Supply Chain Dynamics

by

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Submitted to the Engineering Systems Division in Fulfillment of the Requirements for the Degree of

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Abstract

The strong bargaining power of major retailers and the higher requirements for speed, service excellence and customization have significantly contributed to transform the Supply Chain Management. These increasing challenges call for an integrated and dynamic Supply Chain Management and for a better integration and alignment with key customers, in order to reduce the firm's time-to-market and build competitive advantage.

The thesis aims at providing the partner company, a major player in the consumer goods industry, with a more robust and efficient vendor managed inventory practice, so that the partner can determine the optimum inventory level to satisfy turnover, service level and lead time requirements, whereas minimizing lost sales and total costs in the system.

The team developed a Supply Chain Dynamics framework to help the partner to establish new service level strategies, strongly oriented to the strategic importance of its products and customers, and to map the key system-wide drivers that impact the overall number of inventory turns, service level and total costs. Additionally, in order to run simulations and estimate the outcomes of the proposed recommendations, the team developed a "Multi-Echelon" simulator and used a commercial "Supply Chain Dynamics" simulator.

Thesis Supervisors:

- James Masters, Executive Director of the Masters of Engineering in Logistics (MLOG) Program at the MIT
- James B. Rice Jr., Director of the Integrated Supply Chain Management (ISCM) Program at the MIT

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Ricardo Wagner Lopes Barbosa

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Edward Fan

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Chapter 1: Introduction and Motivation

1.1 Introduction

The thesis project "Supply Chain Dynamics" was a joint initiative between the Masters of Engineering in Logistics Program and Supply Chain Partners Program. In this program, "Partner" company serve as research sites for student thesis work.

For this thesis, the partner is one of the world's largest consumer products companies that produces and markets a wide range of foods and home and personal care products. This multi-billion company operates in all major markets around the globe and has significant presence in the United States.

For the sake of confidentiality, the partner was not revealed and all numbers and specific details mentioned in the thesis were disguised.

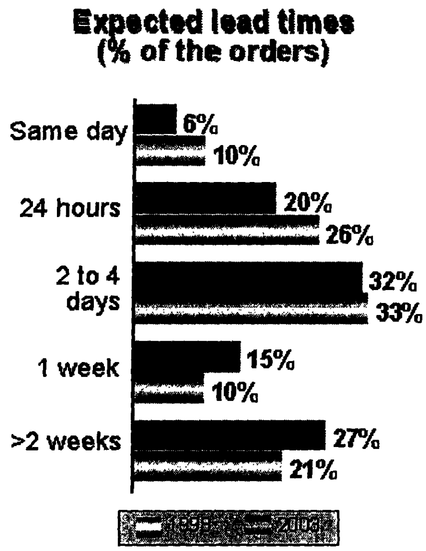
1.2 Motivation for Supply Chain Dynamics

Supply Chain Management is primarily concerned with the efficient integration of suppliers, factories, warehouses and stores so that merchandise is produced and distributed in the right quantities, to the right locations and at the right time, and so as to minimize total system cost subject to satisfying service requirements. (Levi – 2002)

Recently, Supply Chain Management has faced a strong transformation, led mainly by the following key drivers:

- Plummeting costs of transportation and communication (the inter-organizational co-ordination costs are getting similar to the intra-organizational costs)

- Even-more demanding customers and globalization of demand (customers are less forgiving and more demanding of customized products and services, at a larger variety)
- Higher requirements for service aggregation and customization
- Globalization of supply and intense competition (competition has forced new offerings tailored to customers' needs and has increased the pressure on cost reduction - willingness to increase inventory turns and reduce working capital needs)
    - Inventory turns increased by 30% from 1995 to 1998
    - Inventory turns increased by 27% from 1998 to 2000
    - Overall the increase is from 8.0 turns per year to over 13 per year over a five year period ending in year 2000. (Levi – 2002)
- Higher levels of product customization (trend of commoditization has reduced time-to-market)
- Increase in technology and knowledge specialization
- Shortening product life cycles (requirements for lower lead-times)



Source: Benchmarking ELA (European Logistics Association)

Figure 1: Expected Lead Times

Supply Chain Management Trends in the Retail Industry

More specifically, the consolidation in the retail industry, led by the inability of most retailers to compete against the large national players, has contributed to strengthen the bargaining power of the retailers (creation of power customers), and consequently, to increase the pressure on the goods manufacturers for a superior responsiveness and a lower lead-time, so that retailers are able to exceed customer's satisfaction and expectations. In fact, the pricing power of manufacturer has decreased since retailers started to merge. Additionally, their costs of doing business increased because of higher retailer expectations.

In order to thrive in and be able to fulfill the increasing requirements from retailers, the manufacturers are streamlining their supply chains to increase supply chain visibility and customer responsiveness, in an effort to better cooperate with their trade partners. The new business dynamics forced the manufacturers to shift their focus onto supply chain management, as a mean of extracting the value in the chain.

These increasing challenges call for an integrated and dynamic Supply Chain Management. Companies are focusing on the extended supply chain and on promoting better integration and alignment with key customers in order to reduce the time to market

Among the industry's new trends in Supply Chain Management, we can highlight:

- Focus on integrated supply chain systems
- Supply chain synchronization
- Reduced planning horizons
- Investments to acquire visibility throughout supply chain
- Partner collaboration for key activities

1.3 Current status, issues and challenges in the Supply Chain

The partner's Supply Chain Management has significantly improved, as a direct consequence of efforts to reduce costs and improve asset utilization.

Among the supply chain metrics, we can highlight:

- Service level: higher than 95% for most products
- Replenishment lead times: around 5 days for most products
- Modern Supply Chain techniques: collaborative planning and forecasting replenishment (CPFR), EDI, Vendor Managed Inventory
- State of art tools on network design, forecasting and distribution planning

However, in order to achieve the excellence in Supply Chain Management, the partner must deal with the selected following issues:

- There is no single tool that integrate all the links in the supply chain, which makes it difficult to coordinate the actions between players
- The partner company does not track the number of lost sales
- The partner company has no tool to evaluate the cost-benefit from increasing the service level and reducing the lead times, according to customer's willingness
- The partner company does not prioritize the delivery of the SKUs that provide the firm with the highest bottom-line
- The length of the manufacturing runs and its current limited flexibility prevent the company's supply chain from increasing its agility to match the customer's demand

Additionally, the requirements from key customers are getting even harder. They are asking for 99% service levels and for a 3-day lead-time, which really poses a series of challenges to be pursued by the partner firm:

- How much does a 99% service level and a 3-day lead-time strategy cost? What are the implications on the manufacturing run strategy of such service level?
- How can the firm effectively manage customer's inventory and to efficiently assess the daily logistics trade-offs (inventory, lead times, service level, lost sales…)?
- Is the current order pattern "fixed-order point/ fixed-order quantity" (most of the time the order quantity is a truckload) in different intervals of time still appropriate? Is there a better way of ordering?
- How can the firm segment SKUs and establish performance criteria based on that, in order to improve the overall bottom-line?

Chapter 2: Objectives, Scope and Structure

2.1 Objectives of the project

The thesis project aimed at speeding-up the partner company's Health and Personal Care division sales growth, improving key customer's service level and reducing overall costs, by providing the company with a more robust and efficient vendor managed inventory practice.

In order to attain the proposed goal, the thesis will address and try to answer the following questions (each of the following questions will be detailed in a specific chapter):

Thesis Question 1: What is the optimum inventory level to satisfy turnover, service level and lead time, while minimizing lost sales and total costs?

For a selected group of key customers, the thesis team ran several simulations with the use of a commercial Supply Chain Dynamics simulator, developed and customized to the partner firm, and with the use of a "Multi-Echelon" simulator, developed by the team using the Microsoft Excel software.

The goal was to find out the optimum inventory levels to satisfy specific customer's requirements (service level, lead time and inventory turnover), while minimizing lost sales (stock-outs) and total costs.

Thesis Question 2: How can the ordering patterns and the optimal quantities be improved?

The team developed a "trade-off analysis tree" to map the several logistics trade-offs in partner's supply chain (e.g.: higher transportation costs versus lower lead times, and consequently, lower probability of lost sales).

The goal was to improve the partner's ordering patterns and minimum order quantities to attain customer's demand for higher inventory turns.

Thesis Question 3: How to determine which SKU will lead to improved overall bottom-line?

The team analyzed the partner's SKU and customer databases and developed a segmentation criterion to determine which SKU would lead to improved overall bottom-line, whereas attending the customer's demand for higher inventory turns

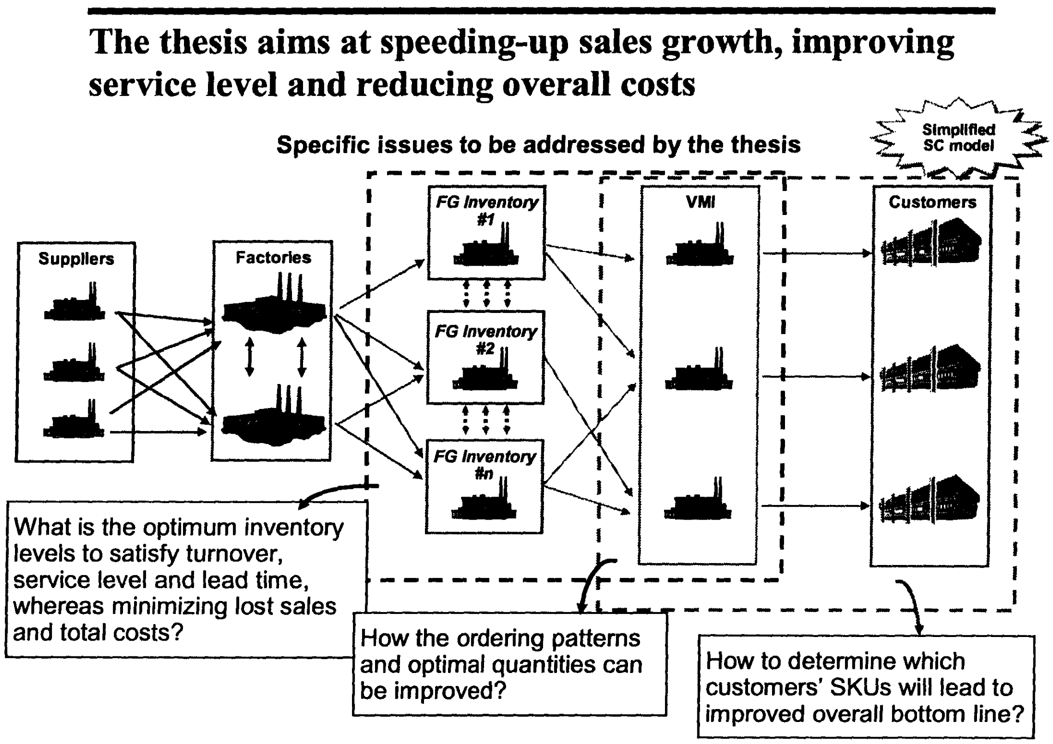


Figure 2: Thesis Questions

Concluding, the thesis project will enable the Partner to better integrate its supply chain with customers, and therefore, to achieve a competitive differential throughout a more efficient and accurate vendor managed inventory practice, as illustrated in the "Figure 3" below.

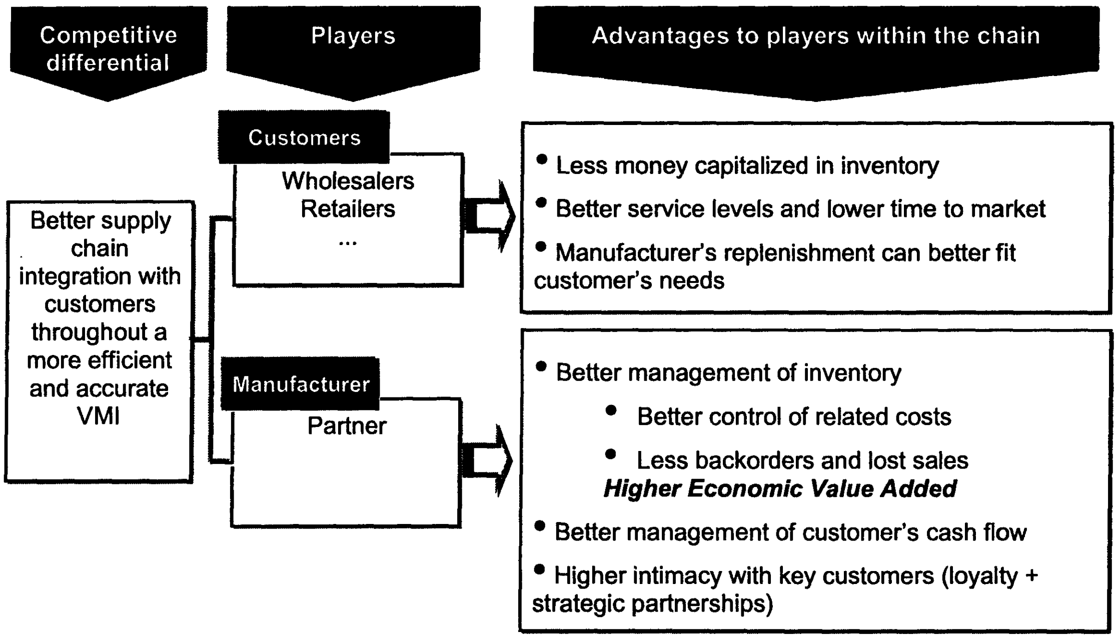


Figure 3: Advantages of the Thesis

2.2 Project scope

While the scope of the partner's overall initiative is the whole extended supply-chain, which ranges from the raw materials purchasing and supplier management through factory production and distribution to customer development and management, the thesis project will focus solely on improving partner's inventory management and control (as shown in the illustration below)

The scope of the thesis is limited and possesses clear interfaces with major "blocks" of the partner's Supply Chain, such as the forecasting and manufacturing processes.

This means that inputs such as the partner's manufacturing lead-times, run strategies, forecasts and warehousing capacities were held constant, and that the effects of changes and their possible impact in these areas were not directly encompassed by the thesis.

However, the thesis project indicated if any of these boundaries or "black boxes" should produce a constraint on the overall outcomes (as detailed in the "Thesis Question 2" section).

Scope of the Supply Chain Dynamics project

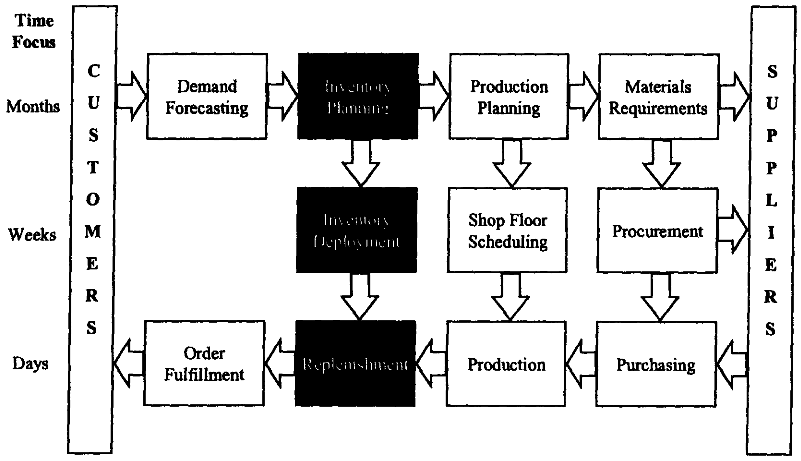


Figure 4: Scope of the Supply Chain Dynamics Project

Additionally, due to its limited scope, the thesis will not deal with:

- the revision of the supply chain macro strategy
- the purchase or the divestiture of assets
- the redesign of processes
- the promotion of downsizing
- the discontinuity of SKUs and of distribution channels

2.3 Thesis Overview

The thesis project focused on the analysis of all SKUs of the laundry category for three major clients that together represent more than 60% of the laundry sales. The proposed macro work plan can be divided in four phases:

Phases	Duration (weeks)	Main tasks
1. Heating-up	4	- Development of a detailed work plan and agreement on the *modus operandis* - Review of the related literature - Test of the Supply Chain Dynamics Simulator - Analysis and selection of tools - Data gathering - Conduction of on-site interviews
2. Pilot Simulation	6	- Simulation for one client (one category) - Perform supply chain simulations - Assessment of constraints and trade-offs - Revision of ordering techniques by SKU - Development of patterns
3. Rollout Simulation	5	- Simulation for two clients (one category) - Perform supply chain simulations - Assessment of constraints and trade-offs - Revision of ordering techniques by SKU - Development of patterns
4. Thesis refining	1	- Refinement of the thesis - Final write-up and documentation

Figure 5: Macro Work Plan

2.4 Main Project Deliverables

The thesis project had four main deliverables:

Deliverable – 1: supply-chain models using the Supply Chain Dynamics and the Multi-Echelon simulators ("thesis question 1")

Deliverable – 2: robust technique for analyzing ordering patterns and suggesting more optimum order quantities ("thesis question 1")

Deliverable – 3: recommendations to support alternative trade-off within the Supply Chain ("thesis question 2")

Deliverable – 4: segmentation criteria to effectively differentiate the partner's SKUs offering ("thesis question 3")

2.5 Thesis Detailed Work Plan

The detailed work plan, developed in the beginning of the thesis project, is shown below. The actual work plan differed from the original as a function of the data collection process.

Additionally, the difficulty of obtaining some data requested fostered the creativity and cooperation among the researchers and the partner's team. These elements played a crucial role in making the thesis project happen.

Fortunately, the team was able to match the majority of the fundamental requirements, leaving just some simulations and analyses, chiefly regarding other key customers' database, to be done in the future, mainly due to the lack, inexistence or lateness of information to conduct the simulations, as detailed in the "Ideas for Potential Future Works" chapter of the thesis.

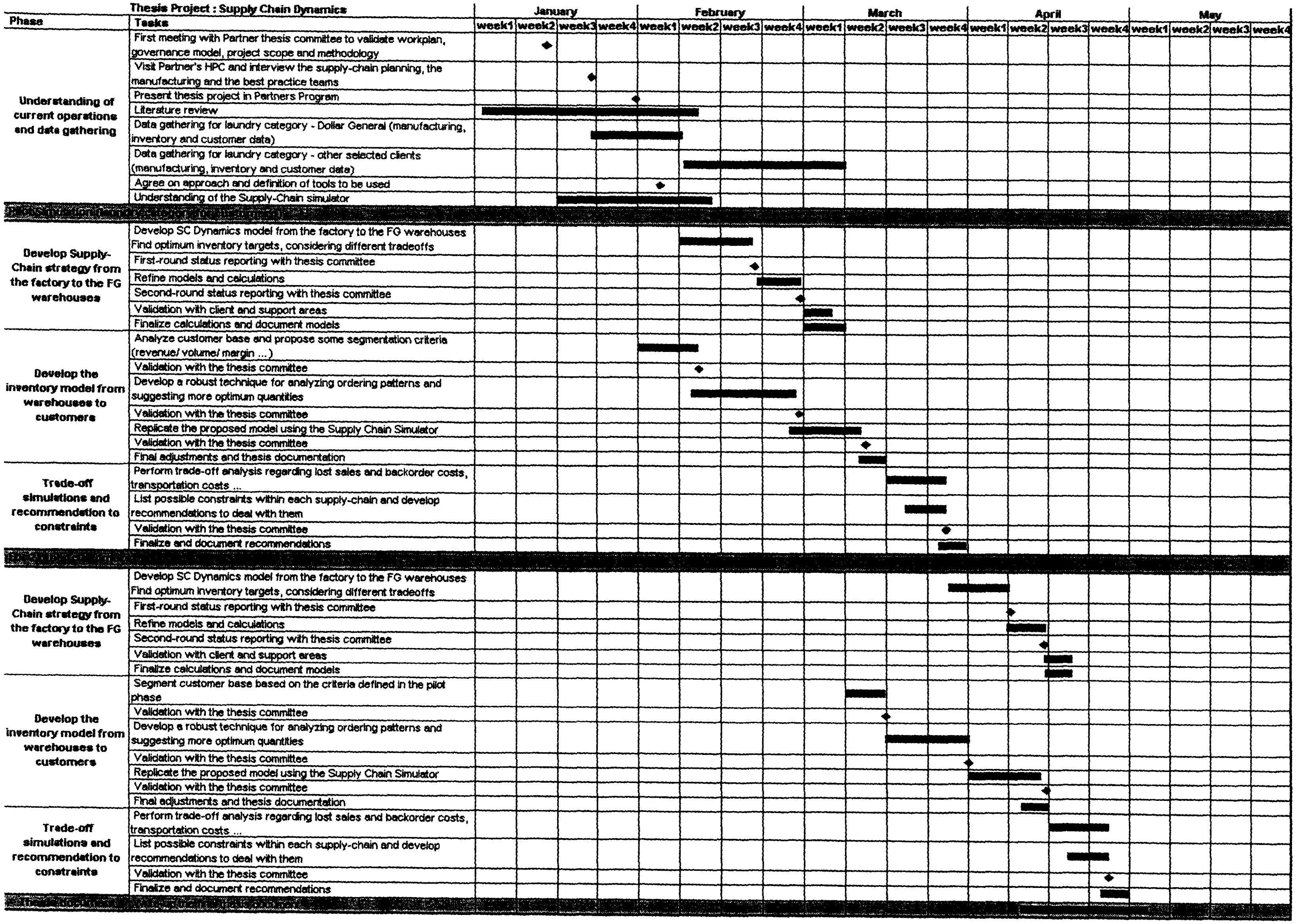


Figure 6: Detailed Work Plan

Chapter 3: Theoretical Concepts

3.1 Total Cost Considerations

The main objective of the Logistics function is to minimize the total costs of the system, rather than to minimize the cost of each component, given the customer service objective. (Lambert – 1992)

The totals costs can be viewed as the summation of the following parcels: transportation costs, warehousing costs, order processing and information costs, purchase costs, production lot quantity costs, inventory-carrying costs and shortage cost (Lambert – 1982).

1) Transportation costs (Lambert – 1992)

Transportation cost, as described by its name, is the cost associated with the transportation function and can be determined by a statistical audit of freight bills for common carriers or from corporate accounting records for private fleets.

2) Warehousing costs (Lambert – 1992)

Comprise all expenses that can be eliminated or must be increased as the result of a change in the number of warehouse facilities (these costs do not change with the level of inventory stocked, but rather with the number of stock locations)

The throughput costs, the costs to unload, inspect, put away, pick, pack, and load the property that moves through the storage facility, are an example of warehouse costs.

3) Order processing costs (Masters – 2002)

Ordering Costs are the additional costs incurred whenever we order, reorder, or replenish the inventory. The ordering cost occurs whenever an order is placed, is fixed with regard to the size of the order, is normally expressed on a per order basis and can be viewed as an administrative cost incurred in the purchasing function (processing the order, invoicing, paying the bill, auditing, etc).

4) Purchase costs (Masters – 2002)

Purchase costs are the costs of the items. If the item is manufactured, the cost is the value of the item at that point in the system, to include all material and direct labor costs. For items that are purchased from outside the firm, this is usually the unit price paid to the vendor. The purchase cost is usually expressed and defined in an inventory model on a per unit basis, for example, as dollars per unit.

5) Production lot quantity costs (Lambert – 1982)

Production lot quantity costs are those costs that will change as a result of a change in the distribution system and usually include: production preparation costs (set-up time, inspection, set-up scrap and inefficiency of beginning operation), lost capacity due to change over and materials handling, scheduling and expediting.

6) Inventory carrying costs (Masters – 2002)

Inventory carrying costs (holding costs) are the costs that accrue due to the actual holding of inventory over a period. They are generally estimated by accumulating all of the following four components and averaging them across all of the items in the inventory system and expressed as a percentage of the inventory being held over a period:

- Storage Costs: the costs of warehousing the inventory. Storage costs are usually a function of land and labor costs associate with running a warehouse, and thus can be expected to vary considerably from location to location. They are different from the throughput costs - the costs to unload, inspect, put away, pick, pack, and load the property that moves through the storage facility.

- Service Costs are out of pocket expenses that arise in addition to the physical storage costs. Two typical examples are insurance and taxes.

- Risk Costs are financial risks associate with holding an item in inventory, once the item may become lost, stolen, damaged, or obsolete while it is being held. Some of these costs can be covered with insurance, but most firms treat damage and obsolescence as risks that are self-insured. Risk costs are significantly different than storage and service costs in that they are inherently probabilistic in nature.

- Capital Costs reflect the idea that an inventory ties up funds which the firm could be using for other productive purposes. As such, the inventory should bear an opportunity cost of capital so that financial decisions about the appropriate level of inventory in the firm will consider the costs of funding the investment in inventory.

<u>7) Shortage costs</u> (Masters – 2002)

Shortage Costs result from not having inventory or from not having enough inventory at the right place at the right time. The four most common scenarios are as follows:

- Backorders: occur when the customer is willing to wait for inventory to be made available. Costs accrue because the firm must maintain a system to record the backorder, maintain it, and fill it when stock becomes available. There may be additional costs due to shipping. Backordering can be seen to result in incremental order processing, handling, packaging, and shipping costs which can be substantial.

- Lost Sales: occur when the customer responds to an out-of-stock situation by canceling the demand. When a lost sale occurs, the firm loses the gross profit margin on the unit that could have been sold. In many cases, the loss extends far beyond the margin on the item which is actually out of stock to contemplate the lost margin on the items whose demand are correlated or complimentary to the item out of stock.

- Lost Customer Cost: occurs when a loyal customer is lost due to poor inventory availability performance. This cost category can be faced as the net present value of the stream of lost gross margins of all the future purchases of this item and all the complimentary ones by the "lost" customer.

- Disruption Costs: occur in a production environment when a shortage of raw materials or component parts causes an interruption to the planned activity. These costs are frequently out of all proportion to the value or cost of the goods in question.

3.2 Vendor Managed Inventory

The thesis partner assumes managerial responsibility for its key customer's inventory. This kind of strategic collaboration characterizes the so-called Vendor Managed Inventory (VMI) practice.

However, before going deep into further detail about the VMI practice, it is important to understand its conceptual differences to other partnering practices in the industry, such as the Continuous Replenishment Program (CRP) and the Vendor Owned Inventory (VOI): (David Simchi-Levi – 2002)

- **VMI** (Vendor Managed Inventory): the supplier manages the customers inventory subject to fill rate and investment guidelines (a true trading partner agreement)

- **CRP** (Continuous Replenishment Program): the supplier continuously replenishes what was consumed "off the shelf" - driven by point-of-sales (POS) or manufacturing data with on-hand status provided by the customer
- **ACR** (Advanced Continuous Replenishment): suppliers may gradually decrease inventory levels at the retailer's store or distribution center as long as service levels are met. Inventory levels are thus continuously improved in a structured way.
- **VOI** (Vendor Owned Inventory): the vendor owns the inventory. This practice is also known as consignment (supplier places inventory at a customer's location and retains ownership of the inventory) and can be found as a integrant part of the VMI/CRP processes
- **QR** (Quick Response): Vendors receive POS data from retailers, and use this information to synchronize production and inventory activities at the supplier. In this strategy, the retailer still prepares individual orders, but the supplier uses the POS data to improve forecasting and scheduling.

Schematically, the table below highlights the differences among the Quick Response, the Continuous Replenishment, the Advanced Continuous Replenishment and the VMI practices, regarding the decision maker, the ownership of the inventory and the new skills employed by vendors.

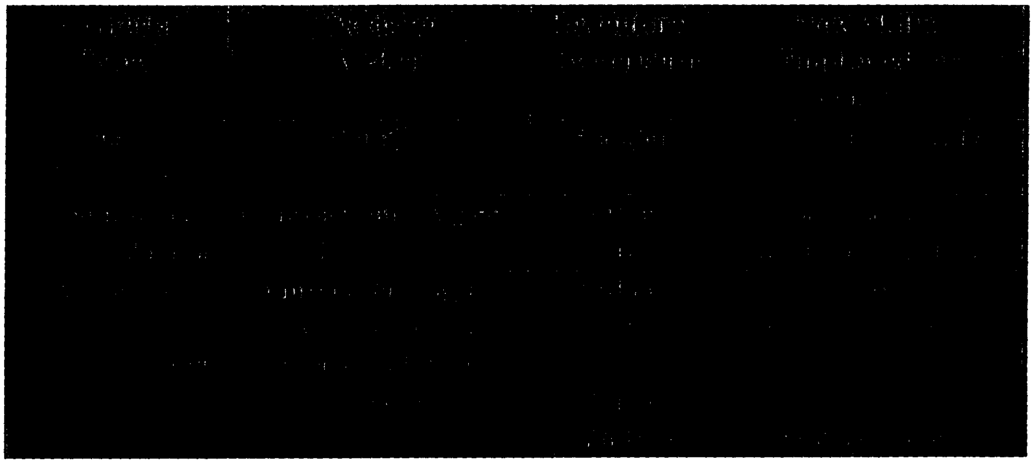


Figure 7: Supply Chain Collaboration Techniques

Understanding Vendor Managed Inventory[1]

Vendor Managed Inventory is a demand-as-is-needed supply chain. VMI also can be defined as a means of optimizing the Supply Chain performance (achieve flawless, continuous product flow, superior customer service, and lower channel costs shared among partners), in which the manufacturer is responsible for maintaining the suppliers' inventory levels (the manufacturer has access to the suppliers' inventory data and is responsible for generating the purchase orders).

In this relationship, the retailer relinquishes control over an item/supplier category in favor of an improved EDI and Logistics process. The following buying strategies must be defined: lead-time, inventory, type of product activity and history needed, service level and requirements, transportation and warehouse strategy, pricing strategy and promotional strategy and communication.

Under the typical business model, when a distributor needs product, they place an order against a manufacturer. The distributor is in total control of the timing and size of the

[1] http://www.vendormanagedinventory.com/ and http://www.promodel.com/glossary/

order being placed and is responsible for maintaining the inventory plan.

Conversely, under the Vendor Managed Inventory model, the manufacturer receives electronic data (usually EDI or via the internet) that tells him the distributors' sales and stock levels. The manufacturer can view every item that the distributor carries, as well as the true point of sale data, and is responsible for creating and maintaining the inventory plan. An important distinction is that under the VMI model, the manufacturer generates the order, not the distributor.

The Vendor Managed Inventory model can both satisfy the objectives of customers (retailers) and vendors (manufacturers).

Major benefits for customers (retailers):

- Inventory level reduction
- Improvement of fill rates and of the overall service level (having the right product at the right time)
- Local customization/ the right mix of products
- Attention to slow moving SKUs
- Leveraging of manufacturer's expertise in the category
- The manufacturer is more focused than ever in providing great service
- Reduction of stock-outs
- Reduction of planning and ordering cost (purchasing overhead), due to the responsibility being shifted to the manufacturer
- Lower total acquisition cost (possible delayed ownership)

Major benefits for vendors (manufacturers):

- Information into customers' inventory levels and buying patterns
- Visibility to the distributor's point-of-sale data makes forecasting easier
- Visibility to stock levels helps to identify priorities (replenishing for stock or a stock-out?). Before the VMI, a manufacturer had no visibility to the quantity and the products that were ordered. With the VMI, the manufacturer could see the potential need for an item before the item was ordered.
- Anticipation of promotional demand
- Strengthening of customer relationships/differentiation
- Reduction of stock-outs or obsolescence at retail
- Feedback to product development
- Perception of cutting edge supply-chain technology
- Promotions can be more easily incorporated into the inventory plan
- Reduction in distributor's ordering errors (which in the past would probably lead to a return)

Additionally, there are common benefits for both parts:

- Data entry errors are reduced due to computer-to-computer communications. Speed of the processing is also improved.
- Both parties are interested in giving better service to the end customer. Having the correct item in stock when the end customer needs it, benefits all parties involved.
- A true partnership is formed between the Manufacturer and the Distributor. They work closer together and strengthen their ties.

- Stabilization of the timing of the Purchase Orders (POs), which are now generated on a predefined basis.

Pitfalls of the VMI

Although VMI does have many benefits, it may have the following pitfalls:

- EDI problems: Extensive EDI testing should be done to validate the data being sent. Is the distributor sending all the data that should be sent? Is each field populated with the correct data?
- Acceptance: Make sure that all employees involved in the process fully understand and accept this new way of doing business. It is not enough to just sell the concept to senior management; all employees who are involved must be willing participants.
- Promotions/Events: Anything that adds or takes away from the normal ordering pattern must be properly communicated.
- Customer Base: Any large customers, either gained or lost, must be communicated to the manufacturer. The distributor must guide the manufacturer on how this will affect sales.
- Over/Obsolete Stock: An agreement must exist between the manufacturer and the distributor on what to do if an overstock does occur (or in the case of an ordering error). Also, both parties must agree on how to handle obsolete stock.
- Time: Both parties involved must understand that this is a learning process. Errors will occur. You will probably not have a perfect process in place from day 1.

Selection criteria for VMI relationships

Good choices for VMI relationships are characterized by the following key factors:

- High concentration — small number of accounts that account for a large volume
- Commodity products — forecastable, regular turn
  - Hard goods (no chance of spoilage) — high or low turn
  - Soft goods (chance of obsolescence) — high turn only
- High level of partner sophistication — facilitates setup and system maintenance

Elements of the VMI[2]

- Electronic Data Interchange (EDI) used for communication
  - 852 transaction — product activity
  - 855 transaction — purchase order acknowledgment
- Demand planning — pull products based upon projected sales
  - 24 months of distributor to retail sales history
  - Use of statistical forecasting over a 6 month horizon
  - Addition of market intelligence for promotions and events
- Network control
  - Manufacturer supply points
  - Distributor warehouse locations
  - Product sourcing rules
  - Transportation modes and transit times
  - Operations calendars

[2] http://www.vendormanagedinventory.com/

- Inventory management
  - Safety stock strategy
  - Scarce product controls — a.k.a. allocations
  - Distributor buying strategies — build/maintain/flush
- Replenishment planning
  - Demand plan, current inventory, safety stock offset
  - Planned arrivals determined
  - Recommended SKU shipments set up using sourcing rules and transit times
- Deployment
  - Recommended line items combined by route
  - Vehicle loads constructed
  - Transportation booked
  - Orders released for fulfillment cycle
  - Shipments received by distributor
- Measurements
  - Customer service level
  - Inventory turns
  - Forecast accuracy

Chapter 4: Thesis Questions

4.1 Thesis Question 1

Thesis Question 1: What is the optimum inventory level to satisfy turnover, service level and lead time, whereas minimizing lost sales and total costs?

Motivation

One of the supply chain executives' biggest managerial challenges is to determine the optimum inventory level to satisfy different customer's requirements, such as turnover, service level and lead time, whereas minimizing the total costs in the system, including the lost sales and the backorder costs.

Notwithstanding, in order to succeed and achieve this goal, it is crucial that the supply chain executives have the full visibility of the supply chain, so that they can properly assess the impact of each managerial decision on the global network.

Contextualization

In order to capture economies of scale in the production process, the product is manufactured at one or a small number of plants, and it moves out to the thousands of retail locations by passing through a series of intermediate distribution inventories. Thus the inventory system consists, not simply of multiple locations, but rather of a series of inter-related layers, or tiers, or inventory echelons through which the stock moves on its way to the retail level.

Currently, the partner does not have an integrated tool or software that provides a dynamic and holistic view of its multi-tiered supply chain. Each part of the chain is supported by a piece of different software and by some systems and spreadsheets developed in-house.

Additionally, the partner does not have a tool to evaluate the cost-benefit from increasing the service level and reducing the lead-times, according to customer's willingness, and he does not prioritize the delivery of the SKUs that provide him with the highest bottom-line (the prioritization criteria was developed by the team and is presented in the "Thesis Question 3" section).

Therefore, one of the major goals of the team was to evaluate the possibility of implementing and adapting a "Supply Chain Dynamics Simulator" – a software that was customized to the company and that has been used by the European business units – to simulate the partner's entire supply chain, from the plants to the customers warehouses. However, due to limitations of the "Supply Chain Dynamics" simulator, as detailed in the following sections, the team had to develop a complimentary "Multi-Echelon" simulator to succeed in modeling the partner's whole supply chain.

4.1.1 The Supply Chain Dynamics Simulator

The Supply Chain Dynamics Simulator is a commercial software customized to the partner company and has been extensively used by its European business units. The simulator covers the immediate supply chain either side of production - from materials procurement to delivery of finished goods to primary distribution centers.

The simulator permits a wide range of alternative scenarios to be evaluated from factory related changes through to business related sourcing and product mix changes. Alternative plant configurations, sourcing, and planning strategies, as well as the impact of uncertainty (e.g. forecast error, supplier and production reliability), may be compared and quantified in both physical and financial terms.

Structure of the Supply Chain Dynamics Simulator

The Supply Chain Dynamics Simulator may be segmented into four major building blocks:

- Service related building block: forecast demand, forecast accuracy, minimum order quantities, safety stock strategy and stock build strategy
- Materials related building block: supplier reliability, supplier lead-times, minimum order quantities and safety stock policies
- Production related building block: line preferences, planning preferences, production rates, production reliabilities, line efficiencies, minimum and batch make constraints, changeover times and waste costs (pack & variety), production calendar, labor requirements and materials requirements
- Distribution related building block: transportation costs, stock holding costs (space rental & interest on working capital) and stock handling costs

Note: the data requirements for the Supply Chain Dynamics simulator, as well as an illustration of its main screen, can be found in the "Appendix I".

Positive points of the simulator

The major strength of the Supply Chain Dynamics Simulator (SCDM) is its manufacturing modeling capability.

Besides providing the advantage of integrating the whole supply chain, the simulator also assists in the development and implementation of the manufacturing run strategies driven by the requirements of the total supply chain. The SCDM can help the company to understand the drivers of total supply chain effectiveness and the trade-offs between inventory, customer service, lead-times, logistics and manufacturing costs, changeovers and capacity. Moreover, it also addresses the frequency and volume of production of each SKU to satisfy customer demand.

Negative points of the simulator

On the other hand, we can highlight some crucial points for improvement:

- The simulator cannot model a multi-node distribution network (it only models one level in the distribution chain)
- The simulator does not consider the lost sales and backorder costs in the calculation of the total costs in the system
- The simulator does not allow the differentiation of the transportation costs, coping with a network scenario in which the company uses LTL, FTL and other kind of modal
- The simulator cannot model more than one factory in the same network configuration. This would require the user to setup "n" different runs in different files, which could damage the "global" solution (loss of visibility in the network)
- The forecast tool is very limited, in comparison to the modern forecasting tools and techniques available in the market

- While the simulator allows users to specify which lines are preferred to produce a certain SKU, it does not allow the users to specify the production sequence in each of the lines (production priority). Therefore, it is impossible to fully replicate the current manufacturing strategy.

Due to the technical gaps discussed above, the team concluded that the simulator could not properly model the partner's network and fulfill the need for supply chain integration. Consequently, besides the simulator's strengths and capabilities, it did not attend the thesis requirements.

Consequently, the team decided to develop a multi-echelon simulator that could be integrated with the Supply Chain Dynamics simulator, in order to most benefit from the manufacturing capabilities of the latter and to acquire additional features, such as the ability to model the whole chain, to treat the inventory more adequately and to calculate the total costs in the system (features of the new simulator).

The integration of the two simulators was definitely a big challenge faced by the team.

4.1.2 Development of a "Multi-Echelon" Simulator

In order to analyze the impact of the new policies over the partner's original one, in terms of total costs, service level and inventory turns, the team developed a multi-echelon simulator to model the flow of the products from the plant facility to the customer's warehouse (3 layers). The partner's multi-echelon distribution network is schematized below.

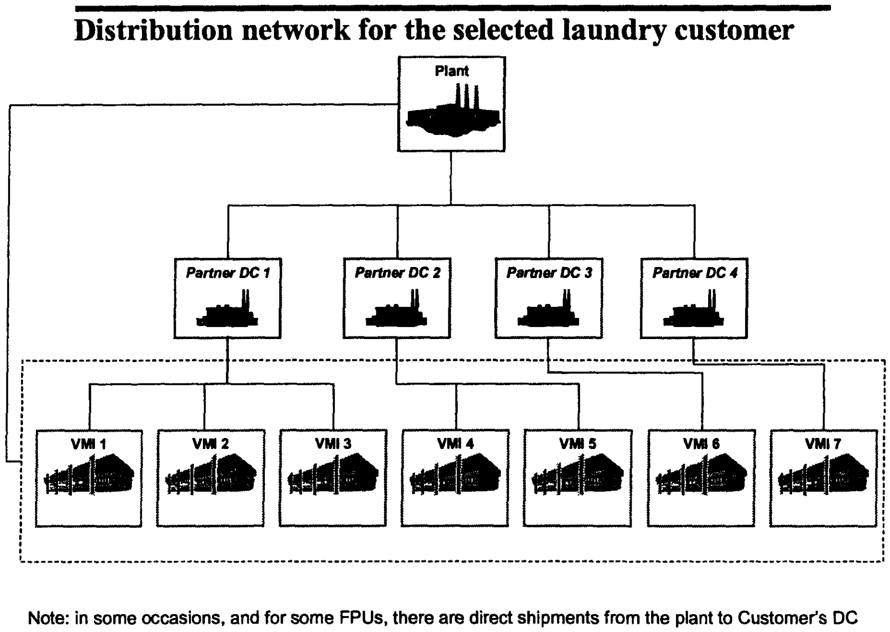


Figure 8: Illustration of the Partner's Distribution Network

The simulators are complimentary, as can be seen in the illustration below. The "Supply Chain Dynamics" simulator encompassed the supply chain from the suppliers to the first level of the warehouse, whereas the "Multi-Echelon" simulator developed by the team encompassed the supply chain from the plant to the last level of warehouse. Therefore, the partner's warehouse is the interface between the "Multi-Echelon" Simulator and the "Supply Chain Dynamics" simulator.

Illustration of the scope of the simulators within the partner's supply chain

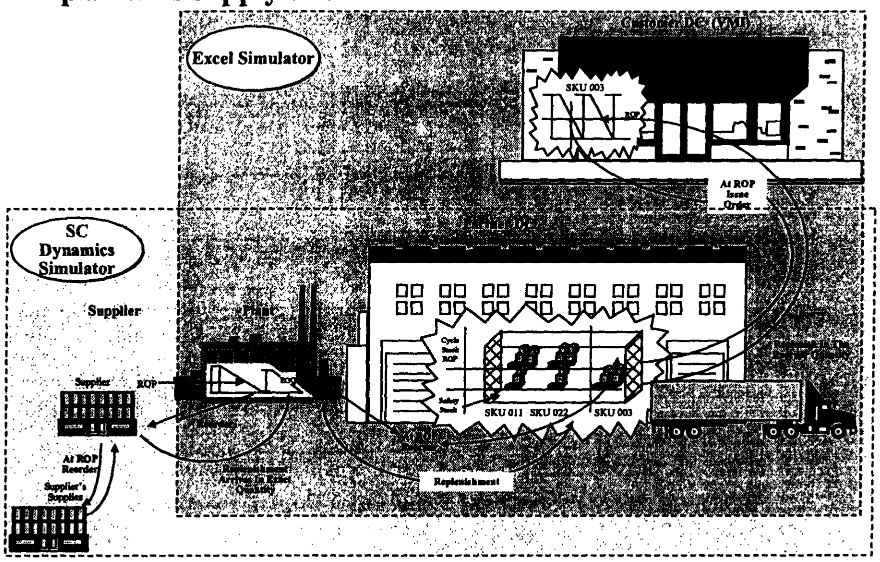


Figure 9: Scope of the Simulators

Basic logic of "Multi-Echelon" simulator

The "Multi-Echelon" simulator was built based on a bottom-up approach. That is, starting from the lowest level in the distribution network (the customer's warehouse).

Firstly, the daily demands are generated randomly from the statistics of current demand data (see the "demand generating toolbox" in the appendix II). Following, as illustrated below, we calculated the optimum reorder point and the safety stock requirements at each customer's warehouse, basically according to system's demand (which draws down inventory at warehouses) and costs (see the "reorder point and safety stock optimization toolbox" section below).

Reorder point and safety stock optimization tool box

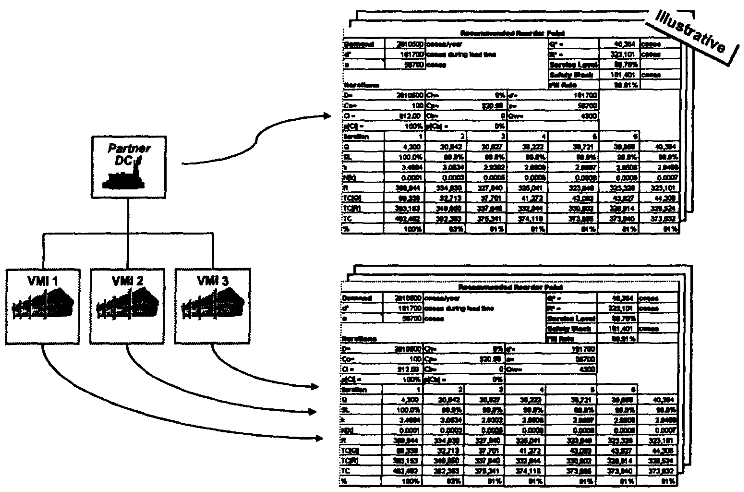


Figure 10: Reorder Point and Safety Stock Optimization Toolbox

Next, the demand was consolidated at the partner's warehouse level, using the Distribution Resource Planning methodology (see the "Distribution Resource Planning" toolbox section below). For each partner's warehouse, we calculated the optimum reorder point and recommended a safety stock strategy.

Schematic overview of the DRP tool box

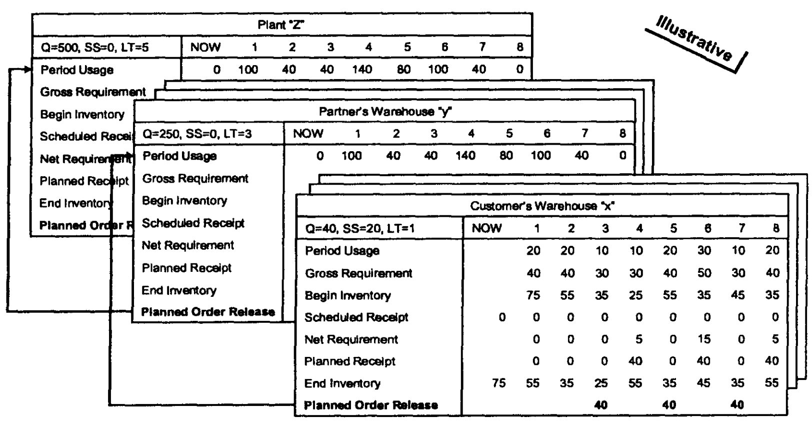


Figure 11: Schematic Overview of the DRP toolbox

Finally, the bottom-up order requirements are consolidated and generates the plant's manufacturing schedule.

Every SKU demanded by a given customer follows this logical flow. The aggregated outcome reflects the customer's Supply Chain, that is, the flow of all SKUs that the selected key customer currently demands, from the partner's factory to his warehouses.

It is important to mention that the "Multi-Echelon" simulator also allows the users to use the "Supply Chain Dynamics" simulator's production schedule. Therefore, at the partner's warehouse level, the inventory level will be determined by the demand from the customer's warehouses and by the supply from the manufacturing level (interface with the "Supply Chain Dynamics" simulator)

The consolidated screen of the simulator allows the partner to have a complete understanding of the relationship with all simulated customers, in terms of total costs, service level and inventory turns (as detailed in the chart below).

