

Optimizing Options Fulfillment in a Configure to Order Business

by

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Master of Science in Mechanical Engineering and
Master of Science in Management

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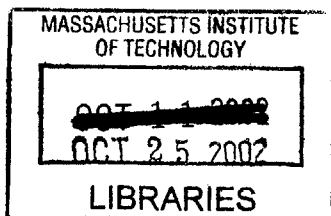
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Abstract

Through this project Compaq wanted to improve its knowledge of and to rationalize its supply chain for options fulfillment for its high-end servers. To obtain this goal, a database was constructed to provide the necessary demand profiles. Once this information was provided, many teams were able to eliminate waste and implement cost saving changes. One of these changes was to optimize the supply chain for options fulfillment. A supply chain optimization model and a decision support tool were developed to determine the best fulfillment model. These tools were used to generate a list of potential changes to the supply chain structures for the options.

Compaq is a Houston, Texas based computer manufacturer. The New Products Introduction Group within High Performance Servers business located in Marlborough, Massachusetts coordinates life cycle activities for Alpha based high-end servers. Within this group Option Manufacturing System Program Managers are responsible for all options installed on the servers. The options can be factory installed, shipped with the system, or shipped separately for field installation. Over 600 options are currently available to be sold. Each of these options has an expected life cycle between 1 and 2 years. The demand for these options can vary from a few to 10,000 per year. The project was initiated to understand the demand profile of these options and to develop tools to optimize the supply chains for the fulfillment of these options.

The tangible results of the project were the following: 1) development of the demand profiling database, 2) development of option supply chain optimization tool, 3) development of cost curves for each commodity class, and 4) recommendations for supply chain structures for each commodity class. The recommended changes have the potential to result in savings in excess of \$700,000 per year. A full description of the optimization tool and a theoretical discussion of the demand profile, cost curves, and recommendations are included in the thesis. In addition to the tangible results, the tools have initiated some cultural changes by making data readily available.

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1.0 Introduction and Overview

1.1 Project Introduction

The combination of the post Dot.com economic slowdown and the consolidation in the computer industry has created an environment in which companies are forced to cut cost and to streamline their product lines. All this is happening in an industry in which the products have between a six month to two year life cycle. The fast pace of the industry enables change to happen very quickly, but also means that companies cannot afford any delays in their product roll out schedule caused by cost cutting efforts or by product migration. Over the past few years most of the computer manufacturers have shifted a large portion of their manufacturing to third party contract manufacturers (Grotzky, 2001). This effort has raised the importance of supply chain management in controlling costs and schedules. The selection of the correct supply chain can result in lower costs and faster times to market.

To enable the selection of the correct supply chains for their products, companies need a clear understanding of the products' demand and the supply chain segments' costs and timing. Additionally, fast paced companies need to balance the need for efficient tools with the accuracy of the tools' results. If too much time is spent on one product or the wrong product, then opportunities on others may be lost. Because the computer marketplace is constantly changing, the longevity of the tools is tied to their ability to adapt to the changes and to be rerun efficiently. All of these factors increase the importance of companies' information and communication systems. This project strived to develop a suite of tools within Compaq to begin to address these challenges.

1.2 Thesis Objectives and Results

This project focused on providing the High Performance Server Division within Compaq Corporation with the tools necessary for them to understand the products' demand and to select the correct fulfillment strategy. The project specifically focused on the options that

are installed onto the High Performance Servers. The original project objectives were the following:

- 1) To raise the awareness about how the options are being consumed;
- 2) To determine the correct fulfillment strategy for each option; and
- 3) To transfer academic knowledge about problem solving methodologies and supply chain design into the organization.

During the course of the project, the need for readily available and easy to use information and tools became apparent. Due to information management infrastructure mergers, Compaq lost the ability to capture a complete picture of the demand for the options. Because of the lack of demand information and the decentralized supply chain cost information, Compaq lacked a data driven supply chain cost model for the options. Because of the fast paced environment and large product portfolios, any tools developed within this environment needed to be very easy to use and tailored to current needs.

During the project the following tools and recommendations were developed to help achieve the projects' objectives:

- 1) Demand profiling database and reports;
- 2) Supply chain optimization model;
- 3) Option supply chain analysis prioritization process; and
- 4) Recommended supply chains for each option.

The demand profiling reports helped groups reduce cost by providing them with historic demand trends upon which to base their decisions. If implemented, the recommended supply chains have the potential of saving Compaq in excess of \$700,000 per year. In addition to the tangible results, the project highlighted the importance of information technology systems within Compaq's environment and illustrated how they could be used to reduce costs. The methodologies used in this project can be immediately applied to other parts of Compaq and potentially in the future to the proposed HP and Compaq merged company. By providing the group with more information, both the methodology and tools started to impact the culture and business practices of the organization. Because of the newly available information, the group is now able to act more proactively in their planning efforts.

1.3 Company Background

This project was performed within the **New Product Introduction (NPI)** group within the **High Performance Server (HPS)** Division in Compaq Corporation. The NPI group is responsible for all supply chain deliverables. The **Manufacturing Systems Program Managers (MSPM)** within the NPI group are the manufacturing representatives on all of the product business teams. The High Performance Server Division is located in Marlborough, Massachusetts and produces Alpha microprocessor based mid-range and enterprise servers. The **Alpha microprocessors** are 64-bit microprocessors originally designed and built by Digital Equipment Corporation. The Marlborough site became part of Compaq during the 1998 merger with Digital Equipment Corporation. The HPS group is beginning to transition its products to being based on the Intel **Itanium** 64-bit microprocessor instead of Alpha microprocessor (Capellas, 2002). Also complicating the situation is the pending merger of Compaq with Hewlett Packard (Compaq.com, 2001).

1.4 Thesis Outline

The thesis will begin in Chapter 2 with a description of the option demand characteristics. Chapter 2 provides the background behind the characteristics and a description of the tools designed to provide insights into the demand profile for the products. Chapter 3 describes both the current and potential supply chains that can be used to fulfill the demand. It highlights the cost drivers and qualitative issues associated with the various supply chain structures. Chapter 4 builds upon the previous two chapters by using them as inputs into the development of a supply chain optimization model. Chapter 4 and Appendix 9.3 fully describe the model. Chapter 5 describes how the team created a process to locate and prioritize the options to be studied to insure that the largest impact on the company was achieved. Chapter 6 provides an overview of how metric, cultural, and organizational issues within Compaq were managed and affected the results of the project. Finally, Chapter 7 summarizes the key findings and recommendations. A list of terms used within the thesis can be found in Appendix 9.1. The terms that are defined are in bold the first time they appear.

2.0 Option Demand Profiling

2.1 Introduction to Option Demand Profiles

For the high-end servers, Compaq has instituted an ala carte ordering process. In the **Configure-to-order (CTO)** process, customers pick a base platform and then choose all of the options they want installed on the system. The **platforms** are individual computer systems. By choosing the platform, the customer defines the following: the specific microprocessor to use, the number of CPU expansion slots, and the cabinet size. The **options** added to an order can be almost any part of the computer system ranging from an additional CPU to a mouse to a system cabinet. The options available to be installed on a platform are limited to the ones already qualified for the platform; however, currently most options are qualified on all of the platforms. This means that any of the over 600 options available could appear on a particular system order.

In addition to options being sold ala carte, the same options can be embedded in the bill of material for base platforms and can also be sold independently. The factory installed ala carte usages of the options that the customer chooses to have installed in the system are defined as **add-on options**. The options included in the platforms' bills of material are defined as **embedded options**. Therefore, the embedded options like one CPU module are shipped with every platform. The add-on and embedded options are collectively defined as **configure-to-order (CTO) options**. The options that are sold independent of systems and are not factory installed in systems are defined as **independent options**. The independent options are either installed by the end customers or used by a third party distributor to build systems.

Each option added to an order is typically only a small portion of the total order. However, since the CTO options need to be installed and tested in the complete system, these options have the ability to prevent the entire order from shipping. If the order is unable to ship, Compaq cannot capture any of the revenue. This makes it very important to guarantee that the small value options do not prohibit a multi-million dollar order from

shipping. Figure 2.1 provides the overall option split between add-on, embedded, and independent options for a typical year. Note that the CTO options (Add-on and Embedded) make up 76% of the total option demand.

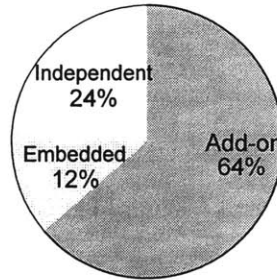


Figure 2.1: Split of options between add-on, embedded, and independent options

The freedom to select options ala carte increases uncertainty and leads to highly variable demand for the options. This also results in a large portion of the revenue being contributed by the options. Figure 2.2 shows daily demand for a typical option.

Daily Demand for a Typical Option

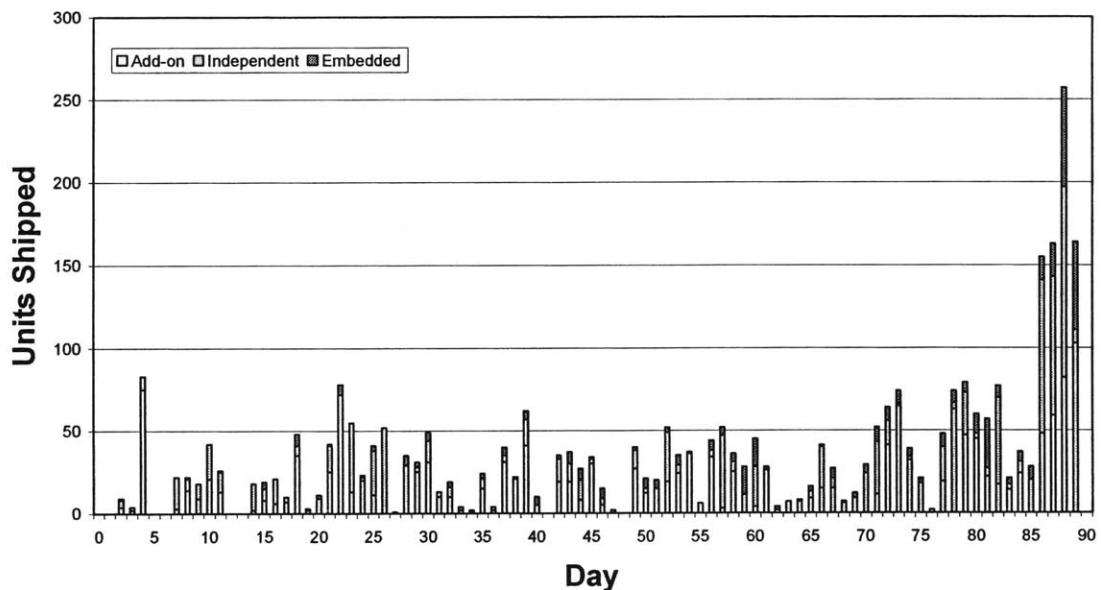


Figure 2.2: Daily demand for a typical option

The skew and variability in the demand shown in Figure 2.2 is representative of the demand characteristics seen on most options. The final days of the quarter's demand is typically greater than twice the normal daily demand.

The fact that the demand for a particular option can vary with geography and over the life cycle of the product also adds complexity to understanding the demand for the option. The typical product life for an option is between one and two years. The length of time depends on how rapidly the technology for the option is changing and how quickly the platform technology is changing. The options used on the Alpha servers can be industry standard parts, parts that are Compaq standard parts, or solely Alpha server compatible parts.

Because of the complexity of the demand profile for the options, Compaq needs tools that give clear and accurate snapshots of the demand over time, across platforms, and across geographies. Prior to the development of the demand profiling database, Compaq only had the ability to capture the overall consumption of the options. These reports and information from the factories on overall usage rates for the options were used to make decisions.

Section 2.2 describes the demand profiling database. It discusses the tools, inputs, and calculations used within the database. Section 2.3 describes the reports generated by the tool and Section 2.4 highlights some of the ways that the reports are being leveraged within Compaq. Appendix 9.2 provides a more thorough discussion of the database calculations.

2.2 Demand Profiling Database System

One of the main priorities in developing the database was to ensure that it provided the users with the ability to create all of the views that they wanted in a clear and easy to use format. To help meet this objective, the initial demand profiling database and reports were developed in Microsoft Access and Excel, so that the system could be functional

quickly. Microsoft Access was used for the calculations, while Excel was initially used for the user interface. Developing the sample reports quickly and within a readily available software platform enabled the solicitation of lead users' feedback early in the process. This feedback was used to refine and add reports prior to converting the system to the production environment.

The production version of the database utilizes the corporate information technology systems. This results in the calculation being performed in a SQL database with a BRIO web interface. In the transition to the production environment, the data inputs, calculations, and reports remained unchanged; however, they were adapted to the new software platform languages.

2.2.1 Inputs to Demand Profile Database

The demand profiling database system has four main inputs located within four separate corporate databases. The separate databases are a function of various legacy systems. Compaq is working towards consolidating the information in a central data warehouse. The four main inputs to the database are the HPS sales line item information, the flattened bill of materials, the options and systems life cycle information, and the options and systems costing information. Since the four inputs reside in separate databases, the prototype database utilized manual data extracts and the production database uses daily auto-updating extracts.

The HPS sales line item information table includes all of the information on the customer's purchase order and factory shipment information. A complete list of the fields included in the sales line item table can be found in Figure 9.2 in Appendix 9.2. The flattened bill of material table is constructed in a separate database. The resulting table provides a list of all of the saleable options embedded within the bill of material of another saleable option. The table provides the parent part number, child part number, and extended quantity used. The option and system life cycle database includes the product introduction dates, product discontinuation dates, and product hierarchical information. A complete list of the fields included in the life cycle table can be found in

Figure 9.2 in Appendix 9.2. The options and systems costing table provides the standard cost and list price information for each product.

2.2.2 Calculations within Demand Profiling Database

This section describes the overall process used in the database calculations. Further detail can be found in Appendix 9.2. The described process is the one used to generate the prototype database. This process is a linear process. The production process performs the same calculation; however, some of the calculations happen concurrently to improve the efficiency of the SQL database. Figure 2.3 lists the steps of the database calculations.

Step	Description
1	Classifying Order Types
2	Finding Embedded Option Usages
3	Calculating Order Values
4	Calculating Leveraged Revenue
5	Assigned Platform Descriptions
6	Adding Standard Cost information
7	Adding Life Cycle Information

Figure 2.3: Demand Profiling Database Calculation Steps

The first step in demand profiling database was to classify the order types. To classify the orders, a temporary table was created of all of the sales line items from orders containing base platforms in the time period. This table was used to mark all of the sales line items for base platforms as “embedded” and to mark all of the remaining sales line items on the order as “add-ons”. The sales line items that were not marked as embedded or add-on were marked as “independent”. If a sales line item part number was a saleable option, then the line items that were marked as add-on and independent were copied to the output table.

The second step was to explode all of the sales lines items classified as embedded in step 1 to identify all embedded options within the base platform. Each option found within a base platform is reported as a separate record in the output table. To do this, the part number field in the sales line item table was linked to the parent part number field in the

flattened bill of material table. The result of this link was appended to the output table carrying through all of the sales line item fields with the exception of the part number and quantity. The sales line item part number was replaced with the child part number(s) from the flattened bill of material table for each embedded option within the base platform. The sales line item quantity was replaced by the product of itself and the quantity used on field in the flattened bill of material table.

The third step was to calculate the total dollar value of each order. The value was obtained by grouping the sales line item information by the purchase order number. This temporary table was then used in the fourth step. In the fourth step, a second temporary table that counted the number of times each part number occurred on an order was created. The leveraged revenue field of the output file for the add-on and embedded order types was updated to the order value divided by the usage count for the part number. The leveraged revenue field of the output file for the independent order types was updated to the line item sales value.

The fifth step was to assign the platform descriptions. Because the cross-product independent orders are field installed into platforms, the platform description for these sales is unknown. For these orders the platform description was set to "independent". For this step the system line item temporary table created in step 1 was used to create a platform description for each order. The platform description of the system line item part number was located in the product hierarchy table. This description was used for all of the add-on and embedded options on that sales order. After assigning this value, the system checked for orders that contained two or more different platform descriptions and marked these as "multiple systems".

The sixth and seventh steps were to update the cost and life cycle information in the output table. The part number in the output table was linked to the option costing and life cycle information tables. The standard cost and list price from the costing table were copied to the output file for each line item. The life cycle dates and status were copied from the option life cycle table to the output file.

2.3 Demand Profiling Reports

Through the involvement of lead users in the development process, a list of standard reports based on the demand profiling database output file was generated. The following were the selected reports:

- 1) Option Unit Profile by Platform Report
- 2) Option Weekly Unit Trend Report
- 3) Option Leveraged Revenue Profile Report
- 4) Option Margin Contribution Report
- 5) Option Attachment Rate Report
- 6) Option Usage Statistics Report
- 7) Option Usage Data Extract Report

This same group was also utilized to refine the format of the reports. Throughout the process the users stressed that the reports should be easy to use, but at the same time flexible. These requirements drove the development of standardized input and output screens. The standardized input screen is shown in Figure 2.4. It is easy to use, yet it gives the user the ability to slice the data along many attributes.

The screenshot shows a software interface titled "WWCIW Development: Compaq Confidential- Need to Know Required" with a date of "12-3-2001". The main title is "PDW_Opt_Prof_Units" and the subtitle is "WWCIW Options Profile - Units Shipped".

The interface contains several filter sections:

- Part Number:** A list box with "ALL*" selected, and other options "10-12312-01" and "10-24051-05".
- Intercompany Flag:** Two checkboxes: "Non-intercompany" (checked) and "Intercompany" (unchecked).
- System Type:** A list box with "ALL*" selected, and other options "AlphaServer 1000 (Noritake)", "AlphaServer 1200 (Wedgwood)", and "AlphaServer 4000 (Wranqler)".
- Plant Code:** A list box with "ALL*" selected, and other options "0005", "0040", and "0064".
- Area:** A list box with "ALL*" selected, and other options "AP", "CQDM", and "DSCN".
- Order Type:** Three checkboxes: "Add On" (checked), "Independent" (checked), and "Embedded" (checked).
- CSS Order Ind:** Two checkboxes: "Volume" (checked) and "CSS" (checked).
- Revenue Flag:** Two checkboxes: "Revenue" (checked) and "Non-revenue" (checked).
- Shipment Year:** A list box with "1999", "2000", and "2001" (selected).
- Shipment Week:** A list box with "11", "12", "13", and "14" (selected).

A "Run Query" button is located at the bottom center of the form.

Figure 2.4: Option Profile Reports Inputs Screen

The user can select a particular value, set of values, or all values for each of the fields. The output format was also standardized to present the output in graphical form

whenever possible. The user also was given the ability to view the pivot table and raw data that drives the graph. Graphical output was chosen based on user feedback and the recommendations of past LFM's (Miciano, 1999).

The Option Unit Profile by Platform Report seen in Figure 2.5 gives the user the ability to understand the demand for a set options in a given time period with their prescribed criteria. It also provides the user with the information around how the options are selling on each of the platforms.

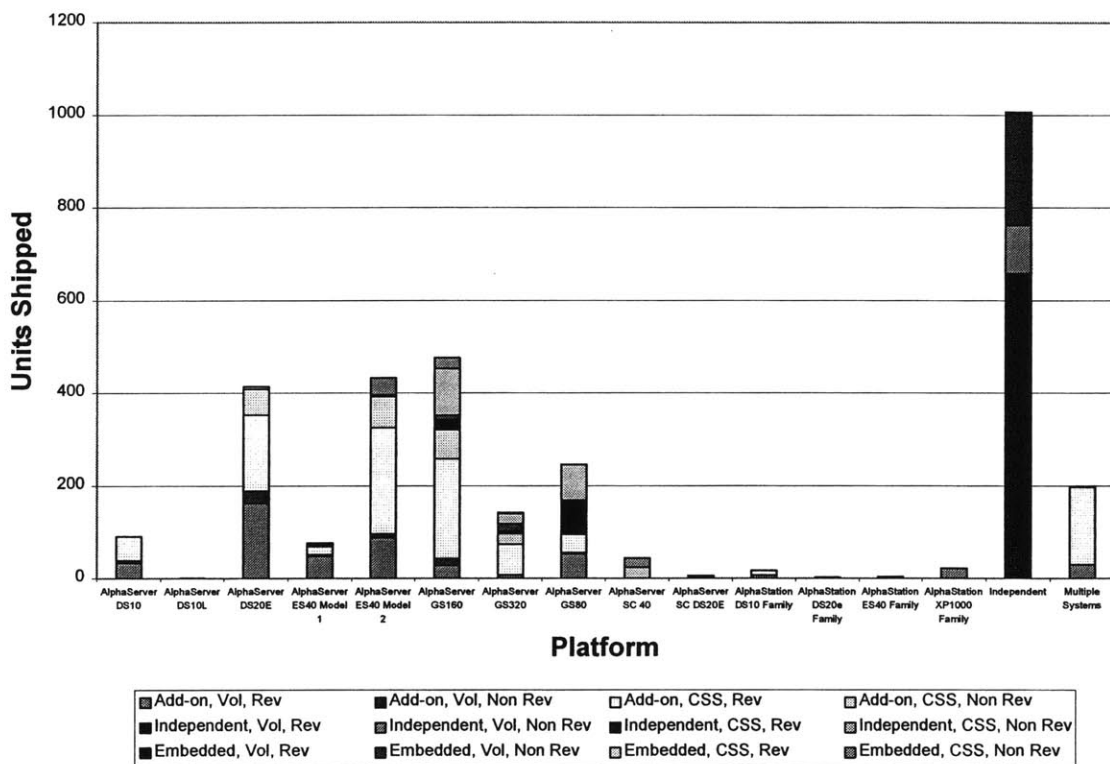


Figure 2.5: Option Unit Profile by Platform Report for Part XYZ in Q1 2001

The Option Weekly Unit Trend Report seen in Figure 2.6 gives the user the ability to understand how the option is being consumed over time for a given set of criteria.

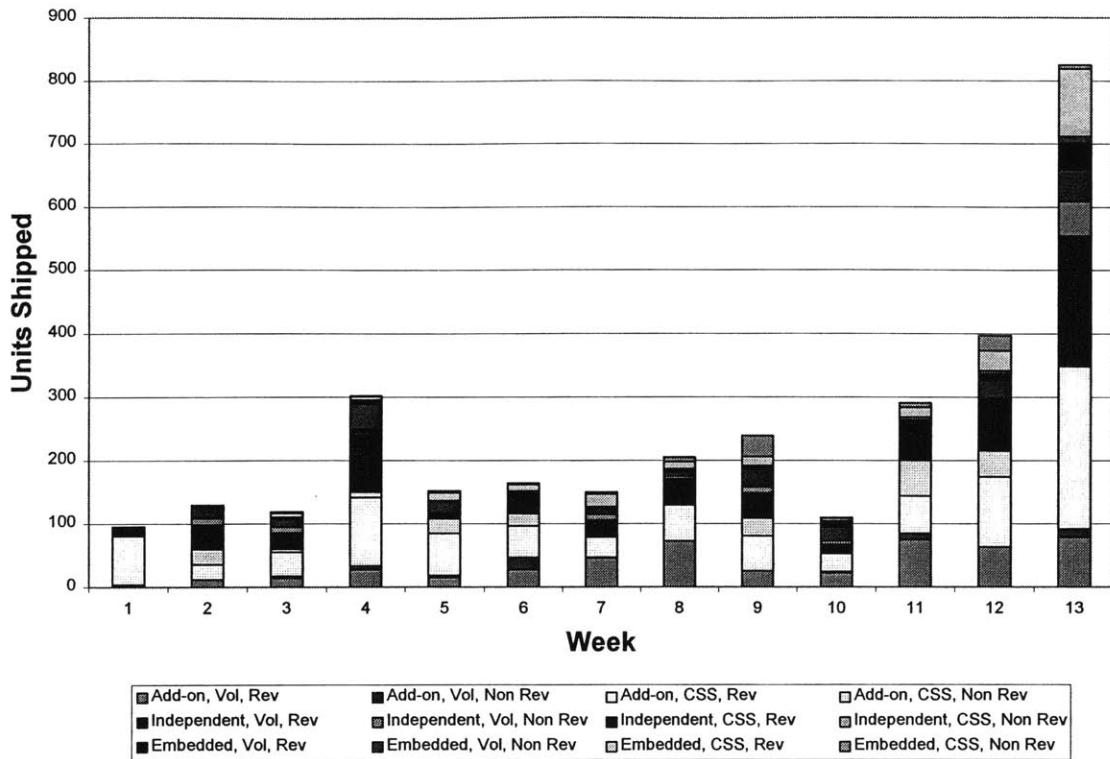


Figure 2.6: Option Weekly Unit Trend for Part XYZ in Q1 2001

The Option Leveraged Revenue Report seen in Figure 2.7 provides the user with the upper bound on the revenue that could be lost if the option is not available for sale. For example, assume a specific memory module that the customer wants goes on product hold and cannot be delivered. If the specific memory type is important enough to the customer, then the customer may decide to purchase the system from one of Compaq's competitors. In this case, Compaq would lose the entire order because the memory module option could not be delivered. Figure 2.7 has been normalized by its maximum value. Figure 2.7 is for the same part and time period as Figures 2.5 and 2.6.

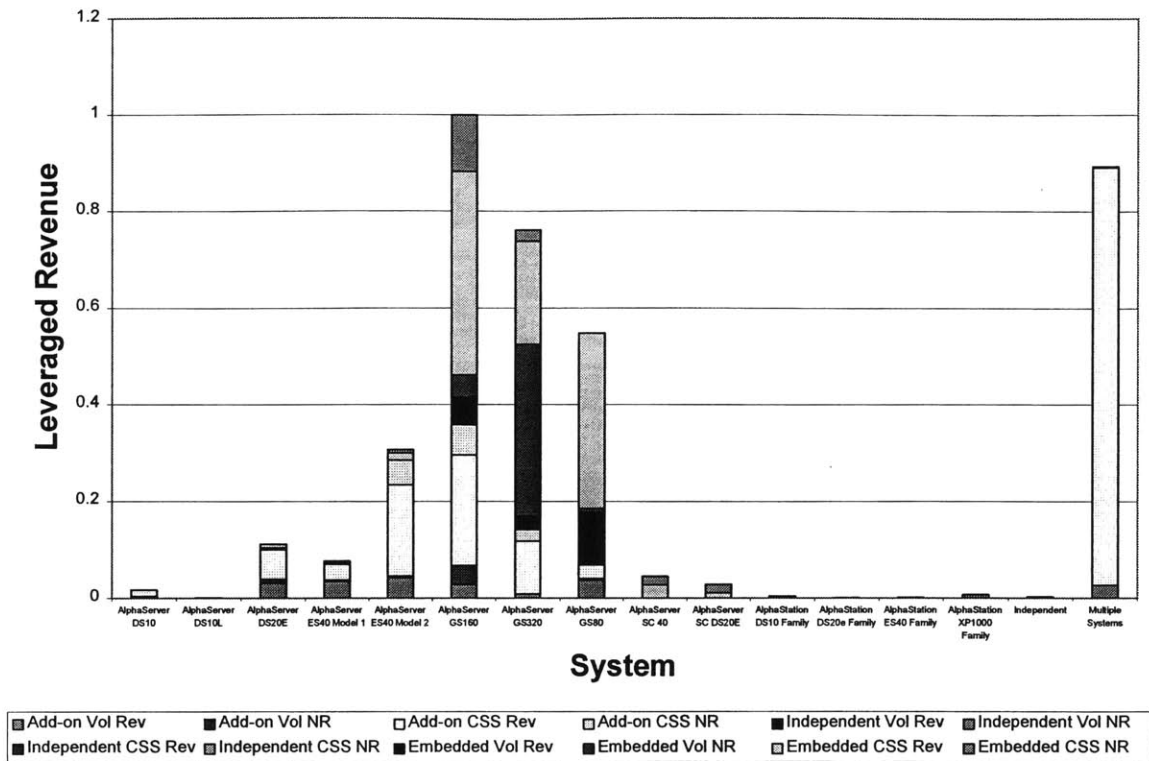


Figure 2.7: Option Leveraged Revenue Report for Part XYZ in Q1 2001

By using the leveraged revenue information found in Figure 2.7 with the unit information found in Figure 2.5, the managers can understand how to allocate the units and resources to maximize revenue.

The Option Margin Contribution Report seen in Figure 2.8 provides the user with information showing how the margin contribution for an option for a given criteria is trending over time. The margin contribution is defined as the estimated sales revenue minus the standard cost of the option. This provides the user with the lower bound on the profit or revenue lost if an option is not available for sale. Figure 2.8 has been normalized by the maximum value in the time period for this part.

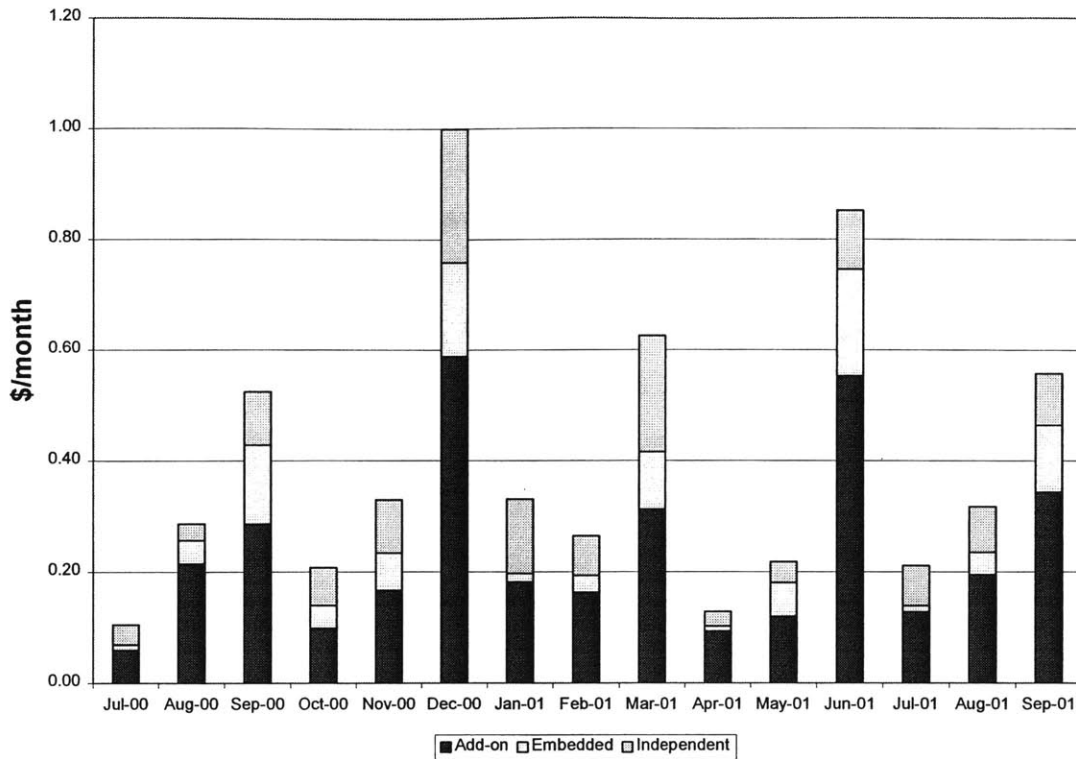


Figure 2.8: Option Margin Contribution for Part XYZ

The Option Attachment Rate Report provides the user with a table that calculates the average number of each option part number installed on each platform system. The Option Usage Statistics Report provides the user with various statistical values for the option. For example, the report generates the average weekly demand and average weekly number of orders. The Option Data Extract Report gives the user the ability to select the raw data that meets their criteria, so that the user can generate their own custom views.

2.4 Uses of Demand Profiling Reports

The primary objective of the demand profiling reports was to provide the inputs necessary to drive the option fulfillment optimization model project. A secondary goal for the internship was to integrate LFM work into daily group activities and to reinvigorate data driven life cycle decision-making. Once the option profiling reports became available, users immediately started incorporating them into their analysis. This

early adoption of the reports combined with the ease of use and a few system demonstrations caused the use of the reports to spread by word of mouth. Some of the initial applications of the reports helped to define qualification roadmaps, product life cycle planning, product demand forecasting, and allocation decisions. These early successes increased the group's credibility for developing tools that provide tangible and accurate results. The credibility also opened several lines of communication that were used later in the project to aid in the development of the option fulfillment optimization model. The reports also had a larger impact on the group than initially projected. It has led the group to ask more questions and to look for more analytical evidence to support their analysis.

3.0 Supply Chain Structures

3.1 Compaq's Supply Chain for HPS Option Fulfillment

Compaq utilizes a couple of typical supply chain paths to fulfill the company-wide option demand. The majority of the options flow through the hub-based supply chain depicted in Figure 3.1.

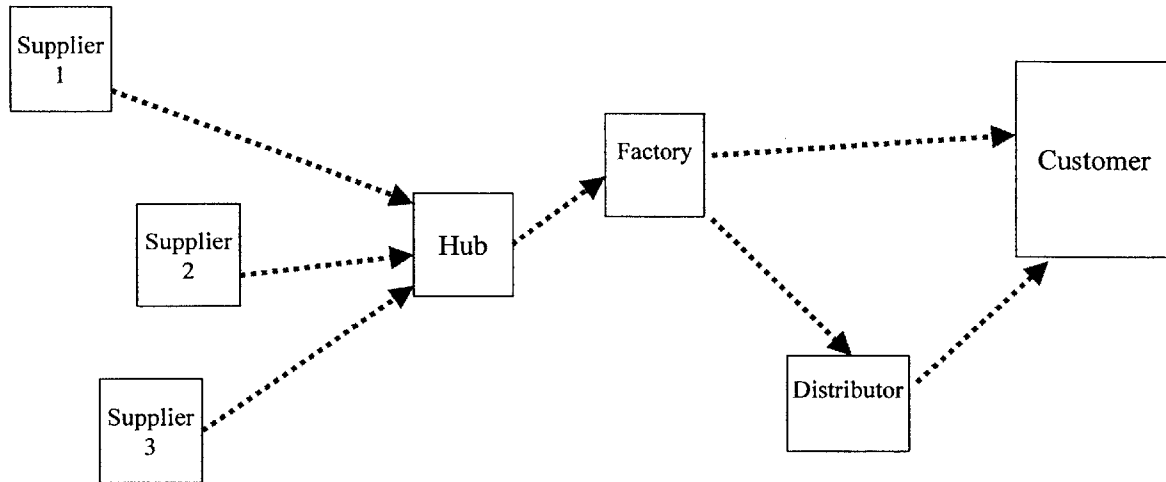


Figure 3.1: Standard Hub Option Supply Chain

In the **hub-based supply chain**, the parts are shipped from the supplier's factory to a hub located near Compaq's factory. The inventory within the hub is owned and controlled by the supplier; however, Compaq does set a minimum inventory level to be held at the hub and some performance requirements. Most of the inventory is in hubs that are operated by a third party company, but some suppliers choose to open their own facility near Compaq's factory. The third party company does not own the inventory. The third party's charges associated with the operation of the hub are passed on to the supplier to include in the material cost. Compaq's factory pulls the parts from the hub inventory to meet the customers' and distributors' demands. In addition to this standard path, a few of the options currently flow directly from the supplier into the factory or to the customer. The options that flow directly in the factory are defined as using a **factory-stock supply chain**. The options that flow directly to the customer are defined as using a **direct ship supply chain**. A supply chain map for each of the supply chain structures can be found in Appendix 9.4.

Several years ago, Compaq's higher volume products' divisions standardized on using the hub-based supply chain for most of its material. This initiative drove the use of hub-based supply chain by Compaq's lower volume products like the Alpha server options. Compaq currently has two new initiatives that are affecting its supply chain structures. To try to reduce costs, Compaq is trying to ship more of its product directly from the supplier to the end customer and to have contract manufacturers handle lower value add assembly and material handling operations. Unlike the Alpha server that has the ala carte factory installed ordering capability, Compaq's higher volume products are not factory configurable. If options are ordered with the system, they ship separately. The direct ship and contract manufacturer initiatives are being applied to the Alpha server options. In the Alpha server space only the independent option orders can be shipped directly. The add-on and embedded options still need to be brought into the factory to be installed in the systems.

In addition to the various initiatives, the stakeholders responsible for different parts of the supply chain have individual metrics that they are striving to obtain. The managers of the factories have overhead, shipment predictability, and cycle time metrics to obtain. This drives them to want supplier owned inventory close to the factory, to fully utilize the factory capacity, and to have large enough inventories to prevent stock-outs. The procurement managers have purchase cost savings and inventory metrics. This drives them to want lower inventory levels and to find areas where economies of scale can help them negotiate lower prices. They want lower inventory levels regardless of who owns the inventory because Compaq is liable for a portion of the supplier owned inventory. The logistics managers have a company-wide total freight cost metric that drives them to want to eliminate supply chain links or to consolidate shipments to obtain economies of scale. The platform and option managers' (MSPM) prime metrics are total delivered product cost and shipment predictability. This drives them to want the most efficient system for their products. The most efficient system could be at the expense of other products or other metrics.

Because of the various initiatives and metrics, a conflict exists between the various managers. For one group to obtain its metric, another group may need to be sub-optimized towards its metrics. This drives a need for a tool that coordinates efforts, defines the various costs associated with each of the possible supply chain paths for a given option, and calculates the effects on the various metrics. This tool would help the platform and option managers understand the trade-offs associated with changing the supply chain structure.

Because of the various initiatives, several possible supply chain paths for each option are being evaluated. Figure 3.2 shows the possible supply chain paths being considered.

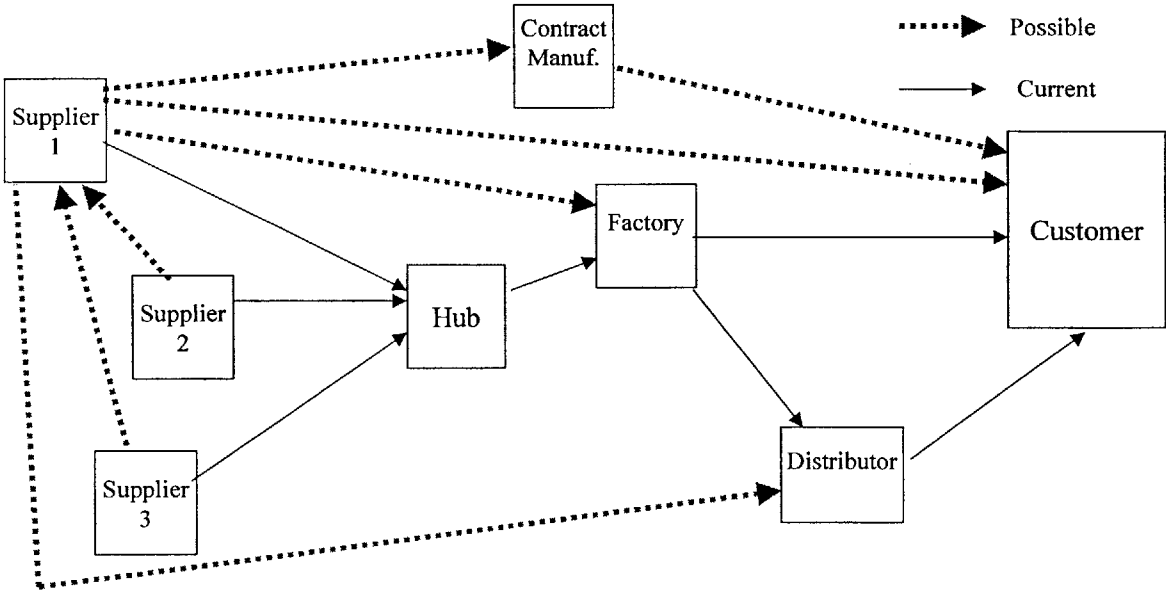


Figure 3.2: Possible Option Supply Chains

Supplier 1 is assumed to be the provider of the primary part of the option. However, if a supplier of some of the secondary parts to the option is capable of shipping options directly to the customer, then they should be considered Supplier 1. The contract manufacturers shown in Figure 3.2 can perform two functions. The contract manufacturer can serve as an assembly or kitting house for products to be shipped to the customers. They can also simply operate as a third party logistics provider for various options by handling the shipment to the customers. This supply chain is defined as a **contract manufacturer supply chain**. The contract manufacturer can also ship products

into the hub or the factory if those products are then needed in larger installations. A supply chain map for each of the supply chain structures can be found in Appendix 9.4.

3.2 Cost Drivers

The selection between the supply chain structures is one of the primary cost drivers of the system. Policy decisions around inventory management, freight methods, and lot sizes are also Compaq decisions that contribute to the overall performance of the supply chain. The demand profile for the option is another key driver. For this analysis, the demand was considered to be exogenous. The quote cycle time for the high end products is long. This leads to delays between the time systems are quoted and when the supply chain needs to respond to the quotes. This helps to smooth the demand for the options and give some predictability to the demand.

The inventory management policies include the decisions of where to hold inventory, how much inventory to hold, and what reordering policy to use. These decisions affect both the total cost of the supply chain as well as the ability of the system to meet the demand within the quoted lead-time. The decision of who should own the inventory at each stage of the system only changes the total system cost if the companies involved have different cost of capital. Who owns the inventory does change some of the key Wall Street metrics. For this study it was assumed that each company had the same cost of capital and that the suppliers passed on the full burden of the inventory carrying cost to Compaq.

The freight methods selected both directly and indirectly affect the total system cost. The freight cost for a given package varies depending on what carrier service is selected, how many other packages can be shipped with it, and the distance of the shipment. The service selected also affects the transport time, thus altering the inventory requirements of the system.

The lot sizes chosen also directly and indirectly affect the total system cost. The decision to bulk or individually package the products directly alters the packaging costs for the product. The bulk package's quantity or the minimum lot size for the individually packaged options can then indirectly alter the inventory or freight costs of the system depending on the supply chain structure chosen and demand for the option. Because of the interdependencies of the costs, the decisions about supply chain structure, inventory management, freight methods, and lot sizes need to be made concurrently.

3.3 Qualitative Issues

In addition to the quantifiable impacts of the supply chain design, the design selected can have some qualitative impact as well. The direct impact of the qualitative issues is hard to capture. In some cases the impact of these issues can be reduced or eliminated by raising the awareness of the issue and taking step to mitigate it. In other cases, the impact cannot be reduced. In these cases the risks need to be weighed against the potential benefits and savings (Fine, 2001).

Figure 3.3 provides a matrix of examples of the qualitative risks associated with the various supply chain structures for the Alpha server options.

Issue	Supply Chain			
	Hub-based	Direct Ship	Factory-Stock	Contract Manuf
Control of customer information	None	High	None	Low/Med
Inventory visibility	None	High	None	High
Split forecast	None	High	None	High
Multiple and control of shipments	None	High	None	Low/Med
Dependency on supplier	Low	High	None	High/Med

Figure 3.3: Qualitative issues associated with various supply chains

The control of customer information issue revolves around the question whether to give the supplier or the contract manufacturer access to the complete customer list for their products. The risk is that in the future the supplier will try to sell items directly to the customers and potentially decrease Compaq's revenue.

The inventory visibility issue stems from the fact that Compaq currently has visibility into the hub inventory levels. In the direct ship and contract manufacturer supply chains, it may become impossible to have this same ability to see and react based on upstream inventory levels. This could lead to lost revenue or increased inventory.

Since only independent options can be shipped directly, the demand forecast for an option will need to be split into two separate forecasts. This potentially decreases the accuracy of the forecast and also requires extra systems be established. The extent of this issue depends on the demand profile for the option. If the option has only independent or only CTO demand, then the issue does not exist. However, some products have both independent and CTO demand; for these products it needs to be determined how to split the forecast. Incorrect forecasting could lead to higher inventory carrying costs or expediting charges.

If the supplier or contract manufacturer is being placed in a position to directly fulfill customers' orders, then Compaq relinquishes some control to meet the customers' expectations. Some customers order several independent options on the same order to meet their various spare parts or upgrade needs. These customers may start to receive several shipments directly from the option supplier rather than the single shipment from the factory. In the past, all of the orders came through the factory for consolidation. This may have an impact on customer satisfaction ratings. This also increases Compaq's dependencies on certain suppliers especially if initial investments are required to establish a direct ship capability. This gives the supplier some negotiating leverage.

There are a number of advantages of the direct ship and contract manufacturer supply chains that offset the concerns. The supplier's demand visibility is improved. The factory's capacity is freed up to focus on higher value add activities. The shorter supply chain will be more responsive to demand variability and staff required to manage the operation may be able to be decreased.

The other potential issue with selecting the ideal path for each option is that it may add complexity to the systems. If it is determined that the independent option demand should be fulfilled with a direct ship supply chain, while the add-on and embedded options should be fulfilled with a hub-based supply chain, then the order entry and forecasting systems would also need to split these requirements. Typically one purchasing agent manages a suite of similar parts. It could be confusing and require extra training if, for example, the supply chain for high volume monitors is direct ship, while the supply chain for low volume monitors is factory-stock. For these reasons, the changes to a supply chain for a specific option need to be considered within the larger picture of all of the option supply chains.

4.0 Optimizing Option Fulfillment

This chapter will briefly describe the optimization model that was created to help the Option MSPM determine the optimal supply chain path for each option. Prior to the development of the model, Compaq was using several simple financial spreadsheets to make supply chain-related decisions. These spreadsheets were not versatile enough to adapt to new uses. The inputs and equations within the spreadsheets were not transparent to the users. The model developed within this project strived to become the standard model for supply chain costing decisions. The model also was developed in a way that the inputs and calculations were clearly presented to the users.

The optimization model was created in Solver within Microsoft Excel. The first section of the chapter describes the model's inputs. The second section describes the calculations, while the third section explains the model outputs. The fourth section describes the methods used to validate the model. In addition to this chapter, Appendix 9.3 provides a full copy of the model's inputs and calculations.

4.1 Model Inputs

The inputs to the model were gathered from resources both within and outside of the NPI group. Figure 4.1 summarizes the input source, location, and classification for each input category. Figure 9.3 in Appendix 9.3 provides a detailed list of the variables in each category.

Input Category	Input Source	Input Location	Input Classification
Product Characteristics	Product Hierarchy Database	Database	Varies by Part
Demand Characteristics	Demand Profiling Database	Database	Varies by Part
Packaging Cost	Product Hierarchy Database	Database	Varies by Part
Hub Cost	Site Procurement	Calculation	Default
Freight Cost	World Wide Logistics	Calculation	Default
Pick/Pack Cost	Site Procurement	Calculation	Default
Order Handling Cost	Acquisition	Calculation	Default
Supply Chain Setup Cost	Direct Shipment Team	Calculation	Default
Cost of Capital	Finance	Calculation	Default

Input Category	Input Source	Input Location	Input Classification
Revaluation Rate	Option MSPM	Estimate	Varies by Part
Lead Times	Acquisition/MSPM	Estimate/Quote	Varies by Part
Order Intervals	Acquisition	Estimate	Varies by Part

Figure 4.1: Description of Optimization Model Input Categories

The input categories can be grouped into three general types: known product characteristics, calculated division characteristics, and calculated product characteristics.

The inputs considered as product characteristics are in the demand characteristics, product characteristics, and packaging cost categories. These inputs are available in various corporate databases. The inputs vary depending on what part is being studied, so each part number's parameters need to be determined before it can be studied. The values of the parameters do tend to be very similar for all of the parts within a product space. To improve the efficiency of loading these inputs into the model, extracts containing the required information for all of the product numbers were taken from the databases.

The inputs considered as calculated division characteristics are in the hub, freight, pick/pack, supply chain setup, and order handling costs categories. These inputs are recorded and tracked at the division level and, therefore, are not directly available at the part level. Allocation equations were developed to distribute these costs to specific parts or transactions. In the model the division characteristics are default values; however, the product characteristics drive the equations that determine which and how the costs should apply. The cost of capital is also a calculated characteristic of division, but it does not vary with product characteristics.

The inputs considered as calculated product characteristics are in the revaluation rate, lead time, and order interval categories. These inputs are tracked within various databases at the part level. However, the actual input at a point in time can vary greatly, so the trend or average value needs to be determined before loading the information in

the model. These inputs like the known product characteristics are typically similar for the parts in a product space.

In addition to these inputs, the model uses its decision variables to drive the model. The decision variables for the model are the percent allocation to each of the supply chain paths. It is assumed that when considering a supply chain for an individual part the resources are not capacity constrained. Because of this, the percent allocation to each supply chain turns out to be a binary or on/off solution.

4.2 Model Calculations

The model inputs are used to determine the inventory, freight, packaging, handling, and supply chain setup costs. The sum of these costs over the year is used as the total supply chain cost. In addition to these calculations, the model has several constraints built into the program to insure that it functions properly.

4.2.1 Inventory Cost Calculations

The inventory in the entire supply chain has three components:

- 1) Work in Process (WIP) Inventory
- 2) Safety Stock Inventory
- 3) Batching Effect Inventory

Once the supplier finishes building the option, the value of the option is increased by the handling, freight, and packaging costs at each stage of the supply chain. To simplify the model, the value inventory at each stage of the model was set to the current value of inventory being held at the factory. By using Little's Law, the WIP inventory is found by determining the total length of the supply chain in days. The WIP inventory is equal to the demand during this time period (Simchi-Levi, 2000).

$$\text{WIP Inventory} = \sum \text{Lead Times} * \text{Ave. Demand}$$

The safety stock inventory is present to buffer the system's performance against demand variability. In a multiple stage supply chain, the safety stock is only required when the stage's replenishment time is greater than its committed lead time (Graves and Willems,

2000). If the committed lead time minus the replenishment time or **slack time** is greater than zero, then each stage can use the previous stages inventory to buffer itself from the demand variability.

$$\text{Slack Time} = \text{Committed Lead Time} - \text{Replenishment Time}$$

In the case where the slack time is less than zero, the stage cannot rely on the previous stage to cover the effects of demand variability and has to hold safety stock. The amount of safety stock inventory required depends on the demand variability and the service level required. (Graves and Willems, 2000). Since the slack time is less than zero, the equation needs to include a minus sign or absolute value function before the square root of the slack time can be taken.

$$\text{Safety Stock} = z * (\text{Std. Dev. Weekly Demand}) * \sqrt{(-\text{Slack Time})}$$

where

$$z = \text{Service Level Factor}$$

By using the slack time rather than the stage's total lead time, the inventory in the system is reduced. This causes some of the stages to sit idle occasionally and the products to be delivered on time but not early. This assumes that the demand is normally distributed and the lead times do not vary. Since the lead times do not vary, the part is requested from the previous stage at the stage's committed delivery date less the previous stage's lead time. The previous stage will sit idle until it receives the order to build the unit. The service level factor is defined as the number of standard deviations above the mean needed to insure the given probability of fulfillment. Because of the known quarterly skew in the demand, the assumption that the demand is normally distributed needs to be validated and the effects understood. The assumption that the lead times do not vary is needed to bound the problem so that the safety stock levels can be found. In the cases where the lead time varies, Compaq's managers work to expedite the orders to alleviate the delay.

The third inventory component arises when using the base stock model in a system where the parts are shipped in batches. If the minimum batch size is greater than the ideal shipment size, then extra inventory is held within the system. The ideal shipment size is the difference between the order-up-to and safety stock levels in the base stock model.

Figure 4.2 shows the effect of batch size on the average inventory level.

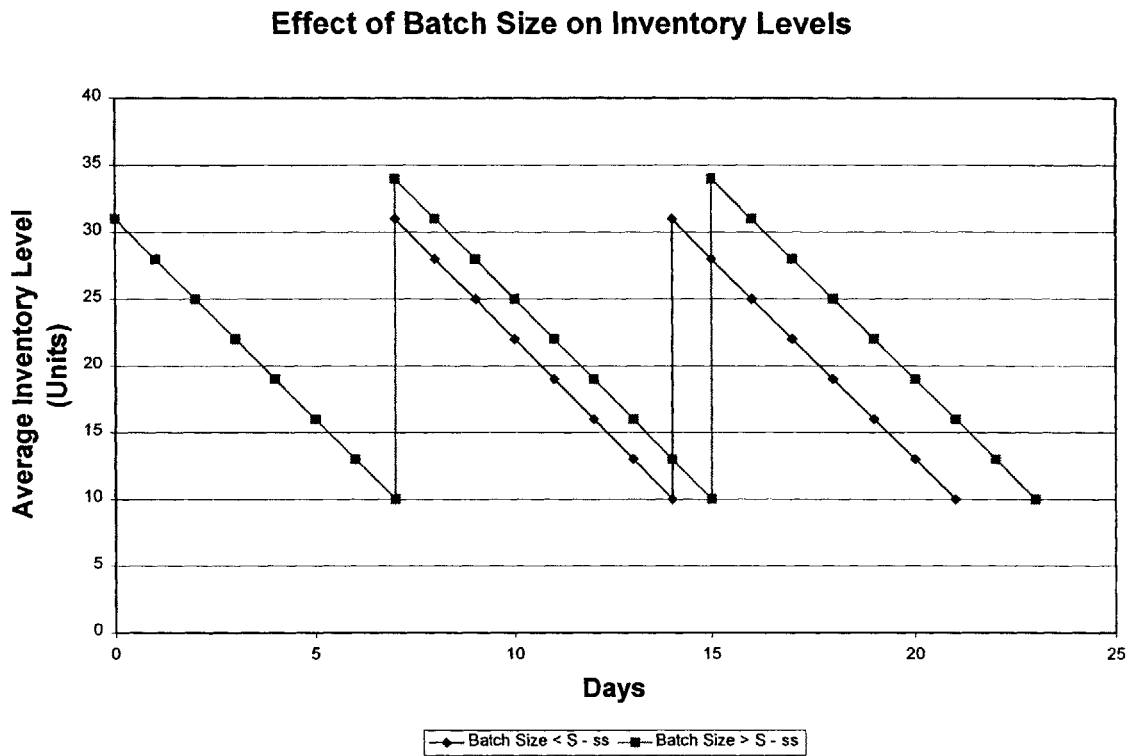


Figure 4.2: Effect of Batch Size on Inventory Levels

In Figure 4.2 the safety stock level is 10 units, the order-up-to level is 31 units, batch size is 24 units. Because the batch size is greater than the ideal shipment size of 21, extra inventory is held in the system. The extra inventory is equal to half the difference between the batch size and the ideal shipment size.

$$\text{Batching Inventory} = (\text{Batch Size} - (\text{Order Up to Level} - \text{Safety Stock Level}))/2$$

If the batch size is less than the ideal shipment size, then the goal would be to balance the orders between multiples of the batch size so that the long run average of the inventory equals that of the ideal shipment size case. Because of order handling cost, the buyer wants to order more than one batch. However, because of the excess inventory carrying

cost, the buyer wants to buy as few batches as possible. The balance point of these costs comes when the long run average of the inventory equals that of ideal shipment case.

Once the three components of the inventory are determined, the inventory carrying cost can be calculated. The inventory carrying cost in dollars equals the inventory value times the sum of the cost capital and option's revaluation rate.

$$\text{Inventory Carrying Cost} = (\text{Inv. Value}) * (\text{Cost of Capital} + \text{Revaluation Rate})$$

where

$$\text{Inv. Value} = (\text{WIP} + \text{Safety Stock Inv.} + \text{Batching Inv.}) * (\text{Standard Cost of Option})$$

The revaluation rate for the option is equal to the average yearly price decrease of the option.

4.2.2 Freight Cost Calculations

The freight costs for all of the segments of the supply chain are calculated based on the weight of the product and the method of shipment. The user chooses the shipment methods for each segment type and then the model calculates cost based on equations provided by the Compaq's worldwide logistics group. The equations provided are of the following form:

$$\text{Freight Cost} = (\text{Variable Cost per lbs}) * (\text{Shipment Weight}) + (\text{Fixed Shipment Cost})$$

Each equation is valid for that shipment type within given weight limits. If the user specifies a shipment method that does not support the shipment weight, then the model prints an error message. The shipment weight used was the number of parts shipped times the unit weight for each part.

4.2.4 Packaging Cost Calculations

The packaging cost consists of two components: bulk and individual. The bulk packaging is used to ship batches of parts between the supply chain stages without individually packaging them. The individual packaging is required once the parts are

ready to be sent to the customer to fulfill an independent option order. The bulk packaging cost is divided across the units shipped in the batch, while the individual packaging cost is a per unit charge. Figure 4.3 summarizes when the packaging charges apply for the various supply chains.

Supply Chain	Bulk Packaging		Individual Packaging	
	Independent Orders	CTO Orders	Independent Orders	CTO Orders
Direct Ship	No	N/A	Yes	N/A
Hub-based	Yes	Yes	Yes	No
Hub-based w/ Supplier Kitting	No	No	Yes	Yes
Factory-Stock	Yes	Yes	Yes	No
Factory-Stock w/ Supplier Kitting	No	No	Yes	Yes
Contract Manufacturer Direct Ship	Yes	N/A	Yes	N/A
Contract Manufacturer to Hub	Yes	Yes	Yes	Yes

Figure 4.3: Bulk and Individual Packaging Charges for Various Supply Chains

In Figure 4.3, the supply chains that are not capable of fulfilling the order type are marked N/A for not applicable. The cost of the bulk and individual packaging varies from product to product. For options that contain more than one part, there is an additional Pick/Pack charge for the options that are individually packed. The charge varies depending on whether the supplier, contract manufacturer, or factory kit the parts.

4.2.5 Handling Cost Calculations

The handling costs include supplier, hub, and factory order processing costs. The supplier order processing costs are broken down to charges per incoming and outgoing shipments. The hub charges include an in, out, picking, and storage per transaction charge. The factory charges include an in and out transaction charge. Various Compaq groups provided estimates of these transactional charges.

4.2.6 Supply Chain Setup Cost Calculations

This section of the model provides the user with the ability to include an initial setup charge for changing the supply chain structure. The model currently uses this feature to allocate the charges associated with establishing a direct shipment capability at a supplier or contract manufacturer. The model uses forcing variables to assess these charges to the

system (Graves, 2000). For example, if either the direct ship or contract manufacturer direct ship supply chain is chosen, then the direct shipment capability charge applies. If neither is chosen, then the charge does not apply. The percent of the total setup charge to allocate to this part and the amortization period are chosen by the user. For this study, the percent allocation is established by calculating the annual expenditure for this option and dividing it by Compaq's total expenditure to the supplier. The following equation uses the time value of money to calculate the per unit charge:

$$\text{Per Unit Supply Chain Setup Charge} = \frac{(\text{Setup Cost}) * (\% \text{ Allocated}) * (\sum_{i=1}^i (1 + \text{Cost of Capital})^i)}{(\text{Amortization Period}) * (\text{Ave. Weekly Demand}) * 52}$$

where

$$i = \text{Amortization Period}$$

The average weekly demand used in the above equation is the total weekly demand of all of the paths that use the resource that is being established.

4.2.7 Constraints

The model is constrained to insure that it only considers feasible solutions. The combination of the selected supply chains needs to fulfill both the independent and the CTO demand. The direct ship and contract manufacturer direct ship supply chain are prevented from fulfilling the CTO demand. The inventory time used in the safety stock equation is forced to zero if the slack time is positive. The inventory time for the stage is also constrained to be less than the stage's committed lead time. The batching effect on the inventory cost is also forced to only be included when the batch size is greater than the ideal shipment size. Forcing constraints are also used to drive the supply chain setup costs. More details about the constraints can be found in Appendix 9.3.

In addition to the constraints that are already included, the user can constrain the model to insure that certain metrics are obtained. For example, the total inventory cost could be constrained to be less than a certain value. In this case the model will only consider solutions that meet this requirement.

4.3 Model Outputs

The optimization model reports out the quantitatively optimal supply chain structure for fulfilling both the independent and the CTO option demand. In addition to the selected supply chain structure, the optimization model outputs the following values for the selected and current fulfillment strategy:

- 1) Total annual inventory cost for each segment and the entire system;
- 2) Total annual freight cost for each segment and the entire system;
- 3) Total annual packaging cost for each segment and the entire system;
- 4) Total annual handling cost for each segment and the entire system; and
- 5) Total annual supply chain setup cost for each segment and the entire system.

These values are summed to find the total supply chain cost for the current and optimum supply chains. A matrix that defines the costs for which Compaq directly pays is included in the model. This matrix is used in the model to obtain the total Compaq cost by multiplying the costs by the matrix. By comparing the optimum costs to the current costs, a strategy for obtaining the proposed savings can be developed. For example, if the model shows that the supplier's inventory carrying cost will decrease as a result of changing the supply chain structure, then the supplier manager needs to negotiate a lower purchase price to capture part of the inventory cost savings.

The model can also be used to answer what-if questions around various inputs or to optimize different objective functions. The user can select to optimize the total supply chain cost, total Compaq cost, or total inventory cost. By comparing the optimal supply chains for each of these objectives, the user can better understand the impact on various stakeholders' metrics.

In addition to solving for several different objectives, the user can link together several of the sheets to create a supplier viewpoint. Linking the sheets together forces the model to choose one supply chain for the entire supplier's portfolio of parts. The resulting value can be compared against the optimal solution for each individual part. The manager of the supplier can then determine if the difference between the total of individually optimized parts and the supplier viewpoint optimized parts is worth the complications resulting from establishing multiple supply chains for the same supplier.

By considering the potential savings, the strategy to obtain the savings, the impact on the stakeholders' metrics, the entire supplier viewpoint solution, and the qualitative issues associated with the supply chains, the team selected the correct supply chain for each of the parts. Because of the time consuming nature of obtaining the required inputs and performing the full optimization analysis, further simplifications of the optimization process were required. Without developing a faster process, the group would not be able to analyze all of the 600 parts in its portfolio. The simplification process is described in Chapter 5.

4.4 Validation Process

Two methods were used to validate the optimization model. The first validation method used was to create a dynamic simulation in Vensim[®]. The simulation was a discrete event simulation. The simulation used the same inputs, rules, and assumptions as the optimization model. The simulation used raw historical daily demand data to drive the model, while the optimization model used statistical averages and standard deviations of the data to drive the model. The inventory was moved from segment to segment based on the base stock model and the appropriate charges were applied to each movement. A daily charge was applied to the entire inventory in the system. The total system cost and the missed shipments for the simulation period were accumulated and compared to the performance of the optimization model system. Figure 4.4 compares the performance of the simulation to the optimization model.

Part #	Time Period	Simulation Model		Optimization Model	
		Total Cost	Missed Shipments	Total Cost	Missed Shipments
Part 1	Period 1	\$5.01 M	2	\$5.02 M	4
Part 2	Period 1	\$1.18 M	0	\$1.19 M	4
Part 3	Period 1	\$0.17 M	2	\$0.17 M	4

Figure 4.4: Simulation Versus Optimization Model Comparison

The simulation runs did not show significantly higher costs or missed shipment rates. The cost differences are caused by the fact that the simulation uses daily order information over a half year period to predict the annual costs, while the optimization

model uses weekly order information over a quarter to predict the annual costs. The missed shipment rate for the simulation model is lower than the optimization model level, because the safety stock levels in the model were set using the data from the first quarter of the time period of the simulation. The skewed demand does result in excess inventory being held during the earlier weeks in the quarter. The inventory does help to prevent missed shipments. It is possible to reduce the inventory carrying cost by establishing a more complex inventory management scheme that varies over the quarter. These enhancements could be implemented after Compaq drives the inventory levels down to the ones defined by the base stock model.

After passing the first validation test, the second test was to switch a few pilot parts to their recommended supply chains and to track the costs. The initial results were promising. As a result the list of pilot parts was expanded. As of the end of the project, the changes required to capture approximately one-third of the recommended savings had begun. A future study would be required to determine the actual savings resulting from the recommended changes.

5.0 Candidate Locating Process

5.1 Introduction

By using all of the functionalities built into the optimization model described in Chapter 4, the user could develop a clear and accurate picture of the supply chain costs associated with a particular option. However, this process was too time intensive to be used on all of the 600 options within HPS's portfolio. For this reason, the candidate locating process was developed to find the best candidates for supply chain structure changes. In addition to making the process faster, the output graphs developed in the process help the user to have a clearer picture around how the results will change as the product inputs or business characteristics change. Once the process located the best candidates, the optimization model was used to develop the implementation strategies for these products.

5.2 Description of the Process

The first step in the simplification was to try to reduce the number of inputs. During this process, it became clear that only some of the known and calculated product characteristics varied across all 600 options. In looking at this data, natural product commodity classes where all of options in the group had similar characteristics could be spotted. The options were grouped into 26 commodity classes like monitors and keyboards. The two parameters that did vary significantly within each group were the average demand for each option and the ratio of the independent and CTO option orders.

Since the solution to the optimization model depends on the demand and the percent CTO orders, it needed to be modified to show the answers for various demand quantities for the given commodity class. To achieve this, the equations in the model were used to calculate the cost of each supply chain path for demand from 1 to 100 units per week. The remaining inputs into the model were based on choosing a representative part for the commodity class. The per unit cost for each supply chain was then plotted on a graph versus the demand volume. This enabled the option managers to pick the correct supply chain for each part in the commodity class and to see how that decision will change as the

volume for the products changes. Figure 5.1 shows a typical set of cost curves for the various supply chains.

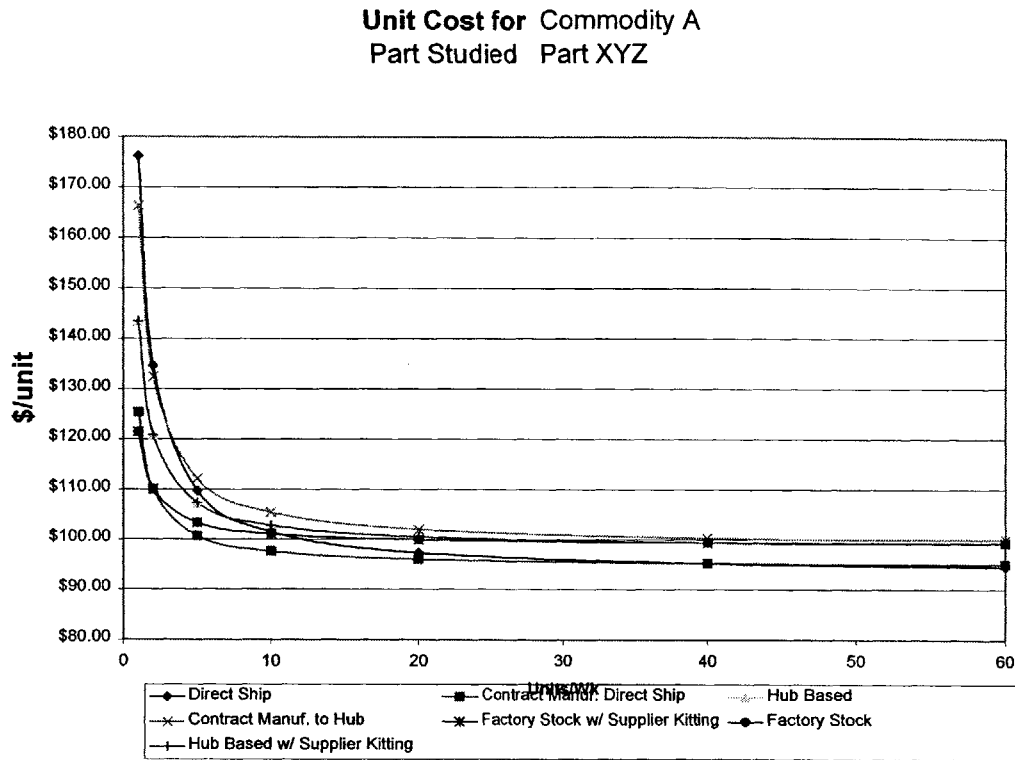


Figure 5.1: Typical Cost Supply Chain Curves for Commodity A

The cost curves in Figure 5.1 could be used to determine the best supply chain for each of the parts in Commodity Class A. The table in Figure 5.2 summarizes a few scenarios.

Part Number	Independent Demand Units/Wk	CTO Demand Units/Wk	Independent Supply Chain	CTO Supply Chain
Part 1	20	0	Contract Manufacturer Direct Ship	N/A
Part 2	40	10	Direct Ship	Factory-Stock
Part 3	3	10	Factory-Stock	Factory-Stock

Figure 5.2: Summary of Commodity Class A Parts Recommended Supply Chains

In the part 1 scenario, the user simply picks the curve with the lowest per unit price at 20 units per week volume. In this case, Part 1 should be shipped from the contract manufacturer to the end customer. The recommendation is very resistant to change

because the contract manufacturer direct ship curve is the low cost curve for most product volumes.

In the part 2 scenario, the user needs to consider both the independent and the CTO demand. The low cost supply chain for the independent demand would be either the direct ship or the contract manufacturer direct ship. Because the contract manufacturer direct ship supply chain cannot fulfill the CTO demand, the factory-stock supply chain is the low cost supply chain for the CTO demand. Since the supplier has to ship the CTO options directly into the factory, it then makes more sense for them to fill the independent demand directly.

In the part 3 scenario, the user again needs to consider both the independent and the CTO demand; however, in this case the best solution comes from combining the volumes. If the user selects the best independent and CTO supply chains separately, then the contract manufacturer would fill the independent demand at \$101 per unit, while the CTO demand would be filled by factory-stocking the parts at \$105 per unit. Because of economies of scale, if factory-stocking is used to fill both demands then Compaq would only pay \$100 per unit. This results in a \$1300 per year savings. If currently the entire demand was being met using the hub-based supply chain at \$102 per unit, Compaq could save \$1300 per year on this product by switching to factory-stocking.

This process was followed for each part in the 26 commodity classes. This resulted in a table that defines the recommended supply chain for each of the products and potential savings that could be captured by switching supply chains. The potential savings on each part was used to prioritize the team's efforts on fully evaluating and implementing the changes. Prior to implementation of the changes the team entered the actual inputs for each part into the optimization model to insure that the difference between its input parameters and the parameters of the commodity class' typical part did not change the results. Additionally, the group revisited the trade-off between switching one or all of a supplier's parts to a different supply chain. This was done by linking the optimization sheets for each of the supplier's parts together and forcing the model to choose one

solution for all of the parts. These results were then compared to the individually optimized solutions to determine if the supplier should use one supply chain to increase simplicity or if the savings from having multiple supply chains were deemed greater than the potential organizational costs associated with multiple supply chains for a supplier.

Because of the efficiency of this process, the team was able to analyze all of the parts in the portfolio and to highlight potential savings in excess of \$700,000 per year. As of the end of the project, the changes required to capture one-third of this value had already been initiated. The development of the cost curves based on the commodity classes will also help the group understand how new parts should be fulfilled. The manager will be able to find a product that has similar input characteristics and use its inputs in the cost curves to predict how the new product should be supplied and how it will perform.

5.3 Conclusions Resulting from the Process

By analyzing the table of recommended supply chains and the table of input parameters, the key parameters of the various supply chain structures were highlighted. The key parameters for the independent option orders are ones that contribute to the freight and inventory costs, while the key parameters for the CTO option orders are ones that contribute to the freight and handling costs.

Figure 5.3 shows how the various supply chains should be used to fulfill the independent option demand depending on the product's freight and inventory costs.

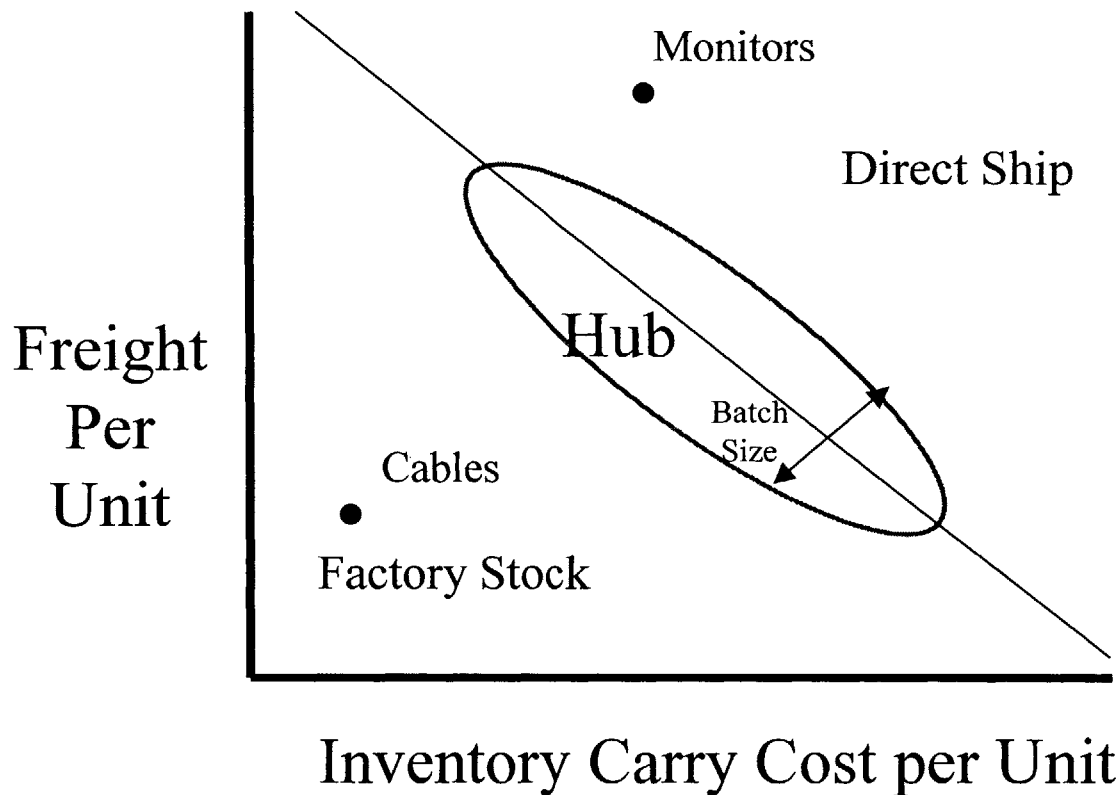


Figure 5.3: Uses of Supply Chain Structures to Fulfill Independent Demand

As the freight cost or the inventory carrying cost for a part increases, the desire to reduce the number of segments within the supply chain increases. For parts like cables where the inventory carrying cost and the freight cost are low, the savings resulting from shortening the supply chain do not offset the setup and other costs associated with direct shipments. The hub-based supply chain is appropriate for the medium freight and inventory cost items. The use of a hub helps to decrease the freight per unit cost by consolidating the shipments and by keeping the inventory off of Compaq's books. The hub can also be used to supply multiple factories, which could result in lower overall inventory levels because of risk pooling. As the batch size for the products increase, the handling charges per unit associated with the hub are reduced. This expands the region where the hub-based supply chain is appropriate.

Figure 5.4 shows how the various supply chains should be used to fulfill the CTO option demand depending on the product's freight and handling costs.

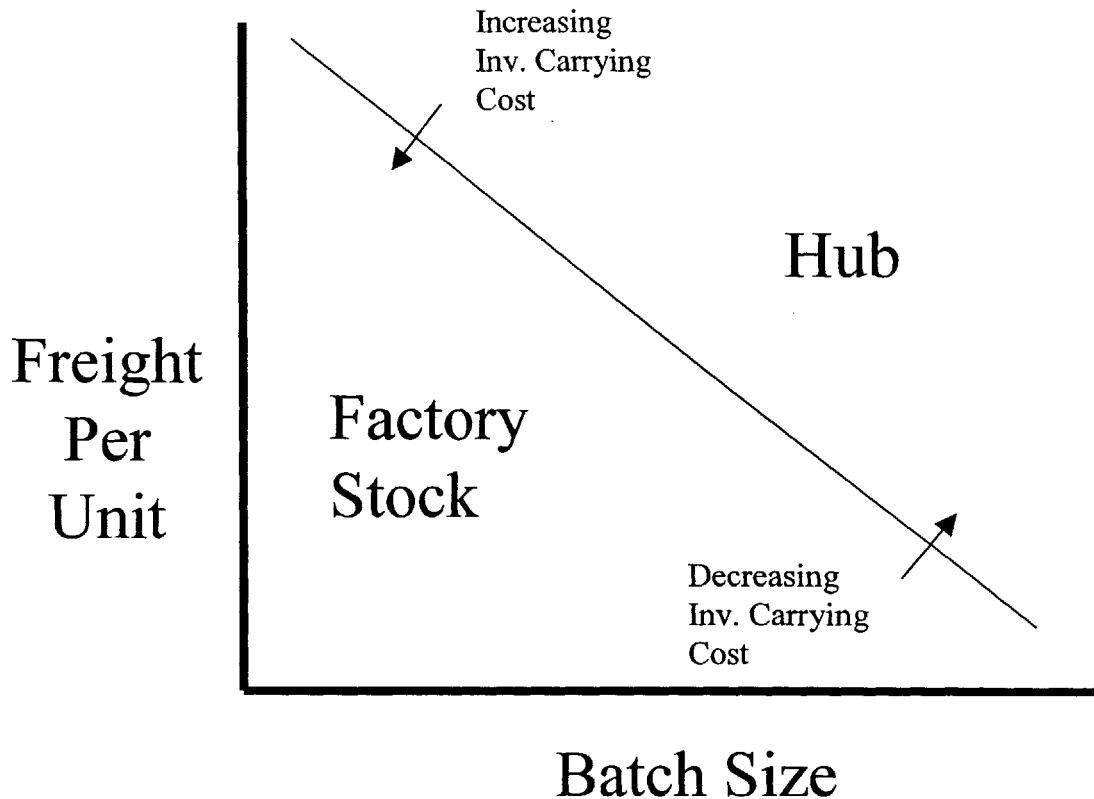


Figure 5.4: Uses of Supply Chain Structures to Fulfill CTO Demand

As the freight cost or batch sizes for a part increases, the desire to reduce costs by consolidating orders and reducing inventory increases. For example, the batch sizes and the freight costs for monitors are relatively high; therefore, they should use a hub to fulfill the configure-to-order option demand. However, for the less popular monitors that have smaller batch sizes, it makes sense to factory-stock a small quantity of them. For items like keyboards or mice, the optimal strategy is to factory-stock the items despite their large batch sizes. This is due to very low inventory carrying cost associated with these products forcing the frontier line away from the origin. As the inventory carrying cost for a product decreases the frontier line between the hub-based and factory-stock supply chain shifts away from the origin.

6.0 Effects of Metrics, Culture, and Organizational Issues

This chapter describes how the project fit into Compaq's organization by looking at how Compaq's metrics, culture, and organizational design influenced the management and implementation of the project. Overall Compaq's organization is grouped around the products except for the support and manufacturing related functions. The supply chain organization as a manufacturing function has a separate management structure from the business units; however, the supply chain managers are also matrix managed by reporting both to the business units and the supply chain organization. Figure 6.1 provides simplified overall reporting structure based on the organization chart.

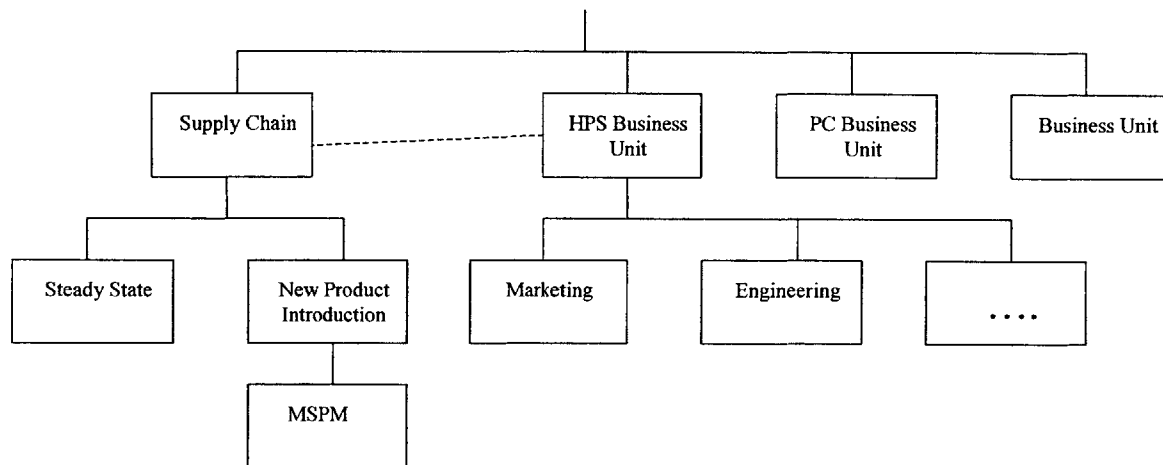


Figure 6.1: Overall Reporting Structure of the MSPM

To help the functional groups within the business units meet the product's needs, the functional organization is augmented with product teams. The MSPM serves as the manufacturing representative on the product teams. The MSPM is responsible for all of the supply chain deliverables. In addition to the product teams, each MSPM is on a supply chain product team that facilitates coordination of the products in the supply chain organization. In both cases the MSPM does not have direct authority over the other stakeholders and, therefore, needs to use influencing skills to implement changes.

The original team assembled to oversee the development of the demand profiling reports and the supply chain optimization model included the MSPMs, HPS finance

representatives, an information technology representative, HPS procurement manager, and myself. I was the formal leader of the team; however, each member's participation was only controlled by how well the project could help him or her meet his or her individual needs. Being an outsider to the organization had both its advantages and disadvantages. I was perceived as less of a threat to usurp the stakeholders' power and more as a resource to use. This enabled me to get information easier, but required me to provide useful results to maintain the support.

As the project progressed, several other teams' efforts were linked to the team. The HPS Steady State Strategy Group located in Houston had formed several teams to look at direct shipping or outsourcing the pick and pack operations for various options. It was decided that the supply chain model could support these efforts. During the initial meeting, the boundaries between the roles of the group members' efforts were established. The Houston teams would be responsible for the implementation process, while the original team would own the recommendations for changes that were discovered by the supply chain model. Each MSPM ultimately owned the decision for their products.

Both the demand profiling and option fulfillment parts of the project had a direct impact on all of the product team members. Each MSPM was the primary link between the team's efforts and the product teams. The initial primary Compaq stakeholders for the demand profiling reports were program managers, commodity managers, demand/supply group, procurement employees, finance, engineering employees, quality managers, and service managers. The stakeholders in the option fulfillment model were the program managers, commodity managers, demand/supply group, procurement employees, finance, factory managers, logistics department, and the strategy group. Figure 6.2 summarizes the stakeholders' key metrics and the extent that the project could influence the metric.

Stakeholder	Primary Metric	Demand Profiling Tool	Option Fulfillment Model
Program Managers	Total Product Cost, On Time Delivery of Products	High	High
Commodity Managers	Product Material Cost, Quality	High	High
Demand/Supply Group	Inventory, Forecast Accuracy	High	Med
Site Procurement	Material Cost	Med	High
Finance	Compaq Cost	Med/Low	High
Engineering/Product Managers	Quality, Product Milestone Dates	High	Low
Quality Group	Quality	Med	Low
Service Group	Customer Satisfaction	High/Med	Low
Factory Managers	Overhead Cost, Shipment Predictability	Low	High
Logistics	Freight Cost	Low	Med
Supply Chain Strategy Group	Overall Cost	Med/Low	High
Segment Strategy Group	Roadmap and Prediction Accuracy	Med	Low

Figure 6.2: Project Stakeholders

Because of the economic slowdown, all of the stakeholders' metrics were tied to getting back to the basics to insure operational excellence in an effort to reduce costs. The demand profiling tool could significantly help each of the stakeholders meet this objective. The supply chain model also helped toward this objective, but the alignment of all of the stakeholders' metrics with this effort was not as clear.

In addition to the stakeholders that are affected by using the tool, the information technology group had a stake in the development and management of the demand profiling tool itself. The acquisition of Digital Equipment Corporation by Compaq generated an environment where the company had redundant information technology systems. The merged company developed an integration plan that called for the elimination of some of the Digital legacy systems. In this transition to adopting the new systems, some of the information in previous reports was lost. This happened because of the different business models and culture. The Digital culture was very engineering driven and the business was built around the configure-to-order low volume products

model. Compaq's culture was more cost driven and focused on a high volume PC market. In a PC market, reports that showed how options were used across the various product platforms were less important. As a result this is one of the bits of information that was lost in the conversion process. This transition has also left the ex-Digital information technology team searching for a way to add value and to define its role. The demand profiling tool provided the group with a project where they could both add value and utilize their past business expertise. By spearheading the projects for the HPS group, the group was defining its value and showcasing its capabilities in the hopes of expanding its impact as more of the business products shift towards the configure-to-order model. The lack of cultural homogeneity between the ex-Digital and traditional Compaq product groups also caused tension between the groups. This increased the level of proof required before cross-divisional representatives would accept changes initiated outside of their group.

Because of the ability for the demand profiling tool to provide useful data that could significantly affect the various stakeholders' metrics and daily decisions, it broke through some of the tension between the divisions. The resulting interest in the tool was high from the initial prototype forward. Demonstrations of the prototype of the demand profiling tool were given at many staff meetings to build interest in the tool and to obtain feedback. This led to interest from many different groups creating a need to expand the scope of the tool. Originally the tool's prototype was designed to help the HPS Option Manufacturing System Program Managers, but the tool quickly needed to add the system and other divisions' perspectives. Since the tool was providing free access to data that was previously unavailable, the various stakeholders could each use the data in their own ways to work towards their metrics. Since each user could adapt the reports to their viewpoints, the system did not create conflicts, but rather started to open up dialogs around how the perspectives of interpreting the data differed and how to use the data. The availability of the data also altered the culture of the group by showing them that data could be obtained to support decisions. This tool opened up lines of communication and served as an early win for the project team. The formal structure of the organization

did not affect the implementation of the demand profiling reports because the stakeholders all wanted the reports.

The momentum from the demand profiling tool was then used both to gather support for the changes required to implement the option fulfillment model and to transition the demand profiling reports to a fully supported production tool. To manage the expectations and needs of the various stakeholders, a timeline for the development of the production reports and enhancements was distributed. This timeline also helped the team shift its focus toward the supply chain model and allowed the information technology group to complete the demand profiling reports with limited involvement from the team.

The credibility gained from the development of the demand profiling tool was strong enough to influence people to provide the required information for the supply chain model, but it was not enough to insure the acceptance of the recommendations. Everybody wanted to see the results and use the model until it suggested changes that adversely affected their metrics. Significant resistance could come to some of the recommendations, because they would adversely affect some stakeholders' metrics. For example, by moving options out of the factory or hub, the factory managers' and hub managers' capacity will be less utilized resulting in fewer products across which to allocate the fixed costs. Therefore, the acceptance of some of the recommendation required more influencing by the MSPM. To aid in the influencing process, the group chose less controversial parts as pilot parts. By starting with these parts, additional momentum and credibility in the model was established. The implementation of the early parts helped to highlight the vision of the group's effort to reduce overall costs.

To also aid the MSPM in the implementation of the changes, the ability to calculate the effect of the changes on various metrics was built into the model. This helped the MSPM know who was likely to offer the most resistance. The standing product teams structure within Compaq's organization also helped force the stakeholders to consider the overall product cost and their own objectives. Years of jockeying for various initiatives has built some additional complications into the team dynamics, but the MSPM is aware of the

history and is accustomed to navigating the changes. For these reasons, the MSPM and not the model was used as the focal point for the changes.

Since the HPS division is currently the only division fully shipping products on the configure-to-order model, the need for understanding how the CTO and independent demands interact is less urgent for non-HPS focused employees. This resulted in a lower priority being placed on the changes suggested by the group. The lower product volumes within HPS also reduced interest in the changes. The effort required to obtain the same level of savings is higher than the effort required in the high volume spaces. In both spaces the products' life cycles are less than two years. This results in less time to build consensus for changes, thus requiring the evidence supporting changes to be well supported and clearly presented. Because of the lack of urgency and the complicated environment, the implementation of the supply chain model's recommendations was slower than expected. Additionally, the sustainability and future use of the tool may be limited in the immediate future. As more of the business transitions to a configure-to-order model, this urgency and desire for the option fulfillment model will increase.

As the model spreads to a larger audience, several enhancements should be considered. The model assumes that the division's characteristics remain unchanged as the supply chains are altered. If, for example, enough of the products are moved out of the hub-based supply chain, the hub cost inputs and allocation equations may need to be adjusted. These new costs should then be entered into the model and it rerun for all of the products to see how the decisions change. By iterating through this process several times, a stable macro level solution will hopefully be found. The next level of enhancement would be to use the part optimization results in a larger division optimization to determine the optimal size of the fixed resources over a few years and the transition path to get to that size. Another enhancement would be to try to capture more of the qualitative issues directly in the model.

In addition to direct results of the team, the development process has generated some insights into how to approach this type of problem within a large organization. The use

of Sloan Leadership Model and the three lenses contributed to the success of the project (Ancona, 2001). Figure 6.3 shows how the team’s efforts map to the Sloan Leadership Model.

Step	Demand Profiling Reports	Supply Chain Model
Discovering the Organization	Interviewed stakeholders and surveyed current systems	Interviewed stakeholders and surveyed current systems
Building Relationships	Attended staff meetings	Demand profiling reports
Small Experiments	Pilot prototype reports	Pilot parts
Creating a Vision	Roadmap for suite of reports	Commodity class approach
Innovation and Change	Use of reports by various stakeholders	Implementation of recommendations
Refining and Learning	Request for more report views and importance of IT systems	Iterative process and integration into larger model

Figure 6.3: Sloan Leadership Model Applied to the Projects

The interviews in the discovering-the-organization stage helped both determine the direction of the project and provided information around how decisions are made within the organization. This process continued in the building-relationship stages. By attending meetings and providing information that helped make day-to-day decisions, some credibility and lines of communication were established. The next step in the process was to start adding value by conducting small experiments that could lead to or highlight the need for changes. For the demand profiling reports project, this involved developing pilot reports. For the supply chain model project, this involved implementing changes to some less controversial parts. From the support, credibility, and knowledge gained during the experiments, a vision and overall initial direction for the project was established. The vision of the demand profiling reports was communicated through the development of a roadmap for the suite of reports to be developed. The supply chain model vision of using representative parts to study the entire product space was established. As the project progressed through the innovation and change-implementation stage, more value was added and refinements were made to the project’s direction incorporating the lessons learned. The stakeholders used and adapted the

demand profiling reports to meet their needs. The supply chain model users began to understand how the results could be incorporated into larger studies.

The Sloan Leadership Model helped break the overall project down into definable steps. At each step the group then considered the environment to determine the best action. Using this process helped to build momentum and aided acceptance of the project. The matching of the tools to the resources available at the given time in the project and the extensive use of communications to build awareness of the work were also critical to projects success.

7.0 Conclusions and Recommendations

This project definitely met the original objectives. The demand profiling reports have provided Compaq with a clear window into understanding the behaviors of the demand for its products. The supply chain optimization model was used to determine the correct supply chain for each option. The overall problem solving process demonstrated to the group how a complex problem could be solved within the boundaries of the company's environment.

The demand profiling reports have raised the awareness within the company with regard to how options are being consumed. This has resulted in cost saving through better product planning, forecasting, and allocation decisions. Some recommendations can also be drawn from the development process of the demand profiling reports. By promoting free access to the demand profiling reports, unforeseen uses of the information were discovered resulting in additional savings. To capture savings similar to these, efforts should be taken to provide employees with more information in an easily understandable format. By providing groups with historical data, they can use it to improve their predictions of the future and to act more proactively. In addition, as information systems are consolidated or transitioned to new systems, great care should be taken to understand how all of the current users utilize the data. If care is not taken, companies can end up in Compaq's position where they were unable to capture a complete demand picture for a product line or to fully analyze a supply chain's costs.

The proper use of the supply chain optimization model has resulted in recommendations that could save Compaq over \$700,000 per year. However, the blind acceptance of model results can have many unintended consequences. The qualitative issues surrounding changing supply chain structures need to be weighed versus the potential savings. Additionally, the model's outputs are only as good as the inputs and as the skills of the person interpreting the results. For example, if the model user does not understand the sensitivity of the decision to changing the input parameters, then the wrong decision could be made. One way that the model tried to counteract this problem was by producing the cost curves for each commodity class. The cost curves give the user the

ability to understand how the business decision may change as the product sales volume changes. Another method used to mitigate the risk of misuse of the model was to support the supply chain recommendations with business terms rather than with the “model says”. The model highlights the sources of cost savings, challenging the user to understand the business reasons or to ask why and to look at the details. This drives a business level understanding by the user.

By analyzing the overall set of recommendations for each option provided to Compaq, some general conclusions were drawn. In a configure-to-order business it is extremely important to understand how the costs associated with the independent and configure-to-order demand interact. Depending on the cost drivers for the option it may make sense in some cases to split the supply chain paths, while for others it does not. The fulfillment of independent demand depends on the inventory carrying and freight costs for the product. If either of these parameters makes up a significant portion of the products cost, then the product should be direct shipped. If both of these factors are low, then the product should be stocked in the factory. The use of a hub only comes into play when the batch sizes are large enough and the economies of scale in the freight and inventory carrying cost can offset the additional handling associated with the hub. This means the strategies for Compaq’s low volume products will differ from the strategies for the high volume products. The fulfillment of the configure-to-order demand depends on the freight cost and batch sizes of the product. Low volume and low freight cost products should be stocked in the factory, while economies of scale associated with the hub strategy can be utilized on higher volume or higher freight cost products.

The use of the Sloan Leadership Model throughout the project contributed to the success of the project. Without building the proper momentum and without considering the environment when choosing the parts to study at each step of the process, the project potentially would not have been completed. Each step of the project both individually added value to Compaq and moved the project closer to the overall vision for the project. The specific tools developed during this process were not as important as highlighting the need for strong information tools and improved communication systems.

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9.0 Appendix

9.1 Appendix: List of Terms

Figure 9.1 defines the terms used in the thesis.

Term	Definition
Add-on options	Options sold ala carte with a platform that are factory installed.
Alpha server	64-bit microprocessor originally designed and built by Digital Equipment Corporation
Configure-to-order (CTO)	Process where the customers orders a base platform and then chooses all of the options they want installed on the system.
CTO options	Embedded and add-on options collectively
Contract manufacturer supply chain	Supply chain where the supplier ships the parts to a contract manufacturer who either assembles the product and ships it to the customer or simply ships the product to the customer.
Direct ship supply chain	Supply chain where the supplier ships the option directly to the customer.
Embedded options	Options that are embedded in the bill of material for a platform.
Factory-stock supply chain	Supply chain were the options flow directly from the supplier into the factory.
High Performance Servers	Alpha processor based servers
Hub-based supply chain	Supply chain where the suppliers ship parts into a hub near the factory and factory pulls from the hub.
Independent options	Options that are sold independent of system and are not factory installed.
Itanium Microprocessor	64-bit microprocessor produced by Intel
Manufacturing System Program Managers (MSPM)	Overall life cycle and program managers for the options or platforms.
New Products Introduction Group (NPI)	Manufacturing representatives on the product business teams that are responsible for all supply chain deliverables.
Option	Can be almost any part of the computer system ranging from an additional CPU to a mouse to a system cabinet
Platform	Base system designed around a specific microprocessor and computing capacity range
Slack Time	The committed lead time minus the replenishment time.

Figure 9.1: List of Terms

9.2 Appendix: Demand Profiling Database Detailed Description

Figure 9.2 lists the input, output, and temporary tables used in the Demand Profiling Database. The table also lists all of the fields included in each of the tables.

Table	Type	Fields Included
Sales Line Item	Input	Area, Shipment Id, Sales Order No, Sales Order Line No, Part No, Css Order Ind, From Plant Cd, Shipment Dt, Intercompany Flg, Delivery Dt, Unit Price Usd, Shipment Qty, Revenue Flag, Ship\$, Customer Ship To Id, Order Type, Leverage Rev
Flattened Bill of Material	Input	Option Part No, Used On Part No, Qty UsedOn, BOM Level
Product Hierarchy	Input	Part No, Part Desc, Life Cycle Stat, Part Intro Date, Part Disc Date, Part EOL Date, Product Class, Product Family
Product Cost	Input	Part No, Std Cost, List Price, Begin Effect Date, End Effect Date
Part Usage	Output	Area, Shipment Id, Sales Order No, Sales Order Line No, Part No, Css Order Ind, From Plant Cd, Shipment Dt, Intercompany Flg, Delivery Dt, Unit Price Usd, Shipment Qty, Revenue Flag, Ship\$, Customer Ship To Id, Order Type, System Type, Leveraged Rev, Std Cost, List Price, Part Desc, Life Cycle Stat, Part Intro Date, Part Disc Date, Part EOL Date
System Orders	Temporary	Area, Shipment Id, Sales Order No, Sales Order Line No, Part No, Css Order Ind, From Plant Cd, Shipment Dt, Intercompany Flg, Delivery Dt, Unit Price Usd, Shipment Qty, Revenue Flag, Ship\$, Customer Ship To Id, Product Family
System Order Value	Temporary	Sales Order No, Sum of Ship\$
Independent Order Value	Temporary	Shipment Id, Sales Order No, Sales Order Line No, Part No, Ship\$
List Systems on Orders	Temporary	Sales Order No, Product Family
Orders w/ Multiple Systems	Temporary	Sales Order No
Part Usage Count	Temporary	Sales Order No, Part No, Count Add-on, Count Embedded, Total Count
Leveraged Rev Value	Temporary	Sales Order No, Part No, Leveraged Rev

Figure 9.1: Demand Profiling Database Tables

The Figures 9.2 describes the queries used in each step of the Demand Profiling Database.

Query #	Cal. Step	Query Type	Fields Joined	Tables Joined	Constraints	Action
1	0	Temp Table	Part No	Sales Line Item, Product Hierarchy	Product Class = System	Make System Orders Table
2	1	Update	Sales Order No	Sales Line Item, System Order		Update Order Type to "Add-on"
3	1	Update	None	Sales Line Item	Order Type = "Is Null"	Update Order Type to "Independent"
4	1	Update	Part No	Sales Line Item, Product Hierarchy	Product Class = System	Update Order Type to "Embedded"
5	1	Append	Part No	Sales Line Item, Product Hierarchy	Product Class = Option	Add add-on and independent lines to Part Usage table
6	2	Append	Part No w/ Option Part No, Used On Part No w/ Part No	Sales Line Item w/ Flattened BOM, Flatten BOM w/ Product Hierarchy		Calculate extended quantity*, Replace part numbers**, and Add embedded lines to Part Usage table
7	3	Make	Sales Order No	Sales Line Item, System Orders		Sum Ship\$, Make System Order Value Table
8	4	Update	Sales Order No, Sales Order Line No	Sales Line Item, Part Usage	Order Type = Independent	Update Leveraged Revenue to Ship\$

Query #	Cal. Step	Query Type	Fields Joined	Tables Joined	Constraints	Action
9	4	Temp Table	Sales Order No, Part No	Part Usage	Order Type = "Embedded" or "Add-on"	Count lines grouped by Sales Order No, and Part No, Add to Part Usage Count table
10	4	Temp Table	Sales Order No, Part No	Part Usage Count, System Order Value		Calculate Leverage Revenue,*** and add to Leveraged Revenue Value Table
11	4	Update	Sales Order No, Part No	Leveraged Revenue Value, Part Usage	Order Type = "Embedded" or "Add-on"	Update Leveraged Revenue on Part Usage table
12	5	Temp Table	Sales Order No, Product Family	System Orders	Unique values only	Make List of Systems on Orders Table
13	5	Temp Table	Sales Order No, Product Family	List of Systems on Orders	Count of Group by Sales Order No > 1	Make Orders w/ Multiple Systems table
14	5	Update	Sales Order No, Sales Order Line No, Part No	Part Usage, System Orders	Order Type = "Embedded"	Update System Type to Product Family from Systems Order table
15	5	Update	Sales Order No, Part No	Part Usage, System Orders	Order Type = "Add-on"	Update System Type to Product Family from Systems Order table
16	5	Update	Sales Order No	Part Usage, Orders w/ Multiple Systems	Order Type = "Add-on"	Update System Type to "Multiple Systems"

Query #	Cal. Step	Query Type	Fields Joined	Tables Joined	Constraints	Action
17	6	Update	Part No	Part Usage, Product Cost		Update Std Cost and List Price
18	7	Update	Part No	Part Usage, Product Hierarchy		Update Part Desc, Life Cycle Stat, Part Intro Date, Part Disc Date, Part EOL Date

* Extended quantity equal the product of shipped quantity and the quantity used on.

** The part number in Part Usage table is updated to the Option Part No from the Flattened Bill of Material table.

*** The leveraged revenue is order value divided by the count of part usages.

Figure 9.2: Description of Queries in Demand Profiling Database

9.3 Appendix: Description of Optimization Model

Figure 9.3 provides a list of all of the optimization model inputs. The table also classifies each of the inputs into a category, defines its variable name to be used in the calculation, and provides the units for input. Figure 9.4 provides a copy of the input worksheet used in the optimization model. Figure 9.5 provides a copy of the input worksheet for the shipment rates and Figure 9.6 is a copy of the optimization model. The data has been removed from all of the figures.

Input	Input Category	Units
Part Class	Product Characteristics	Unitless
Part Number	Product Characteristics	Unitless
Part 1 Supplier	Product Characteristics	Unitless
Part 2 Supplier	Product Characteristics	Unitless
Part 3 Supplier	Product Characteristics	Unitless
Current Independent Supply Chain	Product Characteristics	Unitless
Current CTO Supply Chain	Product Characteristics	Unitless
Service Level Factor	Product Characteristics	Unitless
Assembly Cost	Product Characteristics	\$/unit
Part 1 Cost	Product Characteristics	\$/unit
Part 2 Cost	Product Characteristics	\$/unit
Part 3 Cost	Product Characteristics	\$/unit
Assemblies per pallet	Product Characteristics	Units/pallet
Assemblies Batch Size	Product Characteristics	Units/Batch
Part 1 per pallet	Product Characteristics	Units/pallet
Part 1 Batch Size	Product Characteristics	Units/Batch
Part 2 per pallet	Product Characteristics	Units/pallet
Part 2 Batch Size	Product Characteristics	Units/Batch
Part 3 per pallet	Product Characteristics	Units/pallet
Part 3 Batch Size	Product Characteristics	Units/Batch
Part 1 per Assembly	Product Characteristics	Units/Unit
Part 2 per Assembly	Product Characteristics	Units/Unit
Part 3 per Assembly	Product Characteristics	Units/Unit
Number of parts in Assembly	Product Characteristics	Units/Unit
Weight Per part	Product Characteristics	lbs/part
Average Demand (Total)	Demand Characteristics	Units/week
Average Demand (CTO)	Demand Characteristics	Units/week
Average Demand (Independent)	Demand Characteristics	Units/week
Std. Dev Demand (Total)	Demand Characteristics	Units/week
Std. Dev Demand (CTO)	Demand Characteristics	Units/week

Input	Input Category	Units
Std Dev. Demand (Independent)	Demand Characteristics	Units/week
Orders per week (Total)	Demand Characteristics	Orders/week
Orders per week (CTO)	Demand Characteristics	Orders/week
Orders per week (Independent)	Demand Characteristics	Orders/week
Part 1 Packaging Cost (Bulk)	Packaging Cost	\$/unit
Part 2 Packaging Cost (Bulk)	Packaging Cost	\$/unit
Part 3 Packaging Cost (Bulk)	Packaging Cost	\$/unit
Kit Packaging	Packaging Cost	\$/unit
Hub In Cost per pallet	Hub Cost	\$/pallet
Hub Picking Cost per pallet	Hub Cost	\$/pallet
Hub Storage Cost per pallet per week	Hub Cost	\$/pallet/wk
Hub Out Cost per pallet	Hub Cost	\$/pallet
Hub Allocation per pallet	Hub Cost	\$/pallet
Hub to Factory Freight per pallet	Freight Cost	\$/pallet
Shipment Method	Freight Cost	Unitless
Factory Pick/Pack Cost per unit	Pick/Pack Cost	\$/unit
3rd Party Pick/Pack Cost per unit	Pick/Pack Cost	\$/unit
Sup 1 Pick/Pack Cost per unit	Pick/Pack Cost	\$/unit
Sup 1 In Cost per pallet	Order Handling Cost	\$/pallet
Sup 1 Out Cost per pallet	Order Handling Cost	\$/pallet
Sup 1 Allocation per pallet	Order Handling Cost	\$/pallet
Factory In Cost per pallet	Order Handling Cost	\$/pallet
Factory Out Cost per pallet	Order Handling Cost	\$/pallet
IT Setup Cost (Supplier)	Supply Chain Setup Cost	\$
IT Setup Cost (Hub)	Supply Chain Setup Cost	\$
Amortization Period (Supplier)	Supply Chain Setup Cost	Years
Amortization Period (Hub)	Supply Chain Setup Cost	Years
IT Allocation % (Supplier)	Supply Chain Setup Cost	%
IT Allocation % (3rd Party Hub)	Supply Chain Setup Cost	%
Cost of Capital	Cost of Capital	Percent
Annual Revaluation %	Revaluation Rate	Percent
Lead Time Customer Independent	Lead Times	Weeks
Factory CTO Transformation Time	Lead Times	Weeks
Factory Independent Transformation Time	Lead Times	Days
Hub Independent Transformation Time	Lead Times	Days
Hub Pass through Transformation Time	Lead Times	Days
Sup 1 Independent Transformation Time	Lead Times	Days
Part 1 Lead Time from supplier	Lead Times	Weeks

Input	Input Category	Units
Part 2 Lead Time from supplier	Lead Times	Weeks
Part 3 Lead Time from supplier	Lead Times	Weeks
Supplier 1 shipment interval of parts	Order Intervals	Days
Hub Shipment Interval	Order Intervals	Days

Figure 9.3: Optimization Model Inputs

Figure 9.4: Input Worksheet for Optimization Model

	A	B	C	D	E	F	G	H	I
1	Input	Quantity	Units						
2	Part Class								
3	Part Number								
4	Service Level Factor		Unitless						
5	Average Demand		Units/week						
6	Average Demand (CTO)		Units/week						
7	Average Demand (Ind)		Units/week						
8	Std. Dev Demand		Units/week						
9	Std. Dev Demand (CTO)		Units/week						
10	Std Dev. Demand (Ind)		Units/week						
11	Orders per week		Orders/week						
12	Orders per week (CTO)		Orders/week						
13	Orders per week (Ind)		Orders/week						
14	Assy Cost		\$/unit						
15	Part 1 Cost		\$/unit						
16	Part 2 Cost		\$/unit						
17	Part 3 Cost		\$/unit						
18	Assy per pallet		Units/pallet						
19	Assy Batch Size		Units/Batch						
20	Part 1 per pallet		Units/pallet						
21	Part 1 Batch Size		Units/Batch						
22	Part 2 per pallet		Units/pallet						
23	Inverse of Part 2 batch size		Units/pallet						
24	Part 2 Batch Size		Units/Batch						
25	Part 3 par pallet		Units/pallet						
26	Inverse of Part 3 batch size		Units/pallet						
27	Part 3 Batch Size		Units/Batch						

Figure 9.4: Input Worksheet for Optimization Model

	A	B	C	D	E	F	G	H	I
28	Part 1 per Assy		Units/Unit						
29	Part 2 per Assy		Units/Unit						
30	Inverse of Part 2 per Assy		Units/Unit						
31	Part 3 per Assy		Units/Unit						
32	Inverse of Part 3 per Assy		Units/Unit						
33	Number of parts in Assy		Units/Unit						
34									
35	Hub In Cost per pallet		\$/pallet						
36	Hub Picking Cost per pallet		\$/pallet						
37	Hub Storage Cost per pallet per week		\$/pallet/wk						
38	Hub Out Cost per pallet		\$/pallet						
39	Hub Allocation per pallet		\$/pallet						
40									
41	Sup 1 In Cost per pallet		\$/pallet						
42	Sup 1 Out Cost per pallet		\$/pallet						
43	Sup 1 Allocation per pallet		\$/pallet						
44									
45	Factory In Cost per pallet		\$/pallet						
46	Factory Out Cost per pallet		\$/pallet						
47									
48	Weight Per part		lbs/part						

Figure 9.4: Input Worksheet for Optimization Model

	A	B	C	D	E	F	G	H	I
49	Weight per pallet (Assy)		lbs/pallet						
50	Weight per order (CTO)		lbs/order						
51	Weight per order (Ind)		lbs/order						
52	Hub to Factory Freight per pallet		\$/pallet						
53									
54	Factory Pick/Pack Cost per unit		\$/unit						
55	3rd Party Pick/Pack Cost per unit		\$/unit						
56	Sup 1 Pick/Pack Cost per unit		\$/unit						
57									
58	Cost of Capital		Percent						
59	Annual Revaluation %		Percent						
60									
61	Lead Time Customer Independent		weeks						
62	Factory CTO Transformation Time		weeks						
63	Factory Ind Transformation Time		Days						
64	Hub Ind Transformation Time		Days						
65	Hub Pass through Transformation Time		Days						
66	Sup 1 Ind Transformation Time		Days						
67	Part 1 Lead Time from supplier		weeks						

Figure 9.4: Input Worksheet for Optimization Model

	A	B	C	D	E	F	G	H	I
68	Part 2 Lead Time from supplier		weeks						
69	Part 3 Lead Time from supplier		weeks						
70	Supplier 1 shipment interval of parts		Days						
71	Hub Shipment Interval		Days						
72									
73	Part 1 Packaging Cost (Bulk)		\$/unit						
74	Part 2 Packaging Cost (Bulk)		\$/unit						
75	Part 3 Packaging Cost (Bulk)		\$/unit						
76	Kit Packaging		\$/unit						
77									
78	IT Setup Cost (Supplier)		\$						
79	IT Setup Cost (Hub)		\$						
80	Amortization Period (Supplier)		years						
81	Amortization Period (Hub)		years						
82	IT Allocation % (Supplier)		%						
83	IT Allocation % (3rd Party Hub)		%						
84									
85	Pick one shipping method per row by placing a 1 in the box.								

Figure 9.4: Input Worksheet for Optimization Model									
	A	B	C	D	E	F	G	H	I
86									
87			Next Day Air 10-100 lbs	Next Day Air > 100 lbs	2 Day Air 1- 100 lbs	2 Day Air > 100 lbs	Ground Small Package	LTL	Full Truck Load
88	Sup 1 to Hub Shipment Method (Part 1)								
89	Sup 1 to Hub Shipment Method (Assy)								
90	Sup 1 to Factory Shipment Method (Part 1)								
91	Sup 1 to Factory Shipment Method (Assy)								
92	Factory to Customer (Ind)								
93	Factory to Customer (CTO)								
94	Hub to Customer								
95	Sup to Customer								

Figure 9.4: Input Worksheet for Optimization Model

Figure 9.5: Input worksheet for shipment rates

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	For Cost Curves													
2														
3	Part Number	=Inputs for part!C\$4												
4	Weight per pallet (Assy)	=MIN('Inputs for part!C20,'Inputs for part!C19)**Inputs for part!C49												
5	Weight per pallet (Part 1)	=MIN('Inputs for part!C22,'Inputs for part!C21)**Inputs for part!C49												
6	Weight per order (CTO)	=Inputs for part!C\$51												
7	Weight per order (Ind)	=Inputs for part!C\$52												
8														
9	Distance	1500												
10														
11	Freight Type	Ave Distance	Ship Time (Days)	Fixed Cost	Cost/lbs	Min Cost	Max Cost	Cost per pallet (Assy)	Cost/pallet w/out min (Assy)	Cost per pallet (Part 1)	Cost/pallet w/out min (Part 1)	Cost per order (CTO)	Cost per order (Ind)	Cost per order (Ind) w/out min

Figure 9.5: Input worksheet for shipment rates

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
12	Next Day Air (1-9 lbs)	NA						=IF(\$B4>10,9999,MIN((MAX(\$D12+\$E12*B\$4),\$F12)), \$G12))	=IF(\$B4>10,9999,MIN((MAX(\$D12+\$E12*B\$4),\$F12)), \$G12))	=IF(\$B5>10,9999,MIN((MAX(\$D12+\$E12*B\$5),\$F12)), \$G12))	=IF(\$B5>10,9999,MIN((MAX(\$D12+\$E12*B\$5),\$F12)), \$G12))	=IF(\$B6>10,999,9,MIN((MAX(\$D12+\$E12*B\$6),\$F12)), \$G12))	=IF(\$B7>10,999,9,MIN((MAX(\$D12+\$E12*B\$7),\$F12)), \$G12))	=IF(\$B7>10,9999,MIN((MAX(\$D12+\$E12*B\$7),\$F12)), \$G12))
13	Next Day Air (10-100 lbs)	NA						=IF(\$B4>100,9999,MIN((MAX(\$D13+\$E13*(B\$4-10)),\$F13)), \$G13))	=IF(\$B4>100,9999,MIN((MAX(\$D13+\$E13*(B\$4-10)),\$F13)), \$G13))	=IF(\$B5>100,9999,MIN((MAX(\$D13+\$E13*(B\$5-10)),\$F13)), \$G13))	=IF(\$B5>100,9999,MIN((MAX(\$D13+\$E13*(B\$5-10)),\$F13)), \$G13))	=IF(\$B6>100,99,99,MIN((MAX(\$D13+\$E13*(B\$6-10)),\$F13)), \$G13))	=IF(\$B7>100,99,99,MIN((MAX(\$D13+\$E13*(B\$7-10)),\$F13)), \$G13))	=IF(\$B7>100,9999,MIN((MAX(\$D13+\$E13*(B\$7-10)),\$F13)), \$G13))
14	Next Day Air (>100 lbs)	NA						=IF(\$B4<100,9999,MIN((MAX(\$D14+\$E14*(B\$4)),\$F14)), \$G14))	=IF(\$B4<100,9999,MIN((MAX(\$D14+\$E14*(B\$4)),\$F14)), \$G14))	=IF(\$B5<100,9999,MIN((MAX(\$D14+\$E14*(B\$5)),\$F14)), \$G14))	=IF(\$B5<100,9999,MIN((MAX(\$D14+\$E14*(B\$5)),\$F14)), \$G14))	=IF(\$B6<100,99,99,MIN((MAX(\$D14+\$E14*(B\$6)),\$F14)), \$G14))	=IF(\$B7<100,99,99,MIN((MAX(\$D14+\$E14*(B\$7)),\$F14)), \$G14))	=IF(\$B7<100,9999,MIN((MAX(\$D14+\$E14*(B\$7)),\$F14)), \$G14))

Figure 9.5: Input worksheet for shipment rates

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
15	2 Day Air (1-100 lbs)	NA						=IF(\$B4>100,9999,MIN((MAX(\$D15+\$E15*\$B\$4),\$F15)),G15))	=IF(\$B4>100,9999,MIN((MAX(\$D15+\$E15*\$B\$4),\$F15)),G15))	=IF(\$B5>100,9999,MIN((MAX(\$D15+\$E15*\$B\$5),\$F15)),G15))	=IF(\$B5>100,9999,MIN((MAX(\$D15+\$E15*\$B\$5),\$F15)),G15))	=IF(\$B6>100,9999,MIN((MAX(\$D15+\$E15*\$B\$6),\$F15)),G15))	=IF(\$B7>100,9999,MIN((MAX(\$D15+\$E15*\$B\$7),\$F15)),G15))	=IF(\$B7>100,9999,MIN((MAX(\$D15+\$E15*\$B\$7),\$F15)),G15))
16	2 Day Air (>100 lbs)	NA						=IF(\$B4<100,9999,MIN((MAX(\$E16+\$B\$4),\$F16)),G16))	=IF(\$B4<100,9999,MIN((MAX(\$E16+\$B\$4),\$F16)),G16))	=IF(\$B5<100,9999,MIN((MAX(\$E16+\$B\$5),\$F16)),G16))	=IF(\$B5<100,9999,MIN((MAX(\$E16+\$B\$5),\$F16)),G16))	=IF(\$B6<100,9999,MIN((MAX(\$E16+\$B\$6),\$F16)),G16))	=IF(\$B7<100,9999,MIN((MAX(\$E16+\$B\$7),\$F16)),G16))	=IF(\$B7<100,9999,MIN((MAX(\$E16+\$B\$7),\$F16)),G16))
17	Ground Small Package							=IF(\$B4>100,9999,MIN((MAX(\$D17+\$E17*\$B\$4),\$F17)),G17))	=IF(\$B4>100,9999,MIN((MAX(\$D17+\$E17*\$B\$4),\$F17)),G17))	=IF(\$B5>100,9999,MIN((MAX(\$D17+\$E17*\$B\$5),\$F17)),G17))	=IF(\$B5>100,9999,MIN((MAX(\$D17+\$E17*\$B\$5),\$F17)),G17))	=IF(\$B6>100,9999,MIN((MAX(\$D17+\$E17*\$B\$6),\$F17)),G17))	=IF(\$B7>100,9999,MIN((MAX(\$D17+\$E17*\$B\$7),\$F17)),G17))	=IF(\$B7>100,9999,MIN((MAX(\$D17+\$E17*\$B\$7),\$F17)),G17))
18	Less Than Truck Load							=IF(\$B4<100,9999,MIN((MAX(\$E18*\$B\$4),\$F18)),G18))	=IF(\$B4<100,9999,MIN((MAX(\$E18*\$B\$4),\$F18)),G18))	=IF(\$B5<100,9999,MIN((MAX(\$E18*\$B\$5),\$F18)),G18))	=IF(\$B5<100,9999,MIN((MAX(\$E18*\$B\$5),\$F18)),G18))	=IF(\$B6<100,9999,MIN((MAX(\$E18*\$B\$6),\$F18)),G18))	=IF(\$B7<100,9999,MIN((MAX(\$E18*\$B\$7),\$F18)),G18))	=IF(\$B7<100,9999,MIN((MAX(\$E18*\$B\$7),\$F18)),G18))

Figure 9.5: Input worksheet for shipment rates

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
19	Full Truck Load							=IF(\$B4<1000,999,MIN(MAX(\$D19+\$E19*B\$4),\$F19))	=\$E19*B\$4	=IF(\$B5<1000,999,MIN(MAX(\$D19+\$E19*B\$5),\$F19))	=\$E19*B\$5	=\$E19*B\$6	=IF(\$B7<1000,999,MIN(MAX(\$D19+\$E19*B\$7),\$F19))	=\$E19*B\$7
20														
21	Switch from Ground to LTL if > 100 lbs or more than 6 packages													
22														
23	For Optimization													
24														
25	Part Number	=Inputs for part!C\$4												
26	Weight per pallet (Assy)	=MIN(Optimizer!D14,Inputs for part!C19)*Inputs for part!C49												
27	Weight per pallet (Part 1)	=MIN(Optimizer!D15,Inputs for part!C21)*Inputs for part!C49												
28	Weight per order (CTO)	=Inputs for part!C\$51												
29	Weight per order (Ind)	=Inputs for part!C\$52												
30														
31	Distance													

Figure 9.5: Input worksheet for shipment rates

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
32														
33	Freight Type	Ave Distance	Ship Time (Days)	Fixed Cost	Cost/lbs	Min Cost	Max Cost	Cost per pallet (Assy)	Cost/pallet w/out min (Assy)	Cost per pallet (Part 1)	Cost/pallet w/out min (Part 1)	Cost per order (CTO)	Cost per order (Ind)	Cost per order (Ind) w/out min
34	Next Day Air (1-9 lbs)	NA	=C12					=IF(\$B26 >10,9999,MIN((MAX((\$D34+\$E34*B\$4),\$F34)),\$G34))	=IF(\$B26 >10,9999,MIN((MAX((\$D34+\$E34*B\$4),\$F34)),\$G34))	=IF(\$B27 >10,9999,MIN((MAX((\$D34+\$E34*B\$5),\$F34)),\$G34))	=IF(\$B27 >10,9999,MIN((MAX((\$D34+\$E34*B\$5),\$F34)),\$G34))	=IF(\$B28 >10,999,MIN((MAX((\$D34+\$E34*B\$6),\$F34)),\$G34))	=IF(\$B29 >10,999,MIN((MAX((\$D34+\$E34*B\$7),\$F34)),\$G34))	=IF(\$B29 >10,9999,MIN((MAX((\$D34+\$E34*B\$7),\$F34)),\$G34))
35	Next Day Air (10-100 lbs)	NA	=C13					=IF(\$B26 >100,999,MIN((MAX((\$D35+\$E35*B\$4-10)),\$F35)),\$G35))	=IF(\$B26 >100,999,MIN((MAX((\$D35+\$E35*B\$4-10)),\$F35)),\$G35))	=IF(\$B27 >100,999,MIN((MAX((\$D35+\$E35*B\$5-10)),\$F35)),\$G35))	=IF(\$B27 >100,999,MIN((MAX((\$D35+\$E35*B\$5-10)),\$F35)),\$G35))	=IF(\$B28 >100,999,MIN((MAX((\$D35+\$E35*B\$6-10)),\$F35)),\$G35))	=IF(\$B29 >100,999,MIN((MAX((\$D35+\$E35*B\$7-10)),\$F35)),\$G35))	=IF(\$B29 >100,999,MIN((MAX((\$D35+\$E35*B\$7-10)),\$F35)),\$G35))
36	Next Day Air (>100 lbs)	NA	=C14					=IF(\$B26 <100,999,MIN((MAX((\$D36+\$E36*B\$4)),\$F36)),\$G36))	=IF(\$B26 <100,999,MIN((MAX((\$D36+\$E36*B\$4)),\$F36)),\$G36))	=IF(\$B27 <100,999,MIN((MAX((\$D36+\$E36*B\$5)),\$F36)),\$G36))	=IF(\$B27 <100,999,MIN((MAX((\$D36+\$E36*B\$5)),\$F36)),\$G36))	=IF(\$B28 <100,999,MIN((MAX((\$D36+\$E36*B\$6)),\$F36)),\$G36))	=IF(\$B29 <100,999,MIN((MAX((\$D36+\$E36*B\$7)),\$F36)),\$G36))	=IF(\$B29 <100,999,MIN((MAX((\$D36+\$E36*B\$7)),\$F36)),\$G36))

Figure 9.5: Input worksheet for shipment rates

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
37	2 Day Air (1-100 lbs)	NA	=C15					=IF(\$B26 >100,999,MIN((MAX(AX((\$D37+\$E37*\$B\$4),\$F37)),\$G37))	=IF(\$B26 >100,999,MIN((MAX(AX((\$D37+\$E37*\$B\$4),\$F37)),\$G37))	=IF(\$B27 >100,999,MIN((MAX(AX((\$D37+\$E37*\$B\$5),\$F37)),\$G37))	=IF(\$B27 >100,999,MIN((MAX(AX((\$D37+\$E37*\$B\$5),\$F37)),\$G37))	=IF(\$B28 >100,999,MIN((MAX(AX((\$D37+\$E37*\$B\$6),\$F37)),\$G37))	=IF(\$B29 >100,999,MIN((MAX(AX((\$D37+\$E37*\$B\$7),\$F37)),\$G37))	=IF(\$B29 >100,999,MIN((MAX(AX((\$D37+\$E37*\$B\$7),\$F37)),\$G37))
38	2 Day Air (>100 lbs)	NA	=C16					=IF(\$B26 <100,999,MIN((MAX(AX((\$D38+\$E38*\$B\$4),\$F38)),\$G38))	=IF(\$B26 <100,999,MIN((MAX(AX((\$E38*\$B\$4),\$F38)),\$G38))	=IF(\$B27 <100,999,MIN((MAX(AX((\$D38+\$E38*\$B\$5),\$F38)),\$G38))	=IF(\$B27 <100,999,MIN((MAX(AX((\$E38*\$B\$5),\$F38)),\$G38))	=IF(\$B28 <100,999,MIN((MAX(AX((\$D38+\$E38*\$B\$6),\$F38)),\$G38))	=IF(\$B29 <100,999,MIN((MAX(AX((\$D38+\$E38*\$B\$7),\$F38)),\$G38))	=IF(\$B29 <100,999,MIN((MAX(AX((\$D38+\$E38*\$B\$7),\$F38)),\$G38))
39	Ground Small Package		=C17					=IF(\$B26 >100,999,MIN((MAX(AX((\$D39+\$E39*\$B\$4),\$F39)),\$G39))	=IF(\$B26 >100,999,MIN((MAX(AX((\$D39+\$E39*\$B\$4),\$F39)),\$G39))	=IF(\$B27 >100,999,MIN((MAX(AX((\$D39+\$E39*\$B\$5),\$F39)),\$G39))	=IF(\$B27 >100,999,MIN((MAX(AX((\$D39+\$E39*\$B\$5),\$F39)),\$G39))	=IF(\$B28 >100,999,MIN((MAX(AX((\$D39+\$E39*\$B\$6),\$F39)),\$G39))	=IF(\$B29 >100,999,MIN((MAX(AX((\$D39+\$E39*\$B\$7),\$F39)),\$G39))	=IF(\$B29 >100,999,MIN((MAX(AX((\$D39+\$E39*\$B\$7),\$F39)),\$G39))
40	Less Than Truck Load		=C18					=IF(\$B26 <100,999,MIN((MAX(AX((\$D40+\$E40*\$B\$4),\$F40)),\$G40))	=IF(\$B26 <100,999,MIN((MAX(AX((\$D40+\$E40*\$B\$4),\$F40)),\$G40))	=IF(\$B27 <100,999,MIN((MAX(AX((\$D40+\$E40*\$B\$5),\$F40)),\$G40))	=IF(\$B27 <100,999,MIN((MAX(AX((\$D40+\$E40*\$B\$5),\$F40)),\$G40))	=IF(\$B28 <100,999,MIN((MAX(AX((\$D40+\$E40*\$B\$6),\$F40)),\$G40))	=IF(\$B29 <100,999,MIN((MAX(AX((\$D40+\$E40*\$B\$7),\$F40)),\$G40))	=IF(\$B29 <100,999,MIN((MAX(AX((\$D40+\$E40*\$B\$7),\$F40)),\$G40))

Figure 9.5: Input worksheet for shipment rates

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	
41	Full Truck Load		=C19					=IF(\$B26<1000,99,MIN(MAX((\$D41+\$E41*B\$4),\$F41)),\$G41))	=\$E41*B\$4	=IF(\$B27<1000,99,MIN(MAX((\$D41+\$E41*B\$5),\$F41)),\$G41))	=\$E41*B\$5	=\$E41*B\$6	=IF(\$B29<1000,99,MIN(MAX((\$D41+\$E41*B\$7),\$F41)),\$G41))	=\$E41*B\$7	
42															
43	Switch from Ground to LTL if > 100 lbs or more than 6 packages														
44															
45		Next Day Air 1-10 lbs	Next Day Air 10-100 lbs	Next Day Air > 100 lbs	2 Day Air 1-100 lbs	2 Day Air > 100 lbs	Ground Small Package	LTL	Full Truck Load						
46	Sup 1 to Hub Shipment Method (Part 1)	=C\$34	=C\$35	=C\$36	=C\$37	=C\$38	=C\$39	=C\$40	=C\$41						
47	Sup 1 to Hub Shipment Method (Assy)	=C\$34	=C\$35	=C\$36	=C\$37	=C\$38	=C\$39	=C\$40	=C\$41						
48	Sup 1 to Factory Shipment Method (Part 1)	=C\$34	=C\$35	=C\$36	=C\$37	=C\$38	=C\$39	=C\$40	=C\$41						
49	Sup 1 to Factory Shipment Method (Assy)	=C\$34	=C\$35	=C\$36	=C\$37	=C\$38	=C\$39	=C\$40	=C\$41						
50	Factory to Customer (Ind)	=C\$34	=C\$35	=C\$36	=C\$37	=C\$38	=C\$39	=C\$40	=C\$41						
51	Factory to Customer (CTO)	=C\$34	=C\$35	=C\$36	=C\$37	=C\$38	=C\$39	=C\$40	=C\$41						

Figure 9.5: Input worksheet for shipment rates														
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
52	Hub to Customer	=C\$34	=C\$35	=C\$36	=C\$37	=C\$38	=C\$39	=C\$40	=C\$41					
53	Sup to Customer	=C\$34	=C\$35	=C\$36	=C\$37	=C\$38	=C\$39	=C\$40	=C\$41					

Figure 9.5: Input Worksheet for Shipment Rates

Figure 9.6: Optimization Worksheet

	A	B	C	D	E	F	G	H	I	J
1	Decision Variables									
2										
3		Sup 1 Direct	3rd Party Direct w Kit	3rd Party Kit CTO to HUB	Hub F Kits	Hub S1 Kits	Skip Hub S1 Kits	Skip Hub F Kits	Total	
4	CTO	0	1	0	0	0	0	0	=SUM(B4:H4)	
5	Ind	0	0	0	0	0	0	1	=SUM(B5:H5)	
6										
7	Path Total	=SUM(B4:B5)	=SUM(C4:C5)	=SUM(D4:D5)	=SUM(E4:E5)	=SUM(F4:F5)	=SUM(G4:G5)	=SUM(H4:H5)		
8	Path Constraint	=B7/2	=C7/2	=D7/2	=E7/2	=F7/2	=G7/2	=H7/2		
9	Path On/off	0	0	0	1	0	0	1		
10										
11	Derived Values									
12										
13		Max		Value		Min				
14	Batch Size Assy	= 'Inputs'!B18	> =	= 'Inputs'!B19	> =	1				
15	Batch Size Part 1	= 'Inputs'!B20	> =	= 'Inputs'!B21	> =	1				
16	Batch Size Part 2	=IF('Inputs'!B22=0,1,'Inputs'!B22)	> =	= 'Inputs'!B24	> =	0				
17	Batch Size Part 3	=IF('Inputs'!B25=0,1,'Inputs'!B25)	> =	= 'Inputs'!B27	> =	0				
18	Shipment Interval Sup 1	21	> =	= 'Inputs'!B70	> =	1				
19										

Figure 9.6: Optimization Worksheet

	A	B	C	D	E	F	G	H	I	J
20		Next Day Air 1-10 lbs	Next Day Air 10-100 lbs	Next Day Air > 100 lbs	2 Day Air 1- 100 lbs	2 Day Air > 100 lbs	Ground Small Package	LTL	Full Truck Load	Total
21	Sup 1 to Hub Shipment Method (Part 1)	=Inputs!B88	=Inputs!C88	=Inputs!D88	=Inputs!E88	=Inputs!F88	=Inputs!G88	=Inputs!H88	=Inputs!I88	=SUM(B21:I 21)
22	Sup 1 to Hub Shipment Method (Assy)	=Inputs!B89	=Inputs!C89	=Inputs!D89	=Inputs!E89	=Inputs!F89	=Inputs!G89	=Inputs!H89	=Inputs!I89	=SUM(B22:I 22)
23	Sup 1 to Factory Shipment Method (Part 1)	=Inputs!B90	=Inputs!C90	=Inputs!D90	=Inputs!E90	=Inputs!F90	=Inputs!G90	=Inputs!H90	=Inputs!I90	=SUM(B23:I 23)
24	Sup 1 to Factory Shipment Method (Assy)	=Inputs!B91	=Inputs!C91	=Inputs!D91	=Inputs!E91	=Inputs!F91	=Inputs!G91	=Inputs!H91	=Inputs!I91	=SUM(B24:I 24)
25	Factory to Customer (Ind)	=Inputs!B92	=Inputs!C92	=Inputs!D92	=Inputs!E92	=Inputs!F92	=Inputs!G92	=Inputs!H92	=Inputs!I92	=SUM(B25:I 25)
26	Factory to Customer (CTO)	=Inputs!B93	=Inputs!C93	=Inputs!D93	=Inputs!E93	=Inputs!F93	=Inputs!G93	=Inputs!H93	=Inputs!I93	=SUM(B26:I 26)
27	Hub to Customer	=Inputs!B94	=Inputs!C94	=Inputs!D94	=Inputs!E94	=Inputs!F94	=Inputs!G94	=Inputs!H94	=Inputs!I94	=SUM(B27:I 27)
28	Sup to Customer	=Inputs!B95	=Inputs!C95	=Inputs!D95	=Inputs!E95	=Inputs!F95	=Inputs!G95	=Inputs!H95	=Inputs!I95	=SUM(B28:I 28)
29										
30										
31										

Figure 9.6: Optimization Worksheet

	A	B	C	D	E	F	G	H	I	J
32	Demand (Units/wk)									
33										
34		Sup 1 Direct	3rd Party Direct w Kit	3rd Party Kit CTO to HUB	Hub F Kits	Hub S1 Kits	Skip Hub S1 Kits	Skip Hub F Kits	Total	
35	CTO	=B4*Inputs! \$B6	=C4*Inputs! \$B6	=D4*Inputs! \$B6	=E4*Inputs! \$B6	=F4*Inputs! \$B6	=G4*Inputs! \$B6	=H4*Inputs! \$B6	=SUM(B35: H35)	
36	Ind	=B5*Inputs! \$B7	=C5*Inputs! \$B7	=D5*Inputs! \$B7	=E5*Inputs! \$B7	=F5*Inputs! \$B7	=G5*Inputs! \$B7	=H5*Inputs! \$B7	=SUM(B36: H36)	
37	Total	=SUM(B35:B 36)	=SUM(C35: C36)	=SUM(D35: D36)	=SUM(E35:E 36)	=SUM(F35:F 36)	=SUM(G35: G36)	=SUM(H35: H36)	=SUM(I35:I3 6)	
38										
39	Shipment Cost per unit									
40										
41		Next Day Air 1-10 lbs	Next Day Air 10-100 lbs	Next Day Air > 100 lbs	2 Day Air 1- 100 lbs	2 Day Air > 100 lbs	Ground Small Package	LTL	Full Truck Load	
42	Sup 1 to Hub Shipment Method (Part 1)	=Ship!\$K34/ ((\$D15))	=Ship!\$K35/ ((\$D15))	=Ship!\$K36/ ((\$D15))	=Ship!\$K37/ ((\$D15))	=Ship!\$K38/ ((\$D15))	=Ship!\$K39/ (\$D15)	=Ship!\$K40/ ((\$D15))	=Ship!\$K41/ ((\$D15))	
43	Sup 1 to Hub Shipment Method (Assy)	=Ship!\$I34/ \$D14)	=Ship!\$I35/ \$D14)	=Ship!\$I36/ \$D14)	=Ship!\$I37/ MIN(\$D14,'In puts!\$B18)	=Ship!\$I38/ \$D14)	=Ship!\$I39/ \$D14)	=Ship!\$I40/ \$D14)	=Ship!\$I41/ \$D14)	
44	Sup 1 to Factory Shipment Method (Part 1)	=Ship!\$J34/ ((\$D15))	=Ship!\$J35/ ((\$D15))	=Ship!\$J36/ ((\$D15))	=Ship!\$J37/ ((\$D15))	=Ship!\$J38/ ((\$D15))	=Ship!\$J39/ ((\$D15))	=Ship!\$J40/ ((\$D15))	=Ship!\$J41/ ((\$D15))	

Figure 9.6: Optimization Worksheet

	A	B	C	D	E	F	G	H	I	J
45	Sup 1 to Factory Shipment Method (Assy)	=Ship!\$H34 /(\$D14)	=Ship!\$H35 /(\$D14)	=Ship!\$H36 /(\$D14)	=Ship!\$H37 /(\$D14)	=Ship!\$H38 /(\$D14)	=Ship!\$H39 /(\$D14)	=Ship!\$H40 /(\$D14)	=Ship!\$H41 /(\$D14)	
46	Factory to Customer (Ind)	=Ship!\$N34 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$N35 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$N36 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$N37 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$N38 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$N39 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$N40 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$N41 /Inputs!\$B7* /Inputs!\$B13	
47	Factory to Customer (CTO)	=Ship!\$L34/ Inputs!\$B6* /Inputs!\$B12	=Ship!\$L35/ Inputs!\$B6* /Inputs!\$B12	=Ship!\$L36/ Inputs!\$B6* /Inputs!\$B12	=Ship!\$L37/ Inputs!\$B6* /Inputs!\$B12	=Ship!\$L38/ Inputs!\$B6* /Inputs!\$B12	=Ship!\$L39/ Inputs!\$B6* /Inputs!\$B12	=Ship!\$L40/ Inputs!\$B6* /Inputs!\$B12	=Ship!\$L41/ Inputs!\$B6* /Inputs!\$B12	
48	Hub to Customer	=Ship!\$M34 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$M35 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$M36 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$M37 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$M38 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$M39 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$M40 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$M41 /Inputs!\$B7* /Inputs!\$B13	
49	Sup to Customer	=Ship!\$M34 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$M35 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$M36 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$M37 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$M38 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$M39 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$M40 /Inputs!\$B7* /Inputs!\$B13	=Ship!\$M41 /Inputs!\$B7* /Inputs!\$B13	
50										
51		Next Day Air 1-10 lbs	Next Day Air 10-100 lbs	Next Day Air > 100 lbs	2 Day Air 1-100 lbs	2 Day Air > 100 lbs	Ground Small Package	LTL	Full Truck Load	Total
52	Sup 1 to Hub Shipment Method (Part 1)	=B42*B21	=C42*C21	=D42*D21	=E42*E21	=F42*F21	=G42*G21	=H42*H21	=I42*I21	=SUM(B52:I52)
53	Sup 1 to Hub Shipment Method (Assy)	=B43*B22	=C43*C22	=D43*D22	=E43*E22	=F43*F22	=G43*G22	=H43*H22	=I43*I22	=SUM(B53:I53)
54	Sup 1 to Factory Shipment Method (Part 1)	=B44*B23	=C44*C23	=D44*D23	=E44*E23	=F44*F23	=G44*G23	=H44*H23	=I44*I23	=SUM(B54:I54)

Figure 9.6: Optimization Worksheet

	A	B	C	D	E	F	G	H	I	J
55	Sup 1 to Factory Shipment Method (Assy)	=B45*B24	=C45*C24	=D45*D24	=E45*E24	=F45*F24	=G45*G24	=H45*H24	=I45*I24	=SUM(B55:I55)
56	Factory to Customer (Ind)	=B46*B25	=C46*C25	=D46*D25	=E46*E25	=F46*F25	=G46*G25	=H46*H25	=I46*I25	=SUM(B56:I56)
57	Factory to Customer (CTO)	=B47*B26	=C47*C26	=D47*D26	=E47*E26	=F47*F26	=G47*G26	=H47*H26	=I47*I26	=SUM(B57:I57)
58	Hub to Customer	=B48*B27	=C48*C27	=D48*D27	=E48*E27	=F48*F27	=G48*G27	=H48*H27	=I48*I27	=SUM(B58:I58)
59	Sup to Customer	=B49*B28	=C49*C28	=D49*D28	=E49*E28	=F49*F28	=G49*G28	=H49*H28	=I49*I28	=SUM(B59:I59)
60										
61	Shipment Time									
62										
63		Next Day Air 1-10 lbs	Next Day Air 10-100 lbs	Next Day Air > 100 lbs	2 Day Air 1-100 lbs	2 Day Air > 100 lbs	Ground Small Package	LTL	Full Truck Load	
64	Sup 1 to Hub Shipment Method (Part 1)	=Ship!B46	=Ship!C46	=Ship!D46	=Ship!E46	=Ship!F46	=Ship!G46	=Ship!H46	=Ship!I46	
65	Sup 1 to Hub Shipment Method (Assy)	=Ship!B47	=Ship!C47	=Ship!D47	=Ship!E47	=Ship!F47	=Ship!G47	=Ship!H47	=Ship!I47	

Figure 9.6: Optimization Worksheet

	A	B	C	D	E	F	G	H	I	J
66	Sup 1 to Factory Shipment Method (Part 1)	=Ship!B48	=Ship!C48	=Ship!D48	=Ship!E48	=Ship!F48	=Ship!G48	=Ship!H48	=Ship!I48	
67	Sup 1 to Factory Shipment Method (Assy)	=Ship!B49	=Ship!C49	=Ship!D49	=Ship!E49	=Ship!F49	=Ship!G49	=Ship!H49	=Ship!I49	
68	Factory to Customer (Ind)	=Ship!B50	=Ship!C50	=Ship!D50	=Ship!E50	=Ship!F50	=Ship!G50	=Ship!H50	=Ship!I50	
69	Factory to Customer (CTO)	=Ship!B51	=Ship!C51	=Ship!D51	=Ship!E51	=Ship!F51	=Ship!G51	=Ship!H51	=Ship!I51	
70	Hub to Customer	=Ship!B52	=Ship!C52	=Ship!D52	=Ship!E52	=Ship!F52	=Ship!G52	=Ship!H52	=Ship!I52	
71	Sup to Customer	=Ship!B53	=Ship!C53	=Ship!D53	=Ship!E53	=Ship!F53	=Ship!G53	=Ship!H53	=Ship!I53	
72										
73		Next Day Air 1-10 lbs	Next Day Air 10-100 lbs	Next Day Air > 100 lbs	2 Day Air 1-100 lbs	2 Day Air > 100 lbs	Ground Small Package	LTL	Full Truck Load	Total
74	Sup 1 to Hub Shipment Method (Part 1)	=B64*B21	=C64*C21	=D64*D21	=E64*E21	=F64*F21	=G64*G21	=H64*H21	=I64*I21	=SUM(B74:I74)
75	Sup 1 to Hub Shipment Method (Assy)	=B65*B22	=C65*C22	=D65*D22	=E65*E22	=F65*F22	=G65*G22	=H65*H22	=I65*I22	=SUM(B75:I75)

Figure 9.6: Optimization Worksheet										
	A	B	C	D	E	F	G	H	I	J
76	Sup 1 to Factory Shipment Method (Part 1)	=B66*B23	=C66*C23	=D66*D23	=E66*E23	=F66*F23	=G66*G23	=H66*H23	=I66*I23	=SUM(B76:I76)
77	Sup 1 to Factory Shipment Method (Assy)	=B67*B24	=C67*C24	=D67*D24	=E67*E24	=F67*F24	=G67*G24	=H67*H24	=I67*I24	=SUM(B77:I77)
78	Factory to Customer (Ind)	=B68*B25	=C68*C25	=D68*D25	=E68*E25	=F68*F25	=G68*G25	=H68*H25	=I68*I25	=SUM(B78:I78)
79	Factory to Customer (CTO)	=B69*B26	=C69*C26	=D69*D26	=E69*E26	=F69*F26	=G69*G26	=H69*H26	=I69*I26	=SUM(B79:I79)
80	Hub to Customer	=B70*B27	=C70*C27	=D70*D27	=E70*E27	=F70*F27	=G70*G27	=H70*H27	=I70*I27	=SUM(B80:I80)
81	Sup to Customer	=B71*B28	=C71*C28	=D71*D28	=E71*E28	=F71*F28	=G71*G28	=H71*H28	=I71*I28	=SUM(B81:I81)
82										
83	Supply Chain Length Assy (Days)									
84										
85		Sup 1 Direct	3rd Party Direct w Kit	3rd Party Kit CTO to HUB	Hub F Kits	Hub S1 Kits	Skip Hub S1 Kits	Skip Hub F Kits		
86	Supplier Order Process Time	=Inputs!B66	=Inputs!B66	=Inputs!B66	=Inputs!B66	=Inputs!B66	=Inputs!B66	=Inputs!B66		
87	Supplier to Shipment Time	=J81	=J74	=J74	=J74	=J75	=J77	=J76		

Figure 9.6: Optimization Worksheet

	A	B	C	D	E	F	G	H	I	J
88	Supplier Order Interval Time	0	=D18	=D18	=D18	=D18	=D18	=D18		
89	Hub Transformation Time	0	=Inputs!B64	=Inputs!B65*2	=Inputs!B65	=Inputs!B65	0	0		
90	Hub to _____ Shipment Time	0	=J80	0	0	0	0	0		
91	Hub Order Interval Time	0	0	=Inputs!B71*2	=Inputs!B71	=Inputs!B71	0	0		
92	Factory Transformation Time	0	0	=Inputs!\$B62*7	=(Inputs!\$B62*7*E4*Inputs!\$B6/Inputs!\$B5+Inputs!\$B7/Inputs!\$B5*Inputs!\$B63*E5+(1-E5)*Inputs!\$B7/Inputs!\$B5*Inputs!\$B62*7+(1-E4)*Inputs!\$B6/Inputs!\$B5*Inputs!\$B63)*E9	=(Inputs!\$B62*7*F4*Inputs!\$B6/Inputs!\$B5+Inputs!\$B7/Inputs!\$B5*Inputs!\$B63*F5+(1-F5)*Inputs!\$B7/Inputs!\$B5*Inputs!\$B62*7+(1-F4)*Inputs!\$B6/Inputs!\$B5*Inputs!\$B63)*F9	=(Inputs!\$B62*7*G4*Inputs!\$B6/Inputs!\$B5+Inputs!\$B7/Inputs!\$B5*Inputs!\$B63*G5+(1-G5)*Inputs!\$B7/Inputs!\$B5*Inputs!\$B62*7+(1-G4)*Inputs!\$B6/Inputs!\$B5*Inputs!\$B63)*G9	=(Inputs!\$B62*7*H4*Inputs!\$B6/Inputs!\$B5+Inputs!\$B7/Inputs!\$B5*Inputs!\$B63*H5+(1-H5)*Inputs!\$B7/Inputs!\$B5*Inputs!\$B62*7+(1-H4)*Inputs!\$B6/Inputs!\$B5*Inputs!\$B63)*H9		

Figure 9.6: Optimization Worksheet

	A	B	C	D	E	F	G	H	I	J
93	Factory to Customer Shipment Time	0	0	=J79	=($J79 * E4 * Inputs!B6 / Inputs!B5 + Inputs!B7 / Inputs!B5 * J78 * E5 + (1 - E5) * Inputs!B7 / Inputs!B5 * J79 + (1 - E4) * Inputs!B6 / Inputs!B5 * J78$) * E9	=($J79 * F4 * Inputs!B6 / Inputs!B5 + Inputs!B7 / Inputs!B5 * J78 * F5 + (1 - F5) * Inputs!B7 / Inputs!B5 * J79 + (1 - F4) * Inputs!B6 / Inputs!B5 * J78$) * F9	=($J79 * G4 * Inputs!B6 / Inputs!B5 + Inputs!B7 / Inputs!B5 * J78 * G5 + (1 - G5) * Inputs!B7 / Inputs!B5 * J79 + (1 - G4) * Inputs!B6 / Inputs!B5 * J78$) * G9	=($J79 * H4 * Inputs!B6 / Inputs!B5 + Inputs!B7 / Inputs!B5 * J78 * H5 + (1 - H5) * Inputs!B7 / Inputs!B5 * J79 + (1 - H4) * Inputs!B6 / Inputs!B5 * J78$) * H9		
94	Total	=SUM(B86:B93)	=SUM(C86:C93)	=SUM(D86:D93)	=SUM(E86:E93)	=SUM(F86:F93)	=SUM(G86:G93)	=SUM(H86:H93)		
95										
96	Supplier 1 Commitment Time	=Inputs!B61*7	=Inputs!B67*7	=Inputs!B67*7	=Inputs!B67*7	=Inputs!B67*7	=Inputs!B67*7	=Inputs!B67*7		
97	Hub Commitment Time	0	=Inputs!B61*7	=Inputs!B71+Inputs!B65	=Inputs!B71+Inputs!B65	=Inputs!B71+Inputs!B65	0	0		
98	Factory Commitment Time	0	0	=Inputs!B61*7	=Inputs!B61*7	=Inputs!B61*7	=Inputs!B61*7	=Inputs!B61*7		
99										
100	Supplier 1 Fulfillment Time	=(Inputs!B67)*7+B87-J74	=C96	=D96	=E96	=F96	=(Inputs!B67)*7+J77-J75	=(Inputs!B67)*7+J76-J74		
101	Hub Fulfillment Time	0	=(C96+C90+C89+C88)	=(D96+D90+D89+D88)	=(E96+E90+E89+E88)	=(F96+F90+F89+F88)	0	0		

Figure 9.6: Optimization Worksheet

	A	B	C	D	E	F	G	H	I	J
102	Factory Fulfillment Time	0	0	$=((D97+D93+D92+D91))$	$=((E97+E93+E92+E91))$	$=((F97+F93+F92+F91))$	$=((G96+G93+G92+G88))$	$=((H96+H93+H92+H88))$		
103										
104	Supplier 1 Inventory Time	$=B108*(B100-B96)$	$=C108*(C100-C96)$	$=D108*(D100-D96)$	$=E108*(E100-E96)$	$=F108*(F100-F96)$	$=G108*(G100-G96)$	$=H108*(H100-H96)$		
105	Hub/3PL Inventory Time	$=B109*(B101-B97)$	$=C109*(C101-C97)$	$=D109*(D101-D97)$	$=E109*(E101-E97)$	$=F109*(F101-F97)$	$=G109*(G101-G97)$	$=H109*(H101-H97)$		
106	Factory Inventory Time	$=B110*(B102-B98)$	$=C110*(C102-C98)$	$=D110*(D102-D98)$	$=E110*(E102-E98)$	$=F110*(F102-F98)$	$=G110*(G102-G98)$	$=H110*(H102-H98)$		
107										
108	Supplier 1 Inventory Time Forcing Variable	1	0	0	0	0	0	0		
109	Hub/3PL Inventory Time Forcing Variable	0	1	1	1	1	0	0		
110	Factory Inventory Time Forcing Variable	0	0	0	0	0	1	1		
111										
112	Supplier 1 Inventory Time Constraint	$=B100*(1-B108)$	$=C100*(1-C108)$	$=D100*(1-D108)$	$=E100*(1-E108)$	$=F100*(1-F108)$	$=G100*(1-G108)$	$=H100*(1-H108)$		

Figure 9.6: Optimization Worksheet

	A	B	C	D	E	F	G	H	I	J
113	Hub/3PL Inventory Time Constraint	=B101*(1-B109)	=C101*(1-C109)	=D101*(1-D109)	=E101*(1-E109)	=F101*(1-F109)	=G101*(1-G109)	=H101*(1-H109)		
114	Factory Inventory Time Constraint	=B102*(1-B110)	=C102*(1-C110)	=D102*(1-D110)	=E102*(1-E110)	=F102*(1-F110)	=G102*(1-G110)	=H102*(1-H110)		
115										
116		Value of excess inventory from batching effect								
117										
118		Assy	Part 1	Part 2	Part 3					
119	Supplier 1 Batching	=0*B125	=0*C125	=D129*D125*(((D16)*Inputs!B30-\$B37-\$F37-\$G37)*Inputs!\$B16)	=E130*E125*(((D17)*Inputs!B32-\$B37-\$F37-\$G37)*Inputs!\$B17)					
120	3rd Party Hub Batching	=0*B126	=C126*((D15)/Inputs!\$B28-\$C37-\$D37)*Inputs!\$B15	=D129*D126*(((D16)*Inputs!\$B30-\$D37-\$C37)*Inputs!\$B16)	=E130*E126*(((D17)*Inputs!\$B32-\$C37-\$D37)*Inputs!\$B17)					
121	Hub Batching	=B127*((D14)-\$D37-\$F37)*Inputs!\$B14	=C127*((D15)/Inputs!\$B28-\$E37)*Inputs!\$B15	=D129*D127*(((D16)*Inputs!\$B30-\$E37)*Inputs!\$B16)	=E130*E127*(((D17)*Inputs!\$B32-\$E37)*Inputs!\$B17)					
122	Factory Batching	=B128*((D14)-\$D37-\$F37-\$G37)*Inputs!\$B14	=C128*((D15)/Inputs!\$B28-\$E37-\$H37)*Inputs!\$B15	=D129*D128*(((D16)*Inputs!\$B30-\$E37-\$H37)*Inputs!\$B16)	=E130*E128*((D17)*Inputs!\$B32-\$E37-\$H37)*Inputs!\$B17					

Figure 9.6: Optimization Worksheet

	A	B	C	D	E	F	G	H	I	J
123										
124		Assy	Part 1	Part 2	Part 3					
125	Supplier 1 Batching Forcing Variable	0	0	0	0					
126	3rd Party Hub Batching Forcing Variable	0	1	0	0					
127	Hub Batching Forcing Variable	1	1	0	0					
128	Factory Batching Forcing Variable	1	0	1	0					
129	Part 2 Forcing Variable		0							
130	Part 3 Forcing Variable			0						
131										
132		Assy	Part 1	Part 2	Part 3					
133	Supplier 1 Batching Constraint	0	0	=((\$D16)*In puts!\$B30- \$B37-\$F37- \$G37)	=((\$D17)*In puts!\$B32- \$B37-\$F37- \$G37)					

Figure 9.6: Optimization Worksheet

	A	B	C	D	E	F	G	H	I	J
134	3rd Party Hub Batching Constraint	0	$= (D14 / \text{Inputs!}B28 - C37 - D37) / 10000$	$= ((\$D16) * \text{Inputs!}B30 - \$D37 - C37)$	$= ((\$D17) * \text{Inputs!}B32 - \$D37 - C37)$					
135	Hub Batching Constraint	$= (D14 - D37 - F37) / 10000$	$= (D14 / \text{Inputs!}B28 - E37) / 10000$	$= ((\$D16) * \text{Inputs!}B30 - \$E37)$	$= ((\$D17) * \text{Inputs!}B32 - \$E37)$					
136	Factory Batching Constraint	$= (D14 - D37 - F37 - G37) / 10000$	$= (D14 / \text{Inputs!}B28 - E37 - H37) / 10000$	$= ((\$D16) * \text{Inputs!}B30 - \$E37 - \$H37)$	$= ((\$D17) * \text{Inputs!}B32 - \$E37 - \$H37)$					
137	Part 2 Constraint			$= (\text{Inputs!}B\$33 - 1) / \text{Inputs!}B\33						
138	Part 3 Constraint				$= (\text{Inputs!}B\$33 - 2) / \text{Inputs!}B\33					
139										
140		Variable		Constraint						
141	S1 Batching Variable	1	>=	$= (B4 + B5 + F4 + F5 + G4 + G5) / 6$						
142	3PL Batching Variable	0	>=	$= \text{SUM}(C4 : D5) / 4$						
143	Hub Batching Variable	0	>=	$= (D4 + D5 + F4 + F5) / 4$						
144	Factory Assy Batching Variable	0	>=	$= (D4 + D5 + F4 + F5 + G4 + G5) / 6$						

Figure 9.6: Optimization Worksheet

	A	B	C	D	E	F	G	H	I	J
145	Factory Part Batching Variable	1	>=	=(E4+E5+H4+H5)/4						
146										
147	Cost Calculations (Per Unit)									
148										
149		Sup 1 Direct	3rd Party Direct w Kit	3rd Party Kit CTO to HUB	Hub F Kits	Hub S1 Kits	Skip Hub S1 Kits	Skip Hub F Kits	Total	
150	Material Cost	=Inputs!\$B14	=Inputs!\$B14	=Inputs!\$B14	=Inputs!\$B14	=Inputs!\$B14	=Inputs!\$B14	=Inputs!\$B14		
151										
152	Packaging Bulk	0	=SUM('Inputs!\$B73:B75)	=SUM('Inputs!A73:B75)	=SUM('Inputs!\$B73:B75)	=SUM('Inputs!\$B74:B75)	=SUM('Inputs!\$B74:B75)	=SUM('Inputs!\$B73:B75)		
153	Packaging Individual (Total Weekly Cost)	=Inputs!\$B76*B37	=Inputs!\$B76*C37	=Inputs!\$B76*D37	=Inputs!\$B76*E36	=Inputs!\$B76*F37	=Inputs!\$B76*G37	=Inputs!\$B76*H36		
154										
155	Inbound Freight	0	=J55	=J52	=J52	=J53	=J55	=J54		
156	Hub to Factory Freight	0	0	=Inputs!\$B52/D14*2	=Inputs!\$B52*(Inputs!\$B28/D15)+Inputs!\$B29*Inputs!B23+Inputs!\$B31*Inputs!B26	=Inputs!\$B52/D14	0	0		
157	Outbound Freight (Total Weekly Cost)	=J59*B37	=J58*C37	=(J56*D36+J57*D35)	=(J56*E36+J57*E35)	=(J56*F36+J57*F35)	=(J56*G36+J57*G35)	=(J56*H36+J57*H35)		
158										

Figure 9.6: Optimization Worksheet

	A	B	C	D	E	F	G	H	I	J
159	WIP Inventory Cost	=B94*'Inputs'! \$B14*('Input s'! \$B58+'Inp uts'! \$B59)/7/ 52	=C94*'Inputs'! \$B14*('Inpu ts'! \$B58+'Inp uts'! \$B59)/7/ 52	=D94*'Inputs'! \$B14*('Inpu ts'! \$B58+'Inp uts'! \$B59)/7/ 52	=E94*'Inputs'! \$B14*('Input s'! \$B58+'Inp uts'! \$B59)/7/ 52	=F94*'Inputs'! \$B14*('Input s'! \$B58+'Inp uts'! \$B59)/7/ 52	=G94*'Inputs'! \$B14*('Inpu ts'! \$B58+'Inp uts'! \$B59)/7/ 52	=H94*'Inputs'! \$B14*('Inpu ts'! \$B58+'Inp uts'! \$B59)/7/ 52		
160	Safety Stock Inventory	=(SQRT(B10 6/7+0.00001) +SQRT(B10 5/7+0.00001) +SQRT(B10 4/7+0.00001)) *'Inputs'! \$B 4*'Inputs'! \$B 8*'Inputs'! \$B 14*('Inputs'! \$ B58+'Inputs'! \$ B59)/52/'In puts'! \$B5	=(SQRT(C10 6/7+0.00001) +SQRT(C10 5/7+0.00001) +SQRT(C10 4/7+0.00001)) *'Inputs'! \$B 4*'Inputs'! \$B 8*'Inputs'! \$B 14*('Inputs'! \$ B58+'Inputs'! \$ B59)/52/'In puts'! \$B5	=(SQRT(D10 6/7+0.00001) +SQRT(D10 5/7+0.00001) +SQRT(D10 4/7+0.00001)) *'Inputs'! \$B 4*'Inputs'! \$B 8*'Inputs'! \$B 14*('Inputs'! \$ B58+'Inputs'! \$ B59)/52/'In puts'! \$B5	=(SQRT(E10 6/7+0.00001) +SQRT(E10 5/7+0.00001) +SQRT(E10 4/7+0.00001)) *'Inputs'! \$B 4*'Inputs'! \$B 8*'Inputs'! \$B 14*('Inputs'! \$ B58+'Inputs'! \$ B59)/52/'In puts'! \$B5	=(SQRT(F10 6/7+0.00001) +SQRT(F10 5/7+0.00001) +SQRT(F10 4/7+0.00001)) *'Inputs'! \$B 4*'Inputs'! \$B 8*'Inputs'! \$B 14*('Inputs'! \$ B58+'Inputs'! \$ B59)/52/'In puts'! \$B5	=(SQRT(G1 06/7+0.0000 1) +SQRT(G 105/7+0.000 01) +SQRT(G104/7+0.00 01)) *'Inputs'! \$ B4*'Inputs'! \$ B8*'Inputs'! \$ B14*('Input s'! \$B58+'Inp uts'! \$B59)/52/ 'Inputs'! \$B5	=(SQRT(H10 6/7+0.00001) +SQRT(H10 5/7+0.00001) +SQRT(H10 4/7+0.00001)) *'Inputs'! \$B 4*'Inputs'! \$B 8*'Inputs'! \$B 14*('Inputs'! \$ B58+'Inputs'! \$ B59)/52/'In puts'! \$B5		
161	S1 Batching Inventory (Total Weekly Cost)	=(D119+\$E 119)*('Inputs' ! \$B58+'Input s'! \$B59)/52* B141	0	0	0	0	0	0		
162	3PL Batching Inventory (Total Weekly Cost)	0	=(D120+\$E 120+\$C120) *'Inputs'! \$B5 8*'Inputs'! \$B 59)/52*B142	0	0	0	0	0		
163	Hub Batching Inventory (Total Weekly Cost)	0	0	=(B121)*('In puts'! \$B58+'I nputs'! \$B59)/ 52*B143	=(D121+\$E 121+\$C121) *'Inputs'! \$B5 8*'Inputs'! \$B 59)/52	0	0	0		

Figure 9.6: Optimization Worksheet

	A	B	C	D	E	F	G	H	I	J
164	Factory Batching Inventory (Total Weekly Cost)	0	0	=(B122)*('Inputs'!\$B58+'Inputs'!\$B59)/52*B144	=(D122+\$E122+\$C122)*('Inputs'!\$B58+'Inputs'!\$B59)/52*B145	0	0	0		
165										
166	Pick/Pack Labor (Total Weekly Cost)	=('Inputs'!\$B56*B37	=('Inputs'!\$B55*C36	=('Inputs'!\$B55*D35	=('Inputs'!\$B54*E36	=('Inputs'!\$B56+F37	=('Inputs'!\$B56*G37	=('Inputs'!\$B54*H36		
167										
168	Receiving Labor Sup 1	=('Inputs'!\$B41*('Inputs'!\$B29*'Inputs'!\$B23+'Inputs'!\$B31*'Inputs'!\$B26)	0	0	0	=('Inputs'!\$B41*('Inputs'!\$B29*'Inputs'!\$B23+'Inputs'!\$B31*'Inputs'!\$B26)	=('Inputs'!\$B41*('Inputs'!\$B29*'Inputs'!\$B23+'Inputs'!\$B31*'Inputs'!\$B26)	0		
169	Receiving Labor Hub & 3PL	0	=('Inputs'!\$B35*('Inputs'!\$B28/(\$D15)+'Inputs'!\$B29*'Inputs'!\$B23+'Inputs'!\$B31*'Inputs'!\$B26)	=('Inputs'!\$B35*('Inputs'!\$B28/(\$D15)+'Inputs'!\$B29*'Inputs'!\$B23+'Inputs'!\$B31*'Inputs'!\$B26)*2	=('Inputs'!\$B35*('Inputs'!\$B28/(\$D15)+'Inputs'!\$B29*'Inputs'!\$B23+'Inputs'!\$B31*'Inputs'!\$B26)	=('Inputs'!\$B35/(\$D14)	0	0		
170	Receiving Labor Factory	0	0	=('Inputs'!\$B45/\$D14	=('Inputs'!\$B45*('Inputs'!\$B28/(\$D15)+'Inputs'!\$B29*'Inputs'!\$B23+'Inputs'!\$B31*'Inputs'!\$B26)	=('Inputs'!\$B45/(\$D14)	=('Inputs'!\$B45/(\$D14)	=('Inputs'!\$B45*('Inputs'!\$B28/(\$D15)+'Inputs'!\$B29*'Inputs'!\$B23+'Inputs'!\$B31*'Inputs'!\$B26)		
171										

Figure 9.6: Optimization Worksheet

	A	B	C	D	E	F	G	H	I	J
172	Shipping Labor Sup 1	=Inputs!\$B42/Inputs!\$B7*Inputs!\$B13	=Inputs!\$B42/(\$D15)*Inputs!\$B28	=Inputs!\$B42/(\$D15)*Inputs!\$B28	=Inputs!\$B42/(\$D15)*Inputs!\$B28	=Inputs!\$B42/(D14)	=Inputs!\$B42/(D14)	=Inputs!\$B42/(D15)*Inputs!\$B28		
173	Shipping Labor Hub&3PL	0	=C169*Inputs!\$B38/Inputs!\$B35	=D169*Inputs!\$B38/Inputs!\$B35*2	=E169*Inputs!\$B38/Inputs!\$B35	=F169*Inputs!\$B38/Inputs!\$B35	0	0		
174	Shipping Labor Factory (Total Weekly Cost)	0	0	=Inputs!\$B46*(Inputs!\$B12)/Inputs!\$B6*D35+Inputs!\$B46*Inputs!\$B13/Inputs!\$B7*D36	=Inputs!\$B46*(Inputs!\$B12)/Inputs!\$B6*E35+Inputs!\$B46*Inputs!\$B13/Inputs!\$B7*E36	=Inputs!\$B46*(Inputs!\$B12)/Inputs!\$B6*F35+Inputs!\$B46*Inputs!\$B13/Inputs!\$B7*F36	=Inputs!\$B46*(Inputs!\$B12)/Inputs!\$B6*G35+Inputs!\$B46*Inputs!\$B13/Inputs!\$B7*G36	=Inputs!\$B46*(Inputs!\$B12)/Inputs!\$B6*H35+Inputs!\$B46*Inputs!\$B13/Inputs!\$B7*H36		
175										
176	Direct Ship IT Setup (Total Weekly Cost)	=(Inputs!\$B78*Inputs!\$B82/Inputs!\$B80*(1+Inputs!\$B58+(1+Inputs!\$B58)^2+(1+Inputs!\$B58)^3)/Inputs!\$B80/52)*B5	=(Inputs!\$B79*Inputs!\$B83/Inputs!\$B81*(1+Inputs!\$B58+(1+Inputs!\$B58)^2+(1+Inputs!\$B58)^3)/Inputs!\$B81/52)*C5	0	0	0	0	0		
177										
178	Subtotal	=SUM(B165:B175)+SUM(B150:B152)+B155+B156-B166-B174+B159+B160	=SUM(C165:C176)+SUM(C150:C152)+C155+C156-C166-C174+C159+C160	=SUM(D165:D176)+SUM(D150:D152)+D155+D156-D166-D174+D159+D160	=SUM(E165:E176)+SUM(E150:E152)+E155+E156-E166-E174+E159+E160	=SUM(F165:F176)+SUM(F150:F152)+F155+F156-F166-F174+F159+F160	=SUM(G165:G176)+SUM(G150:G152)+G155+G156-G166-G174+G159+G160	=SUM(H165:H176)+SUM(H150:H152)+H155+H156-H166-H174+H159+H160		

Figure 9.6: Optimization Worksheet										
	A	B	C	D	E	F	G	H	I	J
179	Total Annual Cost	=B178*B37* 52+52*(B153 +B157+B166 +B174+SUM (B161:B164) +B176)	=C178*C37* 52+52*(C15 3+C157+C1 66+C174+S UM(C161:C1 64))	=D178*D37* 52+52*(D15 3+D157+D1 66+D174+S UM(D161:D1 64))	=E178*E37* 52+52*(E153 +E157+E166 +E174+SUM (E161:E164))	=F178*F37* 52+52*(F153 +F157+F166 +F174+SUM (F161:F164))	=G178*G37* 52+52*(G15 3+G157+G1 66+G174+S UM(G161:G 164))	=H178*H37* 52+52*(H15 3+H157+H1 66+H174+S UM(H161:H1 64))	=SUM(B179: H179)	

Figure 9.6: Optimization Model Worksheet

The decision variables for the model are the following cells of the optimization worksheet: B10:H11, B14:H14, D135, E136, B131:E134, B147:B151, E15:H15.

The objective of the program was to minimize the total cost (I185).

The constraints for the model are the following:

B10:H11 = Binary

B114:H116 = Binary

E136 = Binary

E15:H15 = Binary

E131:E134 = Binary

B147:B151 = Binary

D135 = Binary

B10 = 0

B110:H112 > 0

B118:H120 <= B102:H104

B125:E128 >= 0

E136 >= E144

E15:H15 >= E14:H14

I10:I11 = K10:K11

B131:E134 >= B139:E142

B147:B151 >= D147:D151

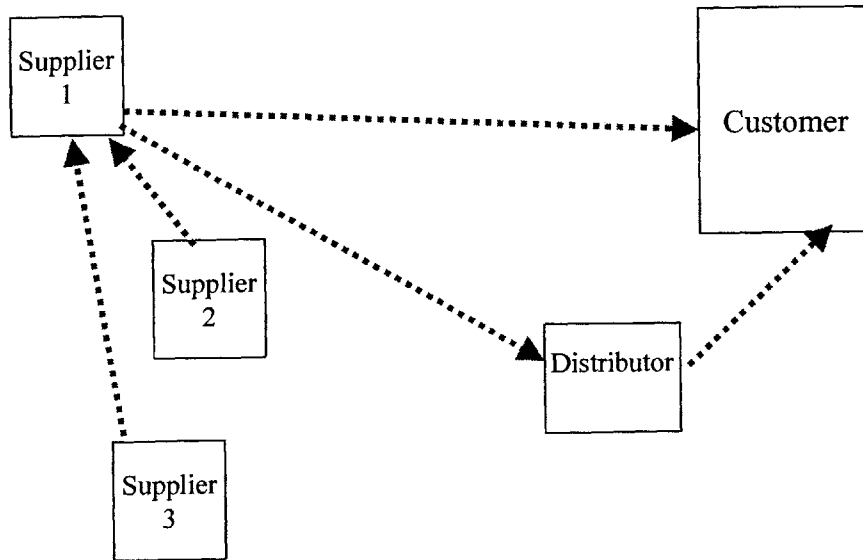
C10 = 0

D11 = 0

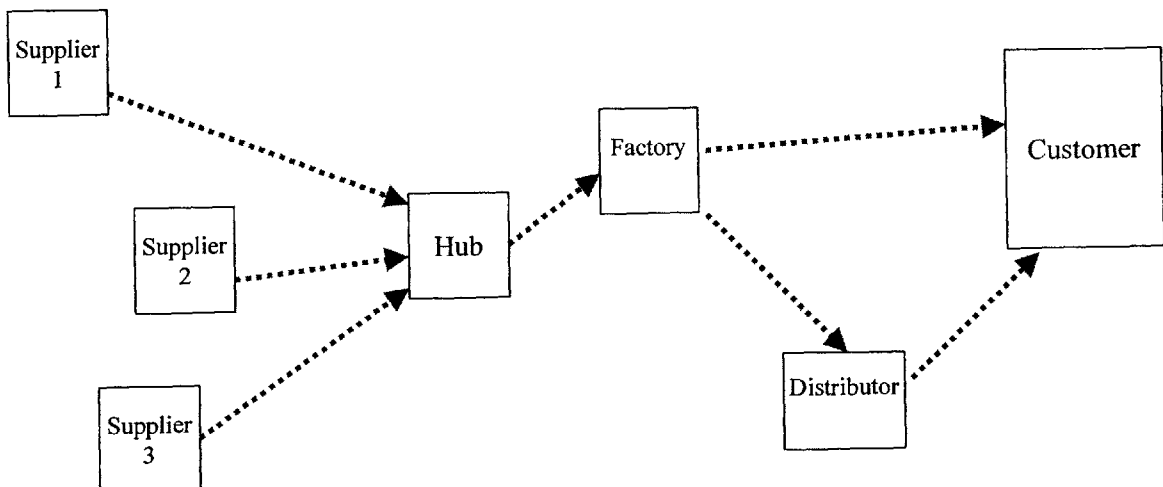
D135 >= D143

9.4 Appendix: Supply Chain Maps

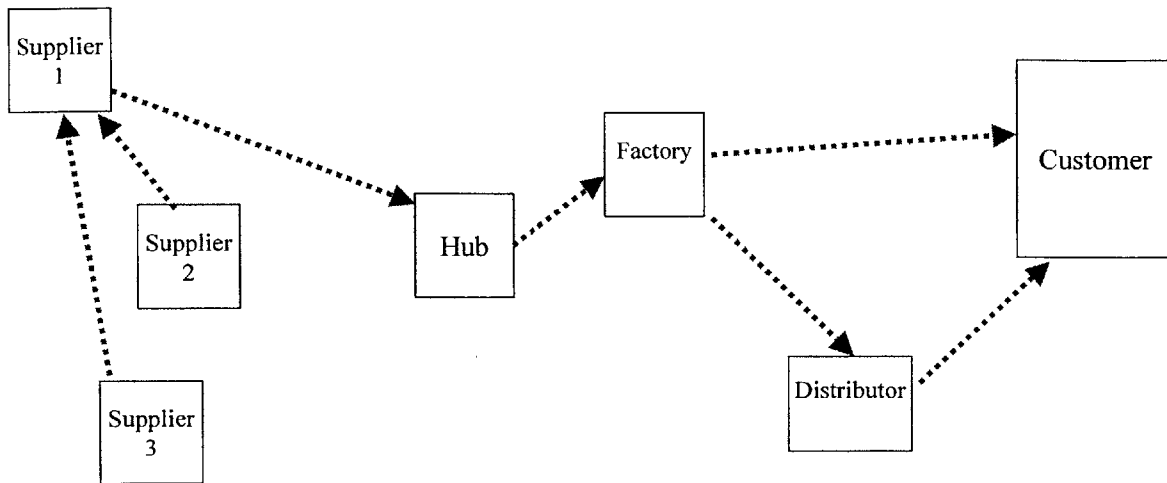
Direct Ship Supply Chain



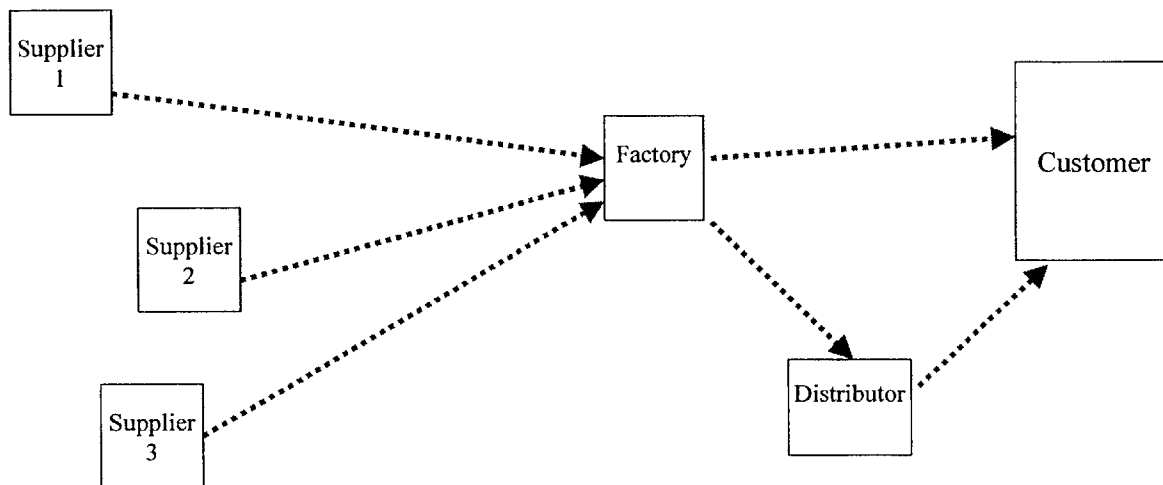
Hub Based Supply Chain



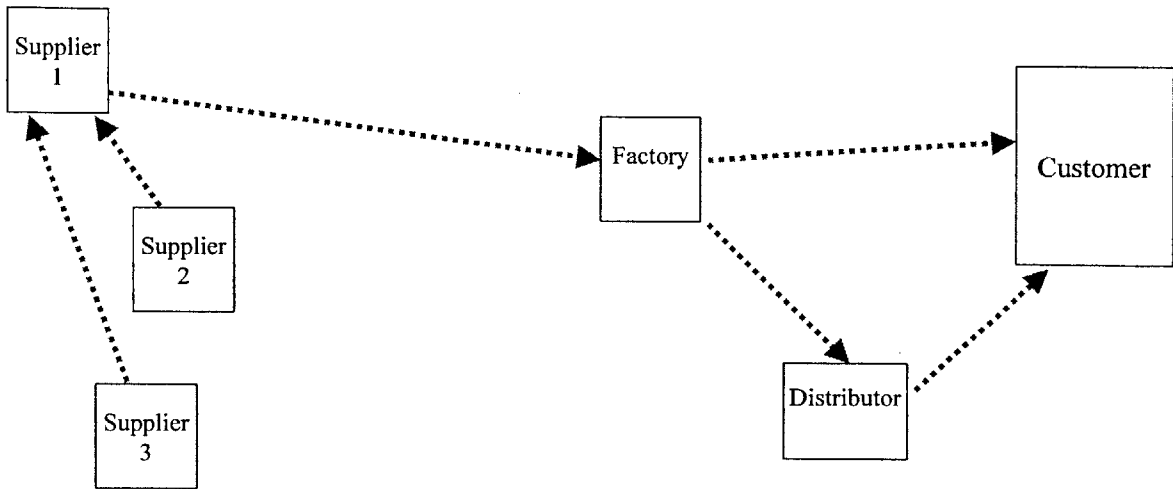
Hub Based w/ Supplier Kitting Supply Chain



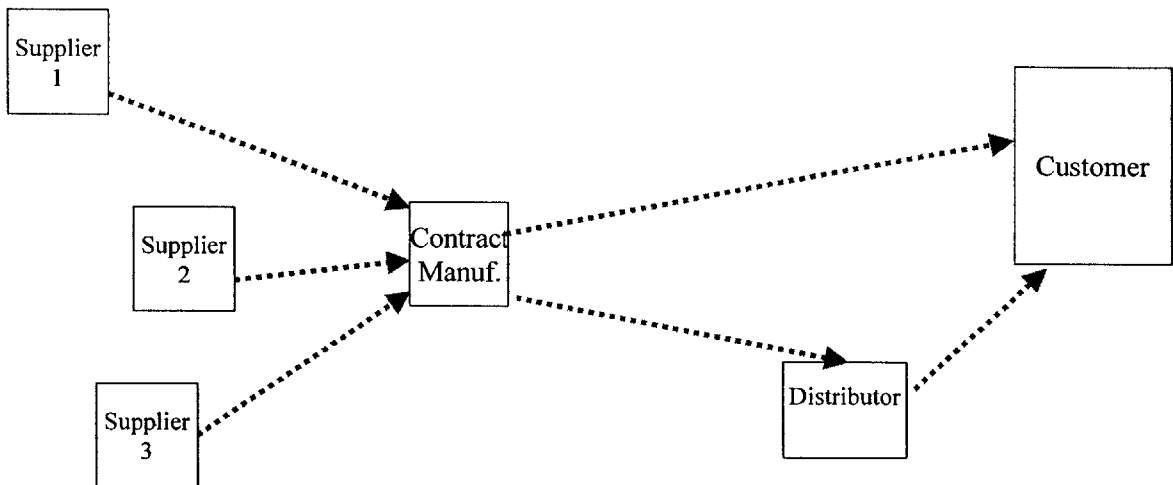
Factory Stock Supply Chain



Factory Stock w/ Supplier Kitting Supply Chain



Contract Manufacturer Direct Ship Supply Chain



Contract Manufacturer to Hub Supply Chain

