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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LEADERS FOR MANUFACTURING PROGRAM

SUPPLY CHAIN MODELING FOR INVENTORY ANALYSIS

by

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Bachelor of Science in Mechanical Engineering, MIT, 1990

Master of Science in Mechanical Engineering, MIT, 1990

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

Master of Science in Management

and

Master of Science in Electrical Engineering and Computer Science

June, 1997

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ABSTRACT

HP Medical's Patient Monitoring Division (PMD) produces and sells systems for monitoring critical medical patients. The next release of one of its product lines will be the first to use a personal computer (PC) as the product platform. PC's, which undergo frequent modifications by their supplier, must become part of the validated, extremely reliable and stable medical systems provided by PMD. When there is an unforeseen modification to the PC, PMD may have to rework the software component of their product. In order to not impact the delivery of the medical systems, PMD plans to hold a safety stock of (validated) PC's to protect against supply disruptions due to these PC changes. This safety stock will also buffer against uncertainties in supply lead times and demand. This thesis presents a supply chain analysis for integrating PC's into patient monitoring systems. The central issue addressed by the analysis is the determination of target safety stock levels for the PC's used in this new PMD product.

The supply chain analysis includes two supply chain models: the Strategic Inventory Placement Model (SIPM) and a dynamic simulation model.. The SIPM explores the locations and quantities of inventory in the supply chain, with supply and demand variability. The dynamic simulation model considers the supply and demand variability, as well as the rework cycle associated with the changes in the PC's and validation testing. These models are used to examine several different safety stock policies. The models demonstrate that the target safety stock can be reduced from PMD's initial estimates, without having a significant effect on customer service. It is estimated that the inventory reduction suggested by this analysis will save approximately $500,000 per year in inventory holding costs.

An overview of this supply chain analysis, including the results, is presented in the initial section as an executive summary. The thesis also includes a general introduction to both supply chain management and inventory in the supply chain.

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Acknowledgments

The author wishes to acknowledge the Leader's for Manufacturing program for the support of this research. The author would especially like to acknowledge the manufacturing organization of Hewlett Packard Company, Medical Products Group, Patient Monitoring Division. The people in PMD were extremely helpful and encouraging throughout this research project. The author would also like to acknowledge the helpful guidance from Prof. Al Drake, Prof. Steve Graves, and Sean Willems of MIT. Their experience in both supply chain issues and thesis projects is appreciated.

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Executive Summary

Challenge at HP Medical

HP Medical's Patient Monitoring Division (PMD) designs, produces, sells, and supports systems for real time monitoring of critical medical patients. The PMD products are purchased by and used in health care facilities such as hospitals, nursing homes, and even emergency response vehicles. The products produced by PMD are market leaders. However, PMD is facing tighter margins and pressure from its customers to provide health care solutions composed of multiple HP products networked together. These market dynamics, combined with the advances in computing performance and reliability, have encouraged PMD to transition some of its products away from proprietary hardware and software. PMD is transitioning its products towards adding value to industry standard components, such as PC's and Windows NT. PMD will transition one of its main product lines from a proprietary platform with custom components to a standard PC platform with both custom and industry standard components in 1997.

The product life of a PMD system is generally between 5-7 years. These systems are often used in critical medical environments for even longer periods. The PC has a product life measured in months; that is, there are changes to the PC's internal components, such as the BIOS[1], every few months. These changes occur throughout the PC industry, across all suppliers. With one of the major components of PMD's system being the PC, there is a challenge in accommodating the changes in the PC industry over the life of a medical product. HP Medical has approached this challenge by designing the system to minimize the dependency on the PC's specific components. Nevertheless, there is a dependency on the operating performance of the PC. HP Medical has developed a suite of validation tests and procedures for the new architecture to ensure reliable performance in life critical operating environments.

[1] Basic Input Output System

This change in product architecture presents a new set of issues, including new sources of uncertainty, for the supply chain and for inventory management. HP Medical does not have much influence with its suppliers as this product represents a very small volume to the PC supplier. Therefore, there HP Medical may encounter delays in delivery as the PC supplier experiences changes in supply and demand. There is also uncertainty associated with passing the validation tests and the related time to address any failures. This rework time may take a few days or may be as long as three months. The third significant source of uncertainty is the demand variability for the new product. This thesis addresses the question of how much inventory should be held and where it should be held to provide predictable, reliable and competitive service in light of these uncertainties.

The product architecture changes underway at PMD require that the supply chain be optimized for reliable solution delivery in a cost efficient manner. (A brief summary of my readings and experience concerning the importance of the supply chain is presented in Appendix 1: **Supply Chain Management.**) At the beginning of this project, the inventory level for validated PC's was projected to be between 4 and 5 months of the expected demand. There was some concern within the company regarding this level of inventory, as it was going to be expensive to hold a large quantity of PC's. However, there was also a great deal of uncertainty in this supply chain and it was believed that this inventory would buffer the customer from the uncertainty. I explored some of the existing reasons for holding inventory, as well as the cost of holding inventory. This exploration included research at HP and reading various publications on supply chain issues. A summary of this exploration is included in Appendix 2: **Inventory In The Supply Chain**. However, to posit that this level of inventory would permit the desired level of service at PMD, a supply chain model for inventory analysis was developed.

Supply Chain Model

The first step in developing the supply chain model was to understand the process flows for both material and information. This led to reviewing the planned quantities and locations of inventory. During this phase of the project, the Strategic Inventory Placement Model (SIPM)[2] was used to gain additional insight into the supply chain for PC's. (The general approach to supply chain modeling is presented in Appendix 3 and a detailed description of the SIPM is presented in Appendix 4.) The PMD manufacturing staff and I learned that some of the assumptions in the SIPM software did not apply to the primary issues at HP Medical. Specifically, we needed to address the rework cycle associated with the changes in the PC and the validation test. Therefore, we developed a Dynamic Simulation Model[3] to incorporate this rework cycle, as well as the supply and demand uncertainty, as part of our analysis.

Process Flows

The first step of the supply chain analysis was to develop the process flows for the central station[4], which is the focus of this research. The first material flow diagram is shown in Figure 1, which shows the central station and the other products that are ordered and shipped with it. The central stations are sent to a merging center where the system is combined with the other HP Medical products that may have been ordered by the customer. These medical products will meet up with the other products in the customer's system, such as network components and accessories, such as printers, at the customer site. At the customer site, the entire set of products is installed and the people who will be using it are trained. This all occurs before the system goes live and is put into use monitoring patients. Figure 1 also shows services in the supply chain. Services are included because there is a limited number of experienced professionals to perform the integration and training. Thus, service is a limited resource, yet it is required to complete the last step in the delivery of the complete system to the HP customer. We also asked a series of other questions about the supply chain at the beginning of our analysis to learn more about the influences and options in the supply chain.

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[2] SIPM was developed by Prof. Stephen Graves, Sean Willems, and John Ruark as part of the LFM research program at MIT.
[3] The Dynamic Simulation Model was developed using the ithink software from High Performance Systems.
[4] A central station is used by a nurse or doctor to monitor several patients from a central location. The product must be highly reliable as it is presenting the vital statistics of several hospital patients to their caretaker.

These questions are presented in Appendix 5: **HP Medical's Supply Chain For** PC's, in the section titled **"Supply Chain Questions"**.

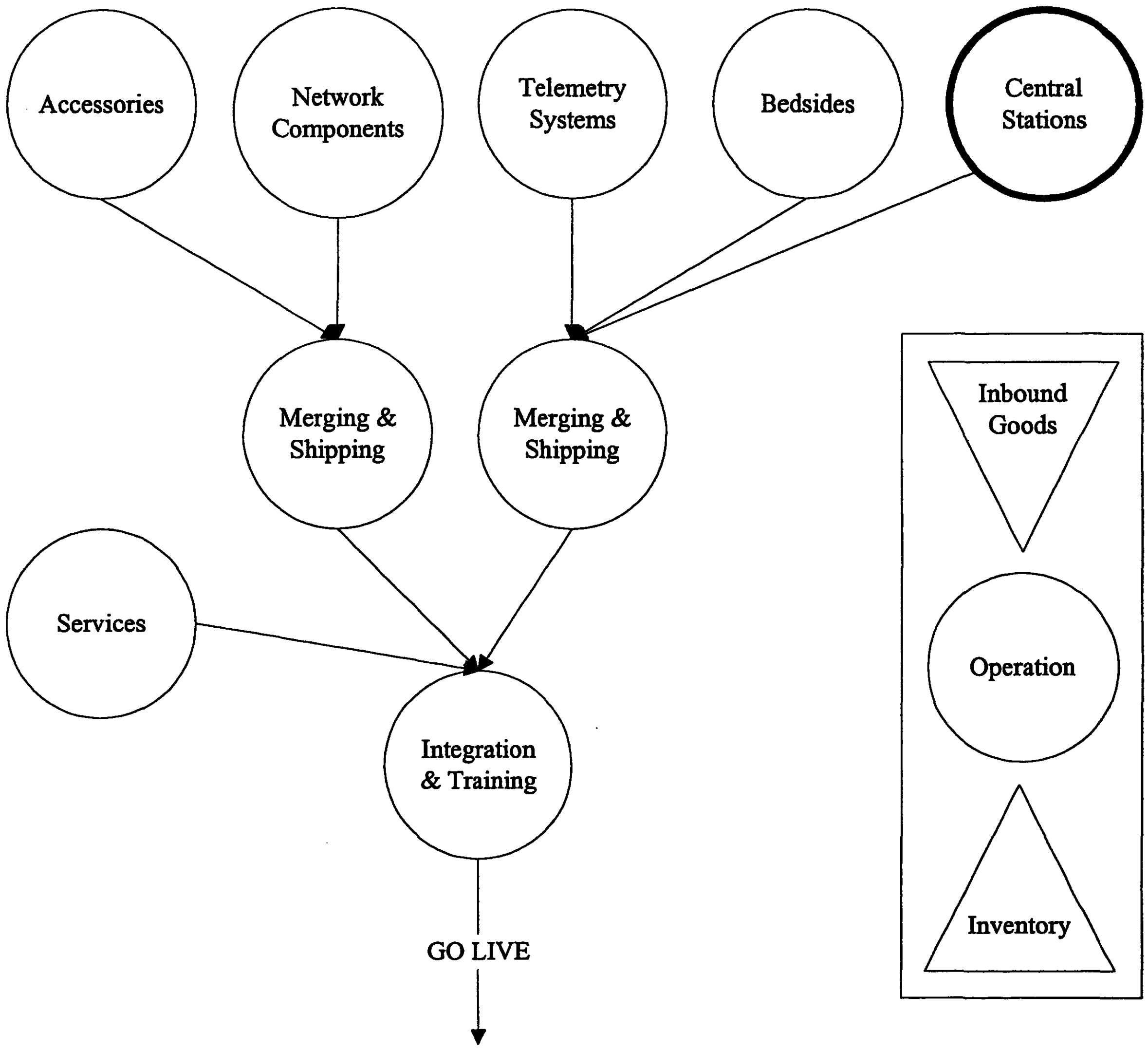

Figure 1: Material flow for Several Medical Products

The supply chain for the central station is broken into more detail in Figure 2. In this diagram we can see that the central station consists of several key components, one of which is the PC.

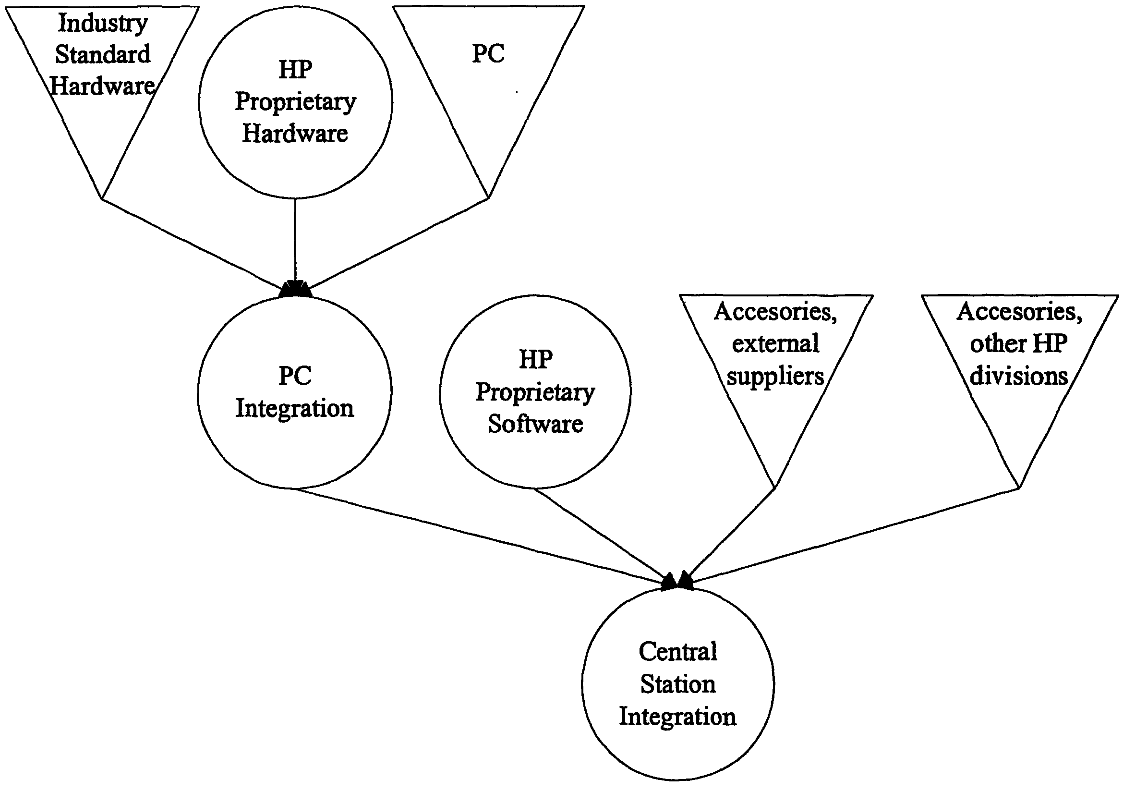

Figure 2: Material Flow for Central Station

We discovered that there was a great deal of uncertainty associated with the PC supply for the central station. When there is uncertainty, there generally is inventory. (See the section titled "**Uncertainty**" in Appendix 2: **Inventory In The Supply Chain.**) Therefore, our next step was to examine the plan for inventory locations and quantities. The inventory locations are shown in Figure 3. We modeled the supply chain in the SIPM software and compared the model results with what was being targeted for inventory quantities. We discovered that there was a large difference between the target level of inventory and the level suggested by the SIPM for the PC component. This difference was explored and it was discovered that the uncertainty associated with the PC was the reason for the high level of target inventory.

The uncertainty associated with the PC supply involved the frequent product changes in the PC industry. This created a need for the PC's to be validated with the other components, including the software, for the central station. The validation process would ensure that the system would perform to the target specifications and be reliable. The critical nature of the final product's use required that the complete system be stable and very reliable from its initial implementation at the customer site. While there are sources of supply and demand uncertainty, the primary source of uncertainty is in the validation and the associated time to correct issues related to changes in the PC. This uncertainty could not be adequately modeled with the SIPM software. Therefore, a simulation model, the Dynamic Simulation Model, was developed to represent the sources of uncertainty and provide metrics for determining an inventory policy to minimize the inventory levels, while meeting the delivery requirements of the central station customers.

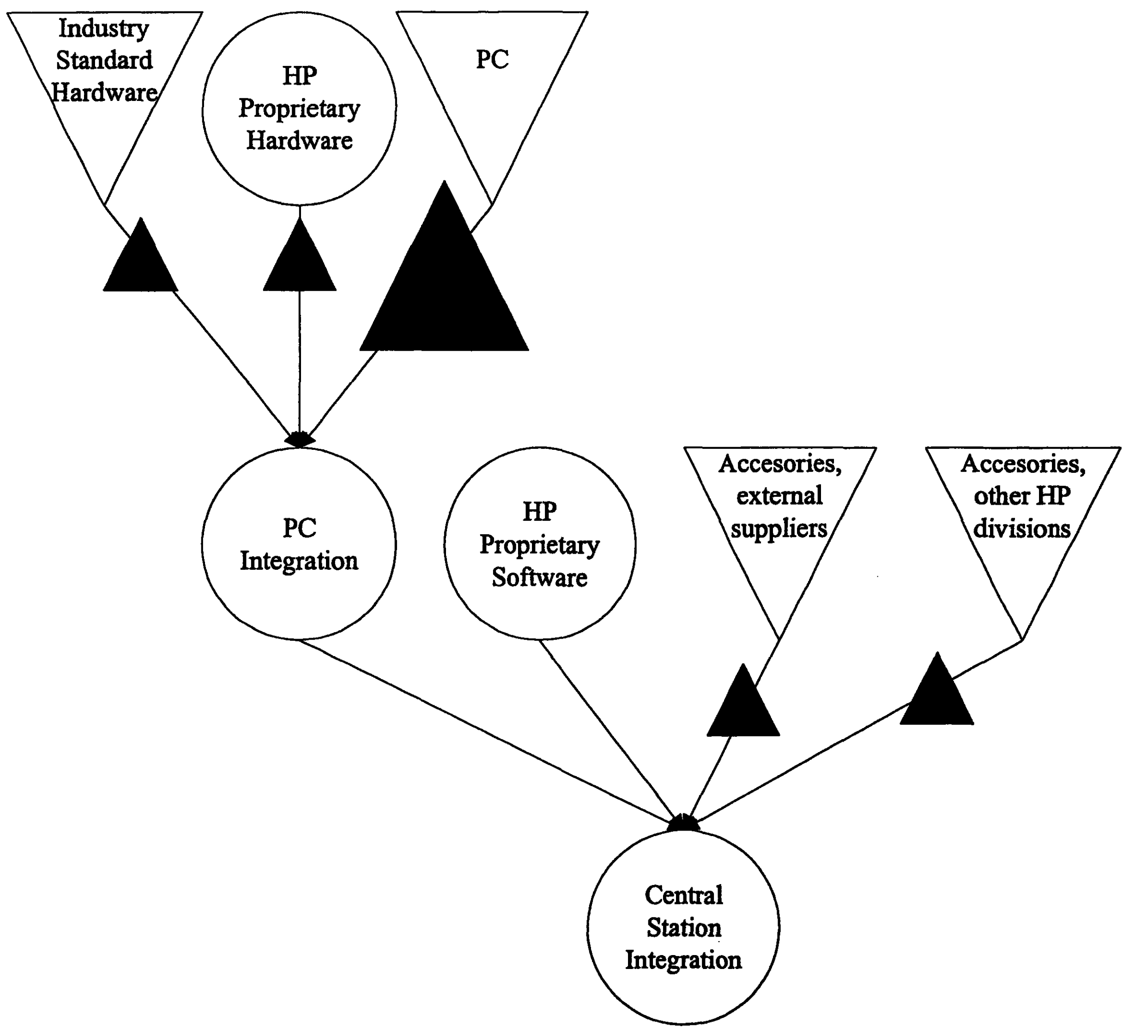

Figure 3: Target Inventory Locations for a Central Station

Dynamic Simulation Model

Figure 4 represents the general architecture of the central station's PC supply chain as it is described in the Dynamic Simulation Model developed at HP Medical. This model is intended to assess the various inventory policies that HP could adopt for the PC section of the central station's supply chain. The Dynamic Simulation Model represents PC's moving from the Source Supplier to the US site where they are validated. After the validation process the PC's will either be shipped to US customers or to the International manufacturing site and on to International customers. There is also a feedback mechanism, "Compute Total HP Medical Order Quantity," in the Dynamic Simulation Model. This is where the model adjusts the order quantities to account for the difference between the actual demand and the forecasted demand. This difference is measured by looking at the inventory on hand and comparing it to the target level. This section also models the negotiation between sites when there is an inventory shortage due to supply delays, validation failures, or unexpected demand.

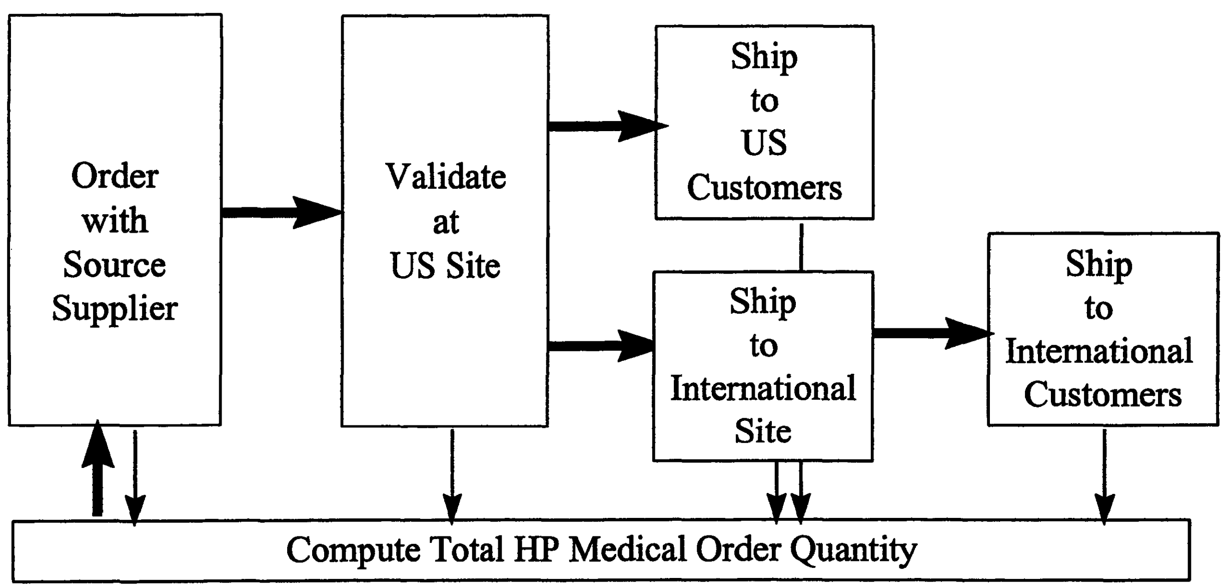

Figure 4: Architecture of PC Supply Chain Model

A more detailed description of the Dynamic Simulation Model is presented in Appendix 5: **HP Medical's Supply Chain For** PC's. The goal of the Dynamic Simulation Model is to describe the tradeoffs between holding inventory and customer service levels under different policies. The service levels are described by the maximum number of days without inventory during each simulation.

Simulation Results

The Dynamic Simulation Model was run under several different scenarios, each representing a different inventory policy. Each scenario was run with different levels of safety stock at the distribution sites. The scenarios simulated were with equal days of safety stock at the US and International sites, as well as one scenario with 3 months of safety stock in the US and 1 month at the International site. Each of the scenarios were simulated for a two year operating period, after a 6 month product ramp.

The inventory policy is specified by the reorder frequency, target safety stock levels, and the inventory adjustment period. This model has the reorder frequency that is required by the source supplier. The inventory adjustment period in all scenarios is set to one reorder cycle. Therefore, the variable considered in the inventory policy is the target safety stock for each manufacturing site.

After running several hundred simulations with the Dynamic Simulation Model, the results indicated that the target inventory levels could be reduced from the original target of 4-5 months, with minimal impact on customer service. Figure 5 shows the annual cost of holding inventory compared to the maximum number of days without inventory in a single year.

The following graphs are presented for the US site only. The data for the International site is similar to the US site due to the negotiation policy of the Dynamic Simulation Model. See the Negotiation section in Appendix 5.

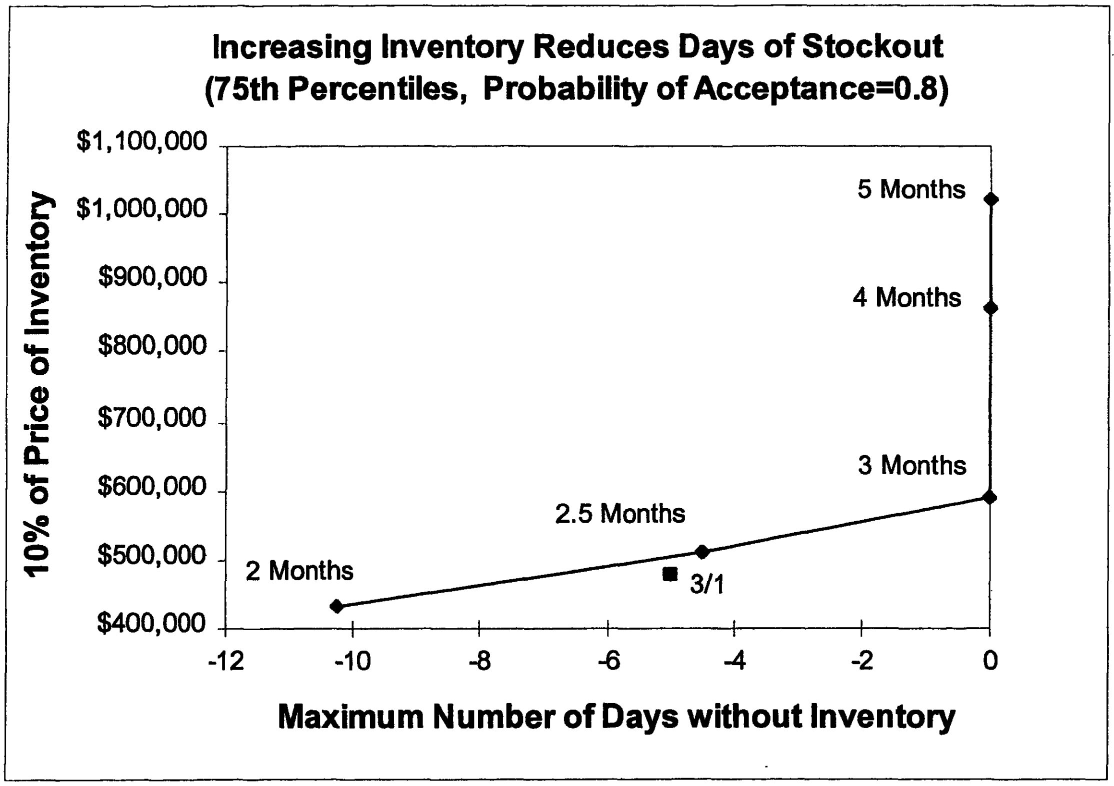

Figure 5: 75th Percentiles of Maximum Number of Days without Inventory in the US

The Dynamic Simulation Model was run 99 times for each scenario. Each of these 99 runs was differentiated by the random number seeds used for the variables. The following graphs present more details regarding the distribution of results from the Dynamic Simulation Model. Figure 6 presents the 95th percentiles of the information in Figure 5, which presents the 75th percentiles. The 95th percentiles in Figure 6 show the maximum number of days without inventory in a single year for 95% of all the runs for each scenario. (The remaining 5% of the runs have a maximum that is higher than those presented.) Figure 7 presents a histogram for the 99 runs for the 2 month scenario, which shows this remaining 5%.

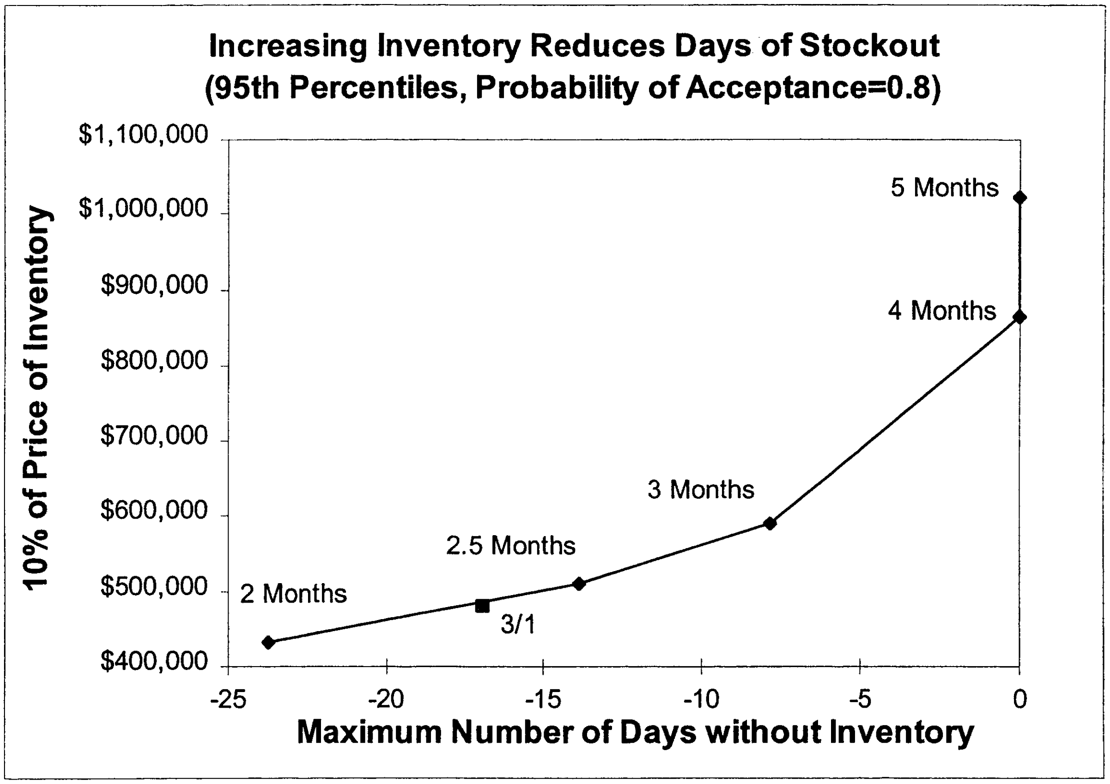

Figure 6: 95th Percentiles of Maximum Number of Days without Inventory in the US

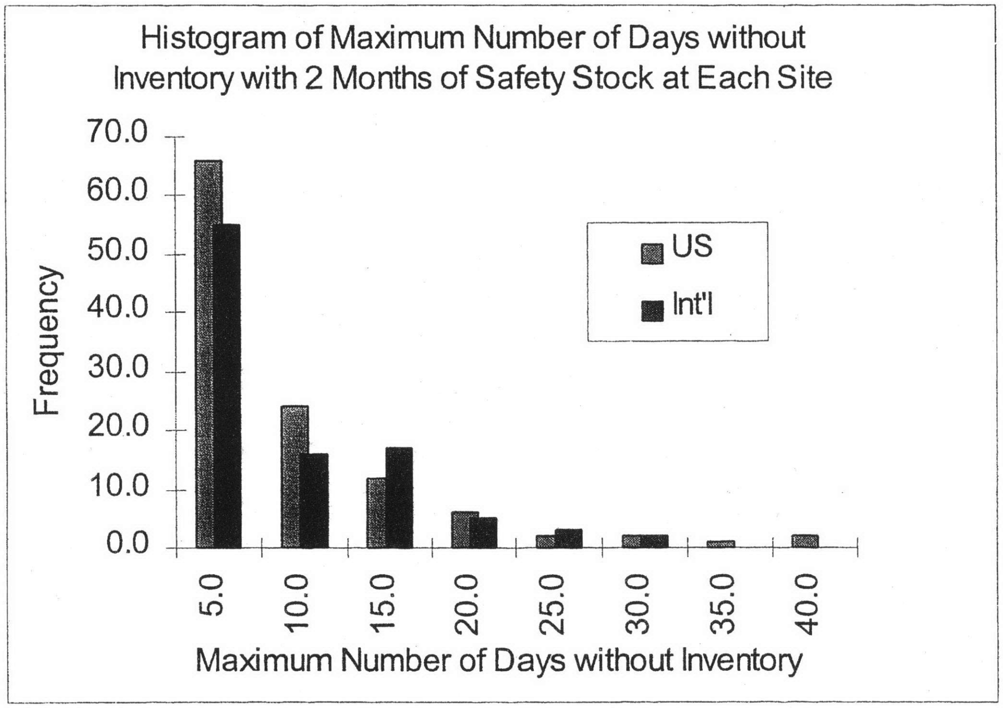

Figure 7: Histogram of Days without Inventory

Figure 8 presents the cumulative distribution of the maximum number of days without inventory in the US. The number of days without inventory is the total number of days without validated inventory available to ship to customers. This total number of days may be spread throughout the year or they may all occur sequentially. A cumulative distribution of the maximum number of sequential days without inventory is presented in Figure 9. These two graphs shows us that it is likely to have a single sequence of multiple days without inventory, as opposed to several single (separated) days without inventory.

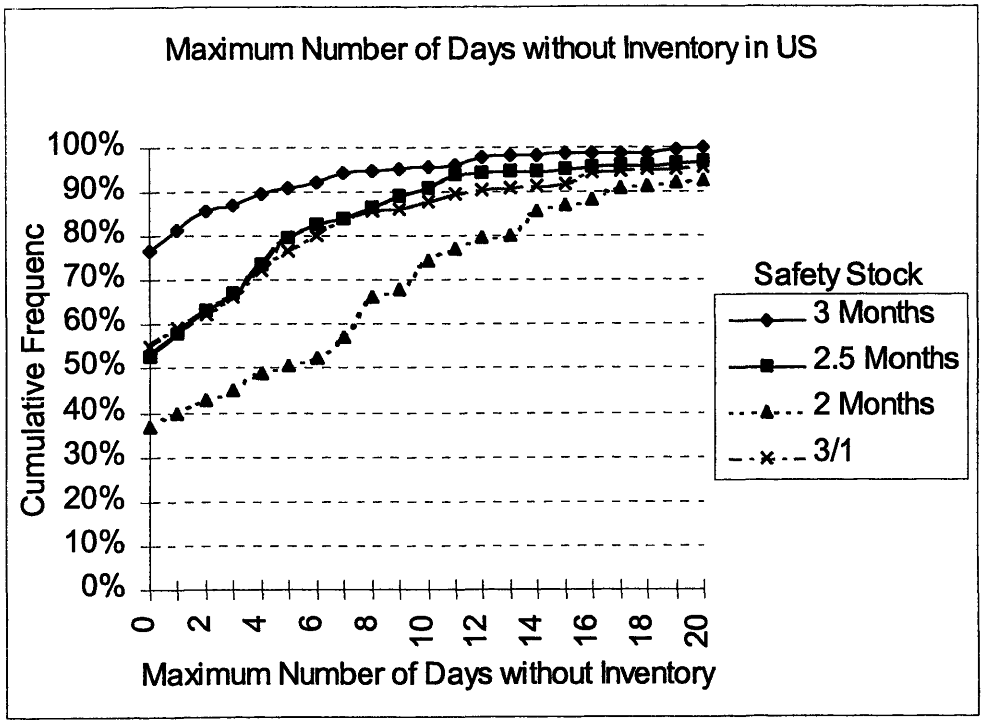

Figure 8: Cumulative Distribution of Maximum Number of Days without Inventory

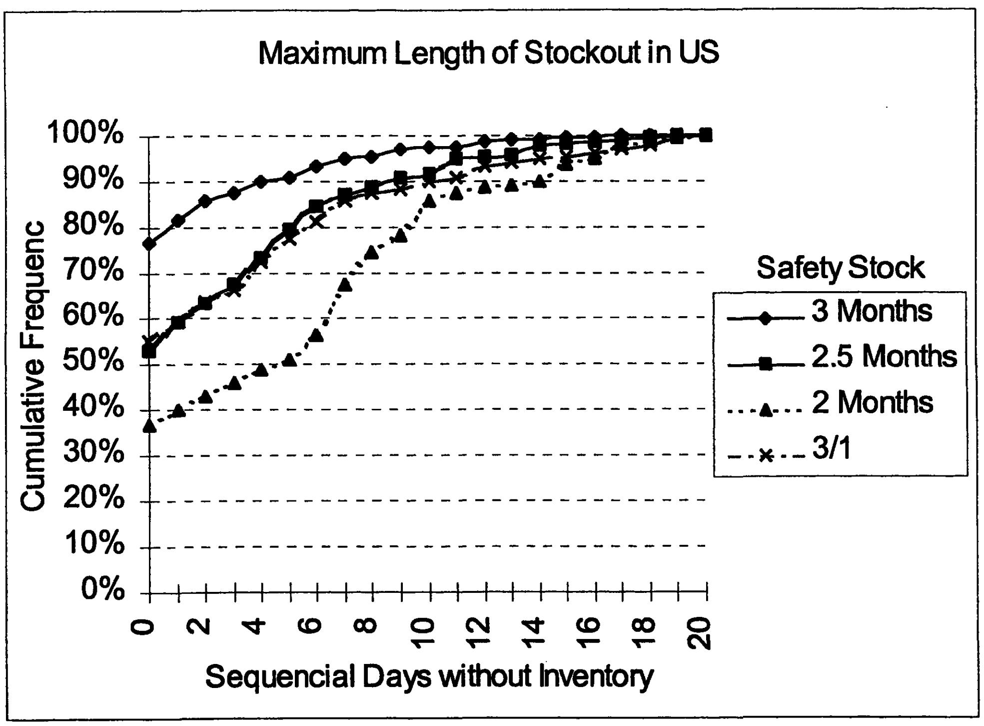

Figure 9: Cumulative Distribution of Sequential Days without Inventory

Figure 10 shows the results of the scenarios when the model has a probability of acceptance equal to 0.9, as well as 0.8. (Figure 11 presents this information for the 95th percentiles.) The probability of acceptance determines how likely it is that any given batch of PC's will pass the validation procedure. (See Appendix 5 for a detailed description of the probability of acceptance in the Dynamic Simulation Model.) Increasing the probability of acceptance implies that either there will be fewer changes in the inbound PC's, or that the other system components are more independent of the PC components. Thus, the system is less likely to fail validation due to industry wide changes in the PC with a higher probability of acceptance. A higher probability of acceptance can also be the result of proactive changes being made to the software component of the system. However the higher probability of acceptance is achieved, the supply chain model results indicate an inverse relationship between the probability of acceptance and the level of inventory required for the same level of customer service.

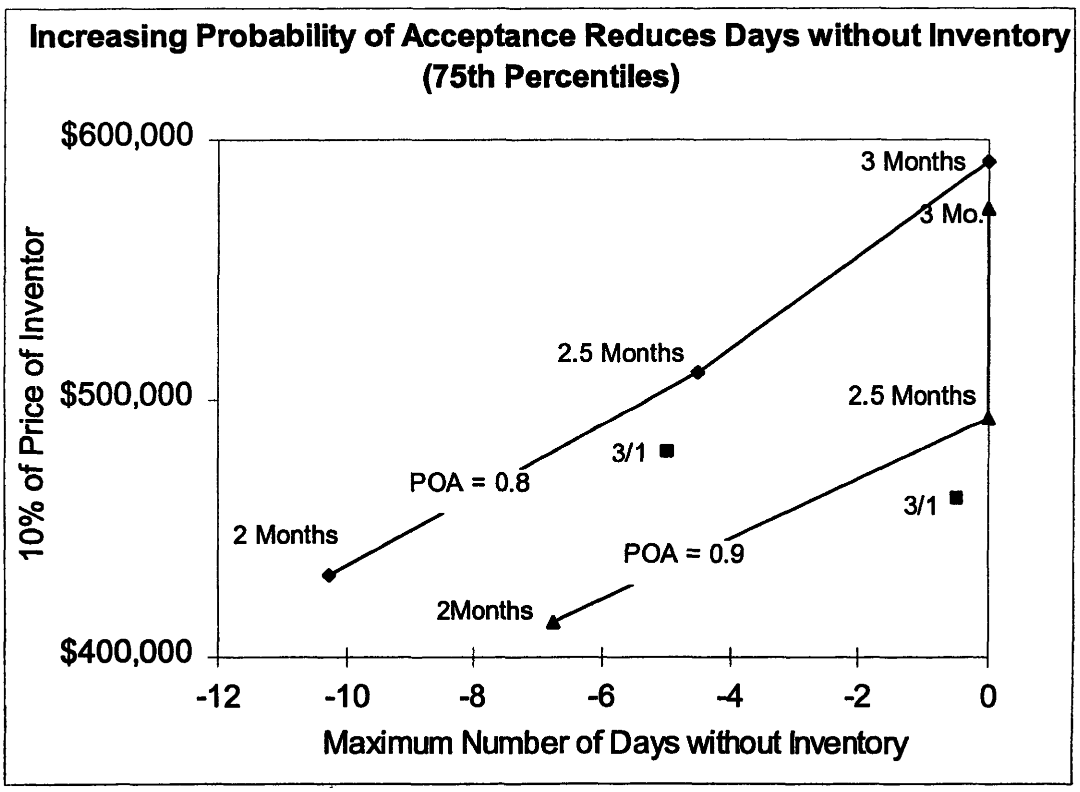

Figure 10: Dynamic Simulation Model Results for Different Probabilities of Acceptance

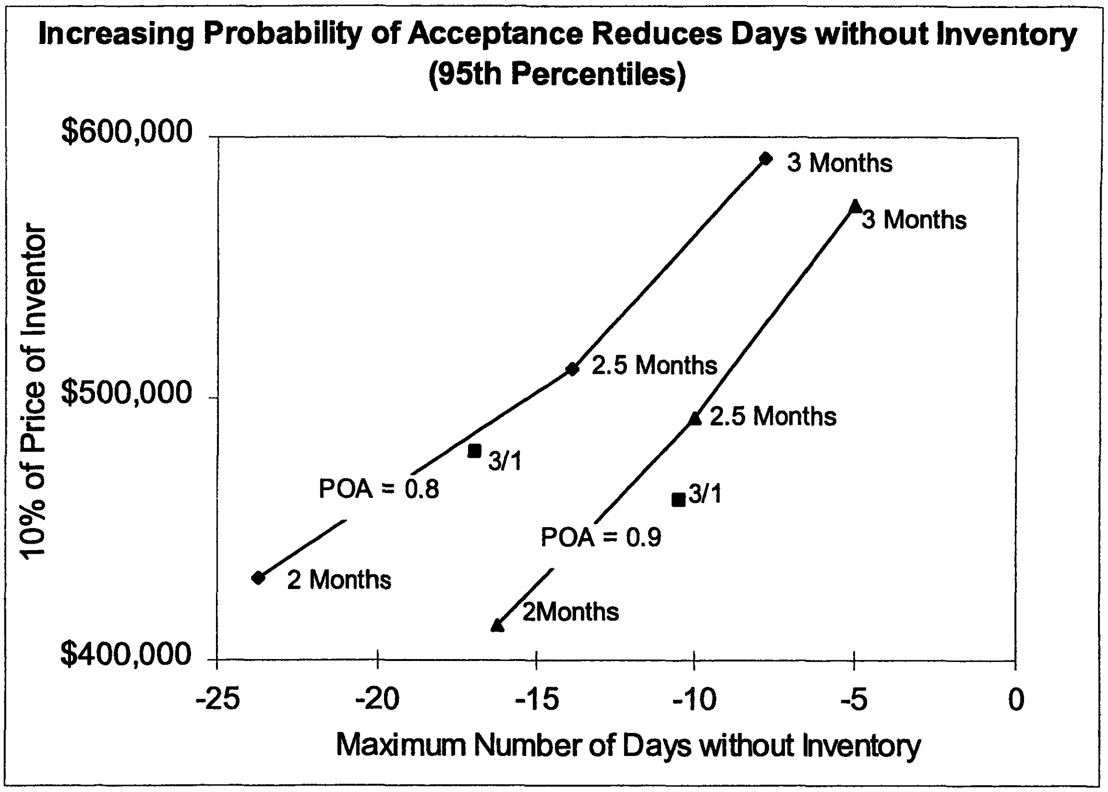

Figure 11: Dynamic Simulation Model Results, 95th Percentiles, for Different Probabilities of Acceptance

Figure 10 also shows that there is little advantage in holding more than 2.5 or 3 months of inventory. The additional inventory does not reduce the predicted number of stock out days, which may impact customer service. Figure 11 presents the risk associated with this statement by presenting the 95th percentiles of the data, which indicate that there is an advantage in holding more than 2.5 months of inventory. However, it is interesting to consider that even in the 2 month scenario, there will be a warning before there is the stockout. At the time of the warning there should be safety stock inventory to satisfy two months worth of expected demand. This warning should also signal a different operating mode for manufacturing and scheduling. Scheduling can conserve the safety stock for those customers that do not have much flexibility in when they can receive their order. This may allow for all customers to receive their systems at the time quoted, even when there may be a lack of inventory at the manufacturing site. In general, the operating procedure should include adjusting customer expectations, especially if it is known how long it will be before there are additional validated components. Knowing how long before additional validated components will be available requires those performing the corrective action to be able to predict the amount of time it will take. It also implies that there needs to be strong communication channels between these people and manufacturing. There should also be a communication channel between manufacturing and those working with the company's customers.

In all of the results presented, the scenario with 3 months of inventory in the US and 1 month at the International site (denoted 3/1 in the previous figures) looks favorable in terms of costs and days without inventory. This scenario is interesting in that the US is holding safety stock for the International site. While the International site has only one month of inventory, it does not experience stockouts as frequently as when it holds two months of inventory. The key to this scenario is the negotiation policy of satisfying equal percentages of demand at each site when there are failures or shortages. This is easier to model in a computer simulation than it is to implement with people doing the negotiation. In most companies there are local incentives that will influence local behavior. For example, in this case the US is holding a lot of inventory compared to the International site, while the customer delivery metrics are similar. If each site is measured on their direct costs compared to the service level they provide, the two sites will have very different scores. However, the model shows that there is merit in working together, if the model assumptions could be implemented in actual operations. The model shares available information between the sites concerning shortages, backlogs, forecasts and actual demand. The model does not simulate the human behavior, negotiating tactics, or gaming that may occur in real life. However, the scenario with different levels of inventory highlights the issue of balancing local incentives with company wide, or supply chain wide, metrics.

Structural Changes

In addition to the inventory policy changes, there are also some structural changes that can be made to the supply chain. A possible structural change is shown in Figure 12.

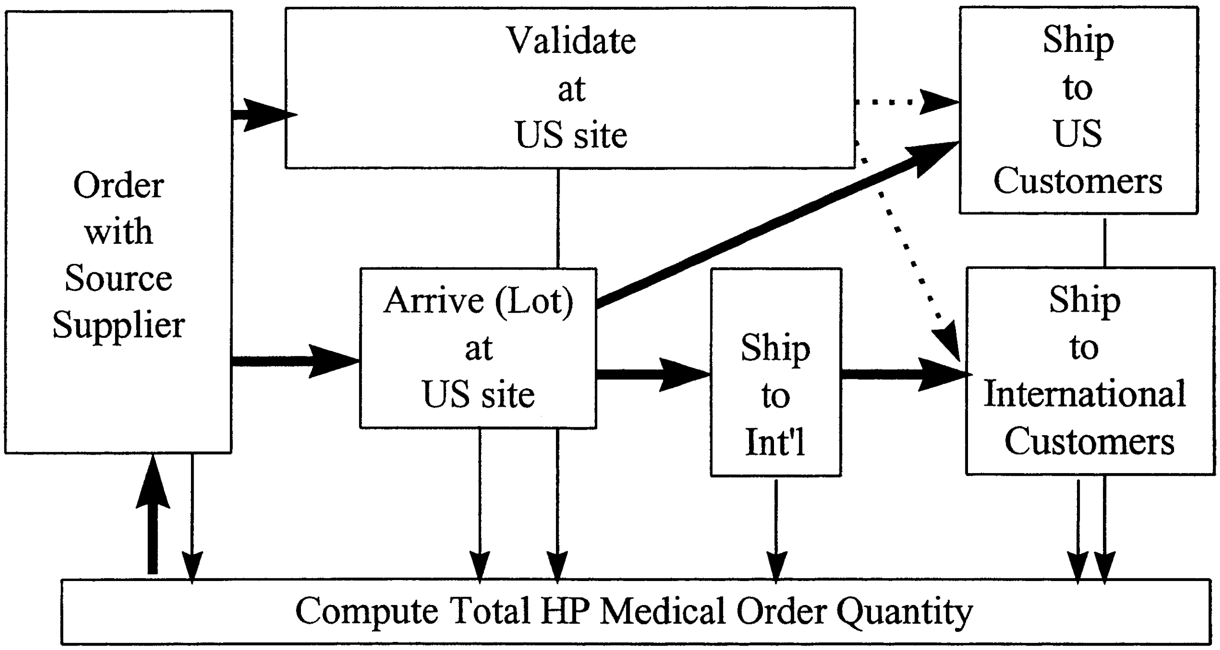

Figure 12: Alternative Supply Chain Structure

In this example of a structural change, the units are sent to the International Site while they are being validated in the US. (Units could even be validated at the source supplier, so that rework could begin while the units are being shipped to the respective sites.) The reason that this structural change is possible is the assumption that the validation and rework is done in software only. It is very easy and efficient to ship software between the two sites. The software can be shipped after the validation and rework cycles, meeting up with the hardware prior to shipping to the end customers. This structural change is simply doing as much in parallel as possible. This will help to minimize the total delay in the system, which will minimize the inventory required to provide the same level of service.

Conclusion

The Dynamic Simulation Model and the process of developing it have presented many new ideas and have brought a lot of information together about the PMD supply chain for this new PC based product. It is with this understanding that the supply chain can be optimized for customer service and reduced levels of inventory. Nevertheless, there are risks associated with the model. While the model indicates that the inventory levels can be reduced by several months, there are simplifying assumptions built into the model that should be understood before using its results. (The Dynamic Simulation Model assumptions are listed in Appendix 5.) The model also uses predicted data for the input of demand, supply delivery, and rework times. The key to getting value out of this type of model is to understand the assumptions and the data used in the model. Generally, it is in gathering the data for the model, talking with those that are responsible for the data, and questioning the model that most of the supply chain knowledge is acquired. Therefore, it is usually the person who builds the supply chain model that understands the approximations and assumptions that went into building the model. This can present a challenge when transferring the ownership of the model to someone new, as well as when the model is applied to new supply chains. Even with general supply chain modeling systems that have a set of assumptions that apply to all models, such as SIPM, there are additional assumptions made about the values of the parameters entered into the model. These assumptions are frequently not captured, which presents a problem when transferring the model and can even be a problem in interpreting the results of the model.

We addressed this issue of interpreting results when we started using the SIPM software. We discovered that the SIPM results seemed very different from what we expected. We knew that we could not represent the rework cycle that was predicted for the new PC based product, but we were not sure how important it was to the supply chain. If we had assumed that the rework cycle was not important and continued with the SIPM model, it is very likely that the model would have suggested reducing the inventory levels even further. The result being that there would be a good chance of having a stockout that impacted customer delivery, if we had not looked at the assumption of the model and examined the results.

It is also important to understand that the actual implementation of the supply chain will differ from the model results, as human beings are making decisions. It will differ in that there are probably several additional sources of information being given to those making decisions, including their prior experience. Software models consider limited amounts of information and very few consider historical trends or experience in decision making. While there are risks associated with using software models, there are also some great benefits.

One of the benefits associated with this supply chain modeling project was the improved communication that occurred between different members of the supply chain. The model helped to determine the major sources of uncertainty in the supply chain and presented the impact of these uncertainties. For example, manufacturing and design engineers were talking about making the software components independent from hardware changes so that the probability of acceptance could be increased. This discussion occurred because the model demonstrated the importance of design decisions on the rest of the organization and to the supply chain, in particular. The model was also useful in discussing options with the PC supplier. The model could be used to compare different supplier relationships, considering response times and transportation delays. The model also demonstrated the impact of forecasting errors on the manufacturing organization. While the model had benefits, there was also a great deal of learning about the challenges of supply chain management associated with building the model.

I learned that the structure of the supply chain is very important to its efficiency, but it is a challenge to design and then implement. I draw this conclusion because of the many organizations involved in the supply chain. It is quite easy and natural for them to focus on their local objectives. When a significant percentage of a supply chain is within a single organization, it may be easier. But many companies are moving away from vertical integration. Therefore, the supply chain needs to be designed and managed across many organizations. There is another challenge associated with the fact that there are multiple organizations involved in the supply chain; there isn't a single person or single organization responsible for the supply chain. In fact, even within a single company there are separate organizations for purchasing components, manufacturing products, and yet another organization for selling and distributing these products. There are very few companies that have a single person looking at the supply chain. Who owns the efficiency of the supply chain?

A result of the supply chain model developed at HP Medical during the LFM internship is that the inventory policy for the new PC based medical system is likely to be lower than originally planned, saving approximately $500K in annual inventory holding costs. Additionally, the structural changes will further reduce inventory requirements. Perhaps the longest lasting benefits of this internship will come from the introduction of supply chain modeling tools, the SIPM software and the Dynamic Simulation Model, as well as from developing a methodology for quantifying uncertainty in the supply chain.

Appendix One: Supply Chain Management

Over the last few years, manufacturing organizations have become increasingly aware of the importance of supply chain management. This may be due to a number of factors: shorter product lives, faster product development cycles, increased availability of information systems, more accessible global markets, and an increased presence of worldwide suppliers. Supply chain management is critical to being able to deliver the right products to customers, with the appropriate level of service and quality, at the right cost. The importance of supply chain management will vary depending on the structure of the business and the market: more competitive markets will require well designed and reliable supply chains to offer the right products to the right customers, with the right service, quality and price. Companies in less competitive markets may be able to get by with lower levels of service, quality or product options, or they may be able to ask higher prices. In these situations, supply chain management may not be as high of a priority. However, in any market the supply chain should be in line with the business objectives of the company and can be a strategic advantage, if designed and managed appropriately. This chapter gives an overview of supply chain management.

The Supply Chain

What is it?

The supply chain is the network of people, processes, and material involved in taking raw materials and delivering a finished product to a customer. It is frequently described with stages of processing that transform a product from its initial state to its final state at the customer site.[5] The initial state of a product can vary depending upon the scope of the supply chain. For example, the supply chain for a PC may start with the process of growing silicon and end with the final delivery of a complete PC to the end user. A simple supply chain may start with ordering components from suppliers, assembling them together, and then shipping

[5] Some companies are now beginning to look at the supply chain through out the entire product life: from raw materials, through finished product use, and then on to returns, reuse, and disposal of the product.

to the end user. There is a multitude of supply chains that can cross organizational, corporate, and geographic boundaries. All products have a supply chain and all products have several options for supply chain designs and management. There are advantages to be gained from a well managed supply chain.

Why is it important?

The supply chain for a product has an enormous impact on the business, and thus there should be a match between a business' strategy and its supply chain. For example, if a business has a monopoly on a particular product, perhaps with a patent or some other guarantee of exclusivity, it may choose to have a different supply chain than a company that is competing in a commodity market. The monopolistic business may have longer lead times and may let their customers wait for delivery. The alternative would be to hold inventory of the long lead time components and provide faster delivery. However, with a monopoly on the market, the business does not risk losing orders by having the customer wait. Thus, the monopolistic company does not need to use its resources to hold inventory. A similar example would be an organization that develops hand crafted goods; the supply chain is likely to consist of artisans building the finished goods from raw materials. In contrast to this, a commodity may be manufactured in large volumes with automated machinery. If the commodity product is not available from one manufacturer there will be another manufacturer to meet the needs of the customer. Thus, with commodity products supply chain issues can easily result in lost revenue. These two products, an art object and a commodity, have a different basis for competition. The hand crafted art is competing primarily on quality (service and cost are far less important) and the commodity product is competing primarily on price. Yet service and quality will have an impact on business of the commodity producer if the service and quality is not comparable with that of the other manufacturers. Therefore, these two products have very different objectives for their supply chains. The hand crafted art would focus on quality, at the expense of service and price. The commodity product would focus on price, but would not be able to ignore quality and service. It is important for an organization to manage its supply chain to understand where efficiencies can be gained and how supply chain management can enable them to be more competitive in their business.

What is the challenge in managing the supply chain?

Supply chain management can be challenging simply because the delivery of the final product to a customer is the result of an entire network of organizations working together. Frequently, each of these organizations is measured on its independent performance and not the performance of the supply chain as a whole. Additionally, some of these organizations may be part of multiple supply chains, in that they work with several different customers. The result is that segments of the supply chain may be working on localized goals; this may be due to the incentives, metrics, or lack of visibility to the other links in the supply chain.

Localized improvements may have negative effects on a product's supply chain as a whole. An example of this would be when one organization decides to reduce its inventory levels because one of its management objectives is to reduce the amount of capital tied up in inventory. With a reduced inventory level and no other changes, it may start to exhibit unreliable service to its customers due to machine failures, unexpected increases in demand, supply delays, poor quality supply, transportation delays, etc. These issues may have been present before the inventory level reduction, but the inventory buffer allowed for reliable service. Unreliable service at one stage in the supply chain will typically be accommodated for with additional inventory being held by downstream stages. The inventory has shifted downstream so that the end customer continues to receive reliable service. Inevitably, the inventory becomes more expensive as it moves through the supply chain as more value is added to the product. In this example, the result of the localized improvement is that the cost of producing the finished product has increased. Generally, because there are inherit inter-relationships between the different stages of the supply chain, changes made at one stage have an effect on the other stages of the supply chain.

Supply chain management involves the performance of the entire supply chain. It involves managing a set of systemic issues; looking beyond local improvements to improve the performance of the entire supply chain. One of the most challenging aspects of managing the supply chain is managing the systemic nature of the entire supply chain. It is further complicated by the fact that the different stages of the supply chain are frequently the responsibility of different organizations, both internal and external to the company that delivers the final product. These organization should be exchanging information with the other stages: demand data (forecasts and backlogs), inventory levels, production plans, and the sources of uncertainty and variability in this information. Unfortunately, even with the best of intentions to communicate this information, doing so is complicated by different information systems, different forecasting methods, and different time periods for updating this information at the different stages of the supply chain. However, the exchange of this information is a key way to reduce the bullwhip effect (Lee, 1995). Without this information, there is a tendency to hold inventory to buffer against uncertainty and variability. Inventory is also held to accommodate for long lead times and for a variety of other reasons. Holding inventory can be critical to providing reliable and predictable customer service, but it can also obscure more efficient methods of providing reliable customer service.

Appendix Two: Inventory In The Supply Chain

There are many reasons for holding inventory in the supply chain. Nonetheless, there is one principle that should drive all decisions regarding inventory: an organization should hold inventory for the purpose of providing competitive, predictable, and reliable customer service. Customer service may be impacted by long lead times, as well as uncertainty in supply, demand, and processes. Inventory is held to buffer against these issues, but it also held because of ordering policies, information systems, incentives and metrics, and other local reasons. Each of these issues is briefly explored, as well as the cost of holding inventory:

Long lead times

When the component lead time and processing time is longer than the time quoted to the customer, inventory is held to meet the delivery time quoted to the customer. For example, if it takes 10 days to get components and 1 day to produce the product, but the market demands that you ship the product in 2 days, then you will need to hold inventory to meet the customer delivery time.

Uncertainty

There are three primary sources of uncertainty that an organization will hold inventory to buffer against: supply, demand and process uncertainty. Sources of supply uncertainty can include product shortages, product revisions (supply changes), variation in transportation times, etc. Inventory is also be used to buffer against demand uncertainty. There is a high degree of demand uncertainty for a new product[6], as the demand is unknown. There may also be demand uncertainty for existing products as the demand varies from day to day or week to week. In addition to the external sources of demand uncertainty, such as market reactions, competitive products, and substitutes, there are internal sources of demand uncertainty as well. The sources of internal demand uncertainty include quarterly sales incentives, sales

[6] New product introductions are subjected to a high degree of uncertainty. There is uncertain demand, suppliers may be new and the components may be newly designed, and there is also process uncertainty in a new product. Therefore, new product introductions are prone to high levels of inventory. This becomes a problem when the inventory policies are not re-evaluated as the uncertainty is reduced.

promotions, and discounts for bulk purchases. The third primary source of uncertainty is from process variations, such as machine failures, labor issues, and wide ranges on control parameters. Understanding these variations is important to inventory policies, as the greater the variation or uncertainty in supply, demand, or processes, the greater the quantity of inventory required to buffer against it.

Ordering Policies

A corporation's ordering policies can force it to hold inventory. A policy may dictate that for ordering efficiency, orders are placed once a month. This may be the point at which the volume of the order is large enough to warrant transportation efficiencies. When the order cycle grows, the inventory required to meet demand between order cycles also increases. Additionally, ordering polices designed to take advantage of price fluctuations can increase the quantity of inventory on hand. (Buy a large quantity while the price is discounted.) While these types of policies can provide significant improvements in efficiencies, they many not be the most cost effective. (See "The Cost Of Holding Inventory.")

Local Incentives

Local incentives can also increase the amount of inventory within a corporation. Some of these incentives include buying at discounts[7], avoiding stockouts[8], and batch processing of orders such that there is a reduced number of setups, but an increased amount of work-in process inventory. Many of these local incentives are intended to provide operational efficiencies or some cost benefits, but they also increase inventory which can have the opposite effect.

Information Systems

Information systems can also contribute to the amount of inventory being held. When there are several systems to coordinate, running a material requirement planning system (MRP) can

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[7] Some purchasing agents are measured by the cost paid per item or the discount they negotiate, not necessarily the total cost of owning the inventory.

[8] I have spoken with manufacturing managers who have seen individuals get fired for stocking out. The remaining manager ensures that there is always inventory on hand.

take so much time that the company can be forced into month long planning cycles. "The long planning cycles increase forecast errors and reduce manufacturing's ability to respond to updated order information. Manufacturing ends up building the wrong products. This leads to high inventory levels and high backorder levels." (Lee, 1992)

There are a wide variety of reasons that an organization may be holding inventory. Managing inventory levels begins with understanding the reasons that inventory is being held, then trying to eliminate or reduce the root cause when possible. An organization should also be re-evaluating inventory decisions to account for improvements in processes and reductions in uncertainty. Eliminating all inventory may not be advantageous to the business as the benefit of holding inventory is in customer service: providing predictable, reliable, and competitive customer delivery of the manufactured solution. While the benefits of holding inventory are clear, the total cost of holding inventory is often disputed.

The Cost Of Holding Inventory

One of the costs of holding inventory that generally goes undisputed is the opportunity cost of the capital tied up in the inventory. Many companies use a figure close to 10% to represent the cost of capital. However, there are additional costs of holding inventory. There are costs associated with the facilities and operations for storing the inventory. These costs would include the floor space occupied and the cost of moving the inventory into storage and back out where it will be used. These facilities and operations also have an environmental cost associated with them, which is often overlooked.

There are also inventory costs associated with short product life cycles and product changes. When the end product goes through a product change, the existing inventory may need to be reworked. If the product "rolls" (entirely new product), the exiting inventory may not be of any use for the new product. These are real costs of holding inventory. The same rapid development cycle is occurring at the suppliers as well. An example of this would be a PC based product, where the product rolls every 6 months, with internal changes even more frequently. When the PC is a component of a turnkey solution, holding a large inventory of PC's can be very expensive, as their value decreases with time. Their value to other organizations, including your customers, decreases as new PC's with more capabilities are introduced at or near the same price point. Thus, the cost of obsolescence is becoming more important to consider in the cost of holding inventory, especially in high tech markets.

There are very real costs, beyond the cost of capital, in holding inventory. Nonetheless, there are very real benefits to holding inventory in the supply chain. A primary aspect of supply chain management is determining how much inventory to hold and where to hold it in the supply chain to efficiently provide competitive, predictable, and reliable customer service.

Appendix Three: Process Mapping and Inventory Analysis

This appendix describes first step in the process of supply chain modeling for inventory analysis. The next few sections will present an approach to analyzing the inventory in a supply chain. Starting with process maps and business drivers, the discussion moves to modeling and optimizing the supply chain. While this methodology uses the SIPM software for supply chain modeling and optimizing the location and quantity of inventory, it is intended to be a general approach that can be used with or without the powerful SIPM software. (The SIPM software is described in Appendix 4: Supply Chain Modeling.) The supply chain modeling software is used to highlight discrepancies between the optimized model and reality. The objective of this approach is to gain a better understanding of the reasons for holding the existing inventory, as well as examining areas for improvement and optimization of the supply chain.

Process Flow

The first step in the inventory analysis is to map the material and information flows of the existing supply chain. This approach can be used at any level of the supply chain, from flows between organizations to flows between work stations in a single manufacturing line. However, for the purpose of this document, we will be working at an aggregate level. We will start by looking at the segment of the supply chain where there is a significant amount of time or money being spent in the supply chain. The supply chain of a digital camera serves as a useful illustration of the inventory analysis process. Figure 13 shows the material flow for a digital camera at the aggregate level.

There are three main components in the digital camera: a traditional camera, a custom-built circuit board, and an imager. The traditional camera and the circuit board are produced by other organizations and the imager is assembled in-house. The imager's main components include a circuit board and software, but there are additional components as well. The miscellaneous components are grouped together at this time because they are all relatively low cost items. After the traditional camera, circuit board, and imager are assembled with the other components, the finished product is shipped to a distribution center. The distribution center then ships the product to meet customer demand at the stores. This gives us a high level view of the material flow for a digital camera. The information flow for this product will compliment this material flow in understanding the supply chain.

The information flow in the supply chain is important to understanding the behavior of the supply chain. The challenge in mapping the information flow is that information is not as tangible as material. Therefore, determining what information is flowing between the different stages can be more challenging, but frequently more important than the material for understanding the supply chain. The information flow for the digital camera example shows that the primary information exchanged, besides orders and money, is demand and lead time information. See Figure 14.

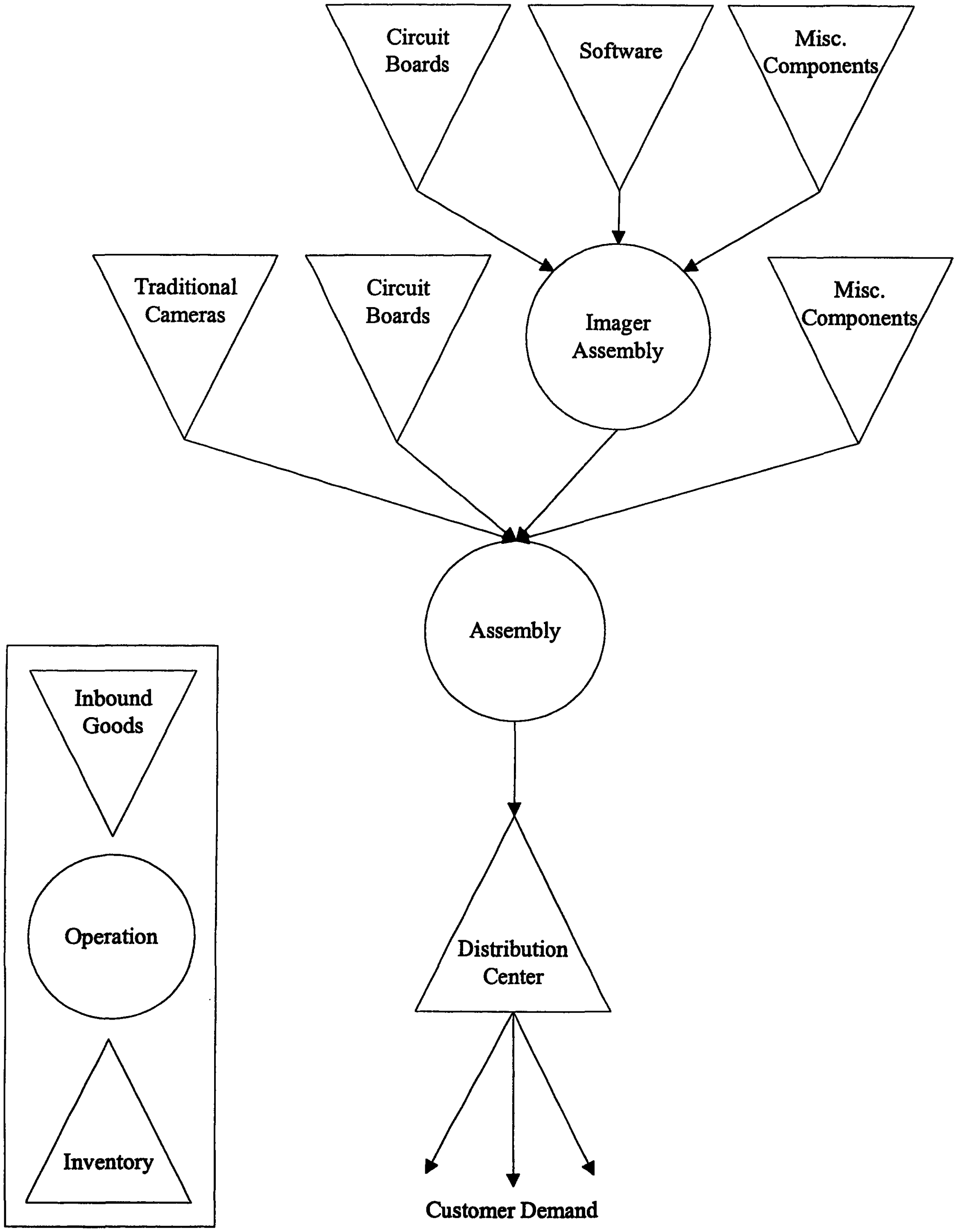

Figure 13: Material Flow for a Digital Camera

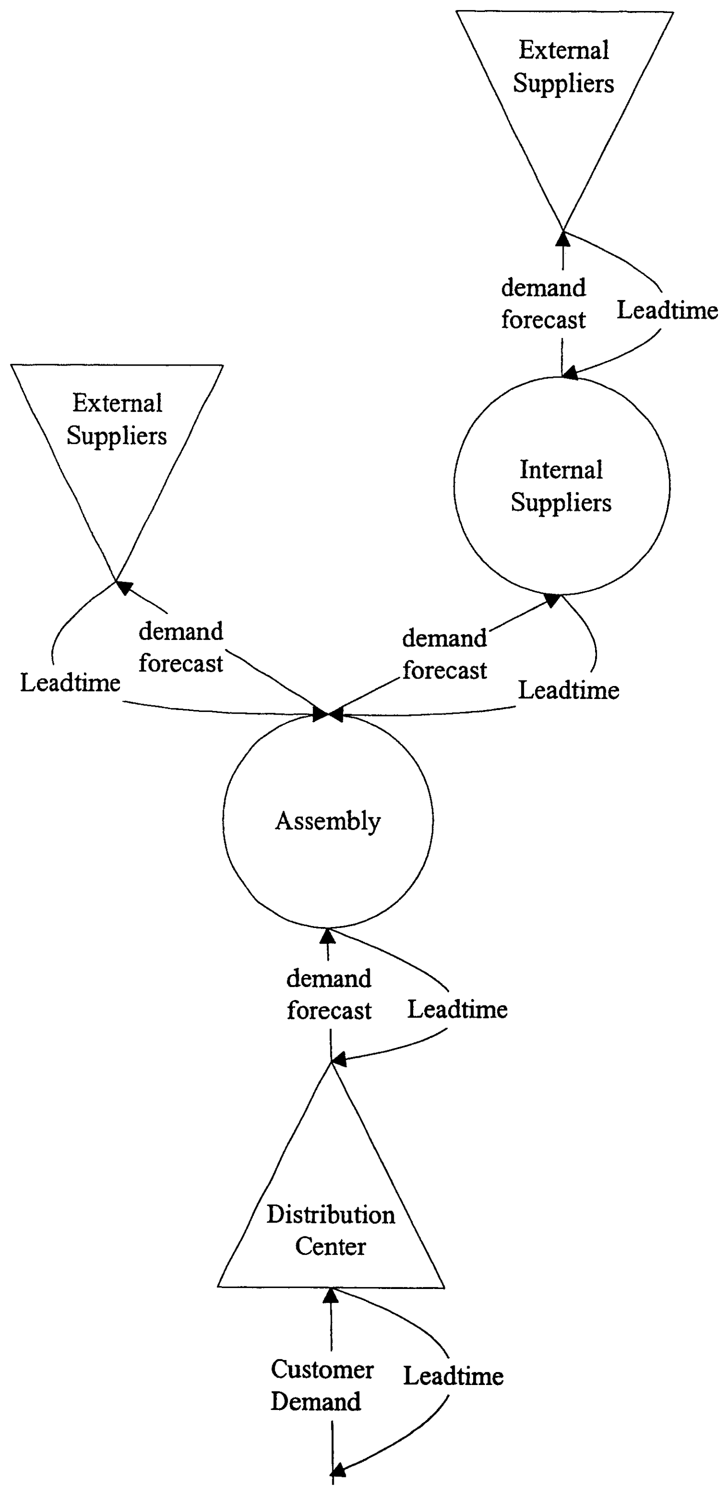

Figure 14: Information Flow for a Digital Camera

It is interesting to note that the distribution center is receiving customer demand data and all other organization are receiving demand forecast data. (An alternative would be to have the actual customer demand data passed back through the supply chain.) This is an indication that this supply chain may be experiencing the bullwhip effect: small changes in raw demand data is exaggerated as the information moves through the supply chain. Understanding the process flows in the supply chain is critical to understanding how effective the supply chain can be in addressing the business drivers.

Business Drivers

Business drivers of concern to the supply chain are the issues facing the business that have an implications for the supply chain. Examples of business drivers may include: seasonal demand, marketing promotions, quarterly sales quotas[9], competitive markets, wide availability of substitutes[10], worldwide distribution and market segmentation[11]. There are also many other business drivers affecting the supply chain when one looks beyond traditional manufacturing.

Supply Chain Constraints

Supply chain constraints are often related to business drivers, but are more directly related to the supply chain. Supply chain constraints can include things such as long term contracts with suppliers or distribution providers, long lead times for certain components, market price points, and delivery of full orders within a fixed amount of time. The demands placed on the supply chain by organizations such as Wal-mart are forcing manufacturing organizations to design their supply chain to meet the delivery requirements of their customers, which some have addressed by holding an excessive amount of inventory. Some of the constraints to

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[9] Seasonal demand, marketing promotions, and quarterly sales quotas cause demand fluctuations or uncertainty.

[10] Competitive markets and wide availability of substitutes imply that delivery is very important to the actual consumption of the product. The competitive market may also indicate that improvement in the supply chain can have a substantial effect on the business.

[11] Worldwide distribution and market segmentation may indicate a wide variety of products for the different markets. Worldwide distribution also implies different lead times for different markets, depending on the location and number of supplying manufacturing sites.

consider across all supply chains include procurement lead times, production lead times, service times, and costs.

In the digital camera example, there are service time constraints for each of the three market segments served: The Americas region has a requirement of 5 days, and the Asia and Europe regions require delivery within 12 days. The cost of the traditional camera, circuit board and imager represent the majority of the total cost of the delivered product and the lead times on these components are over 45 days. There are also some components that are low in cost, but have lead times in excess of 60 days. With this understanding of the process flows, business drivers, and supply chain constraints, the next step in the process is to examine the existing inventory in the supply chain.

Existing Inventory

One must examine the existing inventory in the supply chain to understand the real world reasons for holding that inventory. This is done with initial modeling questions and then by comparing the existing inventory levels and locations with the supply chain model. There may be very valid reasons for holding inventory and there may be areas where the inventory can be reduced. However, it is important to understand the reasons for the existing inventory in the supply chain as well as the reasons for the lack of inventory in the supply chain. Many real world reasons for holding inventory cannot be modeled in an analytical model. However, a successful supply chain analysis includes understanding these reasons.

Returning to the digital camera example, Figure 15 shows that the finished goods inventory is held at the distribution center. (Note that at this level of aggregation, it is as if we are looking at a single product, and not a series of products for different markets.) Traditional cameras, circuit boards, and imagers are also held at the assembly site. In addition to where the inventory is held, we also want to explore how much is held and why.

Finished Goods
Inventory of the finished product is held at the distribution center because of the short service times required by the market segments. It is also held because of the variability experienced in receiving finished goods from the assembly operation. (This inventory decouples delivery to the customers from the variation in delivery from the assembly operation.)

Traditional Cameras
Inventory of traditional cameras is held because of the long lead time and the fact that there is only one certified supplier of the product. Thus, the inventory is serving as a form of insurance for any supply issues that may occur with the product.

Circuit Boards
Inventory of circuit boards is held because of the long lead times and a history of quality problems from the supplier.

Imager Assemblies
There is a large inventory of imager assemblies because the production group operates whenever there is enough inventory of components to produce the full assembly. (They are pushing product to the main assembly operation and generally have a lot of WIP. The line operators in this area are measured on assemblies produced per shift.)

There are a variety of reasons for holding inventory. The point is to realize that some of these issues cannot be modeled, but they should be articulated and understood.

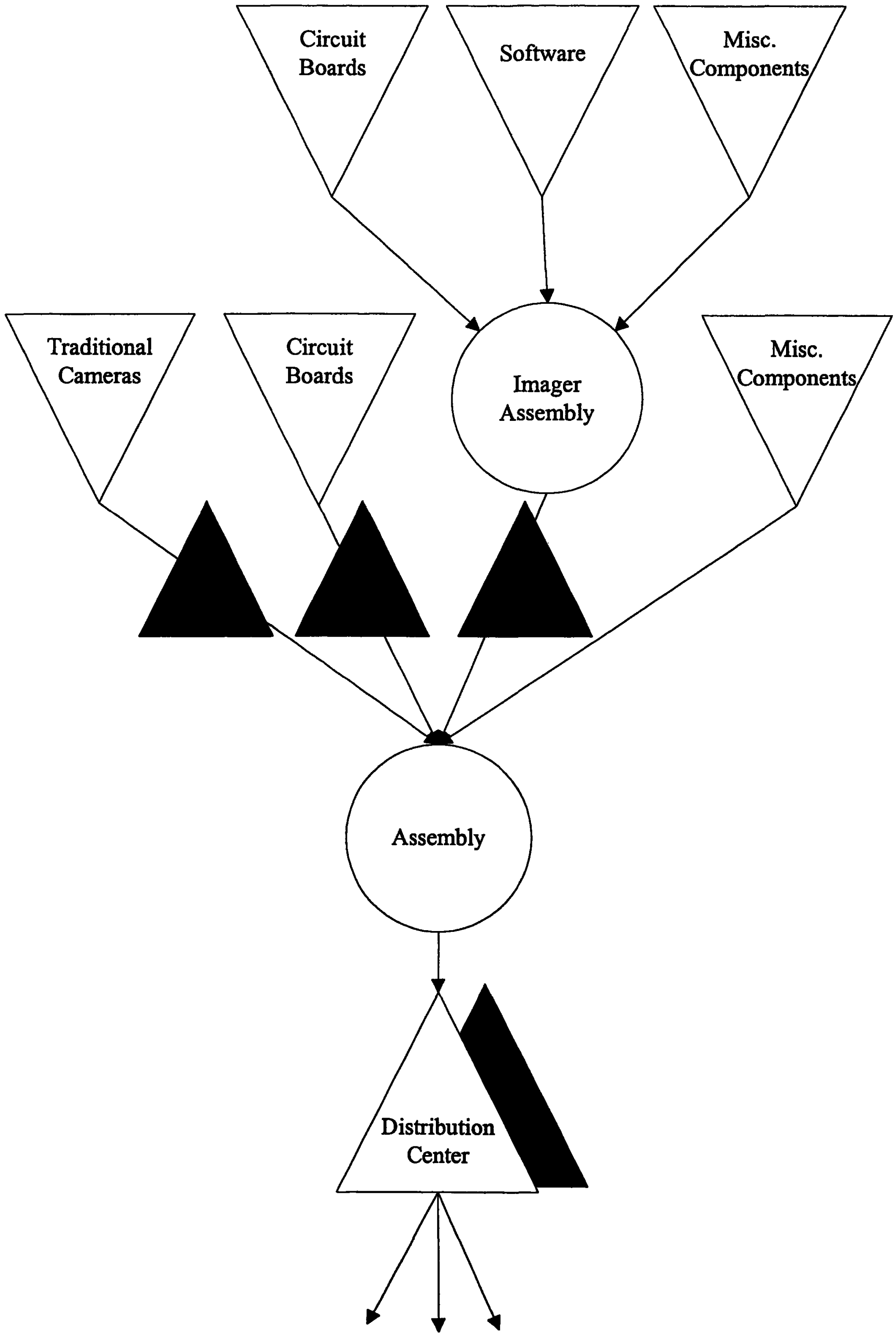


Figure 15: Existing Inventory Locations for a Digital Camera

Appendix Four: Supply Chain Modeling

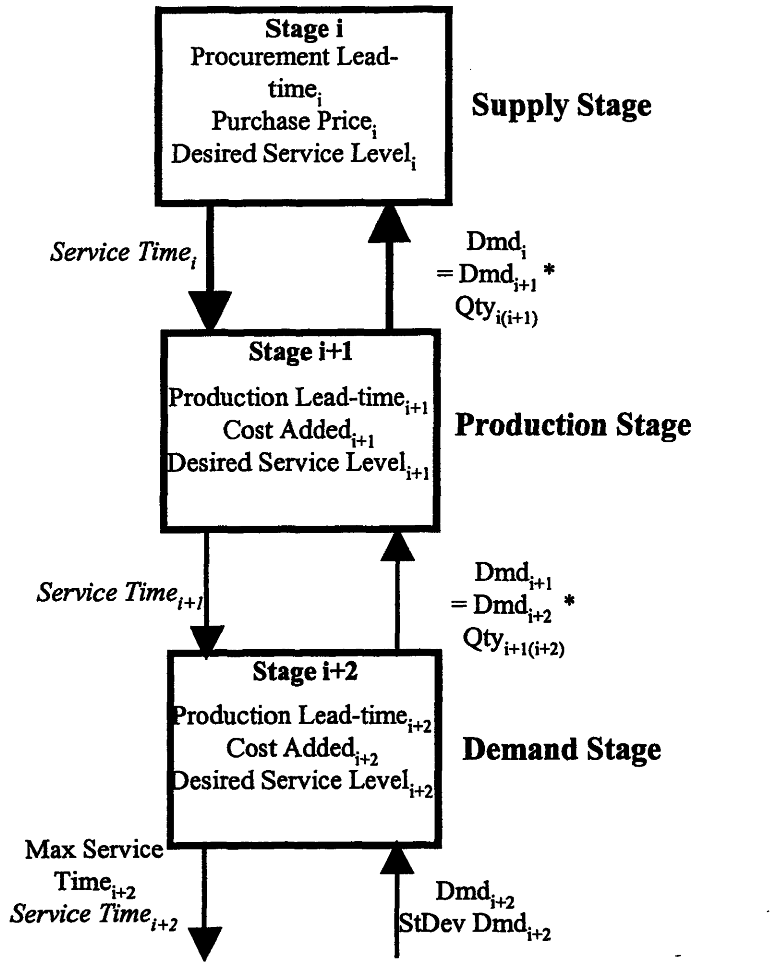
A model, by definition, is an approximation of reality. A model should be used to gain insight into a situation. Much of the learning is done by building the model and exploring the differences between the model and reality. The purpose of the analytical supply chain model is to assess inventory placement strategies in terms of service level and inventory costs. This appendix uses the SIPM software to develop an analytical supply chain model. The SIPM software has the capability to optimize the service times between the various stages, as well as determine both the safety stock and pipeline stock. The optimization function of the SIPM software will seek to minimize inventory holding costs under the constraint of satisfying customer demand within the specified time period. The SIPM will optimize the entire supply chain as a system and may not optimize each individual function within the supply chain. In general, the model can be used to assess the impact of an improvement in one area on the entire system. This is a good starting point for examining the differences between the optimized result and reality. The SIPM is also intended to be used to examine what-if scenarios, which can be helpful in designing the supply chain and negotiating between the various suppliers in the supply chain.

Stages In The Supply Chain

In developing an analytical supply chain model, each stage of the supply chain should be described with a common set of parameters. A stage of the supply chain can be considered a process that may have inventory stored before and/or after it. Examples of a stage include the purchase of raw materials, assembly of a key component, and distribution of the final product. The processes that involve high value add, significant lead times, or strategic value should be represented in the analytical model.

Common Parameters

Each stage in the supply chain will be described by a common set of parameters. There are three types of stages: supply (source stages), production (intermediate stages), and demand (use stages). The parameters of these stages and their values will depend upon the specific function of the stage. A depiction of the three types of stages and their common parameters is shown in Figure 16.



Dmd$_{i+2}$	:Demand on stage i+2, (can be from end customer)
StDev Dmd$_{i+2}$	: Standard Deviation of demand at i+2
Qty$_{i+1(i+2)}$	: Number of stage i+1 units required for the each unit at the i+2 stage.
Dmd$_{i+1}$	: Demand on stage i+1; (In this example, Dmd$_{i+1}$ =Dmd$_{i+2}$ * Q$_{i+1(i+2)}$.)
Qty$_{i(i+1)}$	: Number of i units required for the i+1 stage
Dmd$_i$	: Demand on stage i; ithe demand on stage i+1 times Q$_{i(i+1)}$.
Max Service Time$_{i+2}$	: Maximum amount of time between receiving a customer order and customer delivery.

Optimized Values (Model Decision Variables)

Service Time$_i$	:Time between stage i receiving and fulfilling an order.
Service Time$_{i+1}$	:Time between stage i+1 receiving and fulfilling an order.
Service Time$_{i+2}$	:Time between stage i+2 receiving and fulfilling an order. This will be less than or equal to the Maximum Service Time$_{i+2}$

Figure 16: Common Parameters for Supply Chain Stages

Production Stage Parameters

The production stage describes a process that receives material from either a supply stage or from another production stage and then delivers it to another production stage or to a demand stage.

Production Lead Time

Production lead time is the amount of time it takes the product to get through the current stage, assuming that any required raw materials are already available. Therefore, it is the summation of the following times: the time to get raw materials from the previous stage, the waiting (queuing) time at the current stage, the production time at the current stage and the time to put the product in the current stage's inventory location (if one exists). The Production Lead Time should include:

- Ordering Delay - time between need arising, being observed, and then an order being placed. If this is significant, it should be modeled as a separate production stage to both emphasize its importance and accurately represent the inventory costs.
- Transportation Time - time to transport the product from the previous stage, including delays in scheduling the transportation. When there are multiple suppliers to a stage, the transportation time should represent the longest transportation time - assuming that the process cannot take place until all components have arrived. The transportation time is attributed to the receiving stages because there will be different transportation times from a supplier to its different customers. (For example, if a supplier serves customer A and B and the transportation time is 1 week to customer A and 3 weeks to customer B, then the best place to describe this is with the customer or receiving stage.)
- Set-up Time - time to schedule and set-up the order given that all materials are available
- Queuing Time - time spent waiting for processing. As an example, if there is limited capacity at a production stage, an order may spend time waiting in queue behind other orders.

- Processing Time - time to process the product for the next stage usage
- Staging Time - time to place the goods in an inventory storage location (if one exists) or setup for distribution to the next stage.

The total production time should represent a high confidence level, e.g. 95%, that the actual production time will be less than or equal to the value used in the model. The production lead time should also reflect any capacity constraints at the stage.

Cost Added

The cost added parameter is the direct cost added to the product at this stage of the supply chain. The Cost Added per unit should include the costs for the following:

- Material Consumed
- Direct Labor
- Procurement (may be derived from charge per lot and average lot size)
- Transportation Cost, typically from the previous stage.

Service Time

The service time is the delivery time quoted to the customer. It would represent the amount of time between when an order is received and when it is filled. This parameter is a decision variable for the model unless it is explicitly fixed. The optimized value for the service time will be based on the system constraints and optimization function.

Desired Service Level

The service level is the probability that all of the orders placed in a period are delivered within the quoted service time. For example: If in 80% of the periods, all demand is delivered at the 2 week quoted service time, then the service level is 0.8. Valid values are between 0.01 and 0.99, inclusive.

Supply Stage Parameters

The entire supply chain begins with the supply stages (those without an inflow). These stages represent the inflow of material and information into the entire supply chain.

Procurement Lead Time

The time to procure materials and make them available for downstream processes is the procurement lead time. The value for the Procurement Lead Time should include:

- Ordering Delay - time between need arising, being observed, and then an order being placed.
- Supplier Response Time - time for the supplier to make the material available for usage.
- Transportation Time - time to transport the product from the supplier to the buffer (if applicable), including delays in scheduling the transportation. The transportation time would be 0 for a supplier that provides JIT deliveries. In this case the transportation time would be incorporated into the production time for the stage using the material.

Service Time

Same as Production Stage Service Time

Purchase Price

The price paid for the product(s) procured and any other direct costs, such as procurement and handling.

Desired Service Level

Same as Production Stage Service Level

Demand Stage Parameters

The end stages of the model (those without an outflow) correspond to demand origins or end-items in the supply chain. Thus, they are used to describe the demand for the end-item or finished good. The demand per period is assumed to be normally distributed and thus, is described with a mean and standard deviation.

Production Lead Time
Same as Production Stage Production Lead Time

Service time
Same as Production Stage Service Time

Cost Added
In addition to the costs of a production stage, the demand stage may also include the transportation cost to the customer, if this cost is borne by the supplier. Therefore, a demand stage may include the transportation costs for both receiving and delivering the product.

Desired Service Level
Same as Production Stage Service Level

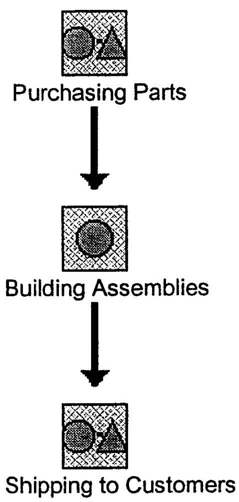
Mean Demand
The mean demand per time unit.

One period of Standard Deviation
The standard deviation of demand per time unit.

Max Outgoing Service Time
The Maximum Outgoing Service Time represents the maximum time to deliver a product to the customer. The Max Outgoing Service Time constrains the entire allowed system to deliver the product within this time frame at the Desired Service Level. The Max. Outgoing Service Time is shown in Figure 16.

Example of Stage Parameters

The following example shows a simple three stage model and the parameters associated with each stage. All of the stages have a Desired Service Level of 0.95. The actual service times



Purchasing Parts is a supply stage with the following parameters:
Procurement Lead Time: 50 days
Purchase Price: $20
Service Time: 21 days

Building Assemblies is a production stage with the following parameters:
Production Lead Time: 5 days
Cost Added: $40
Service Time: 26 days

Shipping to Customers is a demand stage with the following parameters:
Production Lead Time: 3 days
Cost Added: $10
Mean Demand: 10 units/day
One Period of Std. Deviation of Demand: 2 units/day
Maximum Outgoing Service: 2 days
Service Time: 2 days

are represented and fixed in the model (they will not be optimized in this model).

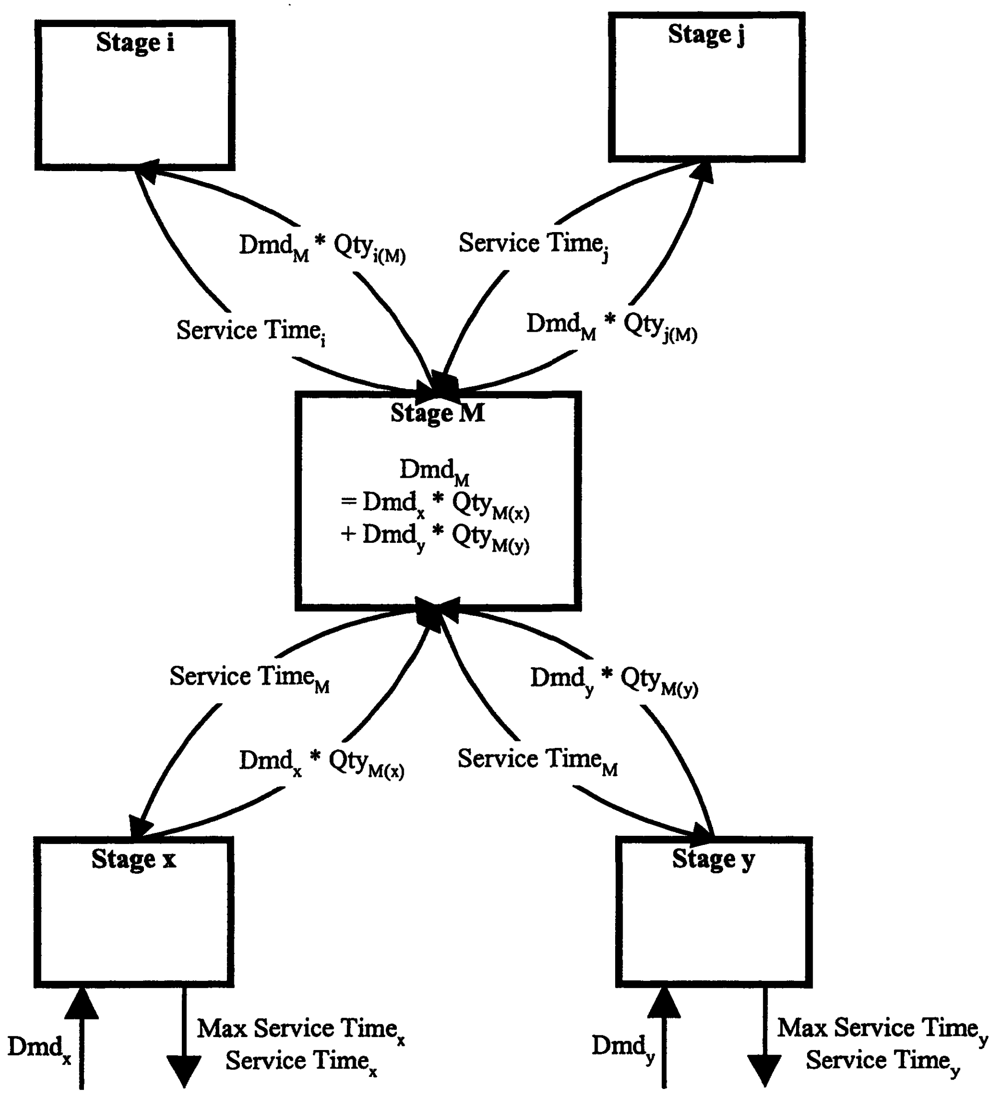
Link Parameters

The link between stages contains the demand multiplier. This multiplier amplifies the unit demand of a customer by the number of units required from the supplier to satisfy each unit of customer demand. For example, if a stage faces a demand of 10 units and each of these units requires 2 parts from a supplier, then the demand faced by this supplier will be 2*10 = 20 units.

Multiple Market Segments

When there are distinct market segments, multiple demand nodes may be used to describe the different characteristics of the market segments. When the demand varies in any of the demand stage parameters, it is useful to use multiple demand stages.

The demand from the end nodes is passed back through the supply chain to the supplying stages. When there are multiple demand stages, the demand faced by the supplying stage is the sum of the demand of all of its customers. An example of the demand flow through a supply chain with multiple market segments is shown in Figure 17.



Dmd_x	:demand on stage x.
$Qty_{M(x)}$	:number of M units required for the x stage.
Dmd_y	:demand on stage y.
$Qty_{M(y)}$	:number of M units required for the y stage.
$Dmd_{(M)}$	:total demand on stage M is the sum of total demand from stage x and stage y.

The service time to Stage M is the maximum of Service $Time_i$ and Service $Time_j$

Figure 17: Link Parameters between Stages

System Parameters

Holding Cost

The holding cost is the fractional cost of holding inventory. It is used with the cumulative cost at a stage to determine the per unit cost of holding inventory. The units for the holding cost will determine the time frame for the cost of inventory. For example, if the holding cost is 20% annually and the cumulative cost of a component is $100 and the expected safety stock is 10, then the annual holding cost would be $100*10*0.20 = $200. However, if the holding cost was 1% per week, then the holding cost would be $100*10*0.01 = $10 each week.

Model Output

Cumulative Cost

Cumulative Cost is the total direct costs, per unit, up to a given point in the supply chain. It includes the cost of performing the operation at the stage. The cumulative cost would be the value of the product held as inventory at the stage (if inventory is held).

Cumulative Cost(i) =
Sum[Cumulative Cost of all Supplying Stages(i-1)] + Cost Added (i)

Service Time

Unless the service time of a stage is fixed in the model, the service times will be the optimized times quoted to the stage's customers for product availability. These optimized values are determined by intelligently enumerating all possible service times and determining the optimal configuration of service times. These times will minimize the inventory holding costs within the constraints of the Max Outgoing Service Time to demand stages at the Desired Service Level.

Replenishment Lead Time

Replenishment lead time of a stage is the amount of time it takes to acquire products from suppliers and prepare them for shipment to the next stage or customer; it includes the time to receive the product, process it, and transfer it to inventory. It is the sum of the maximum service time of any supplying stage and the production time of the stage.

Replenishment Lead Time (i) =
Max service time of any supplying stage(i-1) + Production lead time (i)

Coverage Time

Coverage time is equal to the replenishment time less the service time of a stage (non-negative values). The safety stock at a stage is a function of the Coverage Time. For example, if the replenishment time is 10 days and the service time is 7 days, the coverage time is 3 days. Thus, the stage must hold safety stock to cover the variability in demand over the coverage time(3 days) in order to meet the 7 day service time with 95% confidence. A graphical depiction of the output times is shown in Figure 18.

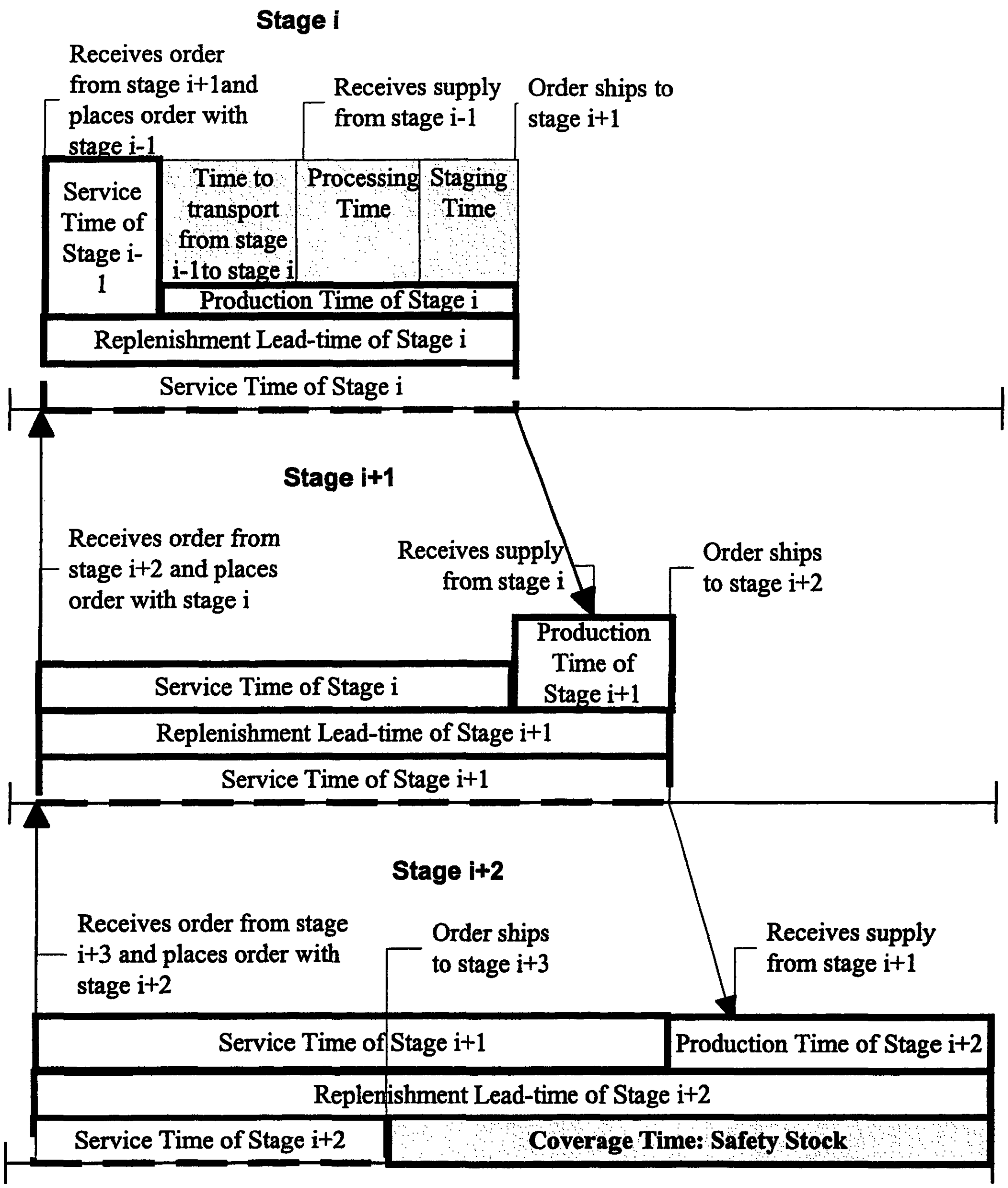


Figure 18: Output Parameters from the SIPM Stages

Safety Stock

Safety Stock is the amount of inventory to be held to minimize the risk of a product shortage. There is safety stock required when the replenishment lead time is greater than the Service

Time of a stage. The safety stock is requested because of demand variability over the time period required to replace the inventory. The safety stock determined by:

$$\text{Safety Stock}(i) = \kappa(i) * \sigma(i) * \text{SQRT}(\tau)$$

$\kappa(i) = \Theta^{-1}$(service level at stage i).
(Θ^{-1} is the standard normal distribution function)
$\sigma(i)$ = one period standard deviation of demand at stage i
$\tau(i)$ = coverage time(i) = replenishment lead time(i) - service time(i)

Total Safety Stock Holding Cost

The total safety stock holding cost is the expected cost of holding the safety stock inventory each time unit, which is determined by:

Total Safety Stock Holding Cost =
Sum over each stage[safety stock units (i) * cumulative cost(i) * holding cost rate]

Pipeline Stock

Pipeline stock is the stock that is in process at any given time at a given stage. It is the mean demand multiplied by the production lead time.

$$\text{Pipeline stock value} = \mu(i) * T(i)$$

$\mu(i)$ = mean demand at stage i
$T(i)$ = Production lead time at stage i

Example of Output

Using the same three stage example described earlier, we can state that the Holding Cost is 20% annually and then look at what the model has produced for us. The model is showing us the level of inventory required, and the appropriate locations, to meet the constraints described by the parameters of the different stages. The output parameters for the three stage example are shown in Table 1. The Safety Stock cost for this state of the model is $311.16 and the pipeline inventory is $1790.30. This represents 20% of the value of the inventory on hand and it is the annual cost of holding this amount of inventory. Inventory is held at all three stages of the supply chain. The quantities of inventory shown in the model should be compared with the actual levels of inventory in a real supply chain.

Production Lead Time	Service Time	Replenishment Lead Time	Safety Stock (product units)	Pipeline Stock (product units)
50 Purchasing Parts	21 Purchasing Parts	50.00 Purchasing Parts	17.72 Purchasing Parts	500.00 Purchasing Parts
↓	↓	↓	↓	↓
5 Building Assemblies	26 Building Assemblies	26.00 Building Assemblies	0.00 Building Assemblies	50.00 Building Assemblies
↓	↓	↓	↓	↓
3 Shipping to Customers	2 Shipping to Customers	29.00 Shipping to Customers	17.09 Shipping to Customers	30.00 Shipping to Customers

Table 1: SIPM Output Parameters

Using the same three stage example we can use the SIPM software to optimize the supply chain by changing the service times of the three stages. The optimized output parameters for the three stage example are shown in Table 2. The Safety Stock cost for this state of the model is $206.85 and the pipeline inventory is $1790.30. The safety stock inventory has been increased at the Purchasing Parts stage, where the inventory is least expensive, and reduced at the other two stages further along in the supply chain. Additionally, there are shorter service times between the stages of this supply chain.

Production Lead Time	Service Time	Replenishment Lead Time	Safety Stock (product units)	Pipeline Stock (product units)
50 Purchasing Parts	0 Purchasing Parts	50.00 Purchasing Parts	23.26 Purchasing Parts	500.00 Purchasing Parts
5 Building Assemblies	5 Building Assemblies	5.00 Building Assemblies	0.00 Building Assemblies	50.00 Building Assemblies
3 Shipping to Customer	2 Shipping to Customer	8.00 Shipping to Customer	8.06 Shipping to Customers	30.00 Shipping to Customer

Table 2: Optimized SIPM output

This type of optimization can be very useful for understanding how improvements can be made within the supply chain. However, in order to apply the results of this model, it is important to understand the different parameters that are used to describe the model and its output, as well as the types of assumptions the model is making about the operation of the supply chain.

Model Assumptions

The SIPM software makes the following operating assumptions:

- **Each stage operates according to a base stock policy**. Base stock is equal to the sum of the Safety Stock + Pipeline Stock. The base stock will be minimized under the operating constraints specified in the model.
- **Each stage has infinite capacity.** The stage is not limited in production capabilities, however capacity limitations can be incorporated into the production lead time as necessary.

- **Demand is an independent and identically distributed (iid) normal distribution from period to period.**
- **Production lead time is deterministic.**
- **Service times are guaranteed.** The service time quoted to a stage is a guaranteed delivery time.
- **Stages have service times that are no greater than the sum of the maximum service time of their suppliers and the stage's production lead time.** The stage will hold inventory only for the purpose of providing a shorter service time to its customers.
  $S_i \le S_{i-1} + T_i$ (Service time at i <= Service Time at (i-1) + Production Lead Time at i)

Understanding the assumptions that the model is making about the supply chain is very important to see the applicability of the results of the supply chain model. As stated at the beginning of the chapter, a model is an approximation of reality, and understanding how the approximation is made is essential.

Modeling for Improvement

The SIPM software can be used to optimize service times between supply chain stages, but it can also be used to show the impact of inventory on customer service levels. Returning to the Digital Camera example, we can see how the SIPM software can help with supply chain modeling for inventory analysis.

Digital Camera Example

Figure 19 shows the Digital Camera as represented in the SIPM software.

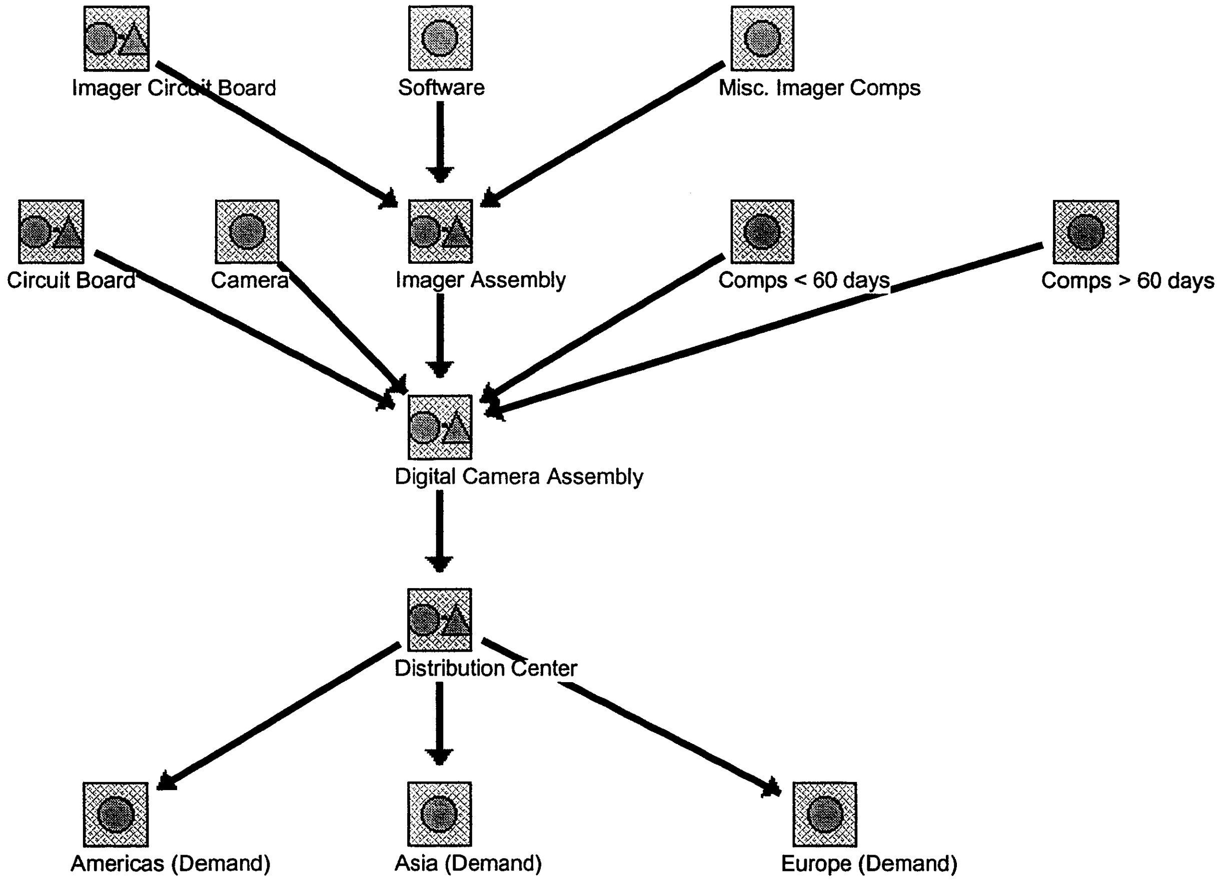


Figure 19: SIPM of Digital Camera

The service times for the digital camera were entered with the other current operating parameters, and therefore are not the optimized values but rather, the actual service times. The service level is 0.95 for all stages. The other parameters for this model are shown below:

Parameters for Supply Stages

	Imager Circuit Board	Software	Misc. Imager Comps	Circuit Board	Camera	Comps < 60 days	Comps > 60 days
Procurement LT	60	1	30	120	90	60	90
Service Time	60	1	30	90	90	60	90
Cost Added	$40.0	$3.5	$1.0	$18.0	$28.0	$2.5	$1.5

Parameters for Production Stages

	Imager Assembly	Digital Camera Assembly	Distribution Center
Production LT	45	2	2
Service Time	70	1	2
Cost Added	$7.5	$10.0	$1.0

Parameters for Demand Stages

	Americas	Asia	Europe
Production Lead Time	3	10	10
Service Time	5	12	12
Cost Added	$2.0	$4.0	$4.0
Maximum Service Time	5	12	12
Mean Demand	100	50	50
One period of Std. Dev.	20	10	10

There is a difference between where the model is showing inventory and where we observe actual inventory being held. The model is showing inventory of Circuit Boards for the Imager Assembly, when there isn't any inventory held in this area. This may be due to the fact that the model assumes a pull system of inventory and in the actual Imager Assembly area, they are building the products as soon as there are components available, which is more of a push method of manufacturing. Another difference is that the model does not show any inventory of Cameras, whereas there is a large inventory of cameras in the factory. The lack of inventory in the model is because with the lead times for the other Digital Camera components being so great, the cameras can be supplied within the time appropriated. The reason for holding inventory in the factory should be explored. In this configuration, the safety stock cost is $13170 at a 20% annual holding cost.

With the model optimizing the service times of the different stages in the supply chain, the inventory is reduced and the inventory holding cost is reduced to $9870. Inventory is held in the locations shown in Figure 20.

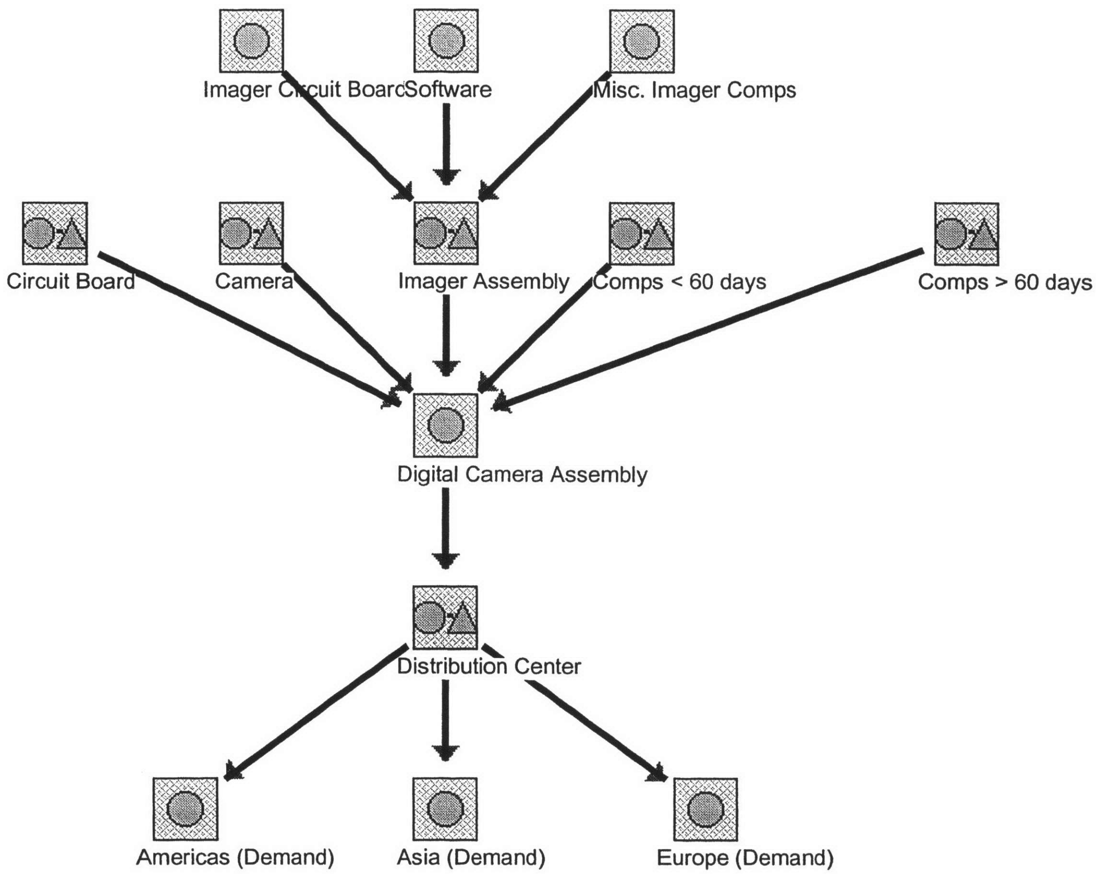


Figure 20: Optimized SIPM of Digital Camera

The optimized model can be further improved by looking at reduced production lead times and procurement lead times. These reductions may be achievable through different modes of transportation or by paying an increased price for the components ordered. Figure 21 shows the locations of inventory in this supply chain with reduced lead times, which are shown in bold type.

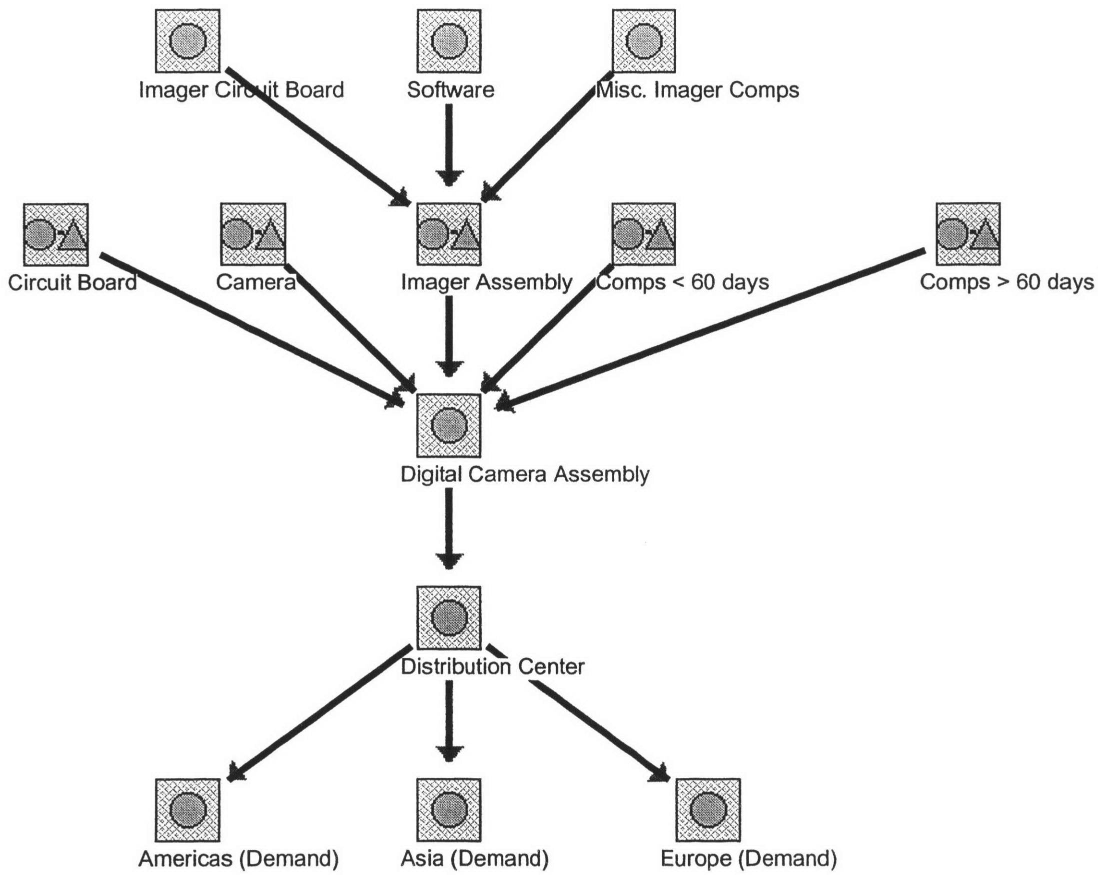


Figure 21: Optimized SIPM of Digital Camera with Reduced Lead Times

This model has the following lead times for the different stages of the model:

Parameters for Supply Stages

	Imager Circuit Board	Software	Misc. Imager Comps	Circuit Board	Camera	Comps < 60 days	Comps > 60 days
Procurement LT	**30**	1	30	**60**	**60**	60	90

Parameters for Production Stages

	Imager Assembly	Digital Camera Assembly	Distribution Center
Production LT	45	2	2

Parameters for Demand Stages

	Americas	Asia	Europe
Production Lead Time	1	5	5

This configuration has a safety stock cost of $6750, which is much less than the other models presented. This would indicate that it may be worthwhile to explore reduced lead times on the indicated components and transportation modes. (The production lead time on the demand stages is primarily transportation.) It is also in line with the fact that it is less expensive to hold inventory earlier in the supply chain, and, with reduced lead times between the distribution center and the customer demand, less inventory is held at the distribution center to meet the service requirements of the demand segments. Conversely, it may be worth exploring the advantages in keeping the inventory at the distribution center to reduce the delivery time to the customer. The value associated with faster response times to the customer may outweigh any inventory cost savings. By quantifying these alternatives with an analytical supply chain model, informed decisions can be made about the actual supply chain.

Appendix Five: HP Medical's Supply Chain For PC's

Supply Chain Questions

The following is a series of questions that we used to help explore the supply chain issues for a new PC based product at HP Medical:

Supply Chain Definition

Should integration, configuration, training, support, preventative maintenance, product updates (HP induced or customer requested), product reuse/recycle, or product recovery be considered? If not, where will they be considered?

What segment of the supply chain is most important (expensive, strategic, etc.)?

Will the supply chain analysis consider returns?

Where do you draw the line between build to stock and customizing to the order?

What type of postponement can be done?

What type of contingency planning should be done?

Coordination of Supply Chain Stages

What are the communication channels between steps and responsible parties?

How are the orders distributed to the various mfg. sites/partners?

How will change orders be conveyed and coordinated?

How and when will forecasts be exchanged?

How will billing occur?

How will the relationship between stages be managed?

How will issues be resolved?

What is the decision making process?

How will other organizations gain access to critical information?

What are the feedback loops between stages and R&D?

How can the supply chain be pro-active vs. reactive? (what systems/information are necessary?)

Who is responsible for each stage?

What are the metrics for the responsible parties and are they aligned with the supply chain objectives?

Are the metrics setup to optimize the whole chain or just the pieces of the chain?

Are their unique people issues to consider (management, motivations, organization, communication, cross-functional expertise, cultural and organizational norms)?

Inventory

What are the safety stock levels and locations?

Who owns the inventory?

Who controls ordering of inventory and component stock?

Where may inventory balloon?

Global Issues

Are their regional variations in the product?

How will the product be localized?

At what point in the supply chain should localization be done?

How many manufacturing sites will there be?

Where should each step be done? Where are the suppliers located?

What are the transportation costs and transportation delays?

Where should the merging centers be located? Customer sites, HP Mfg. Sites, Other

Make/Buy

Are their third parties that can provide more efficient service at the different stages?

Is the stage critical to the long term business strategy?

Does the stage represent a market segment that is evolving at a different rate?

How will the future revisions of the product line be impacted by a competency, or lack thereof, at a stage?

What are the learning opportunities at this stage (product development and support, for example)?

What are the support resources required for each partner (people available via phone/flight/onsite)

Legal Constraints

Can an order be validated at the customer site for FDA approval?

Does each site need to be FDA approved for manufacturing?

Are there FDA imposed testing sites?

Dynamic Simulation Model

While there will always be dynamic information in a supply chain, not all of the dynamics need to be represented in a model. When the situation has a significant impact on the uncertainty in the supply chain, then it may be beneficial to model the dynamics in an analytical model to further understand the behavior of the supply chain. During my LFM internship at HP Medical, we developed an analytical supply chain model to represent the effect of the dynamic nature of the PC industry on the supply chain for a PC based medical product.

Figure 22 represents the general architecture of the central station's PC supply chain as it is described in the Dynamic Simulation Model[12] developed at HP Medical. This model is intended to assess the various inventory policies that HP could adopt for the PC section of the central station's supply chain. The Dynamic Simulation Model represents PC's moving from the Source Supplier to the US site where they are validated. After the validation process the PC's will either be shipped to US customers or to the International manufacturing site where they will then be shipped to International customers. There is also a feedback mechanism, "Compute Total HP Medical Order Quantity," in the Dynamic Simulation Model.

[12] The Dynamic Simulation Model was developed using the ithink software from High Performance Systems.

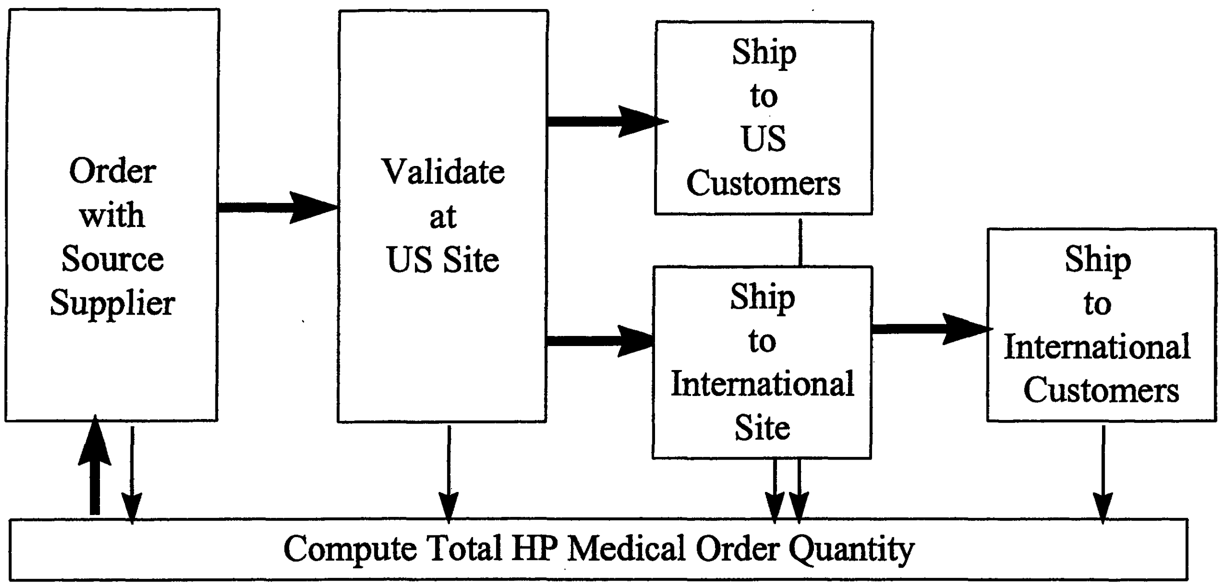


Figure 22: Architecture of PC Supply Chain Model

The goal of the Dynamic Simulation Model is to describe the tradeoffs between holding inventory and service levels to the customer under different policies. The service levels are described by the number of days with a stockout, the number of days with backlog and the number of orders that were affected by the backlog.

Dynamic Simulation Model Sections

Order with Source Supplier

The primary variables considered in the "Order with Source Supplier" sector, where components are ordered from the source supplier, are the supplier lead time and transportation delay.

Supplier Lead-time

The supplier lead-time is the time between placing an order and having that order shipped from the supplier's site.

Transportation Delay

The transportation delay is the amount of time that it takes for the material to be transported to from the supplier to the US site.

Both variables are represented as discrete probability distributions. In the model, the supplier lead-time is close to one month, which means that the order is based on demand forecasted out as far as a few months. The order that is placed with the source supplier is for the needs of both the US site and the International site. There are additional delays in getting the product to the International site, thus the order is placed based on demand forecasts several months out. (Expected values of each of the following are added together to determine the time when the order will be available as accepted inventory: supplier lead-time + transportation delay + rework time + international delays for the international forecast.)

It should be noted that for this model, the application involved homogeneous lots of PC's being ordered from the source supplier at regular intervals. These homogeneous lots move through ordering and validation as entire lots. The homogeneous lots allow for simplified validation.

<u>Validate at US Site</u>

The "Validation at US Site" sector is where components are validates and reworked, if necessary. This validation is primarily concerned with changes in the internal components used on the PC. A validation failure is considered to be a case where a software fix is the only correction required to address the failure. Hardware failures can be incorporated into the model in the supplier lead-time distribution. The primary variables considered in this sector are the probability of acceptance and the corrective action cycle time.

Probability of Acceptance

The probability of acceptance is the probability that any given lot of PC's will pass the validation tests. (This model assumes a lot-based system and that these lots will be homogeneous.) This variable is the most significant in terms of impact on inventory and stockouts. This follows the theory that a design that is independent of the internal components will be more robust, with respect to product rolls in the PC industry. The value used, 0.8, is based on historical test data. It is also in line with the axiom that the PC will roll every 6 months. (If there are monthly orders, one could assume that 10 out of 12 will be accepted, resulting in a probability of acceptance of 10/12 = 0.83)

Corrective Action Cycle Time (Rework)

This is the amount of time it will take to correct any failures that occur during validation. This is a random variable with a normal distribution. It varies from 5 days (includes re-validating) to a maximum of 3 months. Only failures that can be addressed with software are considered in this model. Therefore, the rework time may be as short as 5 days for a simple bug fix or as long as 3 months if there is a change required at the operating system level.

Ship to International Site

This sector of the model represents components being transported to the International site. The primary variables considered are the processing delay, transportation delay, and international order quantity.

Processing Delay

The processing delay is the amount of time it takes to get the components prepared for shipment from the US site. This delay may include the time to move the boxes, schedule transportation, or other delays.

Transportation Delay

The transportation delay is the amount of time that it takes for the material to be transported to from the US site to the International site. It is represented as a normal probability distribution.

International Order Quantity

The international order quantity is the number of units ordered for the International site. This is the quantity needed to satisfy demand and safety stock needs for the International site. The ordering policy employed by the model requires that the International site always be shipped all that it orders and never more that it has ordered. (Every order may not be shipped in its entirety, but all orders will eventually be filled and there are no cancellations.)

Ship to US Customers and Ship to International Customers

These sectors are where the accepted components are held until used in the finished product that is then shipped to the customer. The primary variable in these sectors are the forecasted demand, approximated actual demand, accepted inventory level and the manufacturing capacity. These variables are represented in each of the geographic sectors, US and International.

Forecasted Demand

The forecasted demand is the forecasted customer demand for each of the respective markets. The model uses the forecast for placing orders and determining safety stock levels.

Approximated Actual Demand

The approximated actual demand is a technique to simulate the results of the model when demand is not as forecasted. It is used to represent the uncertainty in the demand forecast. The approximated actual demand figures are a function of the forecast and the multiple is determined from historical monthly deviations from forecast. These multiples were determined for each of the markets. This allows the model to represent fluctuations from forecast in each of the markets, independently.

Accepted Inventory Level

At each site, the model tracks the accepted inventory level and distinguishes accepted inventory from unaccepted or failed inventory. Accepted inventory is inventory that has passed the validation criteria, while failed inventory is inventory that is being reworked and unaccepted inventory is inventory that has not been validated. (The cost calculations do not differentiate between these different states of inventory and computes holding costs for the total inventory owned by the company.)

Manufacturing Capacity

The maximum capacity of the manufacturing site is modeled to represent capacity limitations in meeting demand. In the Dynamic Simulation Model, the manufacturing capacity is used to quantify the delay in recovering from a stockout. The capacity limits the amount by which the backlog can be reduced.

Compute Total HP Medical Order Quantity

This sector represents the primary feedback loop to the other sectors of the model. It is in this section that policies are enforced and material is tracked and ordered. The primary feedback loop involves the order quantity that is transmitted to the source supplier. This order is a function of the current levels of inventory, target safety stock levels, and demand forecasts. The primary variables in this sector are the reorder period, target safety stock levels, inventory gaps, and the worldwide inventory levels. This sector also simulates the negotiations between the US and International sites when there is an inventory shortage.

Reorder Period

The reorder period is the frequency in which orders are placed by the respective manufacturing sites to their direct supplier. (US to source supplier and International to US.)

Target Safety Stock

The target safety stock is the number of days of forecasted demand to be held in inventory as safety stock. For example, the US may decide to hold one month of safety stock which would mean that one month of forecasted demand would be held on site, in addition to the inventory needed to satisfy demand. The international safety stock level can vary from the US target safety stock level.

Difference between actual and expected inventory

The difference between actual and expected inventory is computed whenever an order is being placed. This difference is due to the difference between forecasted demand and actual demand; when the demand is greater than forecasted the actual inventory will be less than the expected inventory. The order quantity is then adjusted to compensate for this difference. There is also a variable called the inventory adjustment period which states the number of order cycles required to replace safety stock to target level.

Worldwide Accepted Inventory

The Worldwide Accepted Inventory is the total inventory available to be shipped to customers, worldwide.

Negotiation

This sector also simulates the negotiation between the two sites regarding actual inventory to be shipped. If there are failures in the system or significant delays in delivery to the US site, then this sector will determine how much to ship to the International site and how much to retain in the US. The algorithm is to satisfy an equal percentage of the demand at both locations (accounting for the time until the next delivery.)

General Parameters

Cost of PC

The cost of the PC is represented at the US site and the International site (the costs can be different).

Inventory Holding Cost

The inventory holding cost is the percentage of the inventory cost to use as the carrying cost for the inventory.

Metrics

The model also tracks several metrics for both the US site and the International site, as well as worldwide metrics. These metrics include the following:

- Total inventory carrying costs
- Cumulative number of days with a stockout
- Maximum length of any stockout
- Cumulative number of days with a backlog
- Total number of components backlogged
- Maximum number of days with a backlog
- Maximum number of components that are backlogged

Model Assumptions

- Homogeneous lots are ordered and they pass or fail the validation process as an entire lot.
- Failures are due to industry changes: if a lot fails, all subsequent arrivals from the supplier will also fail until the software repair work is completed.
- Lots are accepted with probability of acceptance (.8 would represent each lot having an 80% chance of being accepted.)
- Orders are placed on a regular time schedule and order size can vary from month to month.
- Orders that cannot be satisfied in a given day will be backlogged and filled when there is available capacity and material.
- Orders are based on forecasted demand.
- Safety Stock in is specified terms of number of days of forecasted demand (the number of units will change with the demand forecast).

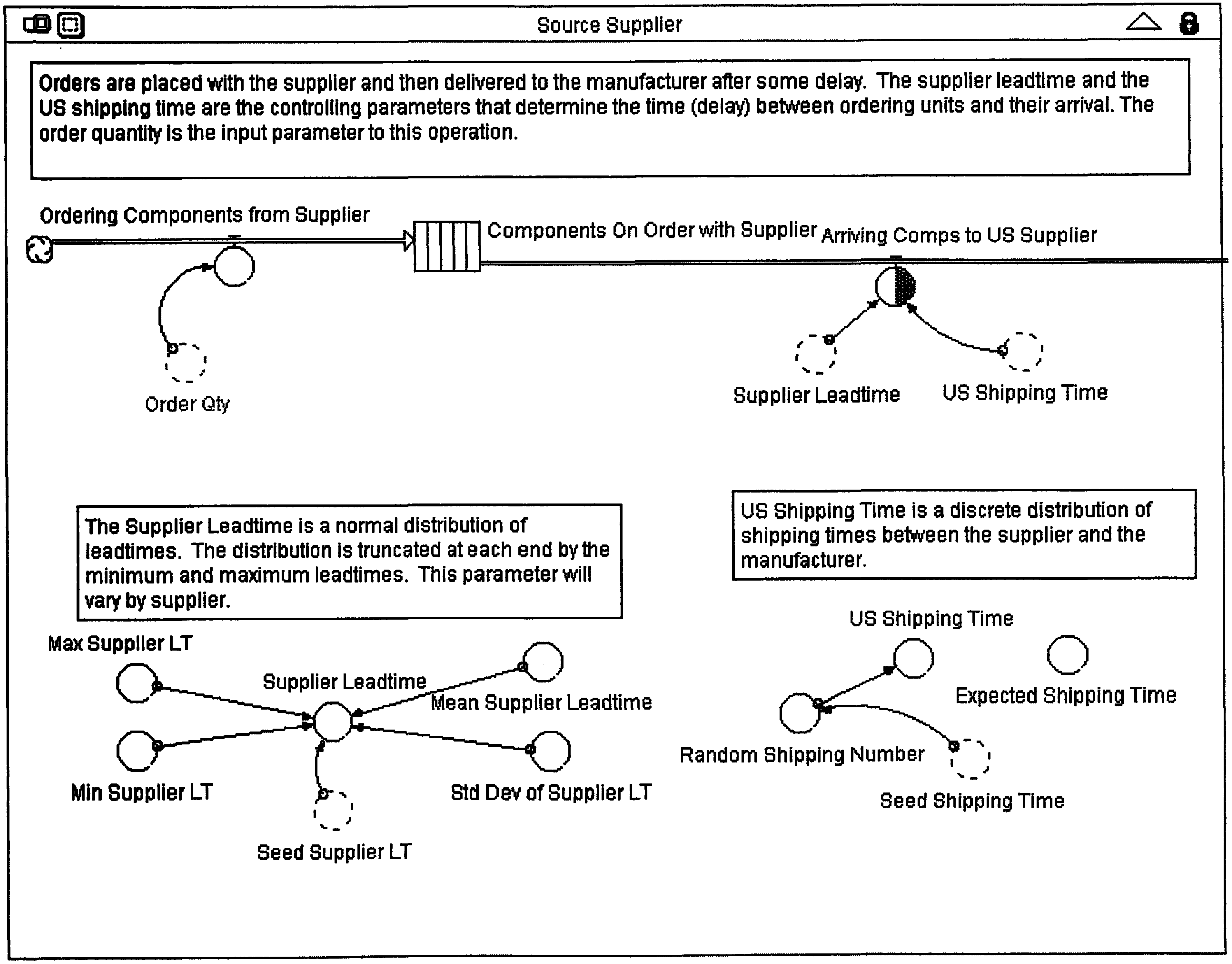
- International orders are placed with US site, which places order with supplier.
- International orders are received by US site and validated before shipment from US site is initiated.
- If there are failed components, satisfy worldwide demand in equal proportion - i.e. 80% of US demand and 80% of International Demand - including delay for delivering components to International site.
- Ship full order to International site (May be multiple shipments, but ONLY when there are failures.)
- Ship only what is ordered from International site.
- Ship one way only - no shipments from International site to US site.
- International site takes ownership of components when shipped from US site (International owns during transport)

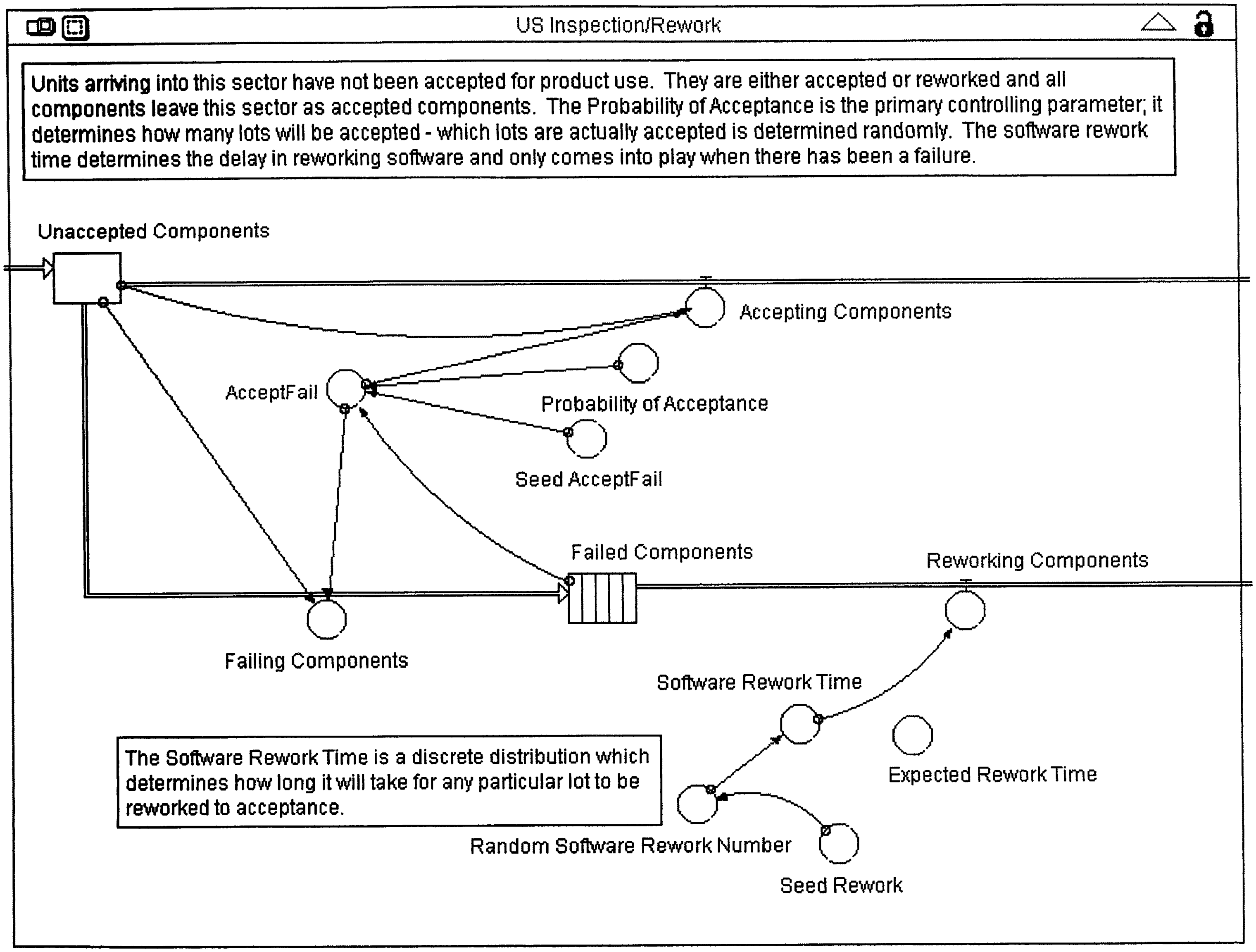
Graphic Description

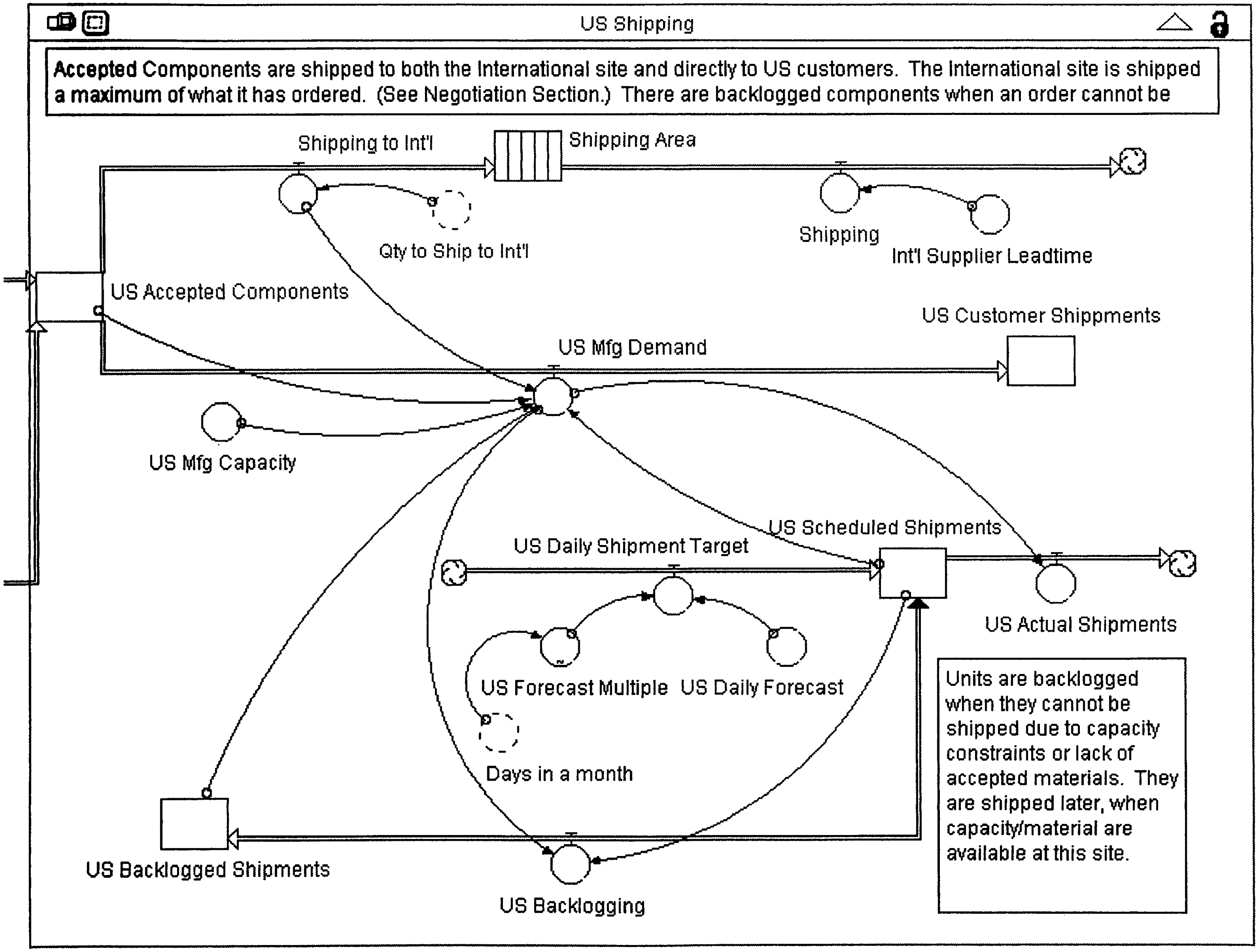
The Dynamic Simulation Model is organized in the following manner:

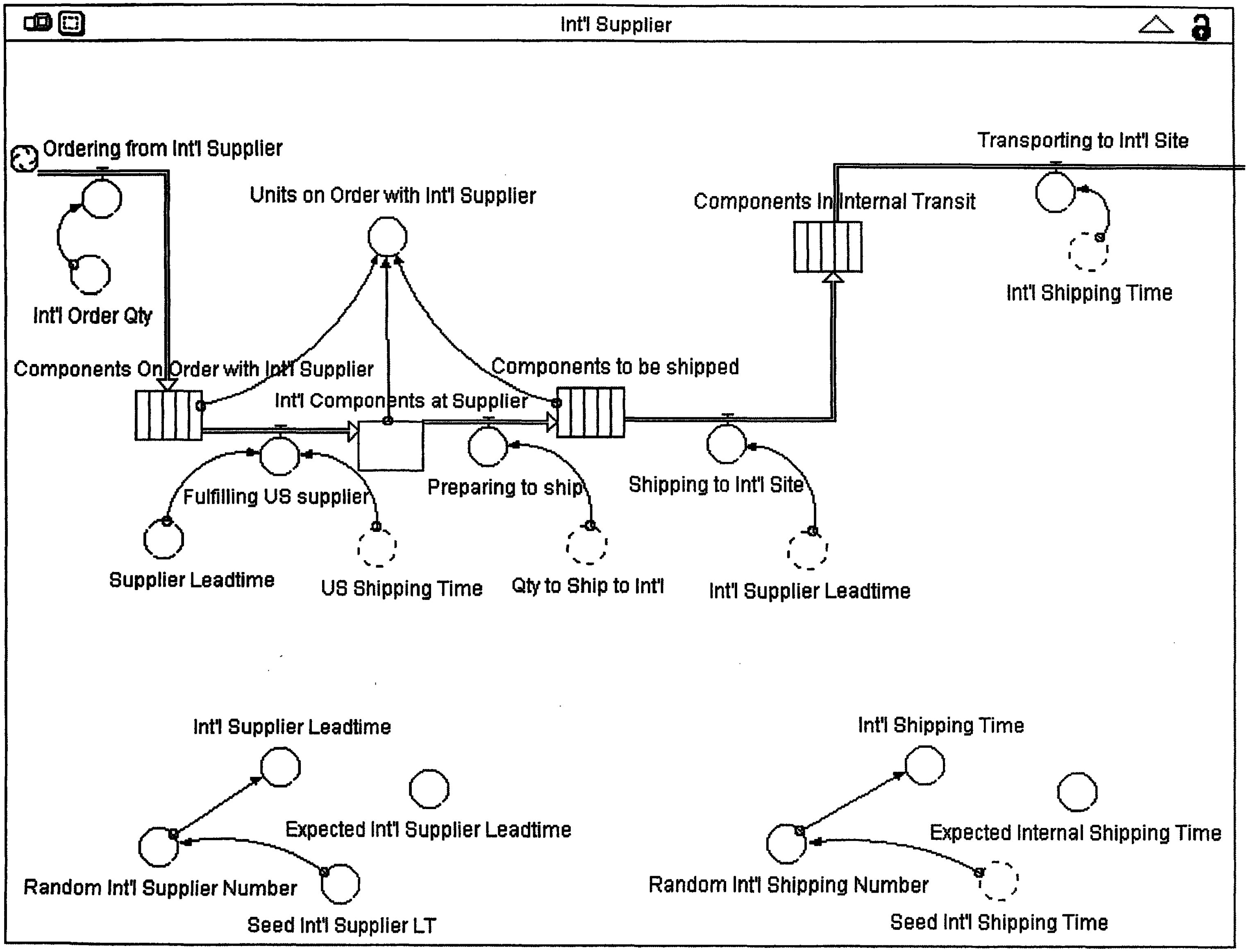
Source Supplier	US Inspection/ Rework	US Shipping	International Supplier	International Inspection/ Rework	International Shipping
US Ordering/Shipping 1-3			International Ordering/Shipping 1-3		
US Metrics 1-2		Worldwide Metrics	International Metrics 1-2		General Parameters

Each of these sections of the Dynamic Simulation Model is presented on the following pages. This image is presented to provide a roadmap to the graphic description.

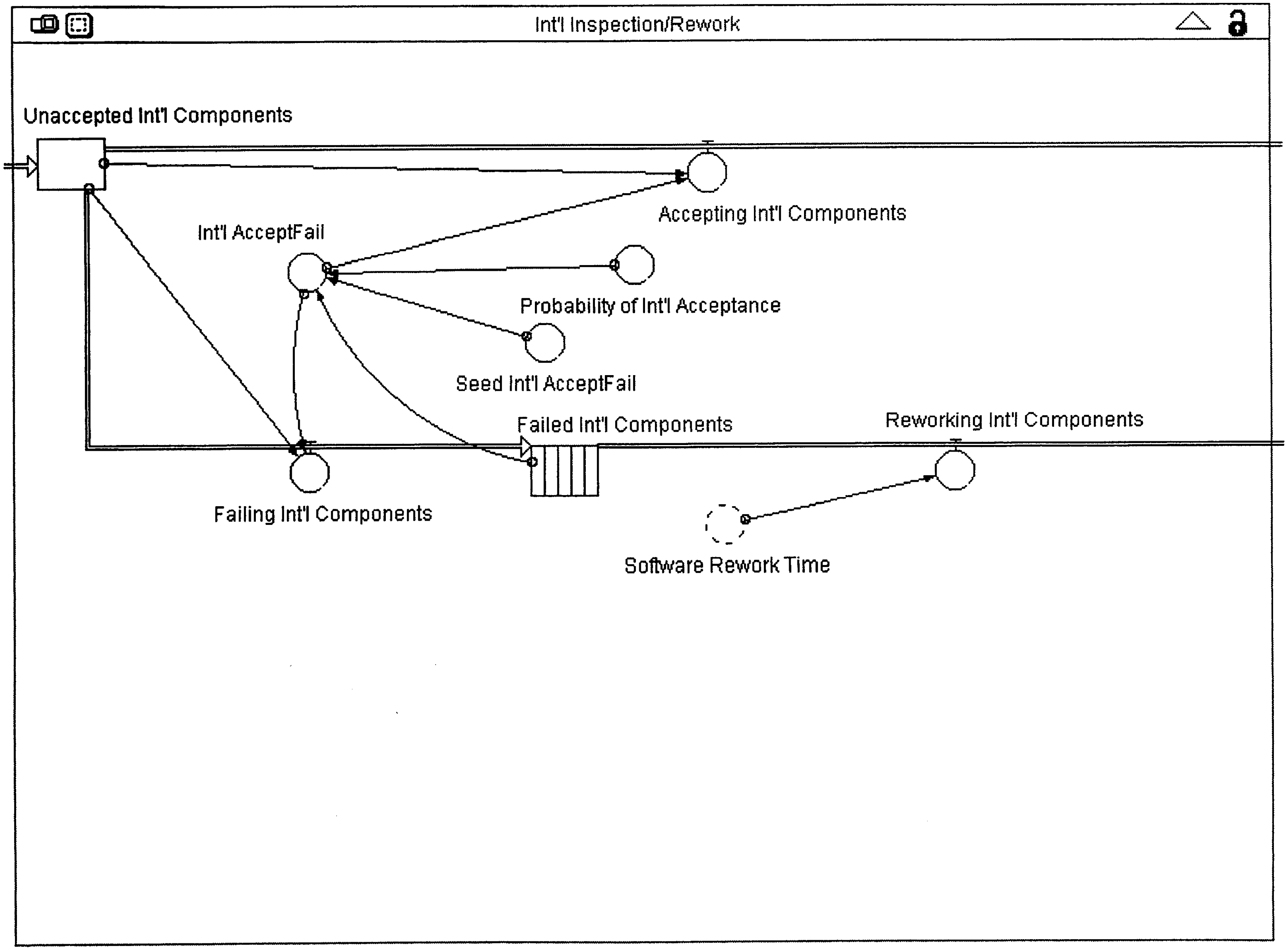

Source Supplier
Orders are placed with the supplier and then delivered to the manufacturer after some delay. The supplier leadtime and the US shipping time are the controlling parameters that determine the time (delay) between ordering units and their arrival. The order quantity is the input parameter to this operation.
Ordering Components from Supplier
Components On Order with Supplier
Arriving Comps to US Supplier
Order Qty
Supplier Leadtime
US Shipping Time
The Supplier Leadtime is a normal distribution of leadtimes. The distribution is truncated at each end by the minimum and maximum leadtimes. This parameter will vary by supplier.
US Shipping Time is a discrete distribution of shipping times between the supplier and the manufacturer.
Max Supplier LT
Supplier Leadtime
Mean Supplier Leadtime
Min Supplier LT
Std Dev of Supplier LT
Seed Supplier LT
US Shipping Time
Expected Shipping Time
Random Shipping Number
Seed Shipping Time


US Inspection/Rework
Units arriving into this sector have not been accepted for product use. They are either accepted or reworked and all components leave this sector as accepted components. The Probability of Acceptance is the primary controlling parameter; it determines how many lots will be accepted - which lots are actually accepted is determined randomly. The software rework time determines the delay in reworking software and only comes into play when there has been a failure.
Unaccepted Components
Accepting Components
AcceptFail
Probability of Acceptance
Seed AcceptFail
Failed Components
Reworking Components
Failing Components
Software Rework Time
Expected Rework Time
The Software Rework Time is a discrete distribution which determines how long it will take for any particular lot to be reworked to acceptance.
Random Software Rework Number
Seed Rework

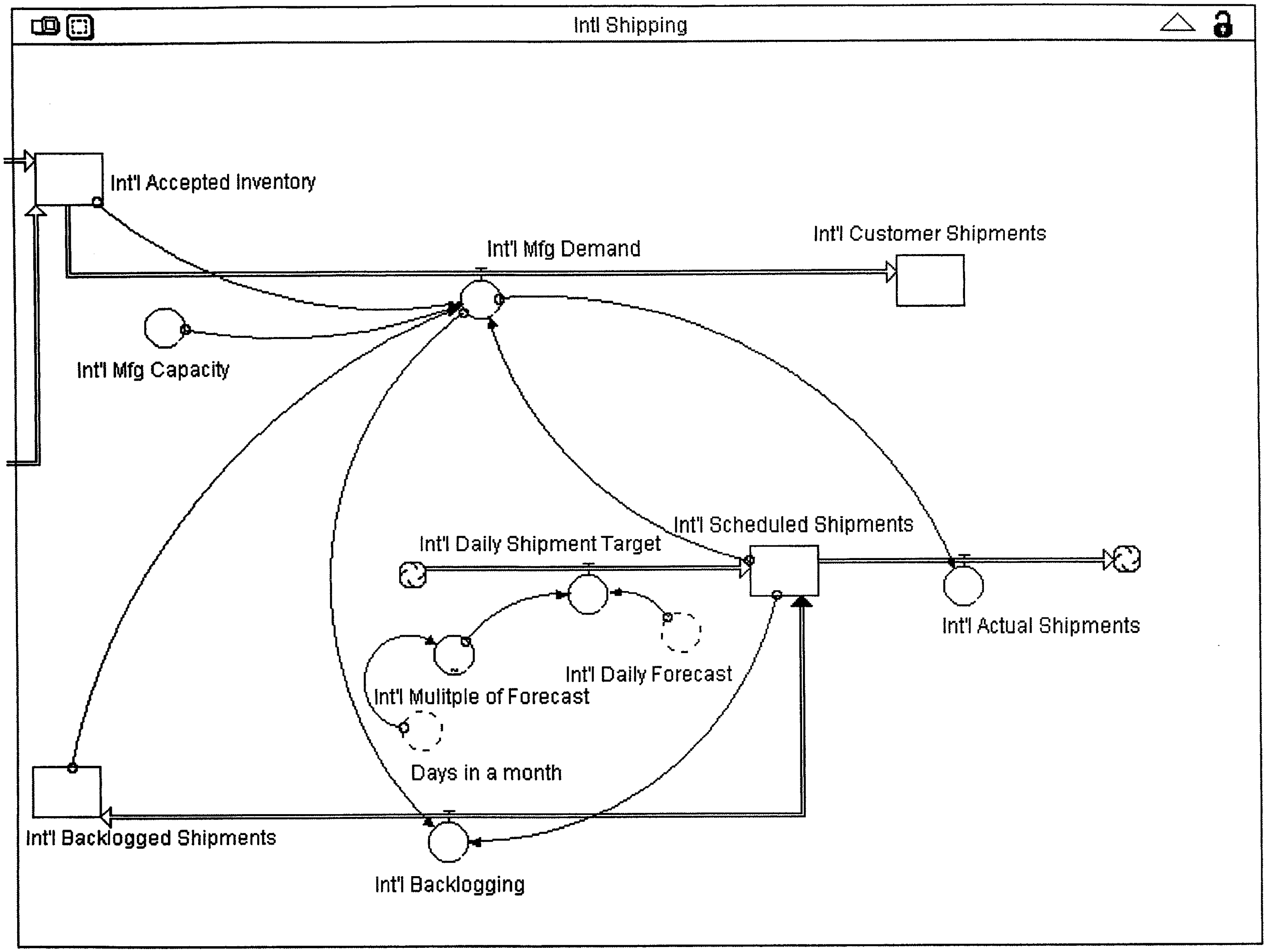

US Shipping
Accepted Components are shipped to both the International site and directly to US customers. The International site is shipped a maximum of what it has ordered. (See Negotiation Section.) There are backlogged components when an order cannot be
Shipping to Int'l
Shipping Area
Qty to Ship to Int'l
Shipping
Int'l Supplier Leadtime
US Accepted Components
US Customer Shipments
US Mfg Demand
US Mfg Capacity
US Scheduled Shipments
US Daily Shipment Target
US Actual Shipments
US Forecast Multiple
US Daily Forecast
Days in a month
US Backlogged Shipments
US Backlogging
Units are backlogged when they cannot be shipped due to capacity constraints or lack of accepted materials. They are shipped later, when capacity/material are available at this site.



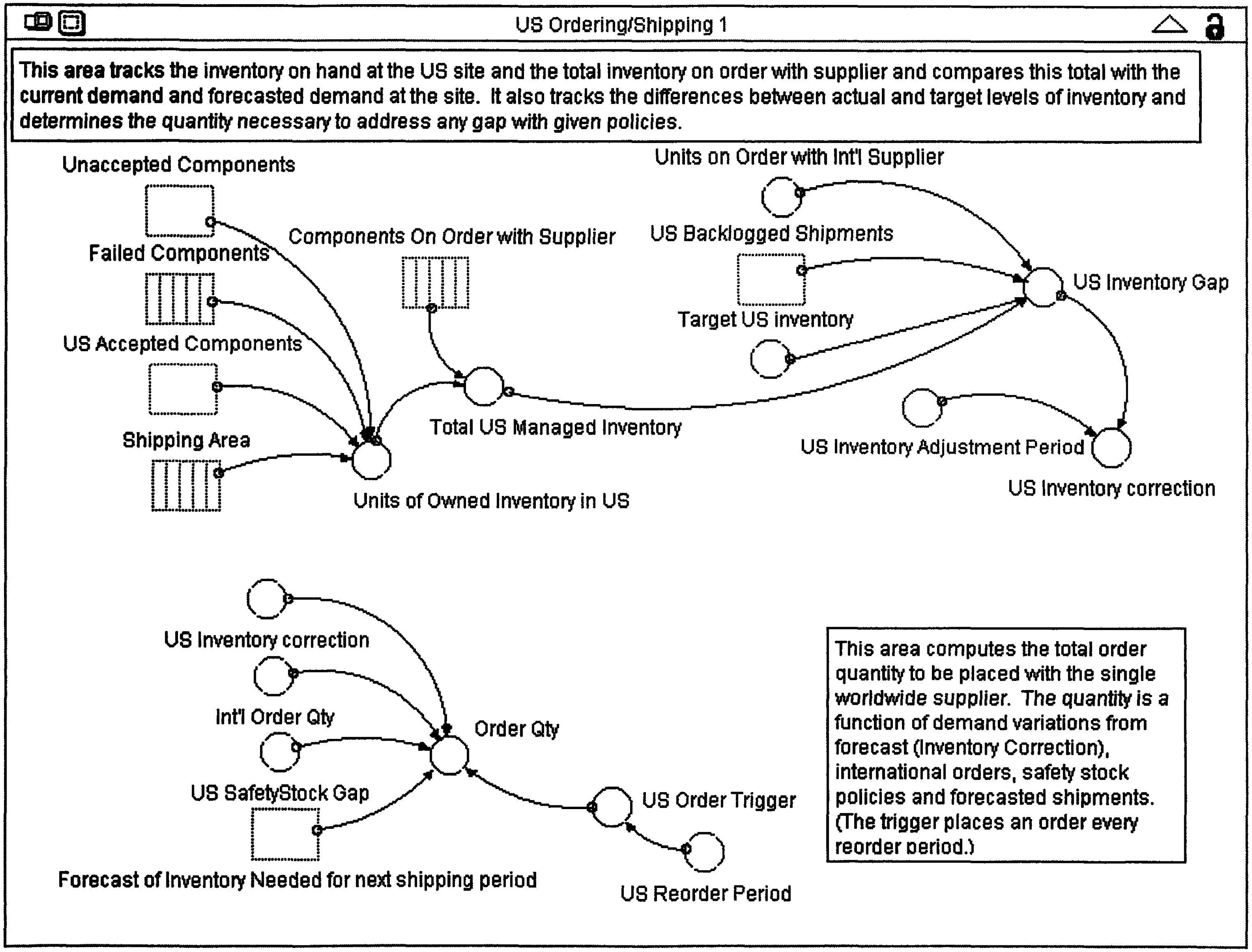
Int'l Supplier
Ordering from Int'l Supplier
Int'l Order Qty
Units on Order with Int'l Supplier
Components In Internal Transit
Transporting to Int'l Site
Int'l Shipping Time
Components On Order with Int'l Supplier
Int'l Components at Supplier
Components to be shipped
Fulfilling US supplier
Preparing to ship
Shipping to Int'l Site
Supplier Leadtime
US Shipping Time
Qty to Ship to Int'l
Int'l Supplier Leadtime
Int'l Supplier Leadtime
Expected Int'l Supplier Leadtime
Random Int'l Supplier Number
Seed Int'l Supplier LT
Int'l Shipping Time
Expected Internal Shipping Time
Random Int'l Shipping Number
Seed Int'l Shipping Time

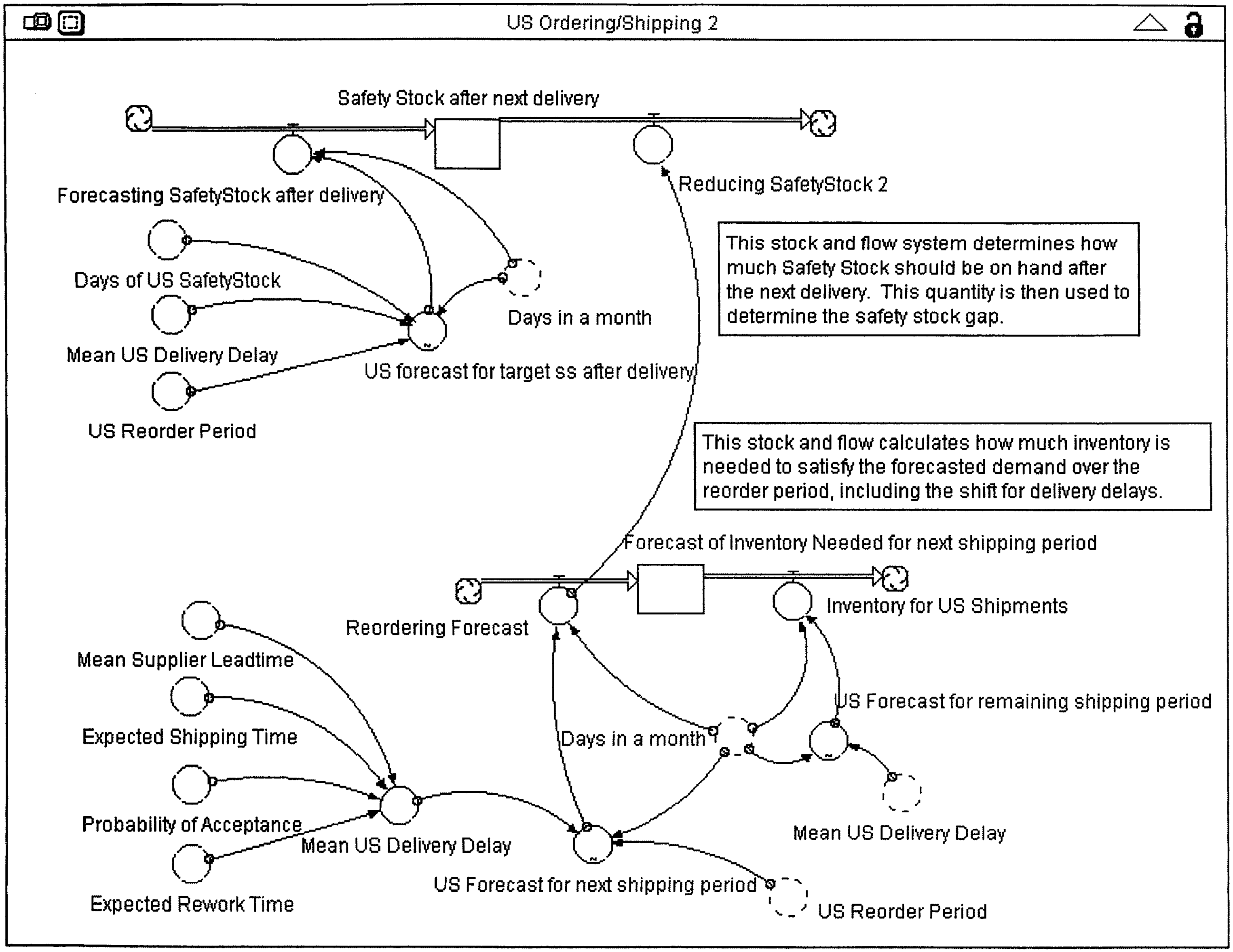


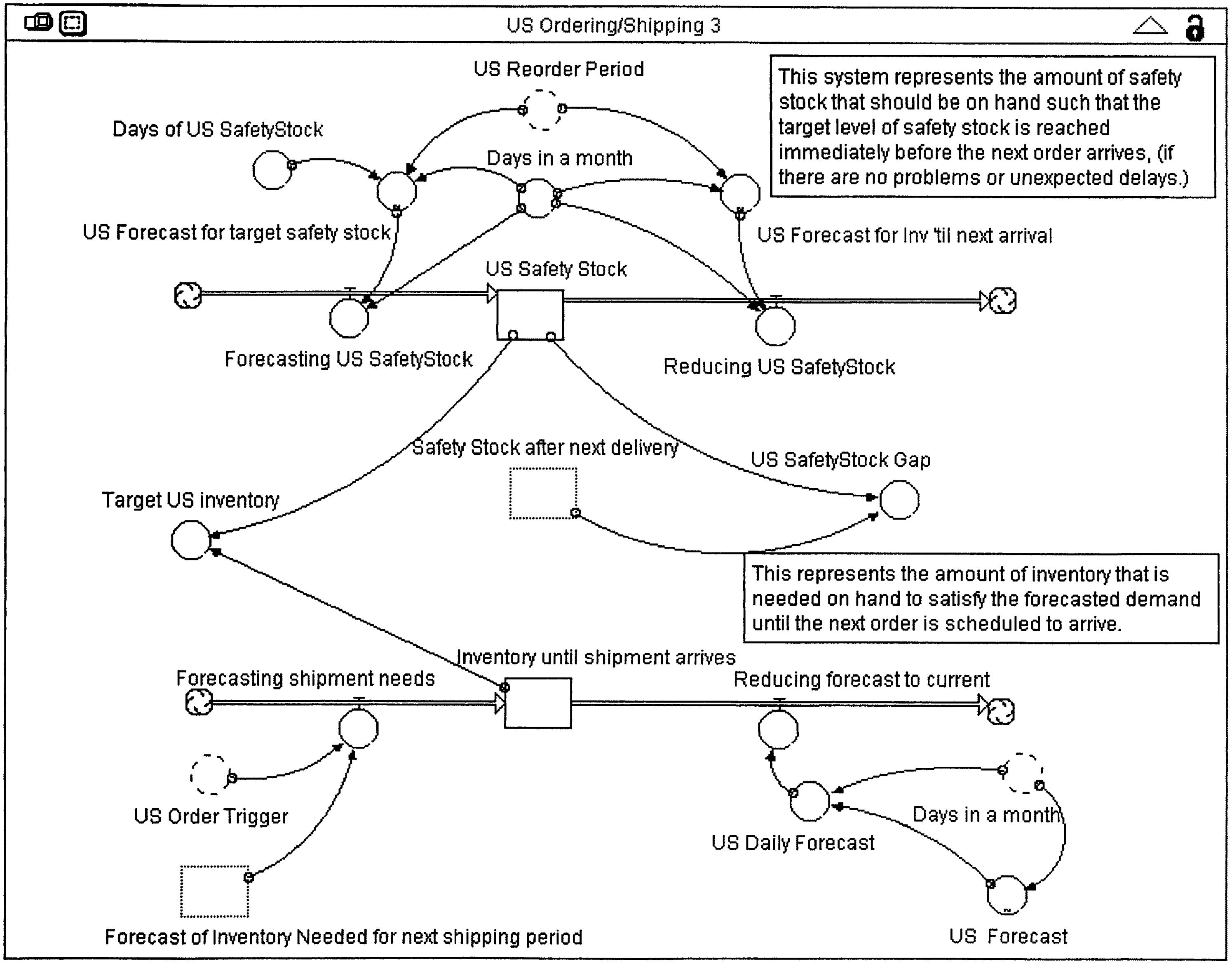
Int'l Inspection/Rework
Unaccepted Int'l Components
Accepting Int'l Components
Int'l AcceptFail
Probability of Int'l Acceptance
Seed Int'l AcceptFail
Failed Int'l Components
Reworking Int'l Components
Failing Int'l Components
Software Rework Time

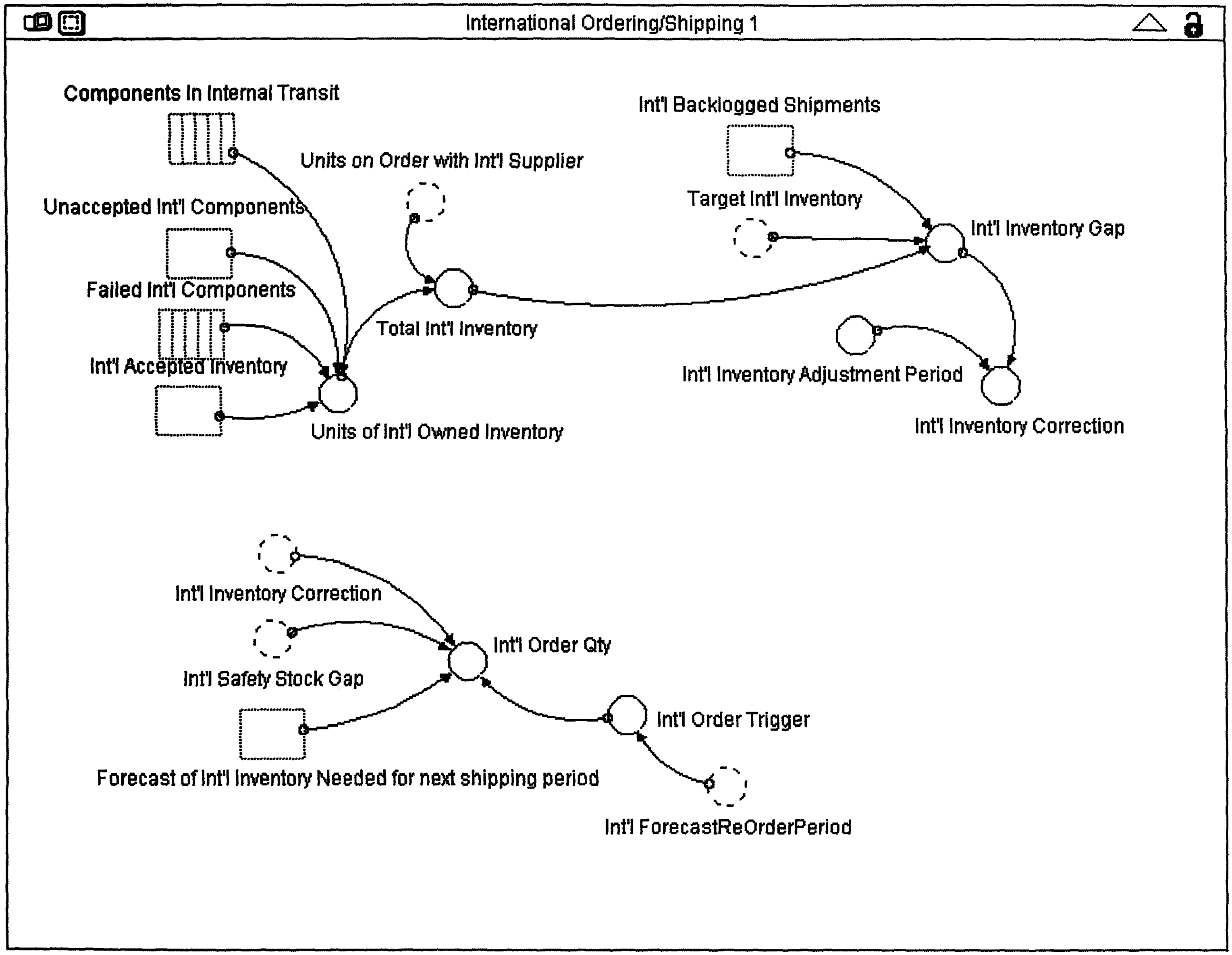


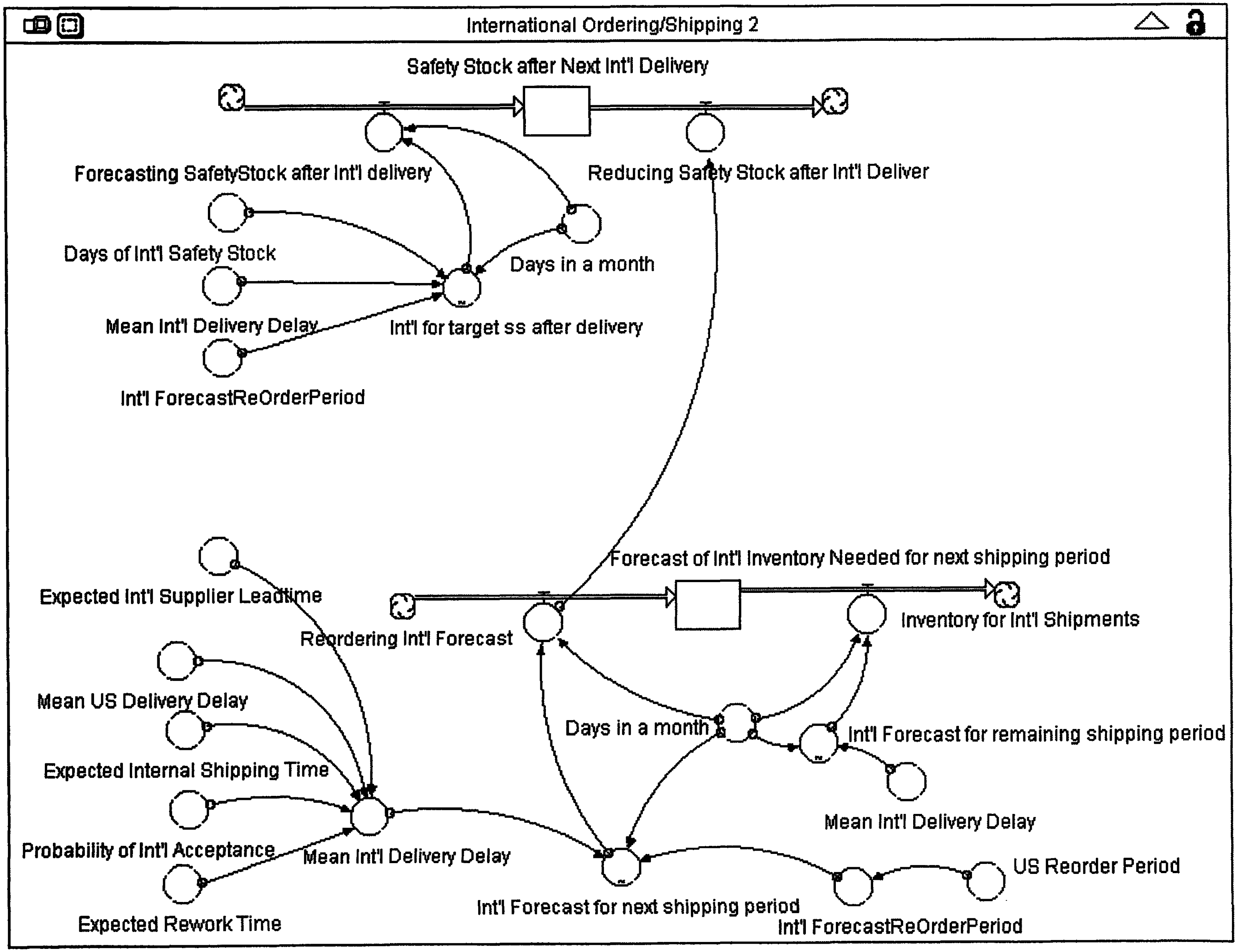
Intl Shipping
Int'l Accepted Inventory
Int'l Customer Shipments
Int'l Mfg Demand
Int'l Mfg Capacity
Int'l Scheduled Shipments
Int'l Daily Shipment Target
Int'l Actual Shipments
Int'l Daily Forecast
Int'l Mulitple of Forecast
Days in a month
Int'l Backlogged Shipments
Int'l Backlogging

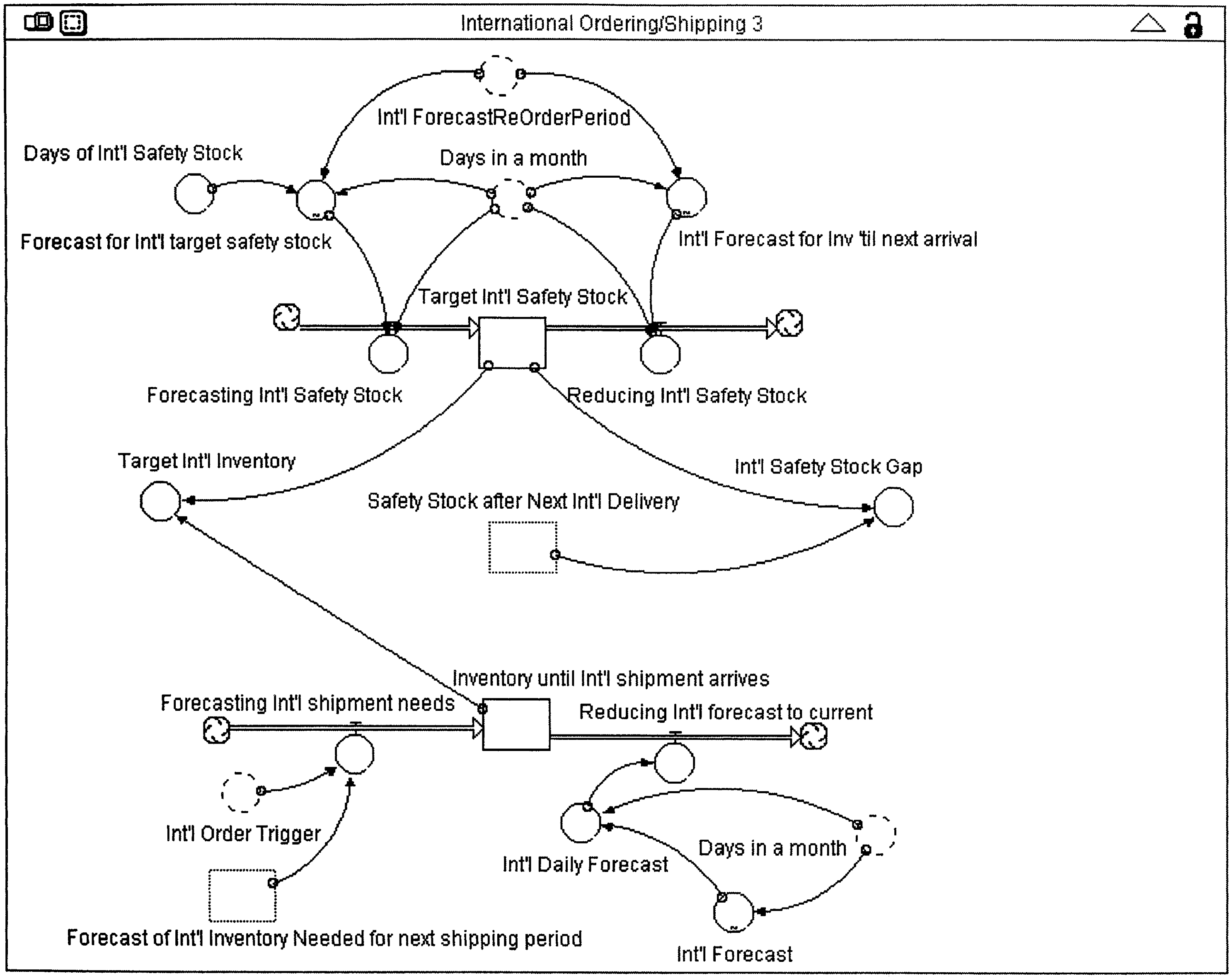

US Ordering/Shipping 1
This area tracks the inventory on hand at the US site and the total inventory on order with supplier and compares this total with the current demand and forecasted demand at the site. It also tracks the differences between actual and target levels of inventory and determines the quantity necessary to address any gap with given policies.
Unaccepted Components
Failed Components
US Accepted Components
Shipping Area
Components On Order with Supplier
Total US Managed Inventory
Units of Owned Inventory in US
Units on Order with Int'l Supplier
US Backlogged Shipments
Target US inventory
US Inventory Gap
US Inventory Adjustment Period
US Inventory correction
US Inventory correction
Int'l Order Qty
US SafetyStock Gap
Forecast of Inventory Needed for next shipping period
Order Qty
US Order Trigger
US Reorder Period
This area computes the total order quantity to be placed with the single worldwide supplier. The quantity is a function of demand variations from forecast (Inventory Correction), international orders, safety stock policies and forecasted shipments. (The trigger places an order every reorder period.)

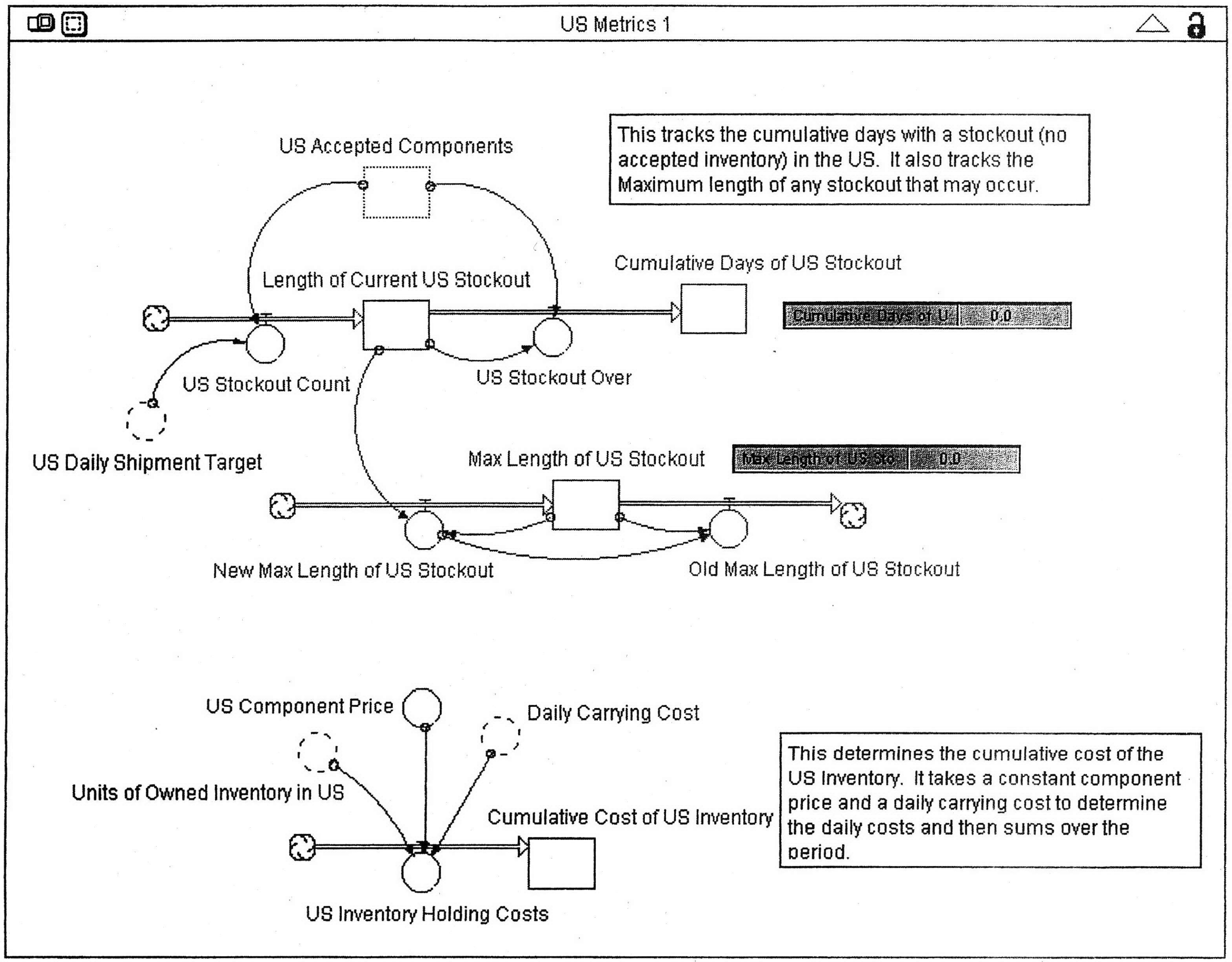

US Ordering/Shipping 2
Safety Stock after next delivery
Forecasting SafetyStock after delivery
Reducing SafetyStock 2
Days of US SafetyStock
Days in a month
Mean US Delivery Delay
US forecast for target ss after delivery
US Reorder Period
This stock and flow system determines how much Safety Stock should be on hand after the next delivery. This quantity is then used to determine the safety stock gap.
This stock and flow calculates how much inventory is needed to satisfy the forecasted demand over the reorder period, including the shift for delivery delays.
Forecast of Inventory Needed for next shipping period
Reordering Forecast
Inventory for US Shipments
Mean Supplier Leadtime
US Forecast for remaining shipping period
Expected Shipping Time
Days in a month
Probability of Acceptance
Mean US Delivery Delay
Mean US Delivery Delay
US Forecast for next shipping period
Expected Rework Time
US Reorder Period

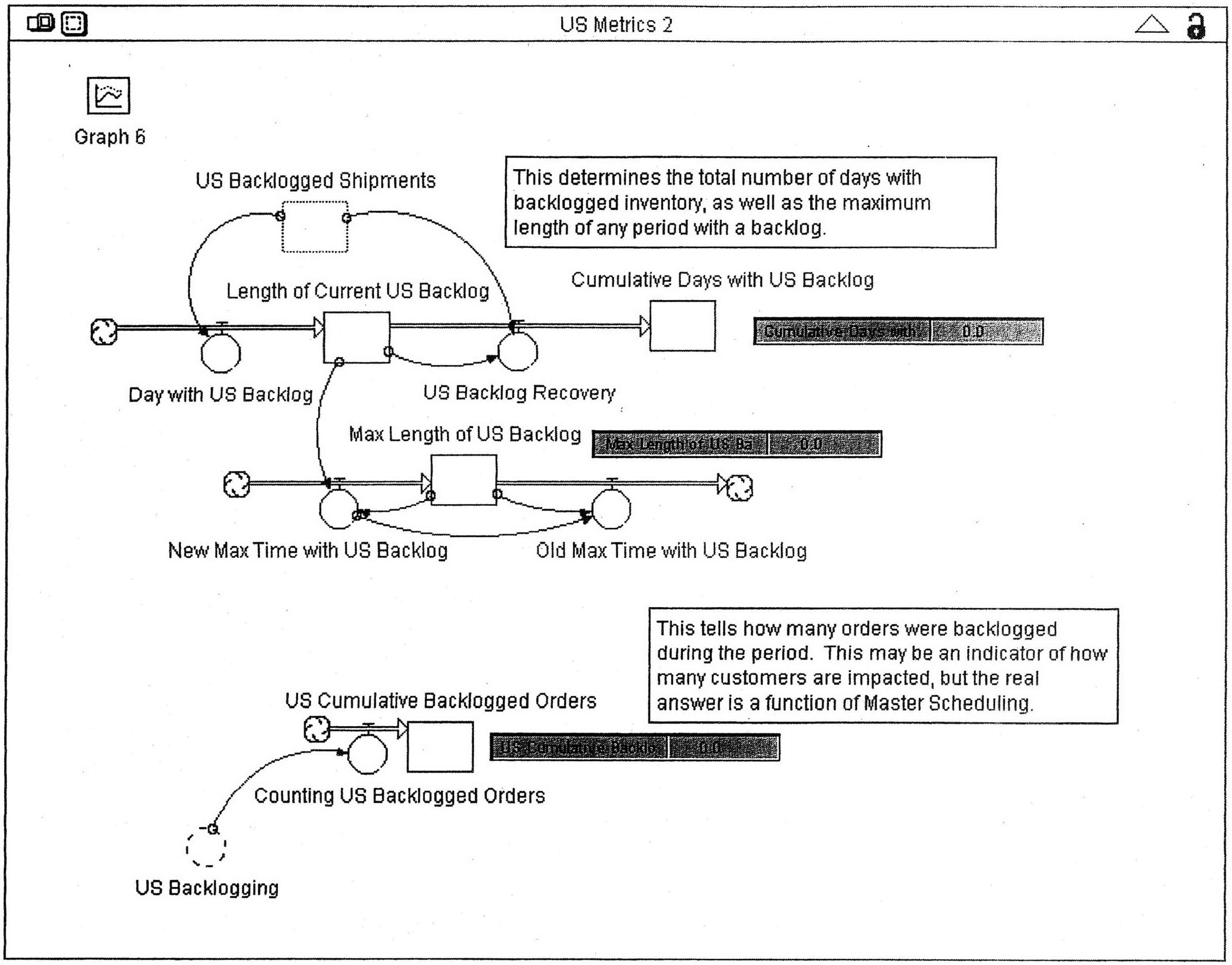

US Ordering/Shipping 3
US Reorder Period
Days of US SafetyStock
Days in a month
This system represents the amount of safety stock that should be on hand such that the target level of safety stock is reached immediately before the next order arrives, (if there are no problems or unexpected delays.)
US Forecast for target safety stock
US Forecast for Inv 'til next arrival
US Safety Stock
Forecasting US SafetyStock
Reducing US SafetyStock
Safety Stock after next delivery
US SafetyStock Gap
Target US inventory
This represents the amount of inventory that is needed on hand to satisfy the forecasted demand until the next order is scheduled to arrive.
Inventory until shipment arrives
Forecasting shipment needs
Reducing forecast to current
US Order Trigger
Days in a month
US Daily Forecast
Forecast of Inventory Needed for next shipping period
US Forecast