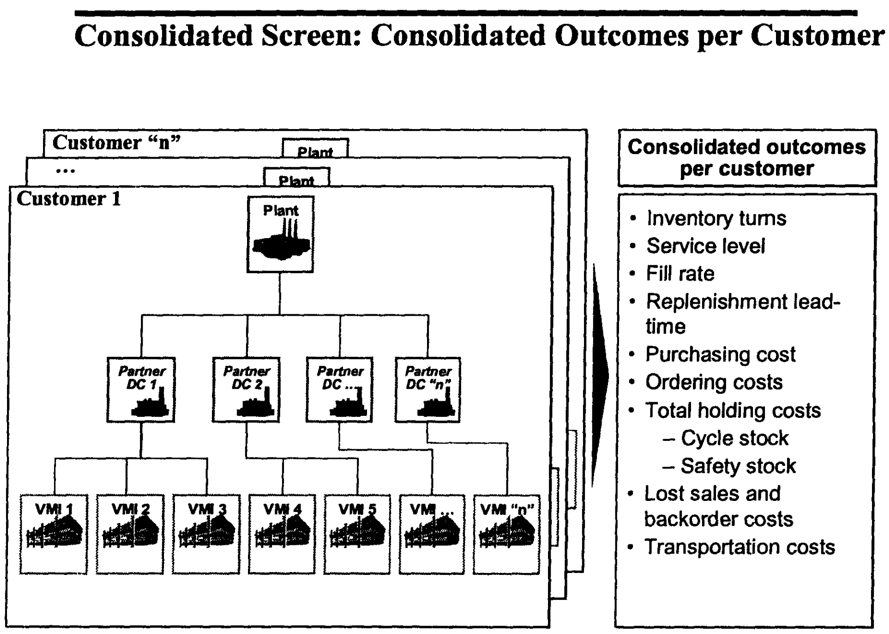


Figure 12: Consolidated Screen of the "Multi-Echelon" Simulator

Note: a more detailed explanation about the "Multi-Echelon" simulator, as well as its reference guide and the illustration of its main screen, can be found in the "Appendix II".

Global assumptions of the "Multi-Echelon" simulator

- The simulator assumes that there is no stock of inventory at the plant level. The only points of stock are the customer's warehouses and the partner's warehouses.
- The simulator adopts the total cost approach and monitors daily lost sales costs, transportation costs, inventory holding costs and ordering costs.

Key features and variants of the "Multi-Echelon" simulator

- The simulator allows the users to choose between setting two different manufacturing run strategies: keeping the current manufacturing schedules or using the production schedules recommended by the Supply Chain Dynamics Simulator. The user can also adjust the manufacturing schedules manually.
- The simulator offers two different ordering pattern strategies (as detailed below). The "pattern 1" uses statistical safety stock calculation and the "pattern 2" ties the ordering pattern to the physical capacity of truck loads.
- The simulator also allows the user to set a fix amount of safety stock coverage (in days)
- The simulator enables the users to create a demand spike (by setting both the date and its magnitude), which provides the inventory managers with the ability of analyzing the reaction of the system under uncertainties.
- The simulator allows the users to generate and specify random variations in the demand data and to choose replenishment lead times between 2 and 10 days.

- The simulator supports late shipments and lead time variances.

- The simulator is currently set to simulate the supply chain for 13 high-velocity SKUs, carefully selected by the partner company.

Output interface of the "Multi-Echelon" simulator (see details in the "Appendix II)

- The simulator provides charts on the inventory and the weekly demand at the partner's warehouse level and at a representative customer's warehouse, the production schedule and the replenishment schedule at this representative customer's warehouse.

- The simulator provides a comprehensive total cost table (transportation, lost sales and inventory holding and ordering costs) per warehouse and consolidated at all echelon levels

- The simulator provides the total costs for the partner and his customer

- The simulator provides the number of inventory turns and the fill rates for each SKU

Structure of the "Multi-Echelon" simulator

The "Multi-Echelon" simulator can be segmented into four major building blocks:

- Control panel and report
- Demand generating toolbox
- Safety stock optimization toolbox
- Distribution resource planning toolbox

The safety stock and the distribution resource planning toolboxes are presented in detail in the following sections, whereas the control panel and the demand generating toolbox are discussed in the "Appendix II".

Reorder point and safety stock optimization toolbox

The reorder point toolbox allows the user to adopt two different ordering strategies:

Strategy 1: optimization based on statistical and economic analysis (reorder point that minimizes the total costs)

Strategy 2: constrained optimization - statistically optimum reorder point with a fixed order quantity (a full truck load)

Rational for the Strategy 1 (Masters – 2002)

Major assumptions:

1. We will assume that the demand is normally distributed.

2. A stock-out can only occur during a lead-time. A stock-out basically occurs when demand during lead-time exceeds the reorder point, the quantity available from stock during lead-time.

3. During a stock outage, demand is either backordered or lost.

4. We will assume that the order quantity is much higher than the reorder point, so that only one replenishment order can exist at a given time.

5. For the sake of simplicity, we will just consider the demand variability in the safety stock calculation

Theoretical description of the methodology developed

The reorder point (R) can be seen as the forecasted demand during the lead-time (d') plus a "buffer stock", the amount over and above expected lead-time usage that we add to the reorder point to control/prevent/eliminate stock-outs.

$$R = d' + \text{Buffer Stock}$$

The buffer stock is frequently described as multiples of the standard deviation of the forecast error of forecasted lead-time usage:

Buffer Stock = ks

where: k = the safety stock factor , and s = RMSE (root mean square error)

When lead-time usage is forecasted with a time-series technique such as exponential smoothing, the forecast errors tend to be approximately normally distributed, even if the demand process or the noise component of the demand process) is not normally distributed. We therefore often assume normality of the forecast errors. This allows us to pick k values so as to obtain any desired stock-out probability.

The service level is defined as the probability that a stock-out does not occur during lead-time (SL = probability of having the demand inferior to the reorder point) and the probability of stock-out is just the opposite, that is, the probability of running out during lead-time (P[SO] = P[d>R]).

The fill rate (FR), or item availability, is the fraction of demand met with off the shelf stock. It is therefore the probability that any given randomly selected demand will be instantaneously satisfied.

For the normal distribution, we can use the table of "Unit Normal Loss Integrals", which converts the safety stock factor "k" into standard deviation's worth of expected units short.

$$FR = 1 - E[US] / Q$$

Where: (E[US] is the expected units short $= \sum (d - R) . p[d]$ *, from d=R to infinite)*

$$E[US] = N[k]s \quad (N[k] \text{ is the unit normal loss integrals})$$

And therefore, $FR = 1 - N[k]s / Q$

General solution to this "mixed stock-out" problem (lost sales and backorders)

For the mixed stock-out problem, let's call:

- p[Cl] the probability of having a lost sale
- p[Cb] the probability of having backorders

Solving simultaneously for optimal values of Q and R, the total average annual cost expression for the cycle stock and the safety stock, considering backorders (with probability of p(Cb)) and lost sales (with probability of p(Cl)), will be:

$$TC[Q,R] = (Co.D)/Q + (Ch.Cp.Q)/2 + Ch.Cp.(ks) + p[Cl].Ch.Cp.N[k].s + (D.N[k].s/Q).(p[Cb].Cb + p[Cl].Cl)$$

Taking partial derivatives with respect to Q and R and setting equal to zero yields two equations which must be solved simultaneously:

$$p[SO]^* = (Ch.Cp.Q^*) / (p[Cl].Q^*.Ch.Cp + D.(p[Cb].Cb + p[Cl].Cl))$$

$$Q^* = ((2.D.(Co + N[k].s.(p[Cb].Cb + p[Cl].Cl))) / (Ch.Cp))\text{^}1/2$$

Since the equation for Q* involves R* and the equation for R* involves Q*, the solution involves initially estimating Q* at Qw and iterating until the equations converge to a solution. “R*” is the cost-optimum reorder point and “Q*” is the cost-optimum order point.

The following table illustrates the heuristics described above.

[Q,R] model					
D=	8327	Ch=	10%	d'=	160.13462
Co=	800	Cp=	20.56	s=	12.460866
Cl =	12.75	Cb=	8	Qw=	4000
p[Cl] =	100%	p[Cb] =	0%		

Iteration	1	2	3	4	5	6	
Q	4,000	2,554	2,551	2,551	2,551	2,551	2,551
SL	92.8%	95.3%	95.3%	95.3%	95.3%	95.3%	95.3%
k	1.4618	1.6734	1.6740	1.6740	1.6740	1.6740	1.6740
N[k]	0.0320	0.0195	0.0195	0.0195	0.0195	0.0195	0.0195
R	178	181	181	181	181	181	181
TC[Q]	5,777	5,234	5,234	5,234	5,234	5,234	5,234
TC[R]	49	53	53	53	53	53	53
TC	5,826	5,287	5,287	5,287	5,287	5,287	5,287
%	100%	91%	91%	91%	91%	91%	91%

Q* =	**2,551**	**cases**
R* =	**181**	**cases**
SS =	**21**	**cases**
Service Level	**95.29%**	
Fill Rate	**99.99%**	

Figure 13: Illustration of the Optimal Reorder Point Heuristics

The outputs of the toolbox, as can be seen in the illustrative example below, are the optimum reorder that minimizes the total costs in each warehouse, the safety stock level, the service level and the fill rate.

FPU	**Customer's DCs**						
"XXX"	1	2	3	4	5	6	7
Q*	2,551	3,100	3,568	2,905	2,688	2,529	3,360
R*	181	254	330	254	191	173	298
SS	21	18	16	47	13	15	19
Service Level	95.29%	96.10%	96.60%	95.83%	95.53%	95.26%	96.39%
Fill Rate	99.99%	99.99%	100.00%	99.98%	99.99%	99.99%	100.00%
TC[Q]	5,234	6,366	7,328	5,951	5,519	5,192	6,899
TC[R]	53	44	41	119	33	39	49
TC	5,287	6,410	7,369	6,070	5,553	5,231	6,948

Figure 14: Output Table of the Reorder Point and Safety Stock Optimization Toolbox

Distribution Resource Planning (DRP) toolbox

The Distribution Resource Planning toolbox models the flow and storage of products throughout the whole multi-echelon distribution system, including multiple warehouses, distribution centers and factories.

The DRP algorithm is very helpful, in the sense it replaces the forecasting mechanism above the base inventory level, by aggregating and consolidating the demand from the lower echelon in the system. The model can also be improved to consider uncertainties regarding the lead time ("safety time") and the safety stock requirements in the chain.

One of the major premises in the Distribution Resource Planning model is that the several layers of inventory create a "lumpy" demand at superior layers, as illustrated below. The lumpier the demand, the larger the reliance on safety stocks, expediting, and re-distribution and the higher the number of stock-outs will be.

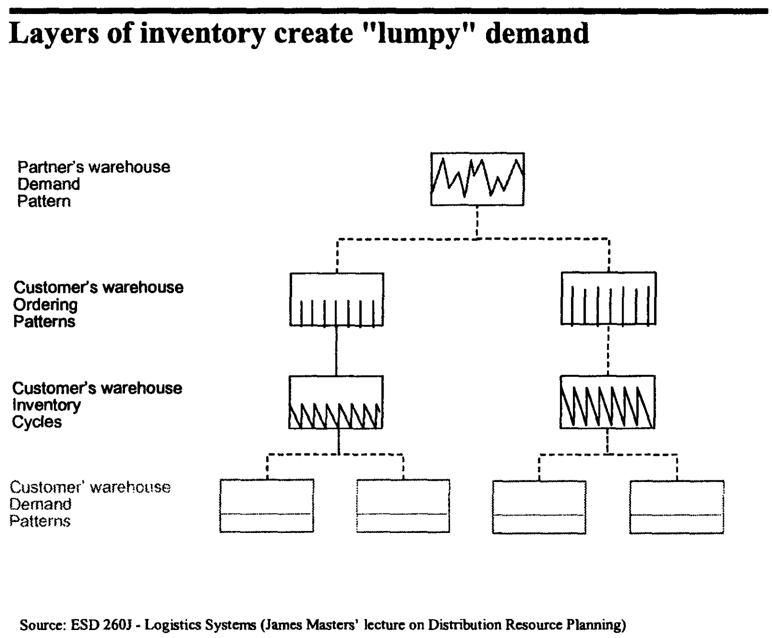


Figure 15: Lumpy Demand in the DRP Toolbox

General assumptions:

- Demands at the customer's warehouse level while this location is stocked out become lost sales without exception.
- No demand is transferred between customer's warehouses.
- There is no transshipment between customer's warehouse, and no expediting of replenishment orders.
- Stock replenishment orders placed by the customer's warehouse on the partner's warehouse are backordered during intervals when the partner's warehouse is stocked out.
- Fixed lead time

Description of the dynamics of the DRP toolbox

The following sections aim at describing the main logic of the DRP toolbox.

At the factory level

The production scheduled is fundamental to "support" the system replenishment and is elaborated by the manufacturing function, based on demand forecasts at the partner's warehouse level.

Additionally, it is important to notice that the production rate is independent of demand downstream. For example, if the user sets the run strategy to manufacture at each 3 weeks, the production quantity is the sum of the demand of the previous 3 weeks (the quantity produced are only available the end of the three week period).

At the partner's warehouse level (Distribution Center)

The demand at the partner's warehouse level is the summation of the orders generated by all warehouses at the customer level during that day.

Additionally, if the beginning inventory plus the amount received from the factory is larger than the actual daily demand, the demand fulfilled will be equal to the actual demand. On the other hand, the demand fulfilled will be equal to the beginning inventory level plus the amount received from the factory.

Summarizing:

- Demand 100% fulfilled: Beginning inventory + Factory replenishment >= Demand

  Demand fulfilled = Demand

- Demand partially fulfilled: Beginning inventory + Factory replenishment < Demand

  Demand fulfilled = Beginning inventory + Factory replenishment

In the case the demand is only partially fulfilled, shipments to all customers' warehouses are reduced by a factor, which is equal to the ratio "demand fulfilled/ demand" during the period (in this case daily) in which the order was received.

It is important to notice that, if an order is not fulfilled during the period it was placed, it will comeback in the next period until fulfillment, since inventory cannot be negative.

At the customer's warehouse level

At the customer's warehouse level, the current demand is randomly generated (see the "Demand Generation toolbox" in the Appendix II).

Regardless of the ordering pattern strategy used, as described above, a new order will be generated if the amount replenished after the lead-time period, considering the original amount in the inventory, will be insufficient to keep the new inventory level over the required safety stock.

For example, if the current inventory is equal to 300 units, the replenishment lead-time is 5 days and the average daily demand is 100 units, at the end of the 5 days, the inventory level will be 100 units (300 – 100*5+300)

If the safety stock requirement is larger than 100, a new order will be generated in the quantity specified by the order pattern. The new order will be received 5 days later, giving that the partner's warehouse can fulfill it.

Main limitations of the "Multi-Echelon" simulator

The simulator currently is not able to handle different customers at the same time. This improvement can be quickly implemented, but is not crucial for the purpose of analyzing the impact of changing some premises and variants in the overall number of inventory turns, total costs and fill rate.

Additionally, for the sake of simplicity, the simulator:

- Consolidates all partner's warehouses (four are utilized by the selected customer) into a single central one, which reduces the total amount of inventory at the partner's warehouse level (centralized x decentralized warehouses)
- Does not consider the possibility of the warehouses reaching its capacity limitation
- Does not include the lead-time variability in the safety stock calculations (considers just the demand variability in the calculation)
- Does not allow the user to elaborate an order fulfillment schedule. That is, all the

orders are independently placed, disregarding the possibility of achieving an optimal arrangement that optimize the shipments and minimize total costs.

4.1.3 Simulated Scenarios and Major Outcomes

In order the test the behavior of the simulators and the impact of changing some crucial parameters on the partner's total costs, service level and number of inventory turns at the customer's warehouse level, we conducted the following simulations:

Simulated Scenario 1:	Analysis of the impact of improving the forecast accuracy on the global system-wide variables (total costs, service level and number of inventory turns)
Set-ups:	Simulating a single SKU with the "Multi-Echelon" Simulator. Scenario 1: Forecast error is 42 cases per day Scenario 2: Forecast error is 84 cases per day (doubled) All other variables were kept constant

Key conclusion:

A significant inventory reduction can be achieved through forecast improvement.

Major Findings and Outcomes:

At the customer side, when the forecast error is doubled, the total costs jumped.

RMSE	Fill rate	Inventory Turn	Inventory cost	Total cost
42	98.5%	176	$91,216	$103,241
84	98.5%	107	$149,551	$161,361

It is important to note that the impact of the increased forecast error was higher at the customer's than that at the partner's warehouse level, since most of the error was absorbed by the excess safety stock at the customer's warehouses.

Practical Implications:

The forecast error can be reduced either by reducing the variability of the demand or by improving the accuracy of the forecasts. See the "Chapter 4.1.4" for a detailed approach on how to manage and reduce the demand variability. See the "Chapter 4.2 – tradeoff 4" for a detailed discussion on forecast improvement.

Simulated Scenario 2:	Analysis of the impact of changing the replenishment lead-time on the retailer' total costs and number of inventory turns.
Set-ups:	Simulating a single SKU with the "Multi-Echelon" Simulator. Scenario 1: Lead time is 7 days Scenario 2: Lead time is 3 days All other variables were kept constant

Key conclusion:

Reducing the lead time from 7 to 3 days, for a given SKU, leads to a reduction of 50% in the total costs in the system. The cost reduction is concentrated at the retailer's side.

Major Findings and Outcomes:

Lead time	Cost to Supplier	Cost to Retailer A	Retailer's Inventory Turn	Fill Rate
3	$29,286,313	$1,893,762	104	100%
7	$29,044,209	$3,800,460	51	100%

A shorter lead time allows the partner company to keep a lower inventory level at the customer's warehouses.

It is important to note that, since the simulation kept the order pattern constant and set to order a full truck load, there was no significant impact of reducing the lead time on the system's transportation costs. The transportation costs were driven by the customer's demand, which is independent of the replenishment lead time.

Practical Implications:

The partner company's replenishment lead-time is currently 5 days and can be segmented in three parts:

- 2 days to create an order
- 2 days from order to ship
- 1 day in transit

Therefore, in order to further reduce its replenishment lead-time, the partner may focus on reducing the first two items.

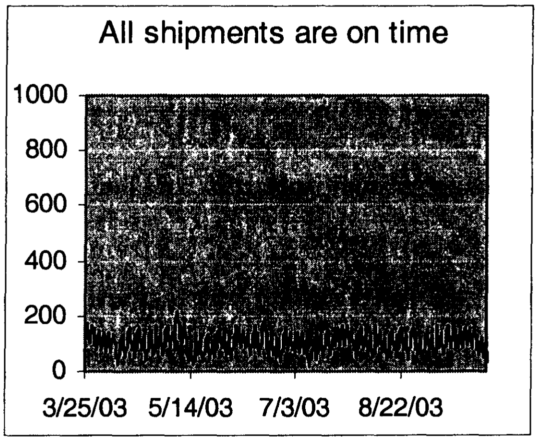
Simulated Scenario 3:	Analysis of the impact of the increase in the lead time variability on the fill rate at the customer's warehouse level.
Set-ups:	Simulating a single SKU with the "Multi-Echelon" Simulator. Scenario 1: Lead time is fixed at 3 days. Scenario 2: 3-day lead time; 100% shipments are 2 day late. All other variables were kept constant

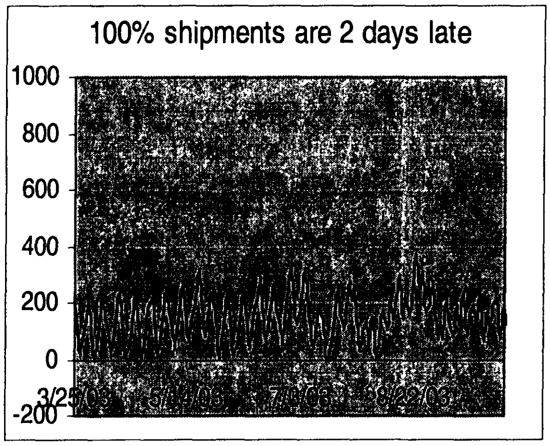
Key conclusion:

An increase in the lead time variability promotes the reduction of the fill rate at the customer's warehouse level. Additionally, the shorter the lead time, the bigger the negative impacts of lead time variability will be.

Major Findings and Outcomes:

The following two charts show the inventory level and the respective fill rate at a representative customer warehouse for two situations: on time and 100% late shipments.





Fill rate = 100%	**Fill rate = 98%**

Simulated Scenario 4:	Analysis of using statistically generated safety stocks on the global system-wide variables (total costs, fill rates and number of inventory turns)
Set-ups:	Tested 18 SKUs that have the highest sales volume. Scenario 1: Safety stock levels are statistically determined Scenario 2: Use the company's current Safety stock levels All other variables were kept constant

Key conclusion:

The partner company's current safety stock level is not optimum and can be significantly reduced with the use of statistical tools

Major Findings and Outcomes

Of the 18 SKUs tested, when using statistical safety stock, the distribution costs (include inventory holding cost, handling cost, transportation cost and cost of capital) were reduced between 10 to 40%. At the same time, the fill rates were reduced between 1% and 13%, due to the reduction of the buffer stocks in the system.

For a representative SKU, as illustrated below, it can be seen that a significant reduction in the distribution costs of 30% was achieved (around 74 million dollars), while the fill rate slightly reduced (1%).

	Safety Stock (Weeks of cover)	**Fill rate**	**Distribution costs ($' 1000s)**	**Inventory Turns**
Current practice	1 week	100%	235,851	26
Statistical Safety Stock	0.2 week	99%	162,020	45
% Change	**-80%**	**-1%**	**-30%**	**73%**

The analysis above corroborates to illustrate that the company can achieve huge savings by reviewing its inventory policy with the help of simulation tools.

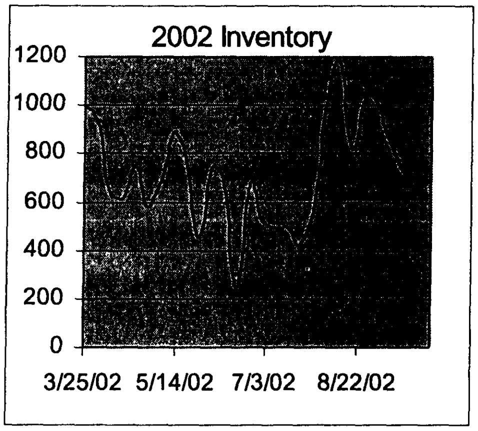
Simulated Scenario 5:	Comparison of the inventory levels for a selected SKU in 2002 with the proposed by the "Multi-Echelon" simulator.
Set-ups:	Simulating a single SKU with the "Multi-Echelon" Simulator. The simulation kept similar demand level and variance as actual data in the year 2002.

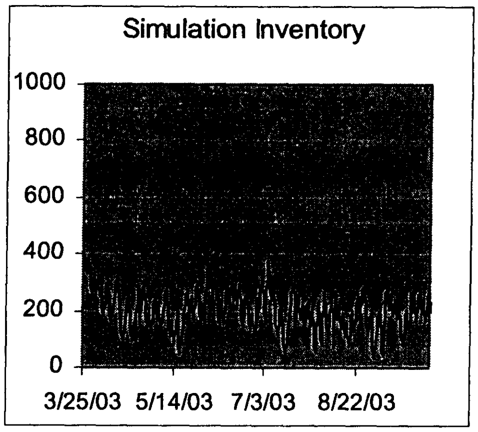
Key conclusion:

The partner company probably held excessive safety stock in 2002.

Major Findings and Outcomes:

The following graphs present the historical inventory and the simulated inventory.





From the charts above, we can infer that for that specific SKU, the inventory level could be reduced from 1.5 weeks of cover to 0.6 week of cover.

Examining other SKUs, we noticed that the magnitude of the inventory reduction varied for different SKUs and for different warehouses, but ranged between 60% and 80%.

Practical Implications:

There are two possible reasons for the difference between the 2002 inventory level and the computer generated optimum inventory level.

1) Inventory planners overruled the computer generated safety stock target. Actually, this happened to over half of the partner's SKUs. Planners usually increase the safety stock target based on a single stock-out incident. They tend to reset the safety stock target without a complete and scientific analysis, based on their comfort level, which is often overly conservative.

2) The high safety stock level was planned to face punctual and rare spikes.

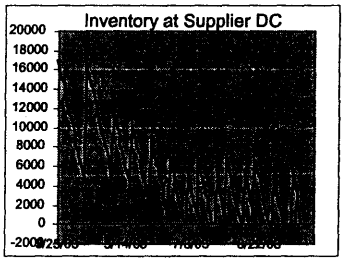
Simulated Scenario 6:	Impact of reducing the fill rate at the partner's warehouse on customer's fill rate and on the system's total cost.
Set-ups:	Simulating a single SKU with the "Multi-Echelon" Simulator. Scenario 1: fill rate at the partner's warehouse is 89% Scenario 2: fill rate at the partner's warehouse is 99% All other variables were kept constant.

Key conclusion:

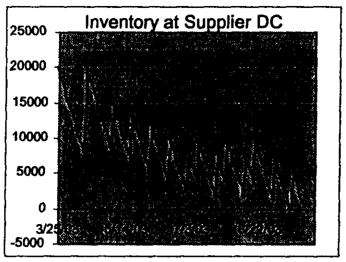
There is a huge cost saving opportunity in finding the optimal fill rates at the partner's warehouse level.

Major Findings and Outcomes:

Fill rate at the partner's warehouse = 88.66%



Boost inventory level at the partner's warehouse, so that the fill rate stays above 98.5%.



In both cases, the fill rates at the customer's warehouses are above 98.5%, which is considered satisfactory by the partner. However, there is a significant cost reduction ($1.5 million in 6 months), just by reducing the fill rate at the partner's warehouse.

Practical Implications:

It is difficult to implement this "low fill-rate" policy at the partner's warehouse, because such change requires a strong mindset and cultural change.

Currently, the company adopts 98.5% as the target fill rate for all SKUs at the partner's warehouse level. It may be possible to pilot the "low fill-rate" policy on SKUs that have lower importance, as extensively discussed in the "Chapter 4.3" of this thesis.

Simulated Scenario 7:	Comparison between the partner's production schedules with the production schedules recommended by the Supply Chain Dynamics Simulator
Set-ups:	Simulating 13 high-velocity SKUs with the "Multi-Echelon" Simulator.

Key conclusion:

There is low integration and communication between the factory planners and the demand planners within the supply chain, which causes significantly large discrepancies between the current and the "ideal/ correct" production schedules.

Major Findings and Outcomes:

The team found out that several SKUs were under produced.

With further investigation, we noticed that the demand forecasts generated by the factory planners are often significantly different from demand forecasts generated by the planners who have direct contact with customers.

Practical Implications:

There are three major reasons for this issue:

1) Available tools do not enable seamless communication among the parts in the supply chain. Multiple stand alone IT systems are used throughout the supply chain and valuable information inside them are not in synchrony. A major opportunity to improve the supply chain visibility is to link these IT systems and enable a more effective communication throughout the chain.
2) This is a multi-echelon system and the variance at the lower level is magnified upstream (bullwhip effect). The complexity of the system creates barriers for people to understand and communicate with each other.
3) Multiple departments are involved in the supply chain and it is very difficult to communicate across departmental boundaries.

Simulated Scenario 8:	Analysis of the relationship between the lumpy demand at partner's warehouse level and the order size.
Set-ups:	Simulating a single SKU with the "Multi-Echelon" Simulator. Scenario 1: Order lot size is 130 cases Scenario 2: Order lot size is 191 cases Scenario 3: Order lot size is 1285 cases The forecast errors at customer warehouses were kept constant.

Key conclusion:

Big order sizes from customer's warehouses create lumpy demand at the partner's warehouse level.

Major Findings and Outcomes:

As can be seen in the following table, the ratio "*Forecast Error at DC* over *Forecast Error at Customer Warehouse*" illustrates the amplification factor the downstream forecast errors were subjected when moving upstream the chain.

Shipment (cases)	Forecast Error at DC/ Forecast Error at Customer Warehouse
130	1.1
191	2.0
1285	6.9

When the lot size is 130, the forecast error is barely magnified. As the downstream orders get bigger, the aggregate demands at the partner's warehouse level become lumpier and provoke higher forecast errors.

Practical Implications:

Lumpy demand is one of the key reasons for high forecast error and high safety stock level. The analysis shows that the company can reduce the demand lumpiness by evening out demand. A good practice to do so is to reduce the order sizes.

In the case studied, the partner company is using a shipment size at around 130, which seems to be an optimal number, due to the low potential of creating lumpy demand at its DC level.

Summarizing, from all simulations above, we can infer that, in order to reduce the total costs in the system and to increase the service level and the number of inventory turns, the partner company should focus on:

- the improvement of the forecast accuracy
- understanding and managing the demand variability (see "Chapter 4.1.4")
- the reduction of the replenishment lead-time
- reducing the lead time variability
- the use statistical tools to estimate the safety stock requirements
- the possibility of reducing the fill rate at the distribution center level to reduce the total costs in the system
- the improvement of the communication and visibility throughout the chain
- keeping the orders at a small and controlled size, in order to reduce the lumpiness at the partner's warehouse level

4.1.4 An Approach to Reduce and Manage the Demand Variability

Reducing and managing the demand variability has become a key issue in supply chain management. High variability in customer's demand and in supply's lead-time means millions of dollars in excess safety stock and lost sales.

Given the importance of managing the demand variability to the global context of this thesis, highlighted by the "Simulated Scenario I", the team decided to further detail this topic and to propose various strategies to reduce and cope with the variability in demand.

Changing the demand generating process to reduce the demand variability

The company can optimize the customer ordering patterns to reduce the demand variability. It can try to even out demand, to use standing orders and to reduce lot size. All these alternatives aim at reducing the lumpiness in demand, and can be easily implemented if a VMI system is already in place. (David Simchi-Levi – 1998)

Using information to deal with variability (David Simchi-Levi – 1998)

With foresight into upstream and downstream the supply chain, the company can improve forecast to cope with variability. The CPFR initiative is based on this premise.

Decoupling to deal with variability (David Simchi-Levi – 1998)

In practice, variability cannot be completely eliminated and consequently must be dealt with. Inventory is traditionally used to deal with such variability. Safety stock at the distribution centers provides a buffer to decouple end-demand from manufacturing. This ensures a consistent level of service when faced with stochastic demand, and serves to reduce the arrival rate variability faced by manufacturing systems.

Differentiating normal variability from spikes

By differentiating the normal variability from spikes, the company may find ways to reduce safety stock. Before, discussing this topic, it is crucial to introduce a new concept – "Spike Safety Stock".

Definition:

Normal Safety Stock: Safety stock determined by conventional statistical methods.

Normal Safety Stock = k factor * Purified RMSE

Here, the Purified RMSE is the historical forecast error with the big spikes removed.

Spike Safety Stock: Safety stock used to prepare for rare demand spikes.

It makes sense to differentiate between these two types of safety stocks for three reasons:

1) The two types of safety stocks discussed above are used to buffer against different kinds of demand variability and if we try to use a single safety stock term to represent both, we risk distorting the optimal solution. For example, as shown in the table below, if we include spikes in calculating RMSE, we inflate RMSE by one to three times; thus, the calculation leads to inflated safety stock level.

Sample Forecast Error Calculation

Warehouse	SKUs	Actual RMSE	Purified RMSE
1	a	667	214
2	b	716	196
3	c	708	228
4	d	320	171
...	...	...	...

2) If we simply neglect the spikes, the resulting solution would be less robust. After all, these demand spiked are a "fact of life".

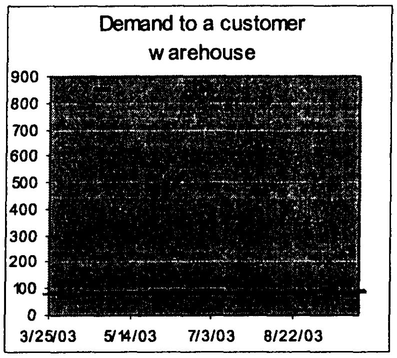
3) The spike safety stock level should be calculated via a procedure much different from that for normal safety stock calculation, since they have different distribution/ pattern from the normal demand variances.

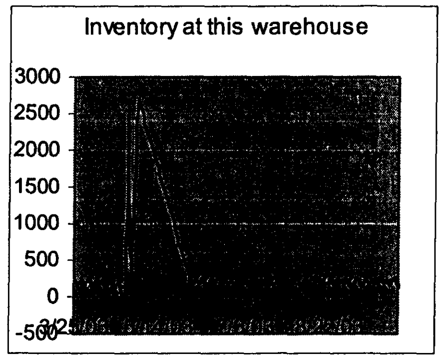
Should a company keep high inventory level to prepare for the rare demand spikes that only occur once or twice a year? The classical answer is it depends! It depends on at least seven factors.

<u>Seven-Factor Analysis of Spike Safety Stock</u>

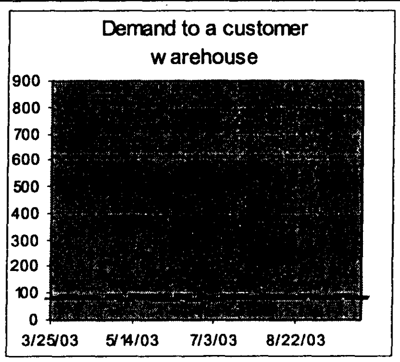
1) Cost: If inventory cost is high and lost sale cost is very low, it doesn't make sense to keep the "spike safety stock" beyond the normal safety stock.
2) Customer: if the customer is strategically important or the SKU is important to the customer's portfolio, it may make sense to keep a reasonable amount of Spike Safety Stock.
3) Replenishment lead time: How fast can the central DC replenish spikes at regional warehouses?

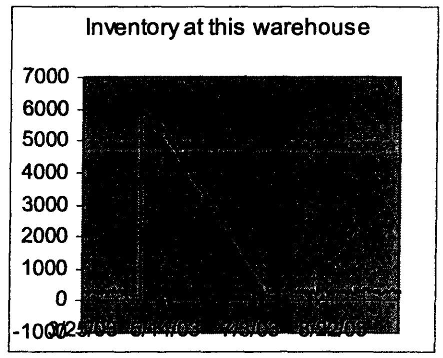
As can be seen in the charts below, if the replenishment lead time is 3 days, the fill rate drops from 100% to 90% with a spike that is 10 times normal and last 7 days.





With a 7-day lead time and everything else the same, the fill rate drops to 75%.



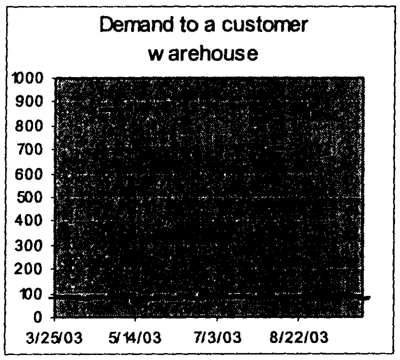


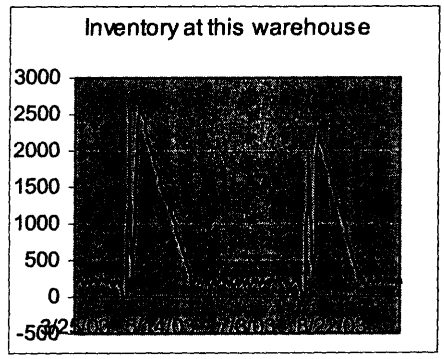
Concluding, for the same demand spike, the fill rate drops much less when the lead time is short. In other words, shorter lead time calls for less Spike Safety Stock.

4) Scope of the spikes. If the spike "cross the boards", then the central DC will be hit hardly. In this case, whether the Spike Safety Stock is put in central DC or regional DC doesn't matter. If the spike only occurs at one customer's warehouse, the central DC can leverage its role for risk pooling, and it may make sense to put the Spike Safety Stock at the central DC.

5) Frequency of the spikes

With a three-day lead time and two 10x spikes, the fill rate dropped from 100% to 84%, instead of 90% as in the case of one spike. Obviously, the more spikes occur, the more necessary the Spike Safety Stock will be.





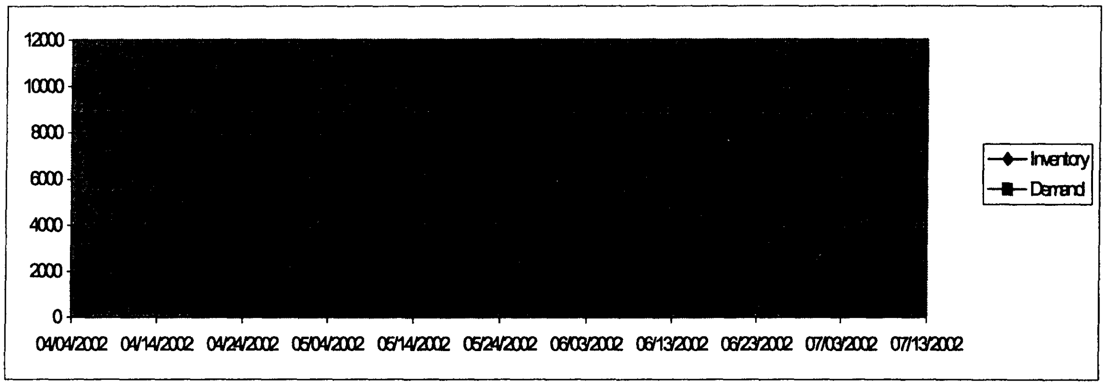
6) Spike predictability

As can be seen in the table below, when the actual demand was 10 times the forecast in the week of 5/13/2002, the company still maintained 100% fill rate.

Real inventory data with demand spike

Week	Demand	Forecast	Inventory	Fill Rate
5/6/2002	2784	965	6150	100%
5/13/2002	**10092**	**1151**	4703	100%
5/20/2002	798	**2314**	3528	100%
5/27/2002	516	1504	5267	100%
6/3/2002	810	1286	6025	100%

How did they do it? The graph below reveals that the company may know that the spike is coming, so they increased the inventory level beforehand.



In fact, if the company does not have the ability to "see" the spike coming, the only way for them to maintain the 100% fill rate is to keep a Spike Safety Stock that equals 10 times the normal demand. This would dramatically increase the inventory costs and significantly reduce the company's competitive position within its business.

7) Spike magnitude

The current inventory system holds inventory that is three times larger than the simulated inventory. The question that remains is: how big can a demand spike be, so that the firm can absorb it and still keep a 98.5% fill rate?

Spike duration	Demand spike
1 day	8 x
2 days	4.5x
1 week	3.3 x

*Lead time is 7 days

The company should analyze the demand pattern of its key SKUs to understand the root-cause of the magnitude of the demand spikes, and to determine if the high Spike Safety Stocks are justified.

Implementation Recommendation

The company should apply the 7-factors analysis for each SKU and determine the optimum strategy regarding the Spike Safety Stock allocation.

As a start, the company should analyze high impacting SKUs, such as the ones with most sales volume and profit margin.

The most important of the 7 factors discussed above is the spike predictability. This coincides with the partner company's CPFR initiative, which gives them visibility downwards and upwards the supply chain.

Future Study

Most studies performed by the team are empirical up to this point. To further understand the impact of the spikes on the Safety Stock, the team must perform more mathematical and statistical analysis.

The Spike Safety Stock study can be generalized as a study on how much flexibility/ buffer should be built into supply chain to enable the company to respond to the unexpected. This issue is especially important today, given the imminent terrorism threat.

4.2 Thesis Question 2

Thesis Question 2: How can the ordering patterns and the optimal quantities be improved?

<u>Contextualization</u>

The simulation of the partner's multi-echelon supply chain under the current manufacturing and vendor managed inventory policies provided the thesis team with the production schedule, the ordering patterns, the optimal quantities to be ordered and with the optimum inventory level to satisfy turnover, service level and lead time, whereas minimizing lost sales and total costs.

The next step in the analysis was to search for new ways of improving the ordering patterns and optimal ordering quantities to reduce the customers' inventory levels (managed by the partner), and thus, to improve their inventory turns (reduce their working capital requirements).

In order to achieve the thesis goal of increasing customer's inventory turns, the team proposed a new formulation for the calculation of the inventory turns, based on the safety stock and on the cycle stock requirements, developed a "trade-off tree" to map all variables that can directly affect the number of inventory turns and to understand whether their effects are positively or negatively related to the goal of increasing the number of inventory turns, and ran a sensitivity analysis for all high-velocity SKUs at all warehouses of a key customer to assess which of the variables played a more important role in increasing the number of inventory turns.

Proposed formulation to calculate the number of inventory turns

Proposed equations: (Lambert – 1982)

$$\text{Safety stock} = k \times \sqrt{\left(\text{RLT} \times \text{STDEV of forecast error}^2\right) + \left(\text{forecast error}^2 \times \text{STDEV of RLT}^2\right)}$$

$$\text{EstOptTurns} = \frac{365}{\text{safety stock} + \frac{1}{2} \times \text{RLT}}$$

Where:

"**k**" is the safety stock factor and is related to the service level provided to the client by the Normal distribution curve.

Rational for the use of the normal distribution: when the lead-time usage is forecasted with a time-series technique such as exponential smoothing, the forecast errors tend to be approximately normally distributed, even if the demand process (or the noise component of the demand process) is not normally distributed. We therefore often assume normality of the forecast errors. This allows us to pick "k" values so as to obtain any desired stock-out probability. (Masters – 2002)

Customer service level is determined by the percentage of orders fulfilled

"**RLT**" is the average replenishment cycle-time, that is, the time between receiving the order and delivering the goods at the customer's site (in this case, warehouse)

Using the partner's lingo, we can divide the replenishment cycle-time into "order cycle time", "lead-time" and "transit time".

Order cycle time: represents the order frequency and is determined using the last 26 weeks of warehouse sales history by weight for all replenishment items shipping together. For example, if the average number of shipments per week is 5.1 and given that the partner's forecasting period is 7 days, then the order cycle will be 1.37 days (7 days/wk / 5.1).

Lead-time: represents the time from the creation of the order to the time it is shipped.

Transit time: represents transit days from shipment to delivery at customer's warehouse.

"STDEV of forecast error" represents the standard deviation of the absolute forecast error (in days) and is determined using the absolute forecast error over the last 26-week period.

Note: In the formula, we are multiplying the standard deviation of the forecast error by the square root of the replenishment lead-time to cope with the fact that the replenishment lead-time is not equal to the forecast interval (7 days)

"Forecast error" represents the absolute accuracy of the forecast to the current demand and is determined using the total history and the total forecast over the last 26-week period.

"STDEV of RLT" represents the standard deviation of the replenishment lead-time and can be viewed as a measure of the estimated variation of the actual replenishment lead-time from the planned replenishment lead-time.

"Target inventory level" is the total inventory in the system (in days) and is the summation of the calculated safety stock with half of the replenishment lead-time (all data in days of coverage).

"EstOptTurns" is the estimated optimal turns based on the target inventory level and is determined by dividing 365 days by the total target inventory coverage (target inventory level in days)

Trade-off tree

The main purpose of the "trade-off" tree tool is to structure the analysis, so that the team can easily map all variables that can directly affect the inventory turns outcome and understand whether their effects are positively or negatively contributing to increase the number of inventory turns (partner's goal).

The tree is self-explanatory and the "up" or "down" arrows emphasize the impact of increasing each of the variables on the number of inventory turns. That is, by reducing the customer service level, for example, the number of inventory turns increase, since reducing the service level reduces the safety stock factor "k", and thus, the safety stock requirements.

For each of the bottom-level variables (last level nodes in each of the branches), the team proposed general recommendations and analyses that would contribute to the increase of the number of inventory turns.

From the set of recommendations in the "trade-off" tree below, the team prioritized the following trade-offs for further analysis:

- Analyze the use of LTL, instead of the use of FTL carriers
- Mix high-velocity and non-high-velocity SKUs in a single truck load
- Reduce the order cycle time variability
- Improve the forecast accuracy
- Review the manufacturing strategy
- Review the ordering management and warehousing processes

Each of these "trade-off analysis" will be further detailed and analyzed in special sections throughout this chapter.

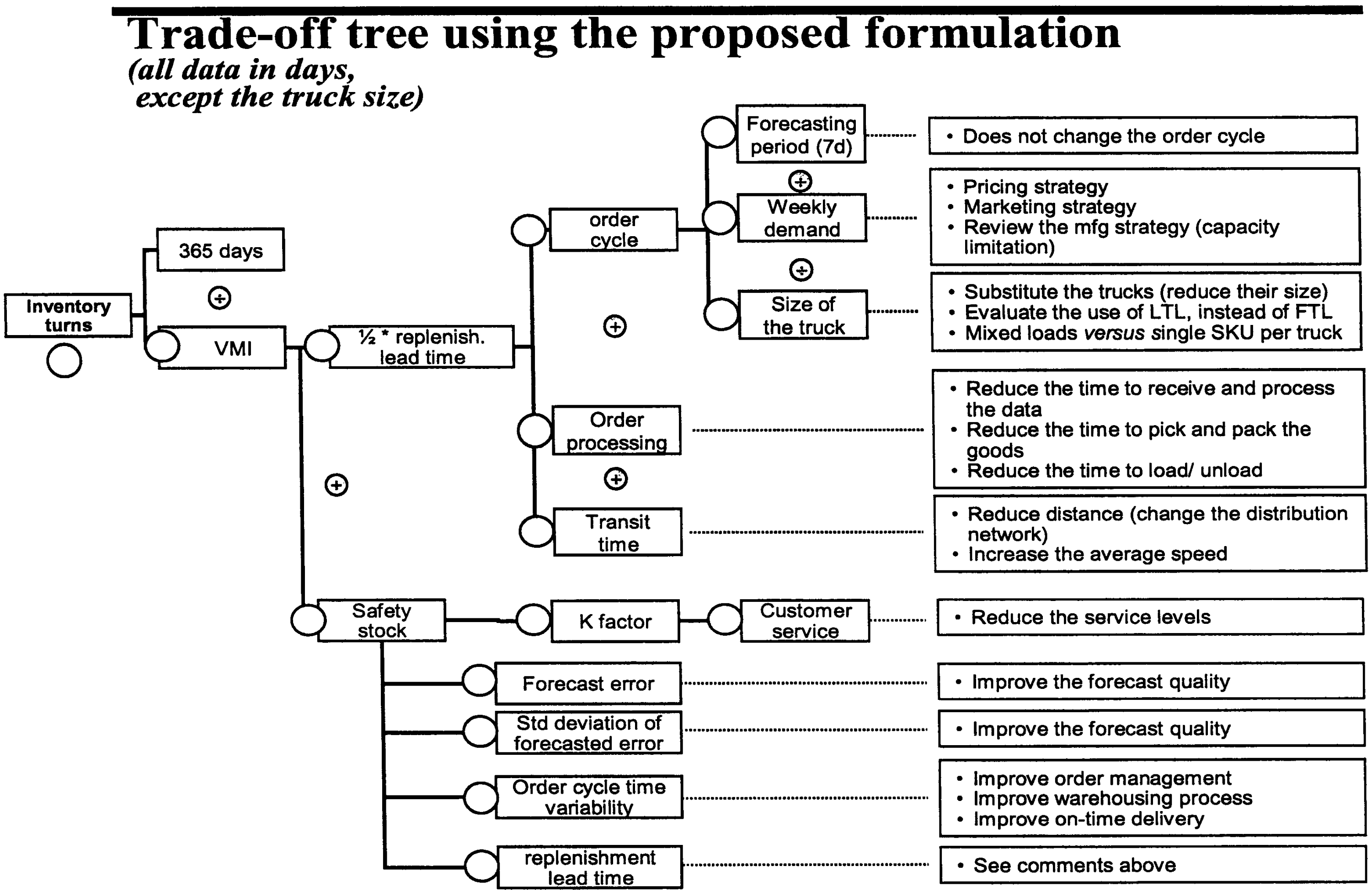


Figure 16: Trade-off Tree

Sensitivity Analysis

The purpose of the sensitivity analysis is to assess the relevance of the impact of each key variable on the overall goal (increase the number of inventory turns). In this sense, the final outcome will be more sensitive to a given variable if a predetermined change in the variable's value leads to a significant impact on the final outcome.

Warehouse	Variable Changed	(%) Changed	Average Inventory Turns Current	New	(%) Changed
All DG DCs	Customer Service	-0.5%	54.23	56.69	5%
		-0.4%	54.23	56.24	4%
		-0.3%	54.23	55.78	3%
		-0.2%	54.23	55.29	2%
		-0.1%	54.23	54.78	1%
		0.1%	54.23	53.65	-1%
		0.2%	54.23	53.02	-2%
		0.3%	54.23	52.34	-3%
		0.4%	54.23	51.59	-5%
		0.5%	54.23	50.74	-6%
	Transit Time (days)	-10.0%	54.23	55.01	1%
		-20.0%	54.23	55.81	3%
		-30.0%	54.23	56.64	4%
		-40.0%	54.23	57.49	6%
		-50.0%	54.23	58.38	8%
	Lead Time (days)	-10.0%	54.23	55.81	3%
		-20.0%	54.23	57.49	6%
		-30.0%	54.23	59.30	9%
		-40.0%	54.23	61.25	13%
		-50.0%	54.23	63.36	17%
	Order Frequency (days)	-10.0%	54.23	55.52	2%
		-20.0%	54.23	56.89	5%
		-30.0%	54.23	58.34	8%
		-40.0%	54.23	59.88	10%
		-50.0%	54.23	61.52	13%
	Order Cycle Variability (days)	-10.0%	54.23	54.51	1%
		-20.0%	54.23	54.76	1%
		-30.0%	54.23	54.99	1%
		-40.0%	54.23	55.20	2%
		-50.0%	54.23	55.38	2%
	Forecast Error (%)	-10.0%	54.23	54.51	1%
		-20.0%	54.23	54.76	1%
		-30.0%	54.23	54.99	1%
		-40.0%	54.23	55.20	2%
		-50.0%	54.23	55.38	2%
	STDEV forecast error (%)	-10.0%	54.23	57.64	6%
		-20.0%	54.23	61.46	13%
		-30.0%	54.23	65.79	21%
		-40.0%	54.23	70.70	30%
		-50.0%	54.23	76.29	41%

Figure 17: Sensitivity Analysis

Note: for the sake of confidentiality, we just disclosed the consolidated outcomes of the sensitivity analysis for a selected key customer. That is, the results in the table above represent all high-velocity SKUs at all partner's warehouses that serve the selected customer.

From the sensitivity analysis above, we can see that, by focusing on the improvement of a single variable, the highest number of inventory turns the partner can achieve for the analyzed customer is 76.29, by improving in 50% the standard deviation of the forecast error (which does not seem to be a simple and immediate improvement).

Summarizing, from the sensitivity analysis above, we can infer that the partner's goal of providing its key customers with hundred inventory turns cannot be achieved by a focused improvement of a single variable. Therefore, the partner must conduct a conjoint effort to improve a set composed of the most relevant variables.

Additionally, in order to succeed, the partner will have to promote revolutionary changes in its supply chain (not just evolutionary), such as reconfiguring its network, redesigning key processes and improving the forecast quality through a better coordination and communication with the key customers (better understanding of their demand).

The major variables to focus on, in order to quickly increase the number of inventory turns, and the key recommendations to improve the selected key variables are summarized in the table below. It is important to mention the variables are displaced in order of relevance that means that, given a predetermined percentage change in the value of the variable, the standard deviation of the forecast error provokes the highest impact on the number of inventory turns.

Major variables to focus on	Key recommendations
Standard deviation of the forecast error	- Review the forecasting methods - Use a less "nervous" method
Lead-time	- Redesign the order management and the warehousing management processes
Order frequency	- Review the ordering pattern - Full a truck versus optimum order quantity - Mixing groups A with B and C
Transit time	Review the transportation schedule - Reduce transportation during intense-traffic hours

Figure 18: Major Variables to Focus on and Key Recommendations

Since the partner's forecasting error is relatively low, on average, for the analyzed customer, a huge improvement in this factor does not generate a significant impact on the number of the inventory turns, as attested by the sensitivity analysis.

The key questions the team raises at this point are i) whether the hundred-inventory-turn goal is a customer's desire (nice to have) or a customer's requirement (must have) and ii) how the incentives will be split within the supply-chain. The reasoning behind these questions is that such efforts to achieve the hundred-inventory-turn goal will require significant investments from the partner's side, which must be balanced with an also significant leverage of partner's sales at the customers' stores and/ or attenuated by customer's financial commitments (non-zero sum game).

These questions and/ or concerns, which are directly related to the partner's market penetration strategy, will remain opened and will not be discussed throughout the thesis (out of the scope of the thesis).

Trade-off 1: Analyze the use of LTL, instead of the use of FTL carriers

The use of less-than-truckload (LTL) carriers, besides increasing the transportation cost (higher unitary freight rate) and ordering cost (higher number of orders, since the partner will ship lower volumes), can reduce the amount of lost sales and backorders in the system and enable the company to reduce its replenishment lead-time (reduce the order cycle), and thus, to increase the number of customer's inventory turn.

Since the company has outsourcing contracts with full-truckload (FTL) carriers, the FTL rates it pays are much lower than the freight rates the LTL market would quote (even considering the partner's scale). Additionally, the cancellation of these contracts with the FTL carriers will culminate in financial penalties.

Therefore, due to the reasons discussed above and to the corporate strong willingness to keep the full-truckload policy, the team rejected this trade-off analysis.

Trade-off 2: Mix high-velocity with non-high-velocity SKUs in a single truck load

Other alternative to reduce the partner's order cycle time, and thus its replenishment lead-time, without changing the transportation policy, is to mix high-velocity with non-high-velocity SKUs, which will culminate in the increase of the partner's order frequency (according to the current ordering pattern, it is equivalent to the time to completely full a truckload and ship it to the customer's warehouse).

Notwithstanding, it is important to mention that some customers have the operational procedure of attributing specific decks to trucks carrying high-velocity SKUs, which will require the partner to ship the high-velocity items separately in a single truck, without having the alternative to mix them with the "group B and C" items.

The table below summarizes the effects on the overall number of inventory turns of mixing all high-velocity with all the non-high-velocity SKUs of a key customer.

		Key Parameters			Inventory		
Warehouse	**Mix Options**	**Order Cycle (days)**	**Stdev forec. error**	**Forecast Error**	**Safety Stock (days)**	**VMI (days)**	**Inventory Turns**
Warehouse 1	Group A	2.09	8.4%	2.1%	3.15	5.70	64.1
	Group B	2.92	9.1%	7.0%	4.16	7.12	51.3
	Group C	2.92	10.6%	1.1%	4.20	7.15	51.0
	Group B + C	1.46	10.2%	4.5%	3.76	5.99	60.9
	Group A + B	1.22	9.1%	4.8%	3.37	5.47	66.7
	Group A + C	1.22	9.5%	1.8%	3.20	5.31	68.7
	Group A + B + C	**0.86**	**9.7%**	**3.7%**	**3.28**	**5.21**	**70.0**
Warehouse 2	Group A	1.71	13.5%	5.8%	5.03	7.38	49.4
	Group B	1.94	13.7%	3.5%	5.06	7.53	48.5
	Group C	1.94	15.8%	3.0%	5.77	8.25	44.3
	Group B + C	0.97	14.6%	4.5%	4.90	6.89	53.0
	Group A + B	0.91	13.5%	5.3%	4.56	6.52	56.0
	Group A + C	0.91	14.6%	5.1%	4.88	6.84	53.4
	Group A + B + C	**0.62**	**14.2%**	**4.9%**	**4.59**	**6.40**	**57.0**
Warehouse 3	Group A	1.76	9.0%	1.6%	3.24	5.62	64.9
	Group B	2.26	12.3%	3.0%	4.66	7.29	50.1
	Group C	2.26	11.8%	3.3%	4.51	7.14	51.1
	Group B + C	1.13	11.9%	3.8%	4.09	6.15	59.3
	Group A + B	0.99	10.7%	2.7%	3.57	5.56	65.6
	Group A + C	0.99	10.5%	2.7%	3.49	5.49	66.5
	Group A + B + C	**0.69**	**11.0%**	**3.1%**	**3.56**	**5.40**	**67.6**
Warehouse 4	Group A	1.45	9.9%	6.6%	3.97	6.20	58.9
	Group B	1.63	12.0%	4.1%	4.40	6.72	54.3
	Group C	1.63	11.3%	3.9%	4.13	6.44	56.7
	Group B + C	0.81	11.5%	4.8%	3.96	5.87	62.2
	Group A + B	0.77	10.9%	5.9%	3.90	5.79	63.1
	Group A + C	0.77	10.6%	6.1%	3.82	5.71	64.0
	Group A + B + C	**0.52**	**11.0%**	**5.4%**	**3.75**	**5.51**	**66.2**
Warehouse 5	Group A	1.33	15.7%	2.8%	5.39	7.55	48.3
	Group B	1.75	17.0%	1.9%	6.05	8.42	43.3
	Group C	1.75	16.7%	1.4%	5.95	8.32	43.9
	Group B + C	0.88	16.7%	3.4%	5.45	7.39	49.4
	Group A + B	0.75	16.1%	1.7%	5.13	7.00	52.1
	Group A + C	0.75	16.0%	3.0%	5.15	7.03	51.9
	Group A + B + C	**0.53**	**16.2%**	**3.2%**	**5.07**	**6.84**	**53.4**
Warehouse 6	Group A	1.40	20.6%	8.0%	7.49	9.69	37.7
	Group B	1.71	18.6%	6.1%	6.85	9.20	39.7
	Group C	1.71	17.4%	7.1%	6.54	8.90	41.0
	Group B + C	0.85	17.8%	7.8%	6.20	8.13	44.9
	Group A + B	0.77	19.4%	7.7%	6.61	8.50	43.0
	Group A + C	0.77	18.9%	8.1%	6.49	8.38	43.6
	Group A + B + C	**0.53**	**18.7%**	**7.8%**	**6.23**	**7.99**	**45.7**
Warehouse 7	Group A	1.60	12.0%	0.2%	4.18	6.48	56.3
	Group B	2.00	9.3%	0.3%	3.37	5.87	62.2
	Group C	2.00	13.4%	0.0%	4.86	7.36	49.6
	Group B + C	1.00	11.4%	0.6%	3.71	5.71	63.9
	Group A + B	**0.89**	**10.6%**	**0.2%**	**3.40**	**5.34**	**68.3**
	Group A + C	0.89	12.6%	0.6%	4.04	5.98	61.0
	Group A + B + C	0.61	11.5%	0.4%	3.56	5.37	68.0

Figure 19: Impact of Mixing SKUs with Different Velocity on Inventory Turns

Note 1: All the scenarios assumed a constant service level of 99% and a 7-day forecasting period.

Note 2: The variability of the replenishment lead-time, for a given warehouse, was not differentiated by SKU group.

Note 3: The consolidated data per warehouse for the groups 2 and 3, more specifically the standard deviation of the forecast error, the forecast error, the variability of the replenishment lead-time and the order cycle, were provided by the partner's senior inventory managers.

From the table above, we can infer that the recommendation of mixing different groups of SKUs to reduce the replenishment lead-time cannot be generalized and will only lead to a higher number of inventory turns under "some special conditions", which will require a detailed step-by-step analysis of the Inventory Manager.

In fact, we can observe in the simulation for the "warehouse 7" that the option "Group A + B" generates a higher number of inventory turns than the option "Group A + B + C", whereas for the other warehouses, the option "Group A + B + C" always led to the highest number of inventory turns.

The reasoning behind this fact is that, by mixing different groups of SKUs, the other variables that affect the number of inventory turns (see discussion above about the sensitivity analysis) may significantly change, so that the positive effect of reducing the order cycle can be overcome by the negative effects of the higher forecast error and the higher standard deviation of the forecast error, for instance, on the number of inventory turns. In fact, by mixing the high-velocity with lower velocity SKUs, we start to deal with

SKUs characterized by a lower volume of sales, and sometimes not steady, which may mean that we are going to face more inaccurate forecasts (the lower and the less stable the demand, the more inaccurate may be the forecast).

On the other hand, the discussion above does not make the alternative of mixing SKUs invalid and unviable. As mentioned before, an efficient mixing procedure must be iterative, in the sense that the inventory manager must recalculate the overall impact of an additional SKU on the number of inventory turns at each time he adds a new SKU to the current base.

Consequently, the target SKUs to be added to the high-velocity base (low-velocity SKUs) will be the ones that will most contribute to increase the number of inventory turns, which is the same to select the SKUs with the lowest standard deviation of the forecast error and forecast error (in this sequence), given that the other variables, such as the transit time, the lead-time and the variability of the replenishment lead-time were kept constant.

Conversely, if all variables are allowed to change, the selection procedure will follow the recommendation of the sensitivity analysis. That is, prioritize the variable that most impact the overall number of inventory turns, select and add the targeted SKU to the base and recalculate the number of inventory turns. When this number decreases, stop adding SKUs to the base.

One additional factor, the contribution of each SKU (added to the "high-velocity base") to the partner's overall bottom-line, plays a significant role in establishing the "prioritization criteria" and in defining the appropriate ordering pattern. This subject will be extensively discussed in the "Question 3" chapter.

By now, it is important to just emphasize the additional trade-off the partner must face: to focus on the increase of the number of inventory turns, and thus, maximizing customers' satisfaction, or to focus on maximizing its bottom-line, by prioritizing the offering of the SKUs with the highest contribution margins (whereas keeping an acceptably high number of inventory turns).

In fact, given what was discussed before, we can state that the partner will maximize the number of inventory turns if he prioritizes SKUs with very low standard deviation of the forecast error and forecast error. However, these SKUs are not necessarily the ones with the highest gross margin (this would be the ideal scenario), which is the same as to say that the partner will be leaving some surplus on the table. In order to compensate for this loss of margin and to capture most of the profits, the partner will depend on a significantly increase in the sales level of the new SKUs added to the original base (this will definitely depend on a conjoint effort with the customers at the store level, such as better position in their shelves, advertising and promotion, etc).

On the other hand, in order to maximize its bottom line, the partner must add to the SKU base the SKUs that bring the highest contribution margin. However, these SKUs must not contribute to the increase of the number of inventory turns as well as those ones discussed in the previous paragraph.

As we can see here, the best solution is dynamics and will consist of a mix of the two alternatives discussed above: prioritization of profit margins or of inventory turns. This success of this initiative will depend on the conjoint efforts from both the partner and its customers, so that the best and most sustainable solution within the supply chain may be reached (a non-zero sum game).

Trade-off 3: Reduce the order cycle time variability

The key idea of this trade-off alternative is to increase the percentage of on-time deliveries, by reviewing the routing procedures of the third party carriers, and therefore, by adopting more flexible delivery schedules to avoid periods with intense traffic that contribute to increase the transit time, and therefore, the replenishment lead-time).

On the other hand, such change in the current delivering procedures may demand higher disbursements from the partner, since the carriers will need to readapt themselves and will probably charge a premium price for this customized service. For example, by shipping during the early morning, the variability of the scheduled delivery time, due to traffic issues, will be lower. However, the distributors may have a higher overhead cost (have to pay drivers a higher per-hour wage, among other factors).

The decision to continue or not with this trade-off analysis depends on a deep analysis of the negotiated contracts, in order to figure out if the partner is subjected to any penalty in case of the cancellation or change of any contract term.

Due to the difficulties presented above and to the low probability of changing the contracts (sourcing contracts), the team decided to abandon this trade-off analysis.

Trade-off 4: Improve the forecast accuracy

The forecast efficiency is directly related to the amount of safety stock in the system, and consequently, plays a fundamental role in helping the partner to increase the customers' inventory turns. In general practice, inaccurate forecasts lead to high cost operation and/ or poor levels of customer service. (Masters – 2002)

After interviewing some company's experts and analyzing all the demand data for the high-velocity SKUs of a key customer, as well as their forecast errors and standard deviation of the forecast error, the team concluded that improving the forecasting process, chiefly reducing the standard deviation of the forecast error, may be a fundamental step to allow the partner to increase its key customers' inventory turns (see the section "rational for forecast the improvement recommendation" below).

Despite the improvement of the forecasting process is outside the scope of the thesis project, the team suggests future studies on the following opportunities for improvement:

- better forecasting methodologies and tools to try to reduce the variability in the forecast error deviation (less responsive to noise). (improvement *versus* the necessary investment)
- better train forecasters
- improve communication throughout the supply chain (better integration with key customers using B2B tools, implementation of a CPFR program, etc)

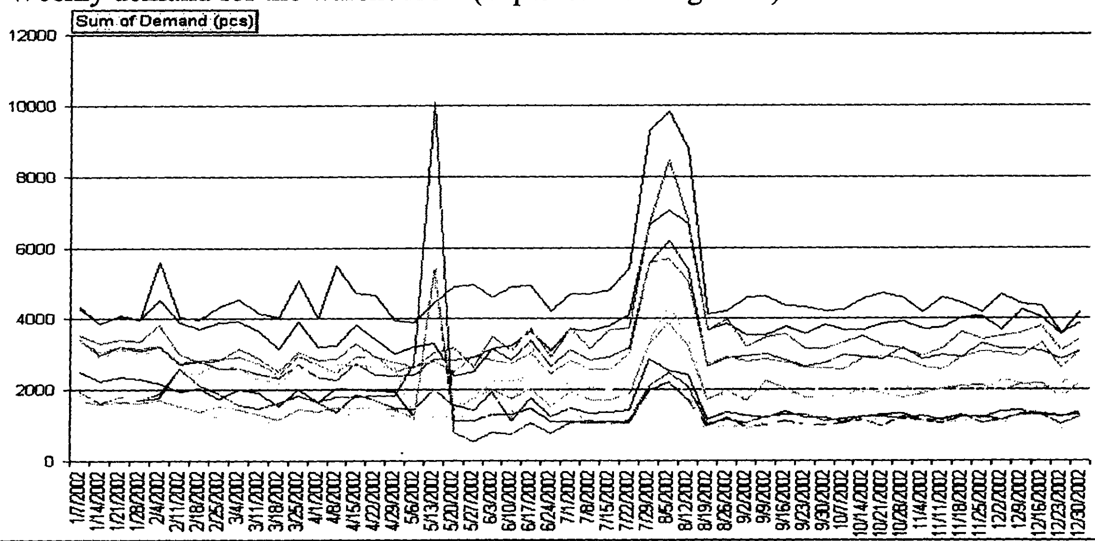
Each of these opportunities will create a trade-off analysis (economic benefits from the forecast improvement *versus* the additional investment and expenses required) that need to be carefully considered by the partner.

Rational for the forecast improvement recommendation

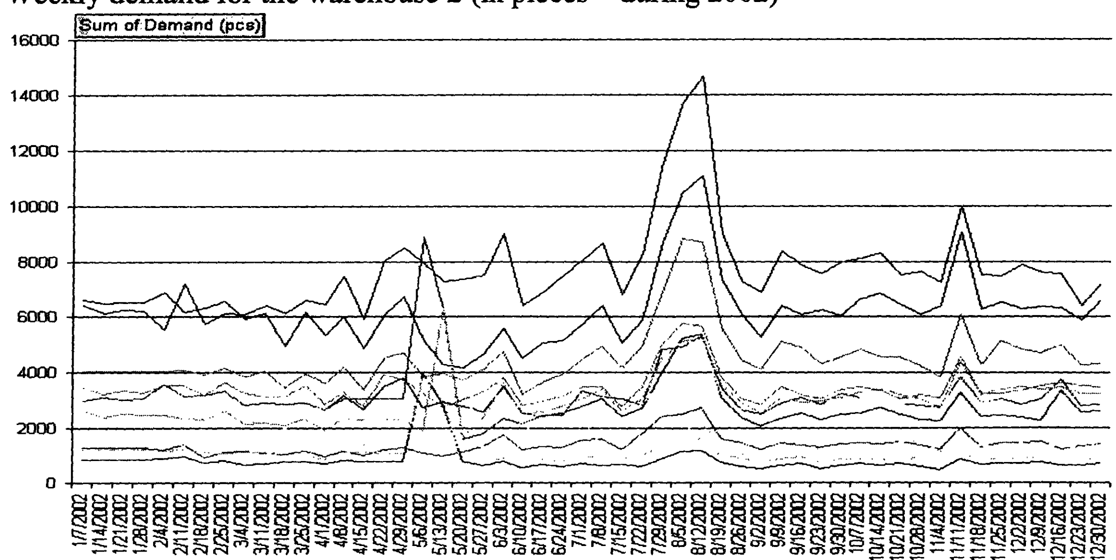
The 2002 demands at each of the seven customer's warehouse for the thirteen high-velocity SKUs, as shown in the table below, are pretty stable, except for two significant spikes during the beginning of May and August (for two warehouses, a small spike in the middle of November can also be noted)

Therefore, since the behavior of the demand for this customer was not extremely complicated, small forecast errors were expected.

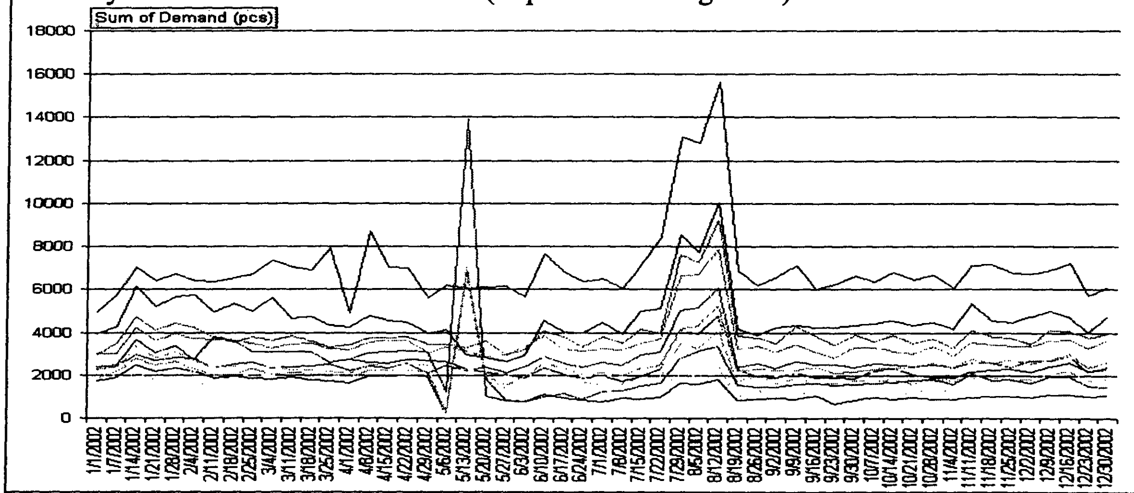
Weekly demand for the warehouse 1 (in pieces – during 2002)



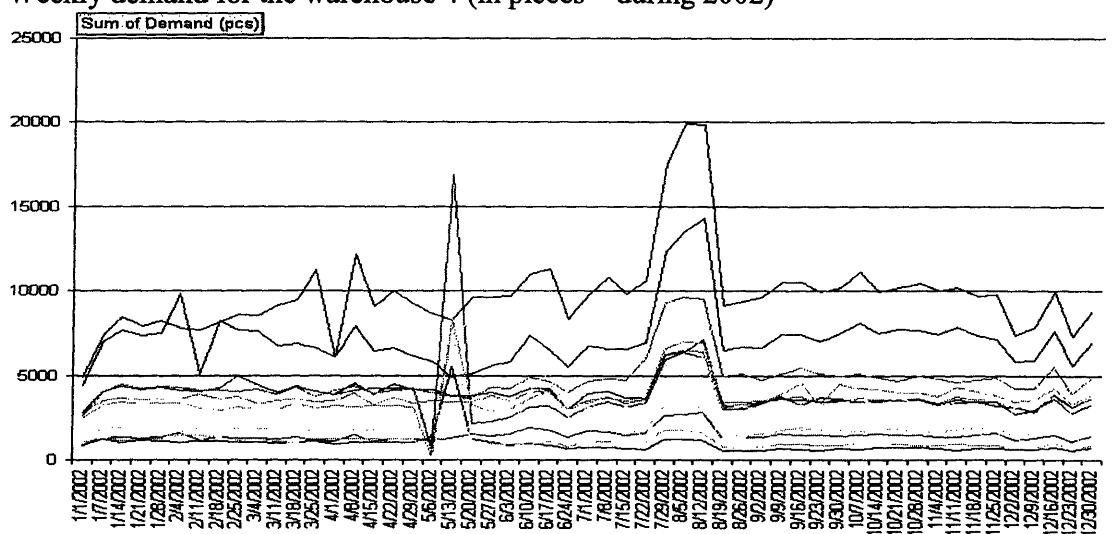
Weekly demand for the warehouse 2 (in pieces – during 2002)



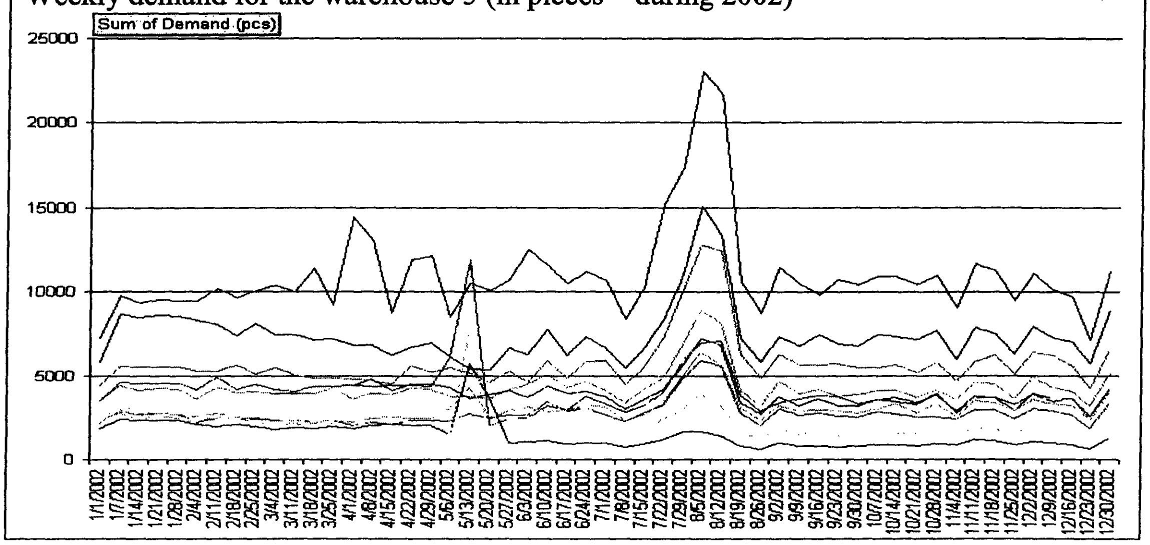
Weekly demand for the warehouse 3 (in pieces – during 2002)



Weekly demand for the warehouse 4 (in pieces – during 2002)



Weekly demand for the warehouse 5 (in pieces – during 2002)



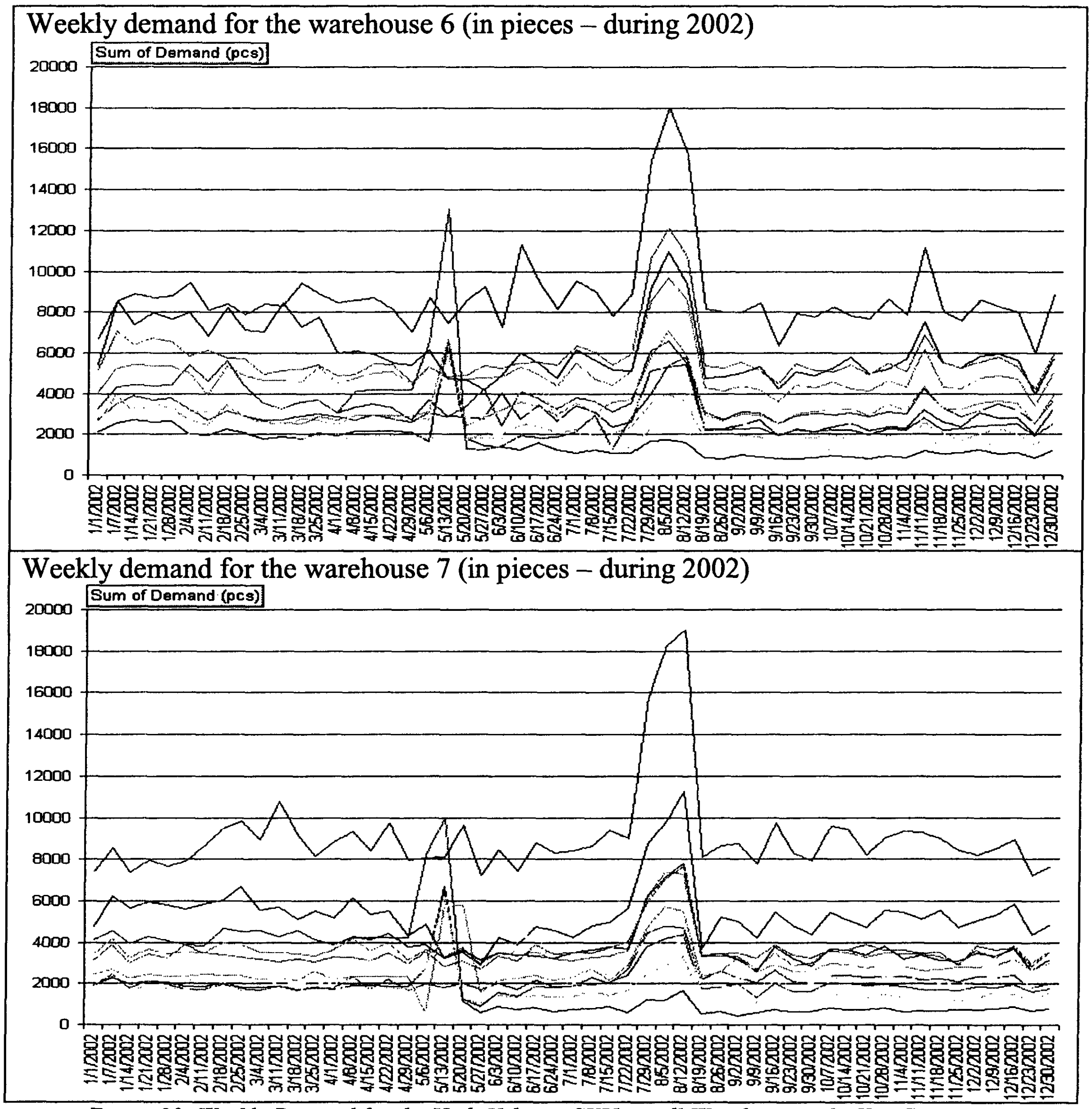
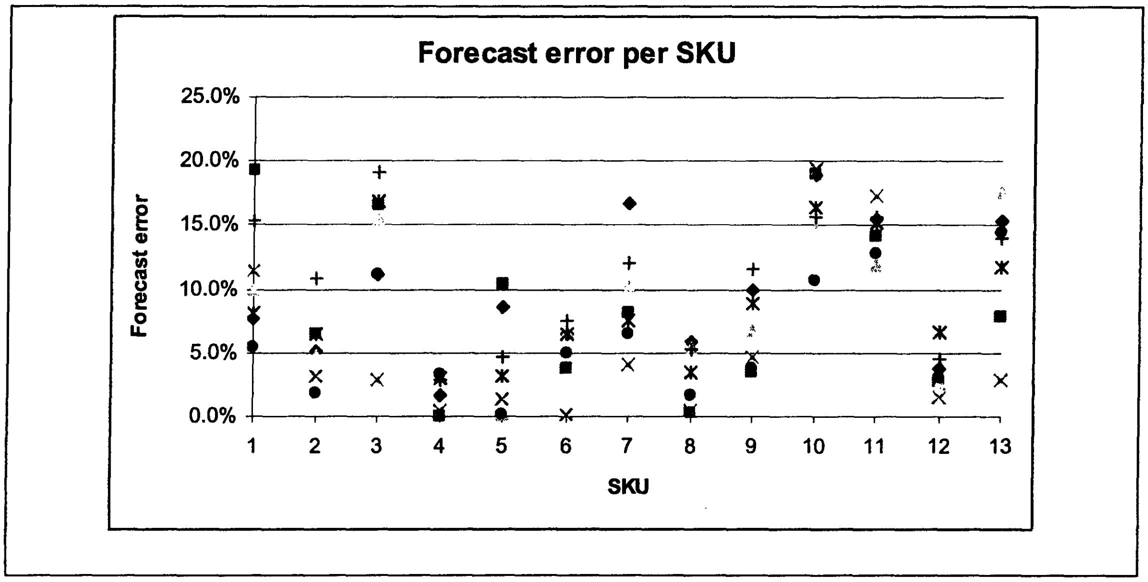
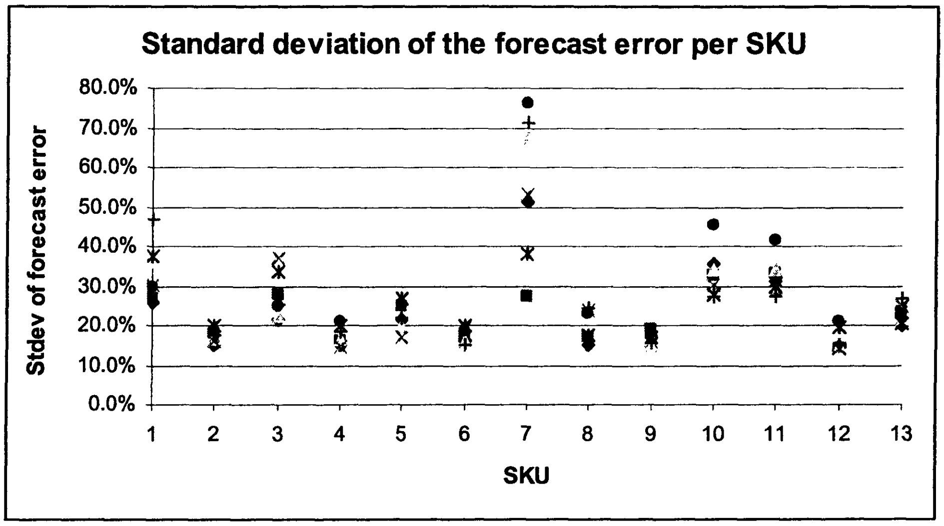


Figure 20: Weekly Demand for the High-Velocity SKUs at all Warehouses of a Key Customer

Conversely, by analyzing the forecast error and the standard deviation of the forecast error per SKU and per customer's warehouse, showed below, some facts immediately call our attention:

- The huge distribution of the forecast error and standard deviation of forecast error for a single SKU throughout all customer's warehouses (columns in the charts below)
- The discrepancies of the forecast error and the standard deviation of forecast error for each of the thirteen SKUs in a single customer's warehouse





Forecast error per SKU (in each warehouse)												
SKU 1	**SKU 2**	**SKU 3**	**SKU 4**	**SKU 5**	**SKU 6**	**SKU 7**	**SKU 8**	**SKU 9**	**SKU 10**	**SKU 11**	**SKU 12**	**SKU 13**
7.7%	5.1%	11.2%	1.6%	8.5%	6.5%	16.8%	5.9%	9.9%	19.0%	15.6%	3.8%	15.4%
19.3%	6.5%	16.5%	0.0%	10.3%	3.7%	8.1%	0.4%	3.5%	18.9%	14.2%	2.7%	7.9%
10.0%	4.9%	15.6%	3.2%	0.2%	6.7%	10.2%	5.4%	6.8%	14.8%	11.9%	2.5%	17.7%
11.5%	3.2%	2.9%	0.5%	1.3%	0.1%	4.0%	0.4%	4.7%	19.4%	17.3%	1.5%	2.9%
8.2%	6.5%	16.9%	3.0%	3.2%	6.5%	7.6%	3.4%	8.8%	16.5%	15.2%	6.6%	11.8%
5.4%	1.9%	11.2%	3.2%	0.1%	5.0%	6.4%	1.7%	3.8%	10.7%	12.8%	3.0%	14.4%
15.3%	10.8%	19.1%	2.8%	4.7%	7.5%	12.0%	5.3%	11.5%	15.7%	15.7%	4.6%	14.0%

Standard deviation of the forecast error per SKU (in each warehouse)												
SKU 1	**SKU 2**	**SKU 3**	**SKU 4**	**SKU 5**	**SKU 6**	**SKU 7**	**SKU 8**	**SKU 9**	**SKU 10**	**SKU 11**	**SKU 12**	**SKU 13**
26.0%	14.9%	21.6%	15.2%	21.2%	16.3%	51.1%	15.1%	16.9%	35.4%	32.0%	14.5%	20.0%
26.8%	17.9%	27.6%	15.9%	25.1%	17.8%	27.4%	17.0%	18.9%	32.7%	33.2%	14.2%	23.4%
36.2%	16.5%	22.3%	16.4%	20.2%	16.2%	67.3%	24.2%	15.2%	34.3%	34.1%	14.9%	21.6%
30.1%	16.0%	37.3%	14.5%	17.0%	19.6%	53.2%	23.8%	15.9%	30.3%	28.6%	14.1%	24.8%
37.4%	20.2%	33.8%	20.1%	26.9%	20.1%	38.2%	17.3%	17.2%	28.0%	29.7%	19.6%	20.6%
29.6%	18.5%	25.0%	20.9%	25.5%	18.3%	75.9%	23.2%	18.1%	45.3%	41.5%	20.9%	22.5%
47.1%	17.8%	25.2%	18.4%	22.2%	15.3%	71.2%	24.6%	15.7%	27.4%	27.5%	15.0%	26.8%

Weekly volume (pieces) in 2002 per SKU (in each warehouse)												
SKU 1	**SKU 2**	**SKU 3**	**SKU 4**	**SKU 5**	**SKU 6**	**SKU 7**	**SKU 8**	**SKU 9**	**SKU 10**	**SKU 11**	**SKU 12**	**SKU 13**
1,314	2,003	1,712	3,643	3,873	9,108	3,236	5,322	3,597	2,351	2,289	2,512	2,783
836	1,398	1,082	3,456	2,918	7,653	3,233	6,262	4,543	1,450	1,472	2,829	2,997
1,432	2,678	2,192	3,575	2,530	7,016	2,346	4,706	3,966	1,554	1,558	2,339	2,473
957	1,459	1,181	3,681	3,937	9,835	3,889	7,198	4,758	1,914	1,945	3,206	3,716
1,490	2,748	2,085	4,306	4,021	11,033	4,083	7,434	5,771	2,500	2,516	3,174	3,007
1,584	3,313	2,493	4,937	3,259	8,817	3,267	6,141	5,799	1,801	1,768	2,838	3,348
1,563	3,031	2,399	2,983	1,560	4,734	1,600	3,849	3,488	1,299	1,295	1,897	1,903

Figure 19: Forecast Error and Standard Deviation of the Forecast Error per SKU per Warehouse

The first fact "the huge distribution of the forecast error and standard deviation of forecast error for a single SKU throughout all customer's warehouses" could be explained by the volume of the SKUs at each of the warehouses. That is, the higher and more stable the volume (demand) of the SKU, the lower would be the forecast error. However, considering the SKU number 6 (which has the highest average weekly volume – see the tables above), it can be seen that it does not have the lowest metrics (forecast error and standard deviation of forecast error) in each of the warehouses.
On the other hand, considering the SKU number 1 (which has the lowest average weekly volume – see the tables above), it can be seen that it does not have the highest metrics (forecast error and standard deviation of forecast error) in each of the warehouses.

The second fact "the discrepancies of the forecast error and the standard deviation of forecast error for each of the thirteen SKUs in a single customer's warehouse" could be justified by the different locations of the warehouses, and consequently, by the different markets they attend (one being more unstable and volatile than the others).
However, going through the forecast error and the standard deviation of the forecast error tables, we can easily notice that there is no single pattern that corroborates to justify that there is a strong and determinant location factor. That is, selecting two rows at any of these tables, which means two different warehouses, and analyzing the behavior of the SKUs, we can see that these two curves cross at some points, which means that the location factor is not a determinant driver (has a extremely high correlation) of the forecast accuracy.
As an illustration, we analyzed the forecast errors for the warehouses "5" and "7"

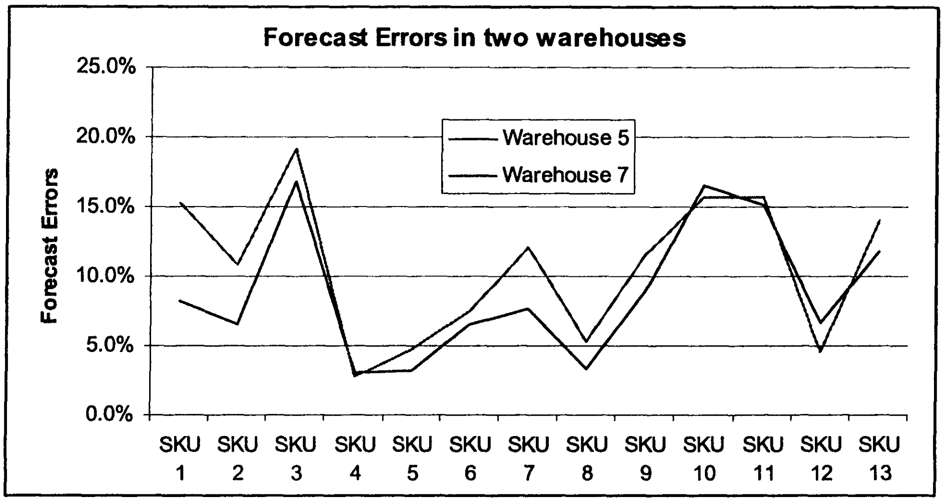


Figure 20: Comparison of the Forecast Errors for the High-Velocity SKU's at Two Warehouses

Although the rational above cannot assure that the forecasting process is inefficient, and even less that the partner can improve it by "x" percent, it corroborates to not only recommend a future study in a higher level of detail, but also to call the partner executives' attention to the performance of the forecasts, which can significantly influence the customers' inventory turns.

In fact, some SKUs at some warehouses have very low forecast errors (below two-digits), which allows the partner to stay in the first tier of industry. However, the same SKUs at other warehouses present a much higher forecast error. The fact that the demand pattern for this specific customer is relatively flat, allied to the consistent high variability of the forecast error and to the fact that the forecast accuracy is crucial in achieving better inventory turns (see the outcomes of the sensitivity analysis), casts some doubt about the forecast accuracy for all the other SKUs and corroborates to reinforce the recommendation of a deeper and broader forecasting analysis.

Trade-off 5: Review the manufacturing strategy

Motivation

Integrating the manufacturing process into an agile supply chain has always been a difficult problem. Manufacturing has traditionally been at odds with both procurement (for procuring shoddy or late input materials) and with sales and marketing (due to manufacturing's inability to satisfy customer needs). (Porteus – 1991)

Manufacturing has therefore typically been considered inflexible at best. In a global economy inflexibility is no longer an option. As a result more firms are looking at reducing cycle time, reducing change over time (between parts), and creating manufacturing systems with an optimal lot size of one. By working out just-in-time (JIT) delivery arrangements with suppliers, 'pull' systems on the manufacturing floor, and 'make-to-order' production schedules, companies can not only reduce inventories but reduce the time from order to delivery dramatically. (Porteus – 1991)

In some cases, the choices that manufacturing management needs to make to accomplish these objectives may seem counterintuitive. For example in highly variable or low volume environments, relying on humans to do a task rather than robotics can be more cost effective because of reduced changeover times, even though a robot can perform the specific task more quickly. In others, switching from a die system to a 'slower' laser cutting system is actually more cost effective due to significantly reduced switchover times. With 100 – 200 switchovers per day, the switchover is far more important than the actual production time (Martin – 1999). The goal for manufacturing should not be producing products at the lowest manufacturing cost. Companies need to look at total cost throughout the supply chain when making manufacturing decisions (Cohen – 1985).

Description of the trade-off

The main idea of this trade-off analysis is to assess the impact of changing the manufacture strategy towards a leaner and more flexible process on the total amount of inventory in the system and on the partner's responsiveness to its customers' demand and to trade it off against the requirements for investments or additional expenses. Additionally, a change in the manufacturing configuration (lines, minimum orders ...) may also minimize the current issues regarding capacity limitation.

However, one important consideration to be done is that this recommendation depends on the analysis of the whole SKU and customer's database, since the best manufacturing configuration (assignment of production lines, crews, minimum orders, changeovers, etc) for one customer may not be the optimum solution for the whole customer base.

Description of the approach taken by the team

In order to assess the impact of the manufacturing run strategy on the overall number of inventory turns, the team modeled all laundry SKUs (around 330 SKUs) produced at five locations (23 manufacturing lines) and conducted some simulations changing the production frequency, the production reliability and the production batch size.

The major conclusions driven from the simulated scenarios, as detailed below, were:

- Increasing the production frequency (from biweekly to weekly) increases the number of inventory turns and the fill rate;
- A more reliable production increases the fill rate and the number of inventory turns;
- Reducing the production batch size allows the partner to keep a lower inventory level, and thus, to reduce the overall costs in its distribution system.

Simulated Scenario 1:	Analysis of the impact of increasing the production frequency on the global system-wide variables (total costs, fill rates and number of inventory turns)
Set-ups:	Database: a selected SKU produced each other week (2-week production cycle) Scenario 1: 2-week production cycle Scenario 2: 1-week production cycle All other variables, such as demand, forecasting techniques, safety stock calculation and unit cost parameters were held constant

Key conclusion:

Reducing the production cycle increases the number of inventory turns and the fill rate

Major Findings and Outcomes:

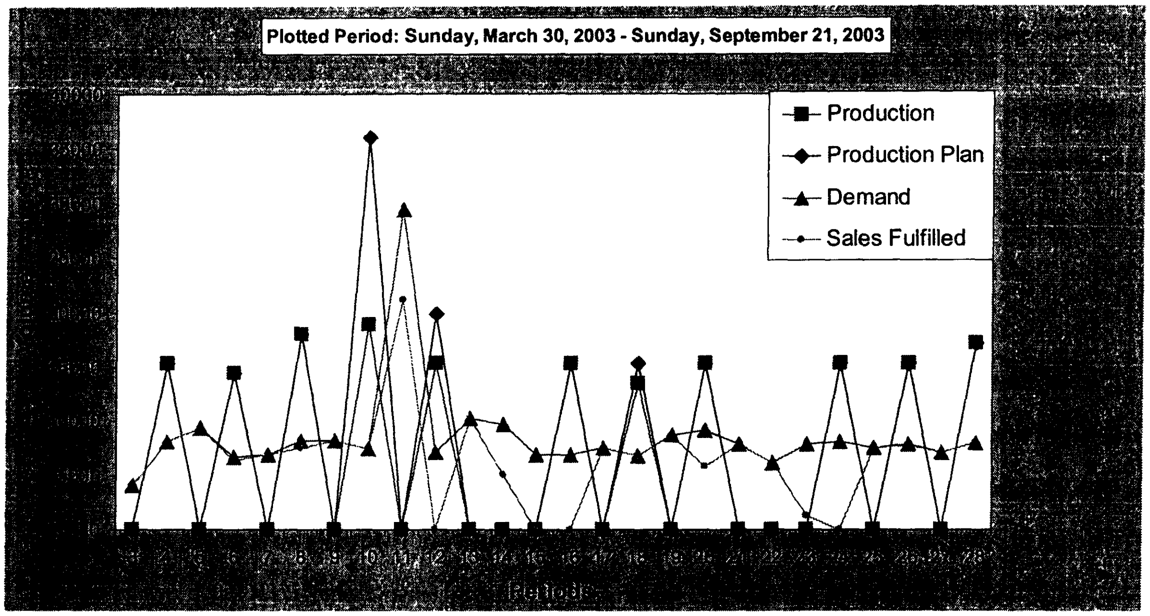
Increasing the manufacturing frequency, for a given SKU, from biweekly to weekly production, we observed a reduction in the total costs within the system, despite the increase of the transportation and handling costs (correlated to the higher frequency of production and shipment), an increase in the fill rate (higher availability of products at the customer's site) and a increase in the number of inventory turns at the customer's warehouse level (reduction of the inventory level at the customer's site).

It can be noted, in the charts below (simulator-generated plots), that the "Sales Fulfilled" line matched the "demand" line much better in the one-week production cycle, which contributed to increase the fill rate.

Production Campaign	Fill rate	Cost ($1000s)				
		Transport	Handling	Stock Holding	Interest on Capital	Total Costs
2 week cycle	76%	103.00	6,513.00	12,650.00	2.53	**19,268.53**
1 week cycle	88%	118.00	7,458.00	10,822.00	2.24	**18,400.24**
% Change	16%	15%	15%	-14%	-11%	-5%

Change in fill rate (%):	From 76% to 88% (16% increase)
Change in the inventory level (%):	As can be seen in the charts below
Change in inventory turns (%):	From 46 to 54 turns (16% increase)
Change in total cost (%):	Reduction of 5% in total costs

2-week production cycle



1-week production cycle

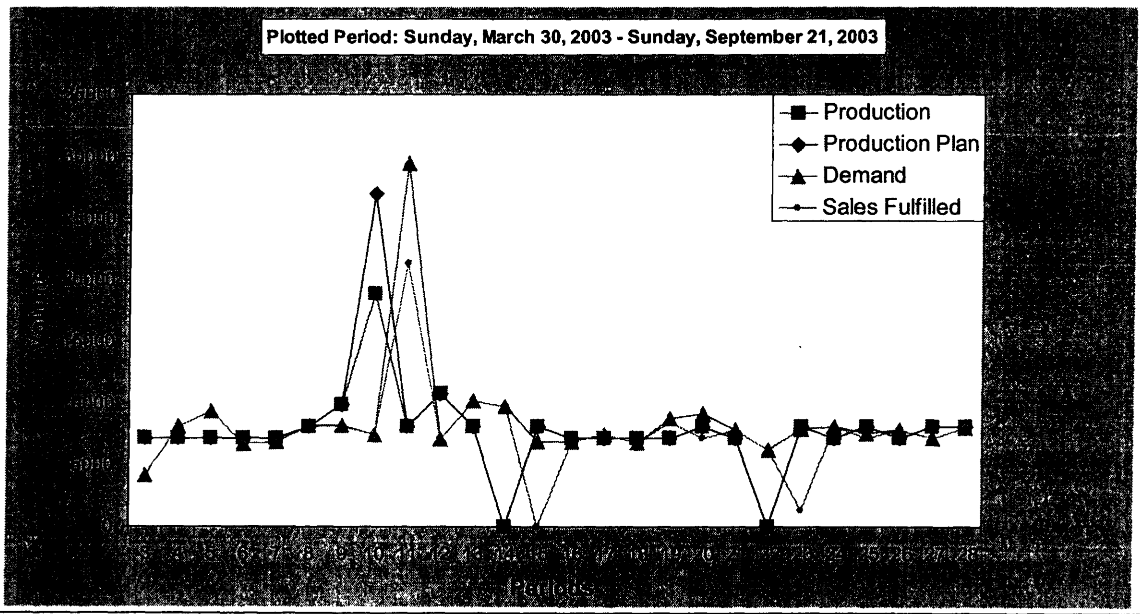


Figure 21: Simulation 1 - Impact of Increasing the Production Frequency on the System

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PAGES (S) MISSING FROM ORIGINAL

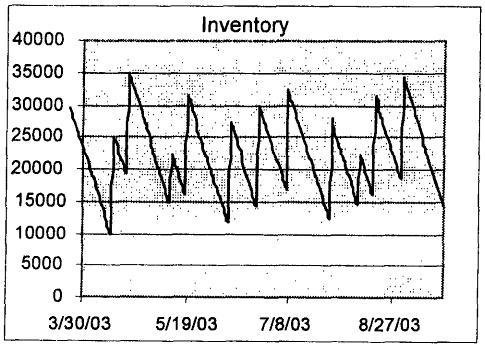
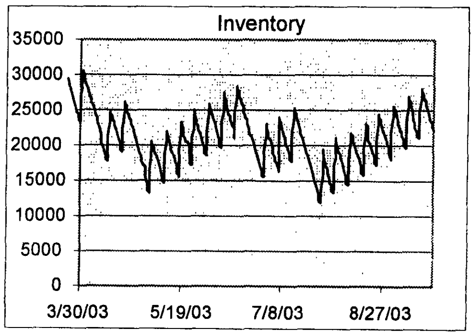
<table>
<tr><td>Simulated Scenario 3:</td><td>Analysis of the impact of reducing the production batch size on the system's total cost.</td></tr>
<tr><td>Set-ups:</td><td>Simulating a representative SKU with the "Multi-Echelon" and the SCDM simulators (altogether).
Scenario 1: Batch size is 8250 cases
Scenario 2: Batch size is 16500 cases (current practice).
All other variables were kept constant</td></tr>
<tr><td colspan="2">Key conclusion:
Reducing the batch size reduces the finished goods inventory and the system's total costs.</td></tr>
<tr><td colspan="2">Major Findings and Outcomes:
Smaller batches size resulted in lower costs in the system.</td></tr>
<tr><td>Batch size is 16500 cases</td><td>Batch size is 8250 cases</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Total cost: $16,300,000</td><td>Total cost: $15,600,000</td></tr>
<tr><td colspan="2">Practical Implications:
The downside of small batch size is that it increases the change over costs.
It is important to verify the feasibility of the computer generated plan with the shop floor personnel, because the simulator does not consider all "real-life" constraints.</td></tr>
<tr><td colspan="2">Further thoughts:
A major opportunity to reduce the costs in the supply chain is to optimize the manufacturing strategy. The key to reduce the inventory level is to avoid moving it upwards/ downwards the distribution system, but to reduce it from the source – factory level, which involves:
1) Continuously reviewing the production plan to see if it is aligned with the current SKU mix. Consider margins, priorities…
2) Continuously reviewing the production plan to see if the resources are efficiently used</td></tr>
</table>

Figure 23: Impact of the Production Batch Size on the System's Total Costs

Trade-off 6: Review the ordering management and warehousing processes

This trade-off alternative aims at reducing the partner's replenishment lead-time, by reducing the time between the order collection and the shipment (order processing and warehousing lead-times), which will require investments in technology systems and in process redesign and reorganization efforts.

The partner is implementing a new order management system, which will contribute to significantly reduce the time required to process and manage customer's order. However, there are still opportunities for improvement in the warehousing process, which currently lasts on average two days, in the sense that the load/ unload and pick/ pack processes can be redesigned to accommodate the current requirements for high speed. This trade-off analysis deals with process redesign and reorganization topics and is outside of the scope of the thesis project. However, it is important to emphasize the importance of these future initiatives if the partner really decides to pursue a major effort transformation to reduce its key customers' working capital requirements (higher inventory turns).

4.3 Thesis Question 3

Thesis Question 3: How to determine which SKU will lead to improved overall bottom-line?

Motivation

Service differentiation is the solution to the high cost and poor service spiral. The dilemma of customer service can be resolved by thinking carefully about your customers' real product requirements, your customer relationships, and your supply chain economics (Byrnes – 2002).

In fact, by setting appropriate service levels for different customers and products, a company can create a fundamental competitive advantage (Byrnes – 2002):

- Service levels, especially for critical products and critical customers, will improve to near-perfect levels, tightly binding your best customers to your company
- Most customers will willingly accept, and prefer, a company's flawless service at jointly-planned service intervals over its competitors' lower service levels
- The sales process can focus on moving customers from non-core to core status by obtaining higher order volumes and loyalty

Historical overview – stages of excellence in customer base segmentation

In the past, the most common approach to differentiate the "good" from the "bad" customers and products was to use the ABC analysis. The logic behind this methodology is that few customers and SKUs account for the bulk of a manufacturer's sales and profits (Lambert – 1982).

The products are ranked by sales (and/or profitability, depending on the availability of data) and classified as "A", "B" or "C" (from higher to lower percentages)

The ABC analysis is still largely used in the industry, due to its simplicity. Normally:

- items "A" have their inventory status daily or continuously reviewed and are stocked in all locations (the lower probability of stockout offsets the higher inventory carrying costs)
- items "B" have their inventory status weekly reviewed and are stocked in regional locations
- items "C" have their inventory status monthly reviewed and are stocked only in the central location (the lower inventory carrying costs offset the higher transportation costs)

However, the evolution of the information technology systems enabled the companies to monitor a larger number of key parameters at different sites in real time. This improvement allowed the companies to better select their customers and to narrow their offering of SKUs (migration to the stage II).

Recently, the high competition within the industry increased the corporate pressure for better economic results. Consequently, in order to thrive in and reach the lion's share, the more a company improves the understanding of its customers' needs, the faster it will be to identify the "best customers" and to offer them the highest margin products (stage III). Today's understanding of customer's needs goes beyond knowing which items are more consumed by each customer (past events). Most importantly, it prioritizes the partnerships and collaboration with customers, which allow companies to develop long-term plans and set strategies that maximize the value generation within the whole chain.

From the considerations above, the immediate conclusion is that nowadays companies are much more prepared to make managerial decisions such as discontinuing SKUs or developing a strategic partnership with a key customer.

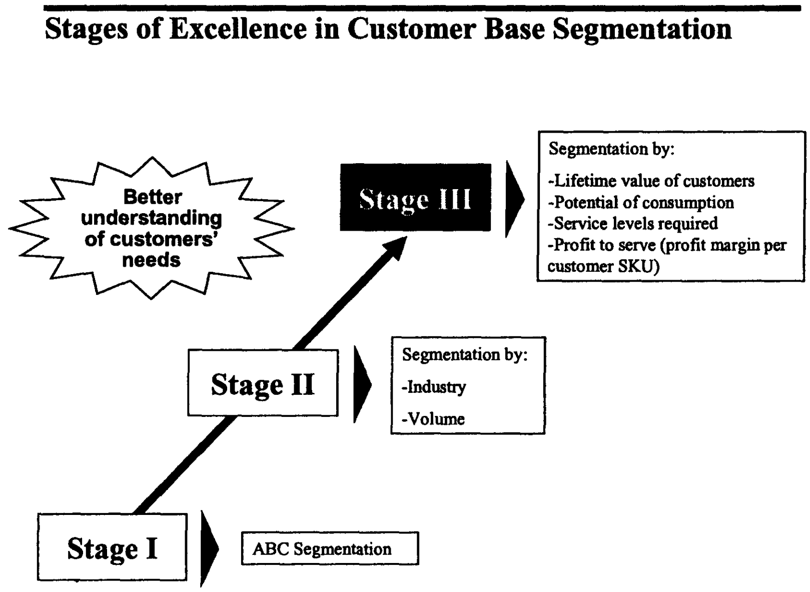


Figure 24: Stages of Excellence in Customer Segmentation

<u>Rational for the development of the prioritization criteria</u>

In order to establish a segmentation criteria for our partner, we developed a two-by-two service prioritization matrix, based on three basic managerial concepts:

1. Different SKUs bring different bottom-lines to the company
2. Customer's requirements for different SKU, in terms of service intervals, differ a lot
3. Customers have different importance to the company

1. Different SKUs bring different bottom-lines to the company

The fundamental justification for this affirmation lies on the fact that different SKUs have different price elasticity of customer's demand. This means that some items may be "more desirable" than the others, which allows the company to establish a higher markup for those items, given the marginal costs to produce them.

The higher the elasticity of the demand, the lower will be the effectiveness of setting a higher markup for this item (the customers have higher options to substitute these items).

2. Customer's requirements for different SKU differ a lot

Products that are fast movers and costly to store require very tight delivery cycles. Products with critical stock-out costs also require very tight delivery cycles. However, many slower-moving products with adequate customer safety stock can easily accommodate slightly longer service intervals (as long as the delivery promise is always kept).

3. Customers have different importance to the company

Not all customers have equal importance to the companies' portfolio and to its future market plan. The important customers with established loyalty and high volumes may be prioritized in comparison to the customers with low, intermittent and uncertain demands. In fact, a series of stock-outs with a loyal and high volume customer costs the company much more than a similar situation with a intermittent customer, in the sense that if the loyal customer decides to change its supplier, the company will lose much more money.

Therefore, managers have to set appropriate order intervals, in advance, for different groups of customers and to develop distribution systems and service metrics that are appropriate for each customer group.

The "Service Prioritization Matrix" has two key drivers: the importance of the brand/ SKU and the importance of the customer in the partner's portfolio.

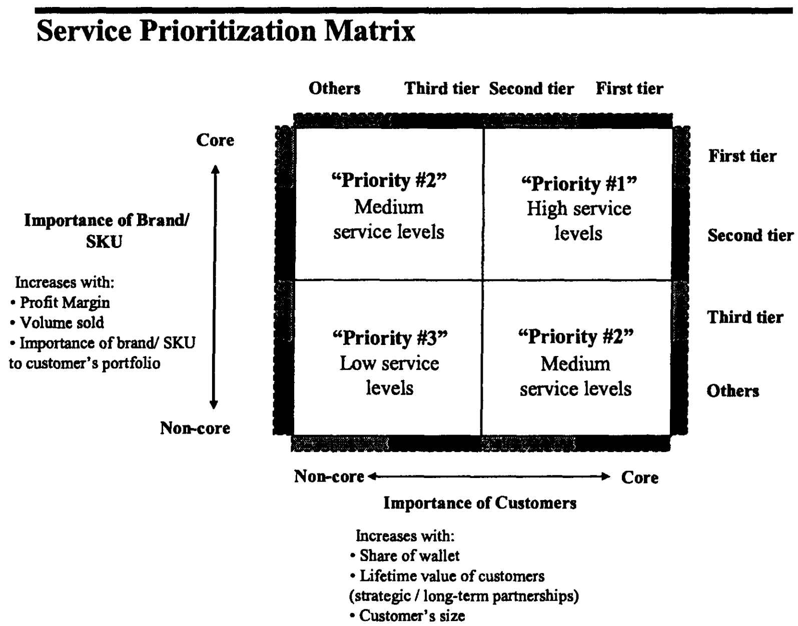


Figure 25: Service Prioritization Matrix

The importance of a single brand or SKU increases with its profit margin (the amount of surplus it can bring), annual volume sold (how fast it can generate the surplus) and its importance to customer's portfolio. The last driver is directly related to the customer's strategic plans and requires a high level of integration between customer and manufacturer.

The importance of a single customer increases with its share of wallet in company's portfolio (how much I sell to this customer), with the customer's size (how significant the customer is in the marketplace) and with the lifetime value of customers (how significant the customer is in company's strategic / long-term partnership plans).

Analisis of the Matrix's key drivers

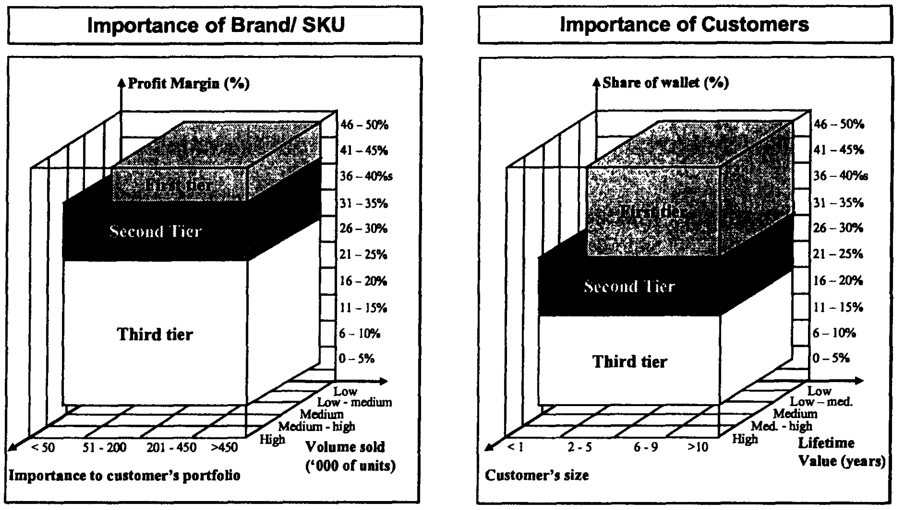


Figure 26: Prioritization Matrix Key drivers

Subjecting all brand/ SKU and all customers database to the "cube analyses" above, we ended up with two lists of brand/ SKUs and customers classified in "first tier", "second tier", "third tier", and "others".

Each of the "tiers" was migrated to a determined range in the core/non-core axes. Then, they were confronted in the two-by-two "Service Prioritization Matrix. For each quadrant, the partner determined a specific service level requirement.

Note: In order to keep the confidentiality of our partner's strategy and information, we just described the general methodology proposed and all the data presented, including the service levels, the variable ranges and the number of subdivisions of each key driver, are purely illustrative.

Interpretation of the "Service Prioritization Matrix" (Byrnes – 2002)

Core customers and core SKU quadrant

This quadrant corresponds to the most important brands/ SKUs ordered by the key customers. Therefore, the strategy the company must adopt is to keep the highest service level for these SKUs, since the probability of profiting from the sales of these SKUs is the highest (core customers and core SKUs).

Additionally, since the SKUs in this quadrant generate high value to the company, the costs of running out of stock are very high (the lost sales are very costly) and highly undesirable.

Finally, since the company is dealing with "core" customers, who have significant bargain power and want to maximize their working capital, it is strongly advisable to keep short replenishment lead-times and keep minimal stocks at the customers' warehouses, so that the customers' requirements can be matched.

Non-core customers and core SKU quadrant

According to the professor Jonathan Byrnes, "the non-core/core quadrant causes the most customer service trouble". The key reason for this statement is that the core SKUs ordered by a non-core customer (probably intermittent and/or very small) may disrupt the continuous flow of SKUs to the core customers with loyal order patterns, which may sign the customers some issues in company's service strategy and contribute to the tightening of their service level requirements (the key customers want to hedge themselves against these uncertainties).

According to Byrnes, "the answer to this difficulty is to agree with non-core customers on a longer, but reasonable service interval. Providing the non-core customers with a higher service interval allows the supplier a margin of time to bring extra stock from a regional warehouse if an unexpected demand peak occurs. Most of the time, even non-core customer orders can be fulfilled more rapidly, but the extra interval time ensures that the supplier will always keep its service promises".

Concluding, since the customers in this quadrant are not part of the "core menu", and thus, do not have enough bargaining power to require a "premium service", the company can set lower service levels in this quadrant than in the core/core quadrant.

<u>Core customers and non-core SKU quadrant</u>

This quadrant is composed of key customers that order some of the company's non-core (low velocity) SKUs.

According to Byrnes, "In the core/non-core quadrant, customers will accept a longer service interval, because they keep ample safety stock and the product is not critical", which allows company's managers to keep the stock in regional or more distant warehouses.

Therefore, the requirement for low replenishment lead-times and the concern about the product availability are not a key issue as in the core/core scenario. In fact, the lost sales are less costly in this quadrant (non-core SKUs mean lower contribution margins), which allows the company to provide the customers with a lower service.

However, it is important to mention that professor Byrnes emphasizes in his paper the importance of keeping some field stock, in order to respond on an exception basis to a core customer experiencing an unexpected crisis.

Non-core customers and non-core SKU quadrant

This quadrant is composed of small and/or intermittent customers that order some of the company's non-core (low velocity and low margin) SKUs.

According to Byrnes, "In the non-core/non-core quadrant, service intervals should be set to enable the company to bring stock from a regional warehouse to the field warehouse for customer transshipment, or to ship directly from centralized stock".

Therefore, given the company's low prioritization of the SKUs ordered and the low relative importance of the customers that are ordering, the company can set the lowest service levels in this quadrant.

Considerations about the impact of the new segmentation criteria on the partner's system

The direct consequence of the new segmentation criteria is that the partner will drastically change its usual pattern of prioritizing which SKU must be offered firstly to its customers. Today, the partner focuses on offering the SKUs with the highest sales level, whereas the new prioritization criteria recommends that the partner focus on offering the SKUs with the highest gross margins, which will contribute to increase the partner's bottom-line.

Prioritization by Profit Margin

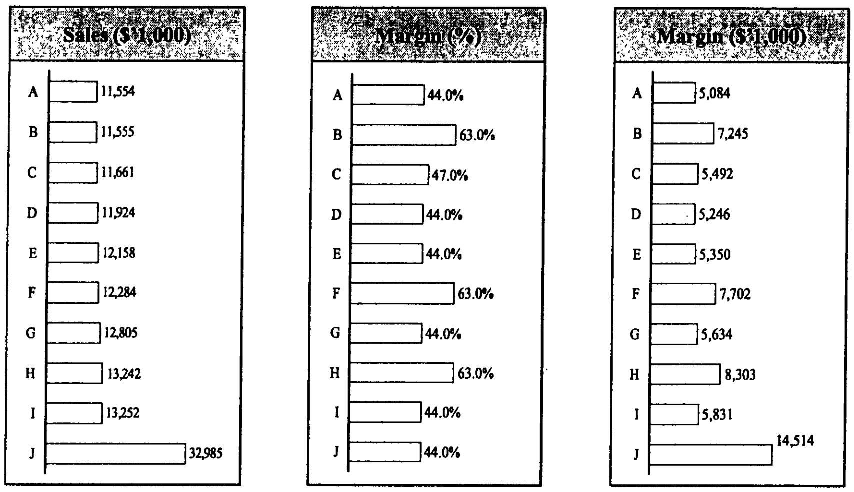


Figure 27: Illustration of the Prioritization Methods

The chart above considers the top-ten SKUs in a given laundry category and illustrates the difference between the old prioritization criteria (based on sales volume) and the proposed one (based on gross margin).

In fact, according to the proposed segmentation criteria, in order to maximize the its bottom-line, the partner must prioritize the offering of the SKUs “J”, “H”, “F”, “B” …, whereas in the old prioritization criteria the partner was offering the SKUs “J”, “I”, “H”, “G” … The SKU “B”, for instance, that is the fourth most profitable in this category according to the Profit Margin Prioritization criteria was just the ninth SKU to be offered in the old prioritization criteria, which may indicate that the partner was leaving a considerable amount of money “over the table”.

One additional important issue to be noted is that under the old prioritization the SKUs from "A" to "I" possess similar sales levels, which does not allow the company to properly differentiate them. However, under the new prioritization criteria, the differences are clear, and thus, the company can better assess which SKUs are the best contributors to its welfare (bottom-line).

In order to assess the impact of the proposed segmentation criteria in the partner's customer service strategy, the team analyzed:

1. The changes in the rank positions (prioritization sequence) caused by the new prioritization criteria

In the first analysis, the team evaluated the changes in the rank positions of the top-ten SKUs from the fabric cleaning and the fabrics conditioner categories, due to the new segmentation by profit margin.

From the ranks in the chart below, we can infer that the fabrics conditioner category was much more affected by the new segmentation criteria than the fabric cleaning was. In fact, the fabric cleaning had nine, out of ten, rank positions changed, whereas the fabrics cleaning category, due to the similar contribution margins of the top-ten SKUs, had none positions changed.

Impact of the prioritization by Profit Margin

Top 10 Laundry SKUs

Fabrics Cleaning		
SKU	Sales rank	Margin rank
• A	• 1	• 1
• B	• 2	• 2
• C	• 3	• 3
• D	• 4	• 4
• E	• 5	• 5
• F	• 6	• 6
• G	• 7	• 7
• H	• 8	• 8
• I	• 9	• 9
• J	• 10	• 10

[illegible] Fabric Conditioners		
SKU	Sales rank	Margin rank
• A	• 1	• 1
• B	• 2	• 5
• C	• 3	• 2
• D	• 4	• 6
• E	• 5	• 3
• F	• 6	• 8
• G	• 7	• 9
• H	• 8	• 7
• I	• 9	• 4
• J	• 10	• 10

The new practice of prioritizing SKUs based on the partner's Profit Margin significantly change the order the SKUs must be "offered"

Figure 28: Impact of the Proposed Prioritization Criteria on the Top-Ten Laundry SKUs

Summarizing, from the analysis above and from the application of the new segmentation criteria to the whole SKU database (strategically non-disclosed in the thesis), we can conclude that the segmentation of the SKUs by Gross Margin, instead of the current segmentation by Sales Volume, significantly changes the "priority order" the SKUs must be "offered" to the customers, in order to maximize the company's bottom-line.

2. The consistency of the applied service levels with the new rank positions

In the second analysis, the team analyzed the consistency of the current service level policy with the proposed rank positions for each SKU, based on their Gross Margin. The key idea in the analysis was to examine whether the SKUs that most contribute to the company's bottom-line (highest Gross Margin) possess the highest service levels.

By analyzing all high-velocity SKUs in all warehouses of a key customer, the team found out that (as exemplified in the chart below):

- Currently, for this key customer, the service level policy has not been differentiated by SKU (based on the SKU's sales volume). As can be seen in the chart below, some SKUs with higher level of sales possess lower service levels than others with lower level of sales. For example, the "SKU 6" in "warehouse 1" is the best ranked by sales and possesses a relatively low service level; on the other hand, the "SKU 1" in "warehouse 1" is the worst ranked by sales and possesses the highest service level
- Under the new segmentation criteria, we also find several inconsistencies between the SKU rank position and its service level (as highlighted in the chart below). For example, by analyzing the new rank positions in the "warehouse 1", we can see that the two best ranked SKUs possess the second lowest service level and that the fourth best ranked possesses the lowest service level, whereas the worst ranked SKU ("SKU 1") possesses 100% service level
- The service levels must be reviewed, so that the best ranked SKUs have the highest service levels.

Impact of the new prioritization criteria for the establishment of the service level strategy

High-velocity laundry SKUs for a key customer

- Illustrative - not exhaustive -

Warehouse 1				Warehouse 2				Warehouse 3			
SKU	Sales rank	Margin rank	Serv. level	SKU	Sales rank	Margin rank	Serv. level	SKU	Sales rank	Margin rank	Serv. level
1	13	13	100%	1	13	13	100%	1	13	13	100%
2	6	8	100%	2	4	6	100%	2	11	11	100%
3	12	12	99%	3	8	9	100%	3	12	12	100%
4	2	3	100%	4	1	1	100%	4	4	4	100%
5	11	7	100%	5	9	7	100%	5	6	6	100%
6	1	2	99%	6	2	3	100%	6	1	2	100%
7	10	6	100%	7	11	8	95%	7	7	7	100%
8	3	1	99%	8	5	2	100%	8	2	1	100%
9	8	11	100%	9	7	10	100%	9	8	10	99%
10	9	10	100%	10	12	12	100%	10	10	9	100%
11	7	9	100%	11	10	11	100%	11	9	8	100%
12	4	4	93%	12	6	5	99%	12	5	5	100%
13	5	5	100%	13	3	4	97%	13	3	3	99%

Figure 29: Impact of the New Segmentation Criteria on the Service Level Strategy

Summarizing, the adoption of the new segmentation criteria may represent a breakthrough change in the way the relationship "product – customer" has been conducted – an evolutionary step towards maximizing the company value based on the dynamic product portfolio analysis.

Other important advantage of the new segmentation criteria is that it highlights some critical SKUs with negative contribution margin, contributing to focus company's attention on the right targets for improvements (maximization of efforts). At the limit, this new way of segmenting the SKU portfolio will fundamentally help the company to take prominent managerial decisions, such as pricing and divesting SKUs and brands.

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5.3 Ideas for Potential Future Works

Due to the large scope of the project and the limited amount of time (3 to 4 months), some analyses were partially incomplete, in the sense that:

- A smaller and simplified sample was analyzed;
- Some data were estimated (cost of a lost sale, ordering cost, transportation cost etc) or even a unrealistic "unitary value" was considered (number of employees per crew per production line, hourly cost of employees, etc);
- The team did not have access to the customer base and to the contribution margin of all SKUs, due to the strategic importance of the data;
- Additional simulations with other customers' databases would make some conclusions more solid and reliable.

Therefore, the thesis team believes that it is crucial for the partner company to go over the analysis and run additional simulations not only to review and understand the fundamental steps developed (Supply Chain Dynamics framework), but also to broaden the comprehension of its supply chain and of the behavior of its key drivers.

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Appendix I – Supply Chain Dynamics simulator data requirement

Supply Chain Dynamics Simulator Inputs

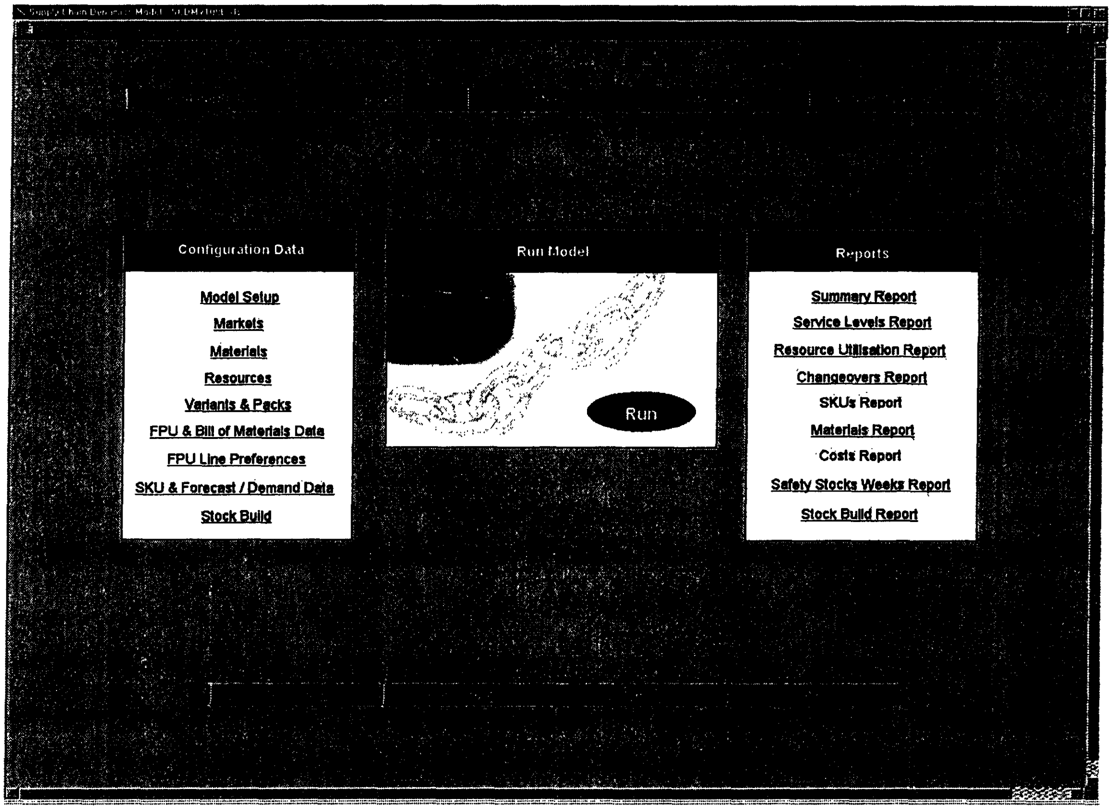


Figure 30: Supply Chain Dynamics Simulator Inputs

As can be seen in the "Figure 28" above, the main inputs of the SCDM are:

a. Model setup

- Safety stock strategies and policies per SKU

- Hours per period (weeks)

- Demand unit

- Production unit

- Load unit

- Transport unit

- Material storage unit

b. Markets

- Specify clients/ market segments

- Attribute load units on a single transport unit (# pallets/ truck) for each client/ segment

- Cost per transport unit (per truck) for each client/ segment

- Warehouse handling cost (per pallet) for each client/ segment

- Warehouse holding cost (per pallet per week) for each client/ segment

- Cost of capital / opportunity cost (% per year) for each client/ segment

c. Materials (include raw materials)

- Specify/ list all relevant materials (materials with significant variability in the delivery lead-time)

- Initial stock per material

- Minimum order per material

- Safety stock per material

- Delivery lead time (in weeks), between placing an order and receiving it, per material

- Material supply reliability (mean – 1 means that on average the amount ordered is delivered in time – and standard deviation)

- Storage unit (units/ pallets)

- Unit costs

- Storage costs (per pallet per week)

- Handling costs (per pallet)

The user is not intended to include all the components of the Bill of Materials in the SCDM, but to only include those materials he wants to examine in terms of ordering policies, lead times, supplier reliability etc.

d. Resources

Changeover information

- Variant changeover time (hours): time required to changeover a line between production runs of different variants
- Labor group required to perform a variant changeover
- Quantity of labor required from a group to perform a variant changeover
- Cost per changeover
- Pack changeover time (hours): time required to changeover a line between production runs of different packs
- Labor group required to perform a pack changeover
- Quantity of labor required from a group to perform a pack changeover
- Cost per changeover

Resource information

- Resource name (e.g. line 1)
- Capacity (hours/ week)
- Plan versus Actual Production (mean and standard deviation - variability of the resource's production reliability around the given mean)

Labor information

- Labor group name

- Availability (man-hours)

- Cost ($/ hour)

e. Variants and Packs

- List variants

- Production cycle per variant (weeks) - 1 = every week; 2 = every other week

- First production period per variant (weeks)

- List pack types

f. Factory Planning Unit (FPU) data & Bill of Materials

- List Factory Planning Unit names

- Assign variant and pack type for each FPU

- Minimum quantities of FPU, which can be produced in a single manufacturing run

- Bill of materials: for each FPU, assign the materials and quantities

g. FPU line preferences

- 1^{st}, 2^{nd}, 3^{rd}, 4^{th} ... (up to ten) resources preference

- Assign the resource name from list

- Production rate for the FPU on the stated resource (tones / hour)

- Assign the labor group

- Assign the number of labor entities

h. SKUs & Forecasts/ Demands

- Forecast generation method

    - enter forecasts/ demands manually

    - generate forecasts from given demands (specify demand quantities for each SKU in each period of the model horizon and the standard deviation of the forecast error for each SKU

    - generate forecasts/demands from statistics (specify the mean and the standard deviation of the demand and the standard deviation of the forecast error)

- Customer Service Level (in case fill percentage)

- Forecast Improvement Factor (factor by which the forecast error is reduced)

- Safety Stock Threshold (weeks): required safety stock cover in weeks, which if exceeded for a given SKU will prompt a warning

- Safety stock can be converted from weeks to actual quantities either by summing the coming "m" weeks forecasts for the SKU or by multiplying the average forecast by "m" weeks

- List SKUs

- Assign Client/ Market segment to each SKU

- Assign FPU from which each SKU is derived

- Minimum order quantity of the SKU (tones) each customer can order

- Demand units per load unit for the SKU (tones/ pallet)

- Production units contained in a load unit for the SKU (tones/ pallet)

- Initial stock (tones): stock of the SKU which is to be present at the start of the model

- Fixed Cost allocation: fixed cost component of the standard cost of the SKU per demand unit (standard cost is calculated by the model and additionally includes materials and labor)

- Mean demand per period for the SKU (tones) – when the user wished to generate the demand form statistics

- Standard deviation of the demand per period for the SKU (tones) – when the user wished to generate the demand form statistics

- Standard deviation of the forecast error (SD FE) for the SKU (tones)

- Mean absolute deviation of forecast error (MAD FE) for the SKU (%): average deviation of the forecast from the actual demand – SD FE = 1.25* MAD FE * forecast average – used when the user wished to generate the demand form statistics or from given demands

- Forecast average (tones), across all non-zero periods)

- Number of periods of safety stock coverage to be held for the SKU (can be calculated by formula)

- Market growth factor: factor by which all demands and forecasts are multiplied (the forecast error will be increased by the same proportion)

<u>i. Stock Build</u>

Stock build is the process of producing stock earlier than required to meet a (probably seasonal) demand which could not be met by the normal process of production due to required volumes being greater than capacity.

Additionally, this option allows the users to have the initial stocks calculated using statistical formulas and to restrict the stock build to maximum weeks forward cover.

Supply Chain Dynamics Simulator Outputs

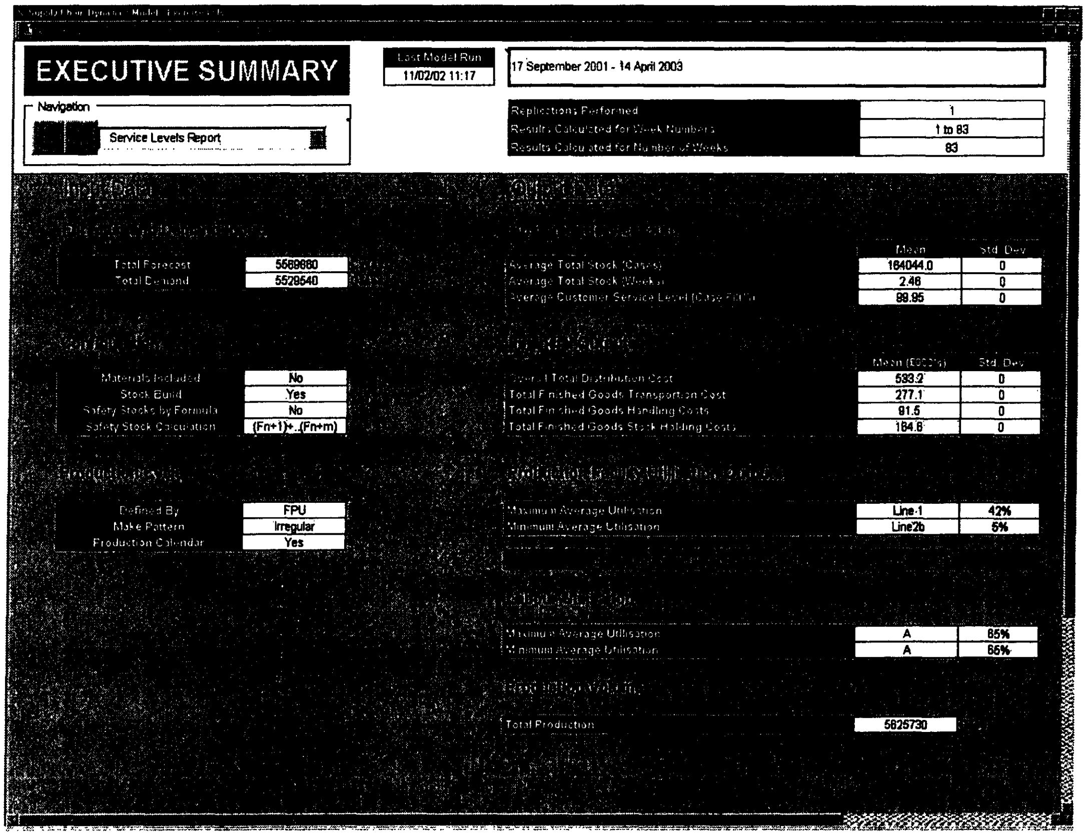


Figure 31: Supply Chain Dynamics Outputs

The main outputs of the SCDM are:

1. Summary Report – executive tabular summary of run strategy & key performance indicators (customer service, stock cover, costs and resource utilization).

2. Service Levels Report – tabular details of service levels by market.

3. Resource & Labor Utilization Report – tabular summary details of equipment and labor utilization statistics with detailed.

4. SKU Report – graphical representation of stock, production, demand etc. through time.

5. Materials Report – graphical representation of Materials opening and closing stocks, deliveries, usage and ordering through time.

6. Costs Report – tabular report of makeup of costs. Report offers further options to view costs in greater detail.

7. Safety Stock Weeks Report – tabular report of the Safety Stock Weeks by SKU whether user specified or derived. SKUs having excessive levels are highlighted.

Appendix II – "Multi-Echelon" simulator reference guide

The "Appendix II" section presents a quick understanding of the "Multi-Echelon" simulator, details the control panel and its main outputs and describes the demand generating toolbox and some other features.

Six-step-understanding of the "Multi-Echelon" simulator

Step 1: For each customer warehouse, daily demands are generated randomly.

Step 2: Demands draw down inventory at warehouses, reorder order point is hit, and a replenishment order is generated. This is the well known (Q,R) policy, where Q and R are both fixed.

Step 3: Replenishment is received after a period that equals to replenishment lead time.

Step 4: Inventory level at the central DC is affected by inflow (supply) and outflow (demand). The demand is the consolidated orders from customer warehouses.

Step 5: The supply is the production from plants, which can be obtained from the Supply Chain Dynamics Simulator or from the actual production schedule.

Step 6: Steps 1 to 5 are repeated daily for 26 weeks. Costs and other performance metrics are calculated.

Exception: Sales are lost if inventory at the customer warehouse cannot satisfy needs.

Exception: At the DC level, if available inventory is less than demand, replenishments to customer warehouses are reduced proportionally.

Control panel and output

The top right part of the control panel, illustrated in the "Figure 32", provides a comprehensive total cost table (transportation, lost sales and inventory holding and ordering costs) per warehouse and consolidated at all echelon levels. The number of inventory turns and fill rate are also provided.

The costs are broken into two parts: the customer's and the supplier's. This allows the partner company to have a better understanding of the relationship with customers in terms of who is carrying most of the distribution costs.

The lower right part shows 3 plots regarding a representative customer warehouse (daily inventory, demand and replenishment schedule), and 3 plots about the supplier's distribution center (inventory, weekly demand and production schedule). These plots help the company to detect any trends, patterns or abnormalities for further investigation.

The top left part of the control panel is where users can adjust simulation settings, which are described next.

Demand generating toolbox

In the simulator, inventory, order pattern and production are all driven by customer's demand, and thus, the quality of the demand data is crucial to the reliability of the simulation outcomes.

The demand is randomly generated and is based on the forecasted demand and on the historical forecast error. Forecast errors are measured using the root mean square error (RMSE).

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} e^2}$$

Where:

- "n" is the number of demand observations, and the corresponding forecasts,

- "e_t" is the forecast error in "t" = actual demand in "t" - forecasted demand in "t"

For the 13 high-velocity SKUs analyzed, the RMSEs of the historical data were significantly high, and in many cases, larger than the mean, which may distort the demand inputs to the simulator. Careful examination of the data and constant interactions with the partner company helped the team to identify periods of irregular demands, and to exclude them from the RMSE calculation. This greatly reduced the RMSE, and allowed the simulator to generate a more realistic demand curve, as shown below.

Sample Forecast Error Calculation (in weeks)

Warehouses	SKUs	Actual RMSE	Clean RMSE
a	1	667	214
b	2	716	196
c	3	708	228
b	4	320	171
...	...	...	...

It is important to note that, if the lead time is not seven days (weekly), we need to adjust the RMSE by using the following equation.

$$RMSE_{Lead\ time} = RMSE_{weekly} \times \sqrt{\frac{Lead\ Time}{7}}$$

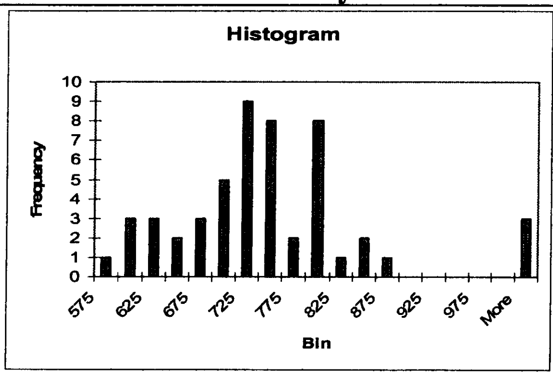
This formula applies whether demand is evenly distributed or normally distributed, as long as the demand exhibits the same distribution throughout the simulated period.

Normally distributed demand

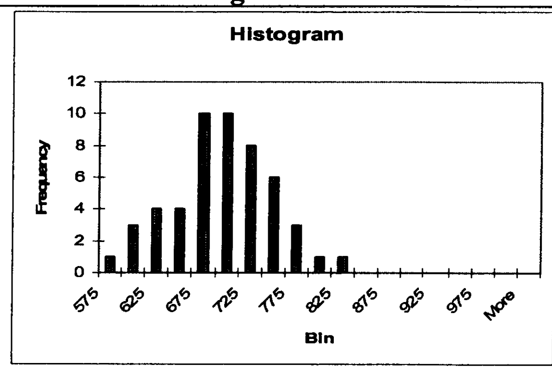
The simulator generates normally distributed demands, by using the following three parameters: the mean and variance of the historical demand, and the probability, which is a random number between 0 and 1.

The charts below compare the current and the simulated demands for a selected SKU. As can be seen, the abnormally high demand (at the right end of the actual histogram) is removed in the simulation, and the simulated demand profile resembles the actual.

Actual demand in year 2002



Simulator generated demand



It is also possible to use uniform distribution to generate the demand. In this case, the demand will additionally vary within a given range. The range can be sized so that the generated demands have the same RMSE as the actual demand.

Theoretically, the uniform distribution is more conservative than the normal distribution, because the demands are not concentrated at the mean (are more spread out). In this project, the team found out that both distributions generate similar results and decided to adopt the normal distribution (more realistic).

Other features of the "Multi-Echelon" Simulator

Ability to fix the fill rate to 98.5%

The simulator also enables the users to fix the fill rate to 98.5%, instead of using the economic order quantity formula (EOQ) to calculate optimal fill rate.

We observed in some simulations that, by setting a high lost sale cost, the optimal fill rate was high (around 99.8%), which contributed to increase the amount of safety stock in the system. However, by fixing the fill rate in 98.5%, the number of inventory turns increased by 40%, which illustrates the "inventory turns x service level" trade-off.

Ability to simulate the impact of other customers at the partner's warehouse level

The simulator does not consider other customers. However, it is necessary to consider the overall impact of the whole customer base at the partner's warehouse on the multi-echelon system.

Therefore, in order to simulate this effect, the team supposed that the demand fraction of the selected customer would remain constant at the partner's warehouse. For example, if the simulated customer is responsible for 50% of the replenishment orders at the partner's warehouse and if the specific demand by this customer in a particular week is "x", the total demand at partner's warehouse will be "2x".

Obviously, this is a simplification, since it is perfectly possible that other customer's demands swings are not synchronized with the simulated customers' demand swing.

Cost calculation

Inventory cost = daily average inventory * 365 * inventory holding cost

Shipping cost = the number of truckload this year * freight rate * fraction of the truck used by this SKU.

Lost sale cost = # of sales lost * Cl (given in Parameters)

Fill rate = total demand filled/total demand

UPC #: 001111156572 **Pack #:** 156575
Name: ULTRA SNGL LQ RFL F/R RFL 6 40 OZ

Replenishment Lead Time: [redacted]
Order Pattern:
Plant Run Strategy:

If order pattern is 1,
Fix reorder point? (Y or N) [redacted]
If Y, fix to [redacted] days of cover

Click here to change safety stock settings.

If order pattern is 2 or 3,
Fix fill rate to 98.5%?
Lead Time Variance: 1 day late in [redacted] cases

Run scenario

Click here to adjust production rate.

	Total cost:
Customer	$1,102,741
Unilever	$12,417,236
Total	$13,519,977

Inventory Turn	58
Factory Demand MAD %	18%
Order release per week:	3

Location	Inventory	Inv. turn	Fill Rate	Inventory cost	Shipping cost	Lost sale
Warehouse 1	142	64	98.75%	$65,532	$ 872	$ 1,501
Warehouse 2	237	95	100.00%	$109,819	$ 1,106	0
Warehouse 3	287	46	100.00%	$132,760	$ 1,503	0
Warehouse 4	586	49	100.00%	$271,187	$ 1,668	0
Warehouse 5	331	81	99.59%	$153,206	$ 2,909	1375
Warehouse 6	408	40	98.17%	$188,881	$ 3,019	3995
Warehouse 7	350	34	100.00%	$161,834	$ 1,574	0
All Customer	2340			$1,083,219	$ 12,650	$ 6,872
Supplier DC	26728		100.00%	$12,374,006	$ 43,230	

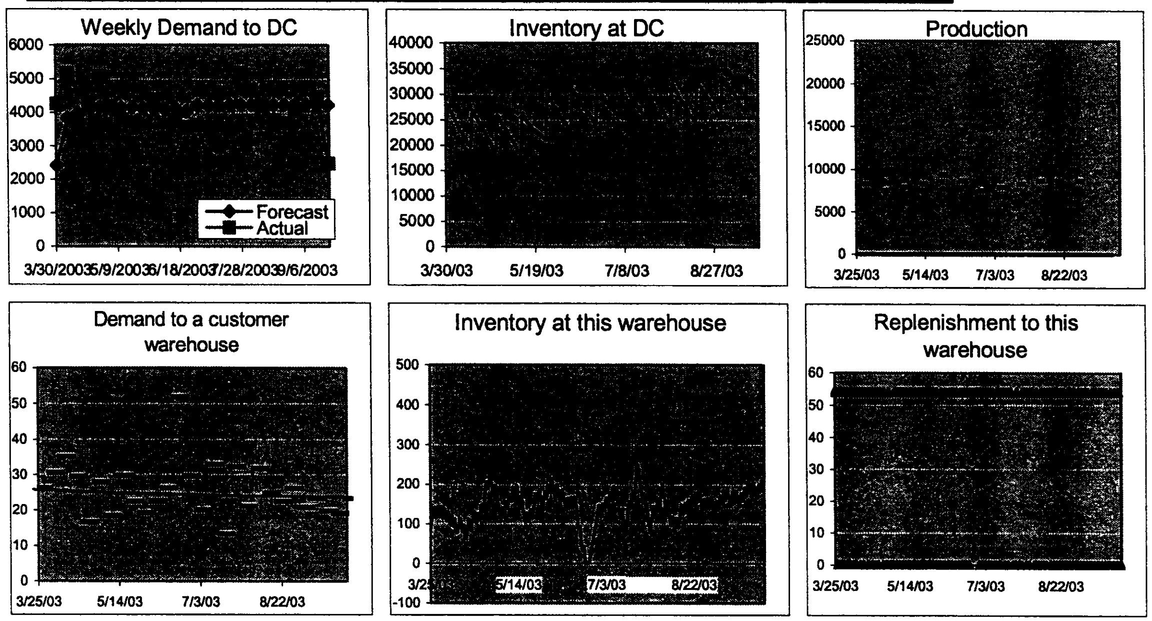


Figure 32: Screen shoot of the Multi-Echelon Inventory Replenishment Simulator's control panel