvin, 1979).

The economic transformation since that time has been dramatic. Many factors, including stability in the political arena and free access to the United States mainland market for goods and capital, have allowed the Puerto Rico economy to move forward at a much faster pace than any of the other Caribbean islands. However, an essential ingredient of the island's success story was the development blueprint under the heading of Operation Bootstrap (Manos a la Obra). The official launch of Operation Bootstrap was on July, 25, 1952, the same day Puerto Rico became a commonwealth of the United States. The groundwork for the program, however, was started in the early 1940's. Due to the limitation on agricultural resources and the high population density, many political leaders in Puerto Rico recognized that industrialization was the only hope for leading a development program and eliminating the country's economic woes. In the fall of 1942, the Development Company headed by Teodoro Moscosco Jr. was chartered with the role to exclusively seek industrial development and not agricultural development. The original plans of the Development Company were to undertake research in natural resources on the island and market the possible new products to promote investment in the new industries (Goodsell, 1965).

The first industries were owned and operated by the government. Some of these corporations included cement, glass, pulp and paper, and shoe and leather manufacturing. These manufactured products were badly needed on the island and most of them, except for the shoe and leather industry, could rely on local raw materials. Except for the cement company, the industries were failures and created only a small number of jobs at an extremely high capital cost. Approximately one thousand jobs were created at a capital cost of roughly $10,000 per job. The unemployment rate continued to climb and a
different approach to encourage industrialization and employment was required (Goodsell, 1965).

2.3.2. Launch of Operation Bootstrap

President Roosevelt had appointed Rexford G. Tugwell as governor of the island in 1940. Governors for the territory were appointed by the United States President until Commonwealth status was granted in 1952, which was the official launch of Operation Bootstrap. Tugwell was an economist who had been familiar with the problems in Puerto Rico and was well aware of the Development Company's past failures.

Luis Muñoz Marín, was the head of the new Popular Democratic Party, began a movement to improve the economic conditions and eliminate poverty. Muñoz Marín convinced the people in Puerto Rico to put aside the debate over the political status of the island in the middle 1940's and instead gather the people to work together to focus on improving the island's economic condition. He had convinced the Puerto Rican people they could not solely rely on the United States to rebuild their poverty stricken island and the only way to improve economic conditions was to depend on their own abilities. Muñoz Marín acted as the catalyst responsible for the reform in Puerto Rico (Goodsell, 1965).

In the late 1940's, Tugwell and Muñoz Marín began to work together to devise the blueprint for the economic development. The only feasible way to industrialize Puerto Rico was to encourage the huge financial resources and entrepreneurial skills of private United States businesses to invest on the island. The shift was signaled by creating the Development Company to assist industry through wage, tax and other incentives. The Development Company began to build factories and lease them under liberal terms to American firms.

In 1947, American firms were attracted further by a tax bill which exempted new industries from all local taxes and the lower Puerto Rican wages were an added incentive
to the United States industrialists, but to a lesser extent. These combined incentives provided United States firms the ability to quadruple their mainland profits and hundreds of new plants were established on the island in the 1950's. Figure 4 shows the tremendous increase in new manufacturing plants from the period of 1942 to 1969. There was little success in the 1940's but after Muñoz Marín and Tugwell provided incentives through Operation Bootstrap, a dramatic growth occurred between 1950 and 1969 (Galvin, 1979).

![Figure 4](image)

2.3.3. Manufacturing Dominance of Puerto Rico Economy

The Development Company had altered the approach from one of public enterprise in the early 1940's, to one entirely dependent on the private enterprise of United States companies. With this, a new agency called the Economic Development Administration (EDA) was formed and replaced the Development Company. There was a tremendous influx of American industry which changed the face of the Puerto Rico economy from primarily an agricultural orientation to a dominant manufacturing orientation. Figure 5 shows the progress of the various sectors from 1941 to 1960. The manufacturing sector had increased the most, while the agricultural sector had fallen off sharply. The chart also shows that both agriculture and manufacturing have consistently contributed to nearly forty percent of the island's economy with manufacturing replacing agriculture's portion.
(Friedlander, 1965). The industrialization of Puerto Rico had taken approximately twenty years.

![Figure 5: Percentages of Total Puerto Rican Income](image)

**2.3.4. Tax Code Incentive**

More recent data suggests that manufacturing has remained the primary contributor to the GNP of Puerto Rico. From 1971 to 1989, the GNP had grown from $5,248 million to $20,051 million. The growth of the GNP is primarily attributed to the growth in the manufacturing sector, due to the tax incentives sparked by Section 936 of the United States Internal Revenue Code. The 936 tax code exemption allows an American based corporation favorable United States income tax treatment as a "possessions corporation" if it derives a certain portion of its income from sources within Puerto Rico (Deloitte, Haskins and Sells, 1980). A possession's tax credit is attached to its operations in Puerto Rico. The effect of the possession tax credit is to exempt from tax any income derived from the active conduct of a trade or business in Puerto Rico. The 936 tax code has provided further incentives for manufacturing investment and Figure 6 illustrates more recent data of the percent of GNP by industry up to 1989. The manufacturing contribution to the GNP of Puerto Rico has grown to more than fifty percent (National Data Book, 1991).
Johnson & Johnson is one of many companies that started operations on the island during this time period. Johnson & Johnson CPI had three plants on the island from the previously separate consumer companies which were joined into one company under CPI.

2.4. Johnson & Johnson CPI Three Plants to One Conversion

The newly formed Johnson & Johnson Consumer Products Incorporated (CPI) absorbed other plants in Puerto Rico from the other consumer companies. Johnson & Johnson CPI was chartered to reexamine the multiple manufacturing facilities and pursue the possible consolidation of the three plants into one plant at Las Piedras. The decision to consolidate the facilities was based on the need to leverage costs by focusing efforts under one management, maximizing facility resources, and eliminating multiple functions.

A two part project was undertaken. First, floor space for manufacturing at one site was made available by out-sourcing some functions to suppliers and reducing warehouse space inventory requirements. Second, the relocation of the manufacturing operations required a smooth transition of both the physical and human resources of the three plants, to the one location. The movement of the plant equipment and personnel
was a large undertaking, with very successful results. Approximately one hundred employees were relocated to various Johnson & Johnson facilities on the island and over another one hundred were retrained for new manufacturing positions at the manufacturing facility in Las Piedras.
3. **Remote Location Manufacturing Description**

3.1. **Las Piedras Factory Description**

The Las Piedras facility has three major classes of products produced in different manufacturing areas. Each area uses the warehouse for raw material storage and finished goods staging. The central facility engineering organization assists the different production areas to optimally utilize the plant resources. The design and installation of new machines for the production areas are also the responsibility of the central engineering group. Production managers for each area are responsible for resource allocations of machine and labor required for the products. Most of the raw materials required for finished good manufacturing is purchased from suppliers located on the continental mainland of the United States. Raw materials that are common to other manufacturing companies on the island, such as corrugated shippers and packers, are supplied by local vendors on the island. The Las Piedras plant manufactures product primarily for the United States market for consumer goods that require distribution centers on the mainland to effectively service the customers.

3.1.1. **Las Piedras Product Flow**

The plant receives raw material shipments from United States suppliers and ships finished goods to the distribution centers. The amount of raw material required for finished good production is determined by the MRP (Materials Resource Planning) system and is based upon standard usage factors and the purchase lead times needed to obtain the material in time for production. The production schedule to determine the finished good requirements is based upon the requirements of the distribution centers. The schedule is planned two months forward by the production planner. The MRP system has a resource
capacity tool to determine if sufficient capacity exists. The numbers used to determine the capacity are based upon average production rates including machine efficiency and the time required to set up the production lines for different products. The schedule is then converted into raw material requirements.

The flow of material through the manufacturing system at Las Piedras begins with the departure of the raw materials in container ships that arrive in Puerto Rico two weeks later. The two weeks required to ship the raw material is defined as the transit time. The raw material is required to be at the Las Piedras warehouse a few days before the actual production start date for incoming quality testing. Other suppliers of raw materials located on the island have a much shorter transit time, but many of these raw materials must also arrive at the plant ahead of time for the quality inspection process.

Once the raw materials are tested and accepted, the production schedule is reconfirmed and production begins. Manufacturing finished good products is the conversion of the raw materials into finished goods. Each manufacturing area follows their production schedule previously set by the planners and production manager. When production is completed, the finished goods are delivered to the warehouse staging area. The warehouse determines the quantity of finished goods to ship to the appropriate distribution center. There are three separate distribution centers responsible for delivery of finished good products to particular customers.

Trailers are loaded at the Las Piedras warehouse and are transported to a container ship. The container ship travels to the appropriate United States port and is then transported by trailer truck to the distribution center. Each distribution center uses a different port. Currently, the shipments from the island to the distribution centers and from the raw material suppliers to the island are on a weekly basis. This is defined as the shipping frequency. A diagram of the flow of material to and from the island is shown in Figure 7. The plant uses a single warehouse with different sections to store raw materials and stage finished goods. The warehouse is a storage location of inventory for finished
goods and raw materials. The warehouse is perceived as a necessary evil required to complete a production plan and ship finished good product to the distribution centers.

Figure 7

Current Product Flow

Suppliers

Warehouse Raw Material

Production Areas

Warehouse Shipping

Distribution Centers

3.1.2. Manufacturing production lines

Each production area has a different degree of manufacturing flexibility. Manufacturing flexibility is the ability of the manufacturing process to rapidly switch production from one product to another product. The time required to perform this switch is called the setup time or change over time. In flexible manufacturing systems the set up time required to switch to another product is small. The less time used for set ups, the more time or capacity the system has to produce finished good product for customers. At Las Piedras a few manufacturing processes are flexible enough to produce product requirements on a daily basis while other areas lack the flexibility and rely on large batch type production processes to effectively utilize capacity.
The main manufacturing systems at the plant are based upon the *mass production* strategy of manufacturing. Mass production strategies use high speed dedicated production lines for a single product to attain economies of scale. Initial plant investments on the island were focused on the mass production system for manufacturing. The set up time required to switch to another product on these machines is substantial. Long production runs are required to effectively use the time of the production lines to produce product and not on the set up for other products. As more products are introduced to the manufacturing system, the changeover time required to setup the production line for the products becomes the major determinant of capacity. With more products, faster machines and longer production runs are required to make up for the lost time due to the increase in setups. Products in some cases are produced in a few days at these high speeds to cover the forecasts for the next four to six weeks until they must be produced again. Over time as more and more products are introduced, the capacity of the manufacturing system is absorbed in set up time and new capacity is needed to satisfy the production requirements.

3.2. Las Piedras Move Toward Continuous Flow Manufacturing

The twenty-four hour conversion component of the Operations Vision increases the importance of lean manufacturing and flexible machines in all the production areas. In order to achieve the objectives, the Las Piedras plant is replacing older high speed dedicated lines with more flexible, but slower machines. The new production strategy of increased flexibility and increased customer responsiveness is the goal of twenty-four hour conversion. The competitiveness of the company increases by both lowering raw material and finished good inventories, and improving customer service by responding more quickly than the competitors.
3.2.1. *Highly flexible machines*

The older dedicated machinery requires large amounts of machine time to be spent performing set ups for the increasing number of products in the market place. The result of the long set up times requires long production runs. The production runs are large enough to cover future demand. Large raw material inventories are required to support the production and larger finished good inventory levels are the result at the distribution centers. The new manufacturing systems being implemented are making the tradeoff of improved flexibility with slower production rates. The increased flexibility and slower production lines increase the available machine capacity. By reducing setup time, the plant can respond quickly to changes in customer demand.

An exception to the increase in flexibility of the production lines is a product which is labor intensive in the final packing operation of the process. This product uses high speed flexible machinery to produce the in process inventory. The final packing is labor intensive and is performed in a lower wage country where the wage rate is only about ten percent of the wage rate in Puerto Rico.

3.2.2. *Reduced raw material inventory*

The increased flexibility of the manufacturing system allows production of smaller production runs. The smaller production runs require fewer raw materials to be on hand at the plant and result in more frequent deliveries from suppliers. Instead of transporting large quantities of raw materials, the increased flexibility of the production line results in deliveries to be as frequent as the current weekly boat schedule. Each week the same raw materials can be acquired but in different quantities according to demand fluctuations.

The increased production flexibility demands closer plant and supplier relationships. The past practices of large volume purchase discounts based upon economic order quantities are changing and supplier relationships involving consignment buying contracts are becoming more important. The agreements allow the benefits of long
term purchasing contracts with suppliers to be combined with flexible payment transfers for the raw materials from the plant to the supplier. For certain raw materials that require long manufacturing lead times for the suppliers, consignment buying provides the supplier with a guaranteed quantity that will be purchased by the plant over a specified time. An example of consignment buying is agreeing to use a single supplier who has been qualified as a ship-to-stock supplier for a certain raw material. A ship-to-stock supplier is permitted to directly deliver raw material to the manufacturing area without prior quality testing. A supplier becomes qualified by consistently demonstrating the required quality specifications for the raw material. In consignment buying, the supplier agrees to hold or carry the inventory at or near the plant location and the plant transfers payments as the raw material is consumed at the plant.

3.2.3. *Warehouse as part of the manufacturing process*

In the past, plant warehouses have been used to carry raw material inventory for future finished good production. After production was completed, the warehouse served as a holding area for the finished good production until the product was ready to be shipped to the central distribution warehouse. Because of this, the warehouse has seldom been viewed as part of the overall manufacturing process. The raw material storage and shipment of finished goods were the responsibility of the warehouse. Production areas released their responsibility for the product when it entered the warehouse.

Today, the warehouse plays a critical role in the lean manufacturing enterprise. Under lean manufacturing, the warehouse is modeled as part of the entire manufacturing system and the entire system is responsible for the delivery of the finished goods to the end customer. The past service function of the warehouse is transformed to a coordinating function responsible for the smooth and continuous flow of material through the plant from raw materials through finished goods. Viewing the warehouse as part of the overall manufacturing process is the first step toward lean manufacturing.
3.2.4. "Wareport" model of scheduling arrivals and departures

The new coordinator role or function of the warehouse requires a change in the thinking of the employees. The concept of modeling the warehouse as an airport with scheduled arrivals and departures is the idea of Felix Rivera, Plant Manager at Las Piedras. The term used to describe the new warehouse is "Wareport". The wareport model views the warehouse as a central hub of the manufacturing system by coordinating the receipt of raw materials based upon manufacturing requirements and the shipment of finished goods based upon the requirements of the distribution centers. The wareport model is shown in Figure 8. This figure illustrates the new role of the warehouse as a coordinator for the continuous flow of material through the plant. The space required for inventory of raw materials and finished goods is minimized because the arrivals of more ship-to-stock raw materials enters directly to the production areas and the finished goods ship immediately to the distribution centers.

The wareport concept is a tool to increase awareness of the importance the warehouse has on the overall manufacturing process. The plant requires the warehouse to perform as a facilitator to provide the raw materials to the production areas and ship the finished goods on time to the desired distribution center. In the old way of thinking, the warehouse was only noticed by production if there was a problem with shortages in raw materials or late deliveries of finished goods. The new wareport concept demands the production areas to think of the warehouse as a central hub necessary to obtain the Operations Vision of twenty-four hour conversion.
3.3. Las Piedras Workforce Description

The education level of the employees is similar to the United States. The plant floor employees are local high school graduates and the plant management or staff employees are college graduates from local and mainland universities. The staff employees are all bi-lingual speaking both Spanish and English. The majority of the plant floor employees speak only Spanish with a small bi-lingual minority.
3.3.1. *Companies Started Favorable Employee Relations*

Many of the companies starting in Puerto Rico had union plants on the mainland and wanted to establish better employee relations with their new plants on the island without the use of unions. The plant in Las Piedras is non union and past employee relations with the plant and CPI have been favorable. Companies wished to establish and worked to maintain positive relations. Learning from their past history with unions, plants included attractive benefit packages to encourage and foster positive employee relations.

Another important reason for the positive relations, is related to the historically higher unemployment rate in Puerto Rico compared to the United States. The unemployment rate in Puerto Rico from 1980 to 1988, has been on average approximately three times the unemployment rate in the United States (National Data Book, 1991). It is more difficult to find a job in a market with high unemployment which influences the behavior of the workers to stay in their current jobs.

3.4. *Training for System Implementation*

3.4.1. *Las Piedras hands on training of system*

A new MRP system was implemented across the company at each plant location. The local plant was responsible for the implementation and the system training for their local employees. The Las Piedras plant utilized a hands-on training approach to allow the employees to learn by making mistakes in a test environment. The language of the software was in English which presented some difficulties in training the plant floor workers. With only a few of the plant floor workers being bi-lingual, the training and selection of who was to be trained on the system was an important decision for the plant. The first to be trained on the new system were the bi-lingual workers who would then become the trainers for the other workers.
Using hands-on training and passing responsibility to the workers at the plant floor level is consistent with past practices by the plant to include employees in more decision making at the lower levels. Past programs including operator self inspection programs were used to establish employee involvement. Instead of final inspection being the means to ensure quality, a program was implemented to improve the quality of the process manufacturing the product. The operator self inspection program trained the production employees in the tools of statistical process control (SPC). The operator self inspection program requires workers to use computers on the plant floor to record and track process quality measurements. After the workers are certified, they are empowered to make timely decisions regarding the process and product quality.

3.4.2. Computers on plant floor

Similar to many manufacturing facilities, the increase in the use of the computers on the plant floor is no different at the Las Piedras plant. Computers are used on the plant floor to record production transactions for the new MRP system. Even if it is simple data input, the addition of the MRP system is not difficult because the employees are accustomed to using computers for other applications such as SPC charting.

3.4.3. Las Piedras training down to production level

A limitation to MRP systems is in the ability for the system to account for uncertainty in the manufacturing process. The methodology behind MRP systems is deterministic using lead times and order quantities, but the manufacturing of products on the plant floor behave in a stochastic manner. Although an MRP system is not able to completely model the plant floor environment, it is currently used as a tool to assist many companies to manage the complexity of their manufacturing system.

The new MRP system assists the company in achieving the Operations Vision by providing a better tool to effectively gather and distribute business information such as
inventories, sales and forecasts. The training for the new MRP system includes employees on the manufacturing lines. As their ability to use the new system increases, they will be able to perform their jobs better by obtaining the information needed to make the right decisions. For example, an employee can utilize the resource capacity tool during the week to determine if sufficient capacity exists in the current schedule, or if overtime will be required to meet the requirements. The employee can also check the inventory levels of the raw materials for the next product to be produced and avoid potential shut downs due to a material shortage by switching to another product that has sufficient raw materials. These activities have a more immediate focus and are in line with the types of decisions expected of the plant floor employees. The new MRP system may allow employees to achieve the lean manufacturing practices at the plant by providing the right information to the right people at the right time.

3.4.4. *Las Piedras wareport as an education tool for lean manufacturing*

The "wareport" concept implemented at the plant is another method or tool that can be used to promote lean manufacturing. The biggest challenge in implementing any new system is to change the conceptions or thinking of the employees from the old system to the new system. The wareport idea provides a new way to think about the complete manufacturing system. Implementation of lean manufacturing is not only for the production area, but should be the focus of the entire manufacturing facility and include everything from the receipt of the raw materials, to the arrival of the finished goods to the customer.
3.4.5. *Production example implementing lean manufacturing*

Driven by the Operations Vision, the employees at Las Piedras have instituted many projects to increase the flexibility of many of the manufacturing processes. An example of this lean manufacturing transition is in an area where high speed production lines are being replaced by more flexible, but slower production lines. The large increase in machine flexibility allows the manufacturing system to produce many different products. The first step of this project is to produce the different products from once every four to six weeks to once a week. This coincides with the current shipping frequency of once a week.

However, the new production line is able to produce many of the different products as frequently as once a day. This increased flexibility of the production line exposes a new constraint for the remote location. The transportation system is the bottleneck of the manufacturing system flexibility. The transportation system must be as flexible as the production line in order to obtain the benefits from a flexible manufacturing system.
4. Model for Remote Plant Constraints to Lean Manufacturing

4.1. Introduction

This model analyzes the benefits and costs of different shipping frequencies of finished goods. The model will determine the finished good inventory level at the plant and the distribution center. These quantities can be converted into finished good opportunity costs for different shipping frequencies.

The marginal opportunity savings in switching from a less frequent to a more frequent shipping schedule can assist in the decision to change the shipping contract and provide more flexibility to the plant. This model will analyze the finished good inventory behavior at the distribution center and the plant. Further extensions for the model include adding the raw material inventory behavior and other operational costs besides finished good inventory.

4.2. Remote Plant Transportation Constraint

Remote plant locations such as Las Piedras have a constraint which many United States mainland facilities do not face. Shipping and transportation is less of a constraint for the manufacturing system flexibility on the mainland. The highway system of the mainland provides the required infrastructure for transportation companies to provide very fast and flexible service. Manufacturing facilities located across the world which serve the United States market constrain their manufacturing systems by the inflexibility of the transportation and shipping systems. The large distance separating the manufacturing facilities from the markets they serve requires expensive transportation by container ships and even cargo planes. While facilities focus on improving the basic machine flexibility in
their manufacturing system, the remote locations must also improve the transportation flexibility or it may become the limiting factor to their manufacturing flexibility.

4.3. Machinery is More Flexible Than Shipping Frequency

The Las Piedras facility is focusing on improving the production line flexibility. Machine flexibility improvements are achieved by reducing the set up time required to switch between products. This provides the capacity to produce different products more frequently. The old production line's cycle of production runs for a product was significantly longer than time between shipments. The cycle for the production runs was every four to six weeks while the shipping frequency is once every week. With new flexible production lines the frequency of the production runs is greater than the shipping frequency. The shipping frequency is limiting the advantages of the production flexibility.

4.3.1. Frequent shipments for continuous flow benefits

Flexible manufacturing systems, including a flexible transportation system, provide advantages by increasing responsiveness to the customer, decreasing inventory requirements, and speeding up new product launches. These benefits of lean manufacturing require flexibility in both the machines making up the production line and the shipment of the finished product to the distribution center. The new production lines create a new bottleneck for flexibility. The shipping frequency is the new bottleneck which will limit the additional benefits from lean manufacturing for a remote location. More frequent shipments are required to utilize the flexibility of the production lines.

4.3.2. Tradeoff costs of frequency and inventory

A reduction in inventory levels at the plant and distribution centers is the most measurable benefit from an increase in flexibility of the manufacturing system. The reduction in inventory at the distribution center is through lower safety stock and cycle
stock requirements. Safety stock inventory is extra finished good inventory to account for the variability of the future in both the demand and supply of the finished product. Cycle stock inventory is the finished good inventory to cover the replenishment time or the length of time until the next shipment of finished product arrives at the distribution center. This length of time is called the shipping period and is the length of time between shipments. A more frequent shipping schedule lowers both the safety stock and cycle stock inventory levels at the distribution center. The inventory held at the plant between shipments also reduces with more frequent shipments of finished product.

4.4. Mathematical Model

In this section we describe a mathematical model which will be used to determine the finished good inventory levels at the distribution center and the plant. The model calculates the required safety stock level and cycle stock quantities for a given shipping frequency. These quantities are used to model the inventory levels for one year. Different shipping frequencies are used to model the effect on the finished good inventory levels. The average inventory levels and the resulting opportunity costs in holding the finished good inventory are then calculated to specify an opportunity savings or cost with a change in the shipping frequency.

4.4.1. Goal to quantify tradeoffs of frequency and inventory

The goal of the model is to determine the benefits of changing the shipping frequency to a distribution center. The benefits are determined by finished good inventory levels at the distribution center and at the plant for a given shipping frequency. The inventory levels at the plant are calculated by the quantity of finished goods that are stored at the plant warehouse until the next shipment departure. The inventory levels at the distribution center are determined by the safety stock and the replenishment stock or cycle
stock levels. The model will also assist in defining how manufacturing flexibility affects the various levels in the organization.

4.4.2. Model description

The plant in Las Piedras has many different products manufactured on different production lines. The production lines have different degrees of flexibility. A new production line with major improvements in flexibility will be used in the model. This line manufactures product A. The model will track the plant and distribution center inventory levels and plant production for product A. The production line produces different quantities of product A on a daily basis. The forecast is assumed to have a normal distribution with a known mean and standard deviation. The actual sales for the product are also assumed to be normally distributed with the same mean and standard deviation as the forecast in order to isolate the shipping frequency decision. The difference between demand forecast and actual sales is also normally distributed.

The production line can manufacture any daily demand requirements for the product A. Production begins at the start of the period and the shipments from the plant occur at the end of the period. For any shipping frequency, the shipment of the finished goods can always be met by the shipping carrier. Whether shipments are once every twenty periods or once every other period, the shipping carriers have sufficient capacity to transport the finished goods. A single distribution center simplifies the model to focus on the inventory levels at a single location. The ending inventory at the distribution center is the beginning inventory level less actual sales plus incoming shipments. The incoming shipments occur at the beginning of the period and the actual sales occur at the end of the period. This provides a common time reference to track inventory levels. Figure 9 displays the simplified flow of the model from the production line to the distribution center.
In describing the model we will first define the different variables and their definitions. From this list we will construct a safety stock and a cycle stock inventory model to track the inventory levels at the plant and distribution center for product A.

4.4.3. Variable description and definition

The list of the variables below breaks down into three groups consisting of decision variables, fixed parameters and calculated variables. The first group is the decision variables. These variables are the variables that can be changed in the model.

Decision Variables

λ  The variable to define the shipping period. The shipping frequency is the inverse of the shipping period. The shipping period is the number of periods between shipment of finished good departures from the plant to the distribution center.

K  The value of K relates the tradeoffs between finished good inventory investment and the customer service level or the cost of a customer order not filled because no inventory is available at the distribution center.

T  The length of time of the model in periods.

The next group are fixed parameters in the model. These parameters are set once in order to better isolate the effects of changes to the decision variables.

Fixed Parameters

L  This is the replenishment lead time required to replace inventory at the distribution center. This time includes the time to procure the raw materials to the time the product arrives at the distribution center.

F  The demand forecast of a product in a period.
D  The actual demand or sales of product in a period.

Z  The amount of time required to transport the finished good inventory from the plant to the distribution center.

v  The value or the cost to manufacture product A.

r  The opportunity cost of the inventory as a percentage per year. This includes the opportunity cost of capital and inventory holding costs.

H  A conversion factor to determine the amount or raw material space required for a finished good inventory space.

u  The variable cost per unit of space to hold the raw material inventory at an outside warehouse location.

The last group of variables are the calculated or determined variables. These variables are calculated in the model from a combination of one or more of the decision or fixed parameters. Further definition for each variable is provided in the model development sections.

**Calculated Variables**

\( \sigma_x \)  The standard deviation of finished good inventory due to supply and demand variations over the replenishment lead time.

\( \sigma_e \)  The standard deviation of the forecast errors over the number of periods in the model.

M  The mean absolute percent error of the forecast demand and the actual demand.

\( \Psi \)  The safety stock level in units of finished good inventory.

\( \Omega \)  The safety time expressed as the number of future periods of finished good forecast to have on hand.

R  The required replenishment finished good stock required for the distribution center to cover safety stock and forecast demand requirements.
W  The wait time at the plant for finished good inventory. This is the average time the inventory waits at the plant before the next shipment.

I  Finished good inventory at the distribution center.

\( \bar{I} \)  The average finished good inventory level at the distribution center.

\( I_p \)  Finished good inventory held at the plant between shipments.

\( \bar{I}_p \)  The average finished good inventory level held at the plant between shipments.

\( Q_s \)  The finished good quantity to ship from the plant to the distribution center.

\( Q_p \)  The finished good production at the plant per period.

\( \bar{I}_{im} \)  The average raw material inventory space converted from finished good inventory space.

\( C_{id} \)  The cost to hold inventory at the distribution center. This cost includes the opportunity cost of capital for the firm.

\( C_{ip} \)  The opportunity cost to carry raw material inventory at an outside warehouse.

\( T_{ci} \)  The total inventory opportunity cost from the finished good inventory at the distribution center and the raw material inventory from an outside warehouse.

With the variables and parameters defined we will construct the safety stock and cycle stock formulas to calculate the finished good inventory levels and the resulting opportunity costs associated with these levels for different shipping frequencies.

4.4.4. *Safety Stocks*

Safety stocks absorb the variations or uncertainties in the demand and supply of products. The variation of supply and demand is measured as the total standard deviation \( (\sigma_X) \) of finished good inventory over the replenishment lead time. The safety stock
level ($\Psi$) is calculated by multiplying the total standard deviation over the replenishment lead time ($\sigma_X$) by a factor $K$ as shown in equation (1) (Silver, Peterson, 1985). The value of $K$ relates the tradeoffs between finished good inventory investment and the customer service level or the cost of a customer order not filled because no inventory is available at the distribution center.

$$\Psi = K\sigma_X$$

(1)

Customer service has many possible measurements. One such measurement is the line item fill rate. This is defined as the percentage of different products that have sufficient inventory at the distribution center to satisfy the demand order. For example, if there is a demand order with ten different types of products and only nine of these products has sufficient inventory to fill the order, the line item fill rate is 90%.

The total standard deviation ($\sigma_X$) is composed of the variations in demand and supply during the replenishment lead time. For the model, the supply variations are assumed to be zero and all variations are attributable to the forecast errors over the required replenishment time. The forecast errors are the difference between the forecast demand and actual demand for a period. The replenishment lead time is the length of time required to replace the finished good inventory at the distribution center from the procurement of raw material to the shipment to the distribution center and is composed of the following:

- Raw material lead time
- Manufacturing lead time
- Average queue time for finished goods at plant until next departure
- Transit time from the plant to the distribution center

The variance of the forecast errors for one period is given by ($\sigma_e^2$). Because the forecast demand and actual demand are normally distributed, the difference or error between
forecast and actual is also normally distributed. The variance of the demand forecast errors \((\sigma_x^2)\) over the replenishment lead time is the sum of the independent individual variances \((\sigma_e^2)\) for each period over the replenishment lead time \((L)\) and shown in equation (2).

\[
\sigma_x^2 = \sigma_e^2 L \tag{2}
\]

The standard deviation of forecast errors over the replenishment lead time \((\sigma_x)\) as a function of the standard deviation of the forecast error \((\sigma_e)\) for a period is shown in equation (3).

\[
\sigma_x = \sigma_e \sqrt{L} \tag{3}
\]

Substituting equation (3) into equation (1) gives the safety stock in terms of the standard deviation of forecast errors for a period \((\sigma_e)\) and the replenishment lead time \((L)\) and is shown in equation (4).

\[
\Psi = K \sigma_e \sqrt{L} \tag{4}
\]

The appropriate value for \(K\) still needs to be determined. There are two approaches to determining \(K\). One method is to calculate the stockout cost, or the cost of being out of stock for a product, and optimize this cost versus the inventory costs. In this approach, stockout costs are very difficult to determine. The cost of not having a product available for a customer is more than the cost of the lost sale. Being out of stock provides the customers the opportunity to switch to other products and can result in the loss of goodwill. The loss of goodwill may have future detrimental effects on new product sales.
and other related products the company offers and it is hard to quantify the costs associated with these occurrences (Silver, Peterson, 1985).

The other method of determining $K$ is based upon on a desired customer service level. Setting a customer service level implicitly applies costs of stockouts, but provides management with a consistent measure for all products providing easy measurements to track improvements. With the example of the line item fill rate, for a normal distribution of forecast errors, $K$ is the number of standard deviations required to satisfy having finished good stock available for a customer order. In Figure 10, the right tail of the normal distribution is the probability of a stockout occurring.

Figure 10

![Standard Normal Distribution](image)

For a line item fill rate of 98%, $K$ has the value of 2.05. This means that the safety stock inventory level should be about twice the standard deviation of the forecast error. A table for different values of $K$ and customer service levels is given in Table 1 (Nahmias, 1989).
In the past Johnson & Johnson CPI, along with many other companies, employed an equal safety time criteria for all products. This type of policy does not take into account that the variability of the forecast accuracy is different for the various products. Using a customer service level for all product allows the forecast accuracy, namely the standard deviation of the forecast errors, to be incorporated to determine the safety stock levels for the different products. It is easier for management to select and implement a common customer service level because of the consistency of the goal across the organization.

Johnson & Johnson CPI uses the customer service level method to determine K. The difficulty in quantifying stockout costs combined with the easier implementation of measuring a customer service level through a line item fill rate are the main reasons Johnson & Johnson CPI uses a customer service level to determine finished good safety stock levels. In addition, the Operations Vision for Johnson & Johnson CPI demonstrates a commitment to the customer and management has set a short term goal of a 98% line item fill rate. Setting this level for the line item fill rate provides a value for K without directly calculating the stockout costs (Silver, Peterson, 1985).

Forecast error in a period is the difference between the forecast value and the actual demand for that period. One measurement of the forecast accuracy is the standard deviation of the forecast errors (\( \sigma_e \)). Another measure of forecast accuracy which does not depend on the magnitude of the values of demand is the mean absolute percent error (M). This is the sum of the absolute differences between forecast demand (F) and actual
sales (D) in time i, divided by the total forecast for a specified time period (T) and is given
by the formula in equation (5) (Nahmias, 1987).

\[
M = \left( \frac{\sum_{i=1}^{T} |F(i) - D(i)|}{\sum_{i=1}^{T} F(i)} \right)
\]

(5)

Johnson & Johnson CPI currently uses the mean absolute percent error as a measurement
of the forecast accuracy. When forecast errors are normally distributed, it can be shown
that the standard deviation of forecast error (\(\sigma_e\)), is given approximately by 1.25 times the
mean absolute percent error (M) (Silver, Peterson, 1985) and is shown in equation (6).

\[
\sigma_e \equiv 1.25 \, M
\]

(6)

Substituting equation (6) into equation (3) results in the total standard deviation in terms
of mean absolute percent error (M) and the replenishment lead time (L) shown in
equation (7).

\[
\sigma_x = 1.25 \, M \sqrt{L}
\]

(7)

The mean absolute percent error is measured as a percentage of finished good
supply over the forecast period. The use of MRP systems by many firms to manage
inventory and safety stock levels results in expressing safety stocks in terms of safety time.
The actual safety stock inventory is calculated by the safety stock time. The safety stock
time is the number of periods to cover future demand forecast. This is also called the
amount of forward coverage and determines the necessary safety stock level. Substituting
equation (7) into equation (1) gives the safety stock measured in periods of supply or safety stock time ($\Omega$) shown in equation (8).

$$\Omega = 1.25 \, K \, M \sqrt{L}$$

(8)

The required safety stock level ($\Psi$) at time index $t$, is the sum of the future forecast demand ($F$) over the length of the safety stock time ($\Omega$) and is shown in equation (9). For example, if the safety time is three periods and the forecast demand for the next three periods is 10, 12, and 15 units, the safety stock to carry now would be 37 units.

$$\Psi(t) = \sum_{i=t+1}^{t+\Omega} F(i)$$

(9)

The shipping frequency changes safety stock requirements by affecting the replenishment lead time ($L$). The part of the replenishment lead time that products wait at the plant until the next departure ($W$) is on average one half the shipping period ($S_P$) as shown in equation (10). This is part of the total replenishment lead time ($L$).

$$W = \frac{S_P}{2}$$

(10)

For example, if the shipping period is 10 periods, sometimes product will wait more than 5 periods and other times product will wait less than 5 periods, but on average the product will wait 5 periods before the next departure.

The safety stock time changes with a change in the shipping period resulting in different safety stock inventory level requirements for different shipping frequencies. The inventory at the distribution center is based upon safety stock levels and cycle stock
shipments. With the safety stock inventory based upon the shipping frequency calculated, we will next determine the cycle stock inventory levels based upon the shipping frequency.

4.4.5. Replenishment Stock or Cycle Stock

The replenishment stock or cycle stock is the distribution center inventory required to cover the future demand requirements during the time between shipments to the distribution center. In our case, the time between shipments is equal to the shipping period. The replenishment stock quantity (R), shown in equation (11), consists of two components, one to cover future demand and safety stock requirements and another to adjust for differences between forecast and actual demand. The first component in the equation is the finished good quantity required to cover future forecasts (F) and safety stock (Ψ) requirements. For each period, the future demand forecast and the future change in the safety stock requirements are added over the shipping period (S_p). The second part of the equation adjusts the finished good quantity for past differences in forecast demand (F) and actual demand (D). This difference is accumulated at the prior finished good shipment date from the plant, and is the same as the addition of the transit time and two shipment periods from the point of view of the arrival date at the distribution center.

\[
R(t) = \sum_{i=t}^{t + S_p - 1} \Psi(i) - \Psi(i - 1) + F(i) - \sum_{i=t - Z - S_p}^{t - Z - S_p - 1} F(i) - D(i) \quad (11)
\]

The replenishment stock only occurs on possible shipment arrival periods. These are periods where the time index t is a multiple of the shipping period. The replenishment stock is zero for periods that are not a multiple of the shipping period. For example, if the
shipping period is every 12 periods, then the times for replenishment stock to arrive at the
distribution center would be 12, 24, 36, and 48, up to the last multiple of 365 periods.

4.4.6. Inventory at the Distribution Center

With safety stocks, forecasts and replenishment inventory defined, the distribution point inventory (I) at the end of time t, can be calculated in equation (12). This is the beginning inventory less actual sales plus shipments to the distribution center. The beginning inventory level is equal to the ending inventory level from the previous period.

\[ I(t) = I(t-1) - D(t) + R(t) \]  \hspace{1cm} (12)

Over the period of time for the model (T), the inventory profile can be determined and plotted for different shipping periods. The average inventory level at the distribution center is shown in equation (13). The average inventory levels at the distribution center (\( \overline{I} \)) can be determined by summing up the ending inventory levels and dividing by the total time period analyzed (T).

\[ \overline{I} = \left( \sum_{t=0}^{T} I(t) \right) / T \]  \hspace{1cm} (13)

By calculating the average inventory at the distribution center, the inventory opportunity costs for different values of the shipping frequency can be calculated.

4.4.7. Inventory and Production at the Plant

We have determined the effects of the shipping frequency on the distribution center. The next section of the model will describe the effects on the plant. The inventory
at the plant is the amount of inventory that builds up between the shipments of the finished goods to the distribution center. The plant is capable of producing finished good quantity requirements for any given shipping frequency. The production line uses the time between shipments from the plant or the shipping period to manufacture the requirements for the next departure of finished goods to the distribution center.

For the shipment to arrive at the distribution center on time, the replenishment stock (R) must depart the plant by the lead time required to transport the shipment to the distribution center. This lead time is the transit time. The quantity to ship ($Q_s$) is offset by the transit time ($Z$) and shown in equation (14).

\[
R(t) = Q_s(t - Z) \tag{14}
\]

The quantity produced at the plant ($Q_p$) in a period shown in equation (15), is the average production required to manufacture the requirements by the departure date. The shipping period is the length of time for the production line to manufacture the finished good quantity for the next shipment. The finished good manufacturing requirement is averaged over the shipping period to result in the required quantity to be shipped to the distribution center. For example, if the quantity to ship on a period is 40 units and the shipping period is 4 periods, then the production quantity is 10 units for the previous 4 periods.

If $Q_s(t + S_p - 1) \neq 0$,

\[
Q_p(t) = \frac{(Q_s(t + S_p - 1))}{S_p} \tag{15}
\]

The quantity to produce at the plant is the same for $Q_p(t)$, $Q_p(t+1)$, $Q_p(t+2)$, up to $Q_p(t + S_p - 1)$. The next time period the quantity to ship is not equal to zero, the steps above are repeated.
This production requirement by period determines the production level and resources required. Tracking the production requirements over the time period, will show the effects of the shipping frequency decision on the plant resources.

With the plant manufacturing requirements and shipment quantities defined, the plant inventory \( I_p \) can be determined by equation (16) at any point in time \( t \) by adding up the quantity produced \( Q_p \) and subtracting the quantity shipped \( Q_s \).

\[
I_p(t) = \sum_{i=1}^{t} (Q_p(t) - Q_s(t)) \tag{16}
\]

This finished good inventory at the plant displaces raw material inventory which is kept at an outside warehouse. The average finished good inventory at the plant can be converted into raw material inventory levels. These raw material inventories can be transferred back to the plant warehouse and result in saving the variable cost of holding the raw material inventory at the outside warehouse. At the plant, the average finished good inventory level \( \overline{I_p} \) can be calculated by equation (17) and is converted into average raw material inventory levels by a conversion factor \( H \).

\[
\overline{I_p} = \left( \frac{\sum_{t=0}^{T} I_p(t)}{T} \right) \tag{17}
\]

4.4.8. Inventory Opportunity Cost

With the inventory levels tracked for both the distribution center and the plant, the next step is to convert these average inventory levels into opportunity costs of holding the inventory to determine the effect of the different shipping frequencies.
The inventory opportunity cost is the opportunity cost associated with carrying the finished good inventory at the distribution center. The components of the cost include:

- Cost of providing physical space to store inventory
- Breakage, deterioration and obsolescence
- Taxes and insurance
- Opportunity cost of an alternative investment

The finished good inventory is an investment, and the opportunity cost of capital to invest in an alternative project is the largest portion of the total opportunity cost measured as a percentage per year similar to an interest rate. The value of the finished good inventory is the average finished good inventory at the distribution center ($\bar{I}$) multiplied by the product cost ($v$). The inventory opportunity cost at the distribution center ($C_{id}$) in dollars is the value of the finished good inventory multiplied by the opportunity cost ($r$) and is shown in equation (18) (Nahmias, 1987).

$$C_{id} = v \cdot r \cdot \bar{I} \quad (18)$$

The average inventory level at the plant ($\bar{I}_p$) can be converted to a raw material inventory level that is stored at an outside warehouse ($\bar{I}_{rm}$) by using a conversion factor ($H$) shown in equation (19). The conversion factor is the amount of raw material space per average finished good inventory level.

$$\bar{I}_{rm} = H \cdot \bar{I}_p \quad (19)$$

The plant inventory opportunity cost ($C_{ip}$) is the average raw material inventory multiplied by the outside warehouse variable cost ($u$) as shown in equation (20).

$$C_{ip} = u \cdot \bar{I}_{rm} \quad (20)$$
The total inventory opportunity cost \( T_{ci} \) for a given frequency shown in equation (21), is the sum of the inventory opportunity cost at the distribution center \( C_{id} \) and the plant raw material savings \( C_{ip} \).

\[
T_{ci} = C_{id} + C_{ip} \tag{21}
\]

The model quantifies the inventory costs for different shipping frequencies. This method tracks inventory over time to determine the average inventory levels and the resulting opportunity costs. The model also determines the plant production levels per period which determine operational effects on the plant for the different shipping frequencies.

4.4.9. Other operational costs affected by shipping frequency not in the model

The savings from reducing inventory is offset by an increase in operational costs at both the plant and the distribution center. The most apparent operational cost increase is in the shipping charges. The shipping charges are based on a variable rate determined by the number of trailers to be transported. This variable cost per container must at least be equal to the fixed cost component divided by the number of trailers on the container ship. The fixed cost is the expense to transfer a container ship from the island or remote location to the United States mainland destination.

Other operational costs associated with the shipping frequency are the direct and indirect labor requirements with a change in the shipping frequency. From the plant's perspective, this includes direct labor of the production lines and the handling of finished goods in the warehouse and the indirect labor in tracking trailer shipments to the distribution center. In both cases, it is assumed that a change in the shipping frequency does not significantly alter the labor costs of the plant. The plant is staffed to handle
finished goods on a daily basis and every trailer that is shipped is already tracked by a ship or vessel name.

The distribution center operational costs are also direct and indirect labor. The arrival of the finished good shipments from the plant to the distribution center is the direct labor. The indirect labor is the recording of transactions for each of the trailers that are received. The level of activity at the distribution center is altered, due to the number of trailers received in a period changing with different shipping frequencies. Less frequent shipments from the plant result in more trailers to be unloaded at the distribution center in a period. This requires a variation in the labor requirements according to the frequency of the shipments. In this model, the labor costs are ignored here and discussed in detail in Chapter 5.

4.5. Solution Method

The parameters that can be changed in the model are the shipping period (\(\lambda\)), the desired customer service level expressed as a line item fill rate which determines \(K\), and the transit time (\(T\)) to the distribution center. A customer service level of 98% results in a \(K\) value of 2.05 (See Table 1) and a transit time of ten periods is used for the model to focus on the shipping frequency effects for a given set of parameters. The shipping period was then changed from one to ten by one period increments, and then every five periods up to a shipping period of thirty. The resulting inventories were tracked and an example of the inventory levels at the distribution center are shown in Appendix B and Appendix C for a shipping period of seven and three periods.

An EXCEL spreadsheet was created to facilitate altering these input parameters and to simplify future changes to the model. The inventory and period production for the three products is calculated for 365 periods. The demand forecast and actual sales figures are generated by a random number generator in EXCEL using a normal distribution with
the same mean and standard deviation, but with different seed number generators. Disguised data is used for product A and is modeled assuming a mean demand forecast of 10 units per period, and a standard deviation of 3 units, in thousands. The spreadsheet works by first choosing a desired customer service level and for this level, various shipping frequencies are input into the model to determine the inventory behavior at the distribution center and the production requirements at the plant for product A. Graphs representing the inventory levels at the distribution center and the required production at the plant display the effects of a change in the shipping frequency. Comparing these graphs for different shipping frequencies provides the analysis tool to determine the effects of the shipping frequency on inventory and production levels.

4.6. Numerical Results and Interpretation

4.6.1. Inventory savings and marginal operational cost tradeoff

All data below is disguised for Product A. The average finished good inventory levels are shown in Appendix B for a shipping period of seven periods and Appendix C for a shipping period of three periods. More frequent shipments of every three periods result in lower average inventory levels at the distribution center.

Transferring these average inventory levels to opportunity costs requires the knowledge of the value added cost of the product and the opportunity cost of capital. An estimated opportunity cost of capital (r) of 30% per year was used. This is the total of the different costs of holding inventory at the distribution center. The value added cost for product A is the sum of the material costs and labor costs that are required to manufacture the product. For product A, this value added cost (v) is $0.80 per unit. The portion of the inventory opportunity cost associated with the average inventory level at the distribution center is calculated using equation (18).
The opportunity cost of the average inventory levels at the plant is based upon raw material inventory that is brought back to the plant warehouse from an outside warehouse. The conversion factor for finished good inventory space into raw material inventory space (H) is 1.8 for product A. The variable cost of carrying the raw material inventory at the outside warehouse (u) is $0.30 per space of raw material. Using equations (19) and (20), the opportunity cost of the average finished good inventory levels at the plant can be determined.

The total inventory opportunity cost can be obtained using equation (21). By plotting these costs for different shipping periods, it is possible to quantify a marginal cost to switch from one shipping frequency to another. The marginal savings of shipping more frequently is the difference in the inventory opportunity cost for the two frequencies. Graph 1 displays the inventory opportunity cost for the different shipping periods and the marginal savings from equation (21). Moving from a frequency of a shipment every 25 periods to a shipment every 10 periods is shown as an example.

Graph 1

**Product A Inventory Opportunity Cost**
The marginal savings is $238M minus $119M which equals $119M. This marginal savings is the maximum amount the company is willing to pay for the more frequent shipments for this product. The graph displays this savings for product A and other products would be added to this total. A relationship between the shipping frequency and the product can be developed to determine the tradeoff as a function of dollars per shipping frequency. Each product will have a different relationship and the total marginal savings can be determined.

4.6.2. Period production at the plant tradeoffs

The other interesting aspect resulting from a change in the shipping frequency is the effect on the plant and the period production rate. One of the assumptions of the model states that the plant can produce any product demand requirement for the distribution center. The variation in the period production requirements of the plant vary with a change in the shipping frequency. Graph 2 displays a measure of this variability by plotting the standard deviation of the period production for product A requirements calculated from equation (15) for different shipping periods. More frequent shipments have a higher variability on the period production of the plant. A higher variation in the period production requires more flexible resources of both capital machinery for the production line and the labor resources to operate the production line.
Another demonstration of the variation in the plant production is shown by plotting the actual plant production by period for different shipping periods. For more frequent shipments, responding to the variations results in larger swings in the production requirements of the plant. For less frequent shipments, the variations in demand are averaged over the time between shipments which allow the plant to produce at a more stable production rate, closer to the average given a longer time horizon. The model assumes that the capacity of the production line for the plant can respond to changes in the customer demand. For different shipping frequencies, the production line may require extra capacity to satisfy the demand variations. In order to quickly respond to demand changes, the capacity of the production line must be equal to the largest likely increase in demand. Graph 3 displays Product A period productions for a shipping frequency of a shipment every one period and Graph 4 displays the period production of a shipment every seven periods. Graph 3 shows a larger maximum of 26 units to be produced for a shipping frequency of every one period versus a maximum of only 15 units of production for a shipping frequency every seven periods in Graph 4. The time period for the model is
365 periods. This length of time was chosen to provide significant data points to determine longer term effects of the shipping frequency. Other time horizons can be chosen, but do not change the basic effects of the shipping frequency.

Graph 3 (Every Period)

**Product A  Period Production Between Shipments**

Graph 4 (Every 7 Periods)

**Product A  Period Production Between Shipments**
Shipping every period will require the production line to be built with a maximum capacity of 26 units in order to respond to the fluctuations in demand. This may require additional capital to purchase the required machinery or increase the labor requirements for the production line. Shipping more frequently requires a higher capacity for the production line because the fluctuations must be responded to more quickly. These extra costs for more frequent shipments are not calculated but discussed later in Chapter 5.

An alternative approach to the question of production line capacity would be to hold extra finished good inventory and have a lower production line capacity. This tradeoff between inventory and capacity requires comparing the costs of capacity to the costs of inventory. The extra capacity costs take into account not only current demand requirements, but must also be positioned for future changes to the demand requirements. This makes deciding on the capacity level for the production line more difficult because it must be considered in a dynamic, not a static environment. The extra finished good inventory to carry would add to the safety stock levels and which will also change over time.

4.6.3. Flexible production lines spread risk

Another advantage of flexible production lines is that one machine can produce many products. A flexible production line enables the plant to spread the risk or chance of demand variations reaching the capacity of the line. For example, if there were three products each having the same capacity requirements, using dedicated machinery, three machines each with the same capacity are required. Using a flexible production strategy, only one machine, with less than three times the capacity, would be required for the three products. However, to the extent that forecast errors are correlated, the capacity and cost savings of the flexible line are reduced. As in the economic theory of the diversification of risk, the benefits of diversification increase with the inverse of the correlation between the risks.
4.7. Summary and Model Extensions

4.7.1. Lower operational costs versus benefits of lean manufacturing

The benefits of lean manufacturing are reduced for remote locations. Firms may still find it profitable to engage in mass production at a remote location if they can obtain lower operational costs in other areas such as lower wages or tax incentives. For example, the labor intensive final packing of the product being produced in a country with lower wages described in Chapter 3 is a case where flexibility is sacrificed for lower operational costs. To provide an increase in the responsiveness to the customer, the entire manufacturing system must be examined and result in the elimination of the barriers to become a complete flexible manufacturing system.

The higher operational costs are offset by lower inventory opportunity costs and by the increase in customer responsiveness. The effect of an improvement in the responsiveness to the customer is not easy to quantify. A more satisfied customer will likely make repeat purchases and improve the profitability of the company. New product launches can be accomplished more rapidly by designing the products to fit into the flexible production lines. With consumer needs changing more rapidly, the company that can get new products to market the fastest will have a significant advantage.

Flexible transportation systems, necessary for lean manufacturing, will increase the demand for the remote locations to have more flexible shipping services. As more companies adopt lean manufacturing and request the increase in transportation flexibility, the transportation systems will work to accommodate the market demand and improve the overall transportation system by both improving frequency and transit time to the destination.
4.7.2. *Extensions for the model*

A more frequent shipping frequency can improve the benefits for lean manufacturing in the remote facility. Other parameters such as the transit time from the remote location to the distribution center must also be improved to decrease inventories at the distribution center. The remote locations must look at the entire manufacturing system to fully accomplish the benefits of lean manufacturing. The model should be extended to include the system from the supply of raw materials to the distribution to the end customer. Looking at the entire system and uncovering potential areas to shorten lead times can increase flexibility and improve the customer responsiveness and lower overall operational costs.

The demand forecast and actual sales were generated using a normal distribution. Seasonality or growth effects on forecast were ignored to focus on the shipping frequency effects. Including these effects and more products, can provide a more accurate cost picture for the opportunity cost of the inventory. The different products may have alternative models for the forecast distributions.

The model starts with the production of finished goods. The raw material procurement is not included. The frequency of the raw material shipments to the island can be included in the model to examine the raw material inventory levels as a function of the incoming shipping frequency. Variability in the supply of the raw materials could lead to a type of raw material safety stock at the manufacturing facility. This may keep the production lines from being starved by a lack of raw materials. This type of extension would lead to a complete model of the manufacturing system from the raw materials to the finished goods at the distribution center and lead to appropriate inventory levels in the system to decouple variations between the manufacturing processes.
5. Decision to Change the Shipping Frequency

5.1. Hierarchy Framework

There are various people affected by a change in an operational procedure or a
decision such as the shipping frequency. These individuals are from the plants, the
distribution warehouses, and the corporate offices. These decision makers can be placed
into three distinctive levels. The top level, is responsible for decision variables cascading
to other levels. These decision variables include the shipping period (λ) and the customer
service level expressed as the line item fill rate which determines the value for K. The
middle level acts upon the direction set by the top level and provides information to the
top level to make decisions for these values. A lower level performs day to day activities
affecting the operational budget and works toward the objectives set by the top level and
communicated through the middle level.

5.1.1. Top level description

The bottom line profits of the company are the primary performance measure. The
profits are a function of the service levels demanded by the customers. The variables that
determine success are comprised of where to produce products, where to set up
distribution centers for products, and the resulting frequencies in shipping material to and
from these locations. These decisions are performed at the top level with information on
overall costs and benefits supplied by support staff in the middle level.

Controlling and reducing operational costs associated with the manufacturing of
the product has and will continue to be a primary method in increasing a company's
profitability. Mission statements, vision statements and goals set by this top level are used
to communicate desired behavior to the other levels which result in increased profits for
the company.
5.1.2. Middle level description

Given decisions by the top level and the mission, vision or goal statement, the
individual plant and distribution locations are required to manage the local facilities under
given budget constraints and performance criteria. The decisions by the top level of what
and where to manufacture determine the constraints at the middle level. These constraints
are expressed in the operational budgets for this level. The middle level can alter these
constraints by providing a cost and benefit analysis from other middle level individuals.

5.1.3. Lower level description

The lower levels are the individuals at the local plant or distribution center
empowered to act upon the middle level requirements. These day to day activities include
scheduling resources for production and tracking the past and present operational budget
performance measures. These individuals are closest to the customer and respond to
complaints and demand variations by the customers. Rapid feedback allows this level to
see the effects of their decisions on the performance measures. The lower level can adjust
their behavior accordingly, but are constrained by top level decisions.

5.1.4. Matrix of levels

The matrix shown in Table 3 illustrates an example of these levels. This is a simple
example showing three levels. The performance measures and decision variables for each
level are examples of a possible scenario among the three levels. The matrix demonstrates
the relationship of decisions among the different levels.
<table>
<thead>
<tr>
<th>Level</th>
<th>Performance Measures</th>
<th>Decision Variables</th>
<th>Position Title Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>Company profitability</td>
<td>Location of plants and distribution centers</td>
<td>VP Manufacturing VP Marketing VP Finance Etc.</td>
</tr>
<tr>
<td></td>
<td>Customer satisfaction</td>
<td>Operational Vision Desired customer service levels</td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td>Meeting operational budget</td>
<td>Product and process improvement projects Staffing levels</td>
<td>Plant Manager Warehouse Manager Product Director</td>
</tr>
<tr>
<td></td>
<td>Attaining customer service levels set by top level</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operational cost improvements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td>Customer service levels</td>
<td>Plant floor resource scheduling Operational budget spending</td>
<td>Production Area Manager Materials Manager Finished Good Inventory Manager</td>
</tr>
<tr>
<td></td>
<td>Operational budget</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Each level makes decisions on a different time horizon. The top level has a long range planning horizon of many years. These decisions by the top level produce results over a longer time period and results are not easily traced back to specific decisions by the top level because of the long response time required. The middle level has a shorter time horizon of one to two years. The results based upon these decisions are also not easily traced back to the decisions. The lower level has the shortest time period of a few months. This short response time has the best direct cause and effect relationship. An example is the scheduling of production and its immediate effect on the customer service levels and line item fill rates.

For each of these levels, there is a link to the decisions by the top level that create constraints on the other areas. These decisions set the boundaries of control for the middle and lower levels. There are more in most companies and the cascading effect of the decisions from the top level affects the constraints at the other levels.
5.2. Description of Different Decision Makers

In order to better understand the decision makers, a list of different potential titles and positions is given below. Each of these titles can be placed into the hierarchy of levels described earlier and includes the performance measures, decision variables and constraints that are specific to each position.

*Vice President of Manufacturing*

This individual is responsible for many key decision variables such as where to produce and distribute the various products. This includes the decision of the shipping frequency between the plant and the distribution warehouses. The decisions made by this individual determine the operational budgets at the various levels. These decisions are based upon information from a middle level reporting to this individual and have an overall goal to increase profitability. Profitability is the measure used to assess the performance of the Vice President of Manufacturing.

*Plant Managers*

A plant manager is affected by the shipping frequency decision by a change in the operational budget. How well the plant manager estimates and manages the operational budget is a performance measure for this individual. Other performance measurements include customer service levels such as line item fill rate and successful new product launches for products produced at the plant.

An assumption of the model assumes that for a given shipping frequency, the plant can produce any demand. This requires the plant manager to invest in the appropriate level of resources to satisfy the demand. A more frequent shipping decision results in a higher capacity requirement for labor and machine resources. This extra or idle capacity
provides flexibility, at an additional cost to the plant manager's operational budget. If the production line is labor intensive, the head count decision or level of employees is difficult to manage from period to period due to the varying finished good product demand. One period's requirement may push the line to the maximum capacity while the next period's requirement result in no work and sending workers home. This has cascading effects on training and morale of the workers that adds to the difficulty in maintaining a skilled workforce. These situations are costly and the plant manager uses this information as input to the vice president of manufacturing's decision on variables affecting the operational costs of the plant.

Distribution Warehouse Managers

A distribution warehouse manager is influenced by the shipping frequency decision by a change in the finished goods inventory levels. These levels are a performance measure for the warehouse manager. Other performance measures include meeting required operational budgets, achieving customer service levels, and completing successful projects to lower operational costs and improve the customer service level. As with the plant manager, the warehouse manager must decide to invest in resources to accomplish the performance objectives. These resources can be through labor or capital investment and are a function of the shipping frequency. The unloading of a trailer at the distribution center is labor intensive. A less frequent shipping frequency will require more labor on a shipment date to unload the trailers. Conversely, a more frequent shipping frequency will provide a more stable labor requirement by unloading fewer trailers more frequently. Table 2 shows an example how two different individuals may desire a certain shipping frequency based upon their performance measures. The plant manager and warehouse manager have conflicting performance measures and may request an opposite shipping frequency decision from the Vice President of Manufacturing to improve their individual performance measures.
Table 2

<table>
<thead>
<tr>
<th></th>
<th>More Frequent Shipping</th>
<th>Less Frequent Shipping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Manager</td>
<td>Higher operational costs either from a higher possible capacity resulting in increased labor or machine resources.</td>
<td>Lower operational costs from a steady or more stable production, requiring a lower capacity of labor or machine resources.</td>
</tr>
<tr>
<td>Warehouse Manager</td>
<td>Lower operational costs from unloading fewer trailers more frequently resulting in a more stable labor requirement.</td>
<td>Higher operational costs from a higher capacity of trailers in a period resulting in a higher labor requirement.</td>
</tr>
</tbody>
</table>

Marketing Product Directors

Product directors are responsible for product attributes that are required to satisfy customers needs. This includes physical attributes of the product and service features such as on time delivery. The product director's performance measures are influenced by the shipping frequency in altering the responsiveness to customer demand with respect to on time delivery and rapid new product launches. Marketing Product Directors only see the benefits of flexible manufacturing because their operational budgets are not affected by the shipping frequency decision.

Area Production Managers

Production managers are responsible for manufacturing a set of products from their area to meet customer demands on time and within a set operational budget. The scheduling of physical and human resources required to produce the products are the primary performance measures for the production manager. Included in the performance measures are the customer service levels and the level of backorders for their products. A backorder is a group of customer orders for products that are out of stock at the distribution warehouse. Eliminating backorders will result in 100% customer service level
as defined by the line item fill rate. The shipping frequency affects the local production areas' scheduling of employees or resources. The operational budget of the area is set for a given frequency. An increase in the shipping frequency makes the scheduling of employees problematic by requesting large variations in the labor or capital resources required for a period. A decrease in the shipping frequency provides more flexibility in scheduling for the production manager to satisfy the demand requirements over a longer time horizon.

*Production Planners*

These individuals assist in the coordination and scheduling of production with the production manager. Required raw materials and their procurement are handled by the production planners. The performance measures for these individuals include raw material level inventory, production delays due to material shortage, and customer service levels for the products they plan. The decision variables of what and when to produce are greatly affected by the shipping frequency decision. A more frequent shipping schedule provides increased flexibility to the scheduling activity by providing more finished good departure dates to the distribution center. This helps to improve the performance measures of backorders and customer service levels of line item fill rate for these individuals.

*Materials Managers*

These individuals are primarily responsible for the flow of material through the plant. The inventory of raw material and finished goods at the local plant are performance measurements. Keeping these inventory levels as low as possible while maintaining the customer service level is their objective. This requires holding the appropriate amount of raw material inventory to prevent shortages and possible backorder situations. A change in the finished goods shipping frequency will greatly influence the performance of this
individual for a fixed customer service level requirement. A less frequent shipping schedule requires more raw material and finished good inventory to be kept at the plant. A more frequent shipping schedule allows the plant to have lower raw material and finished good inventory levels.

In every organization each of these positions has different levels of responsibility. The performance measures, decision variables and constraints for the decision making presented here are examples and vary from company to company.

5.3. Shipping Frequency Change Affect on Decision Makers

In this three level hierarchy, the decisions to change the shipping period ($\lambda$) occur at the top level with the cost and benefit information such as inventory costs ($T_{ci}$) being provided by a staff of middle level individuals. Each level looks at the shipping frequency decision to optimize its individual performance measures such as inventory costs.

At the top level, they attempt to minimize the overall operational costs over different shipping period values. Operational costs of inventory, shipment, labor, capital expenditures for machinery, training and any others, should be included by the middle level individuals to provide the proper information to the top level. With this information the top level looks at the long range implications of the decision and minimizes the operational costs to meet the performance objectives of increased profitability at a desired customer service level.

The lower level individuals who schedule the activities for their areas have an interest in the shipping frequency decision. At the warehouse the lower level individual prefers a more frequent shipping schedule to facilitate the day to day scheduling of resources. At the plant, the lower level individual prefers a less frequent shipping schedule to provide a more stable schedule of production requirements. These individuals have a
similar conflict with the middle level individuals. Without other performance measures these levels attempt to optimize their individual portions without regard for an optimal decision for the company.

These problems of conflicting objectives may escalate and employees may begin to behave in a manner that is detrimental to the company. Employees may begin to alter or hide information to provide their area with apparent measurement advantages. This is not desirable for the company and the upper management must examine ways to promote the proper behavior of the employees to maximize the profits of the company.

5.4. Common Performance Measures for Different Levels

In order for the optimal solution to be obtained, it is necessary to have some common performance measures across the levels. This is the top level's responsibility to provide the proper incentives to all the levels to obtain the optimal solution and behavior at all levels.

Using the customer service level performance measure across the organization is an example where the contribution of the individual levels achieves the overall goal for the company. The line item fill rate is a responsibility of all the levels. Measuring the company employees with a line item fill rate along with their other performance measures, encourages the employees to work together to increase profitability.
6. Conclusion

6.1. Model Flow of Complete Manufacturing System

In order to understand the different effects of a manufacturing system, the process should be modeled to include all of the events required for the delivery of the product to the end customer. Flexible manufacturing requires each stage of the process to be flexible. The manufacturing process, from the procurement of raw material to the delivery of the product to the customer, must be well understood. If one of the stages is not flexible, such as the transportation of raw materials to the plant or finished goods to the distribution warehouse, the benefits of lean manufacturing are reduced.

6.1.1. Transportation flexibility provides potential lower inventory levels

Remote locations are faced with a difficult task of attaining flexibility throughout their manufacturing processes. The purchase of flexible machinery is a start, but other parts of the manufacturing process require the remote location to extend their efforts to the transportation system. Given flexible production lines, the model presented indicates that the benefits to lean manufacturing are constrained by the transportation system, but lower finished good inventory levels are possible with an increase in the shipping frequency.

6.1.2. Feasibility of flexible manufacturing in a remote location

In this model the transportation flexibility constraint is examined. The transportation system also includes the length of time to transport the product to the warehouse or transit time (Z). A reduction in the transit time will lower finished good inventory levels by lowering the safety stock requirements through a reduction in the lead
time \((L)\). Changing the transit time requires a significant investment by the shipping carriers that may not be economically feasible.

Another barrier is lower wage countries attracting manufacturing by providing lower operational costs. The lower wages or other incentives to reduce operational costs is often offered in areas that are severely constrained by their transportation system. Increasing the flexibility of the transportation system will significantly increase the shipping costs. Complete flexible manufacturing in such a remote location may be more difficult to economically justify.

6.1.3. **Manufacturing location can create flexibility**

Changing the transportation system in remote locations is costly and at times may not be a viable alternative. The location of the customers and suppliers can influence the decision of where to locate the manufacturing facility. Placing a manufacturing facility close to customers and suppliers will alleviate some of the transportation flexibility requirements and also reduce lead times for raw materials and finished good product. The benefits of lean manufacturing are easier to obtain when suppliers and customers are located close to the manufacturing location. The manufacturing facility can respond quickly to customer demands and create new products by being physically closer to the customer.

6.2. **Difficulty to Change One Area Without Affecting Other**

In making the decisions of what, where and how often to manufacture products, firms, and specifically upper management must consider the cascading effects of the decisions to other levels of the organization. These other levels may work to optimize their performance measures under a given budget constraint. The opportunity exists for these levels to persuade upper levels into decisions without realizing the effects on the
other areas. Upper management receives information from other levels and must work to create an open environment willing to share information. Without this, the upper management decisions may result in sub-optimization for the company.

Upper management must put in place other performance measures and objectives to focus the behavior of the different levels toward an optimum for the entire company. Creating these common goals encourages all levels of the company to make decisions to improve the company. In this way, upper management can create trust and respect among the different levels and deter the levels from maximizing a single area without regard to the impact on the other levels. A common performance measure of customer service through a line item fill rate is an example of an overlapping performance measure to prevent a sub-optimization in the different levels of the organization.

6.3. Flexible manufacturing impact on plant operations

6.3.1. Flexible machines may reduce capacity requirements and spread risk

The plant investment in capital equipment required to obtain lean manufacturing benefits is of significant importance in the decision to use a flexible manufacturing strategy. However, a flexible production line enables the plant to spread the risk or chance of demand variations exceeding the capacity of the line. The flexible machine can provide the plant with the opportunity to have lower investment in machinery by providing a single machine to perform what previously required many dedicated machines. Lean manufacturing can spread the risk of finished good demand variations and lower capital investment costs for the plant.
References


Appendix A - Johnson & Johnson Credo

Our Credo

We believe our first responsibility is to the doctors, nurses and patients, to mothers and fathers and all others who use our products and services. In meeting their needs everything we do must be of high quality. We must constantly strive to reduce our costs in order to maintain reasonable prices. Customers' orders must be serviced promptly and accurately. Our suppliers and distributors must have an opportunity to make a fair profit.

We are responsible to our employees, the men and women who work with us throughout the world. Everyone must be considered as an individual. We must respect their dignity and recognize their merit. They must have a sense of security in their jobs. Compensation must be fair and adequate, and working conditions clean, orderly and safe. We must be mindful of ways to help our employees fulfill their family responsibilities. Employees must feel free to make suggestions and complaints. There must be equal opportunity for employment, development and advancement for those qualified. We must provide competent management, and their actions must be just and ethical.

We are responsible to the communities in which we live and work and to the world community as well. We must be good citizens — support good works and charities and bear our fair share of taxes. We must encourage civic improvements and better health and education. We must maintain in good order the property we are privileged to use, protecting the environment and natural resources.

Our final responsibility is to our stockholders. Business must make a sound profit. We must experiment with new ideas. Research must be carried on, innovative programs developed and mistakes paid for. New equipment must be purchased, new facilities provided and new products launched. Reserves must be created to provide for adverse times. When we operate according to these principles, the stockholders should realize a fair return.
QOH at End of Period for Shipping Frequency of Once Every Seven Periods

Inventory

Period

QOH per period
Average
Safety Stock Level
Appendix C - Finished Good Inventory for Three Day Shipping Period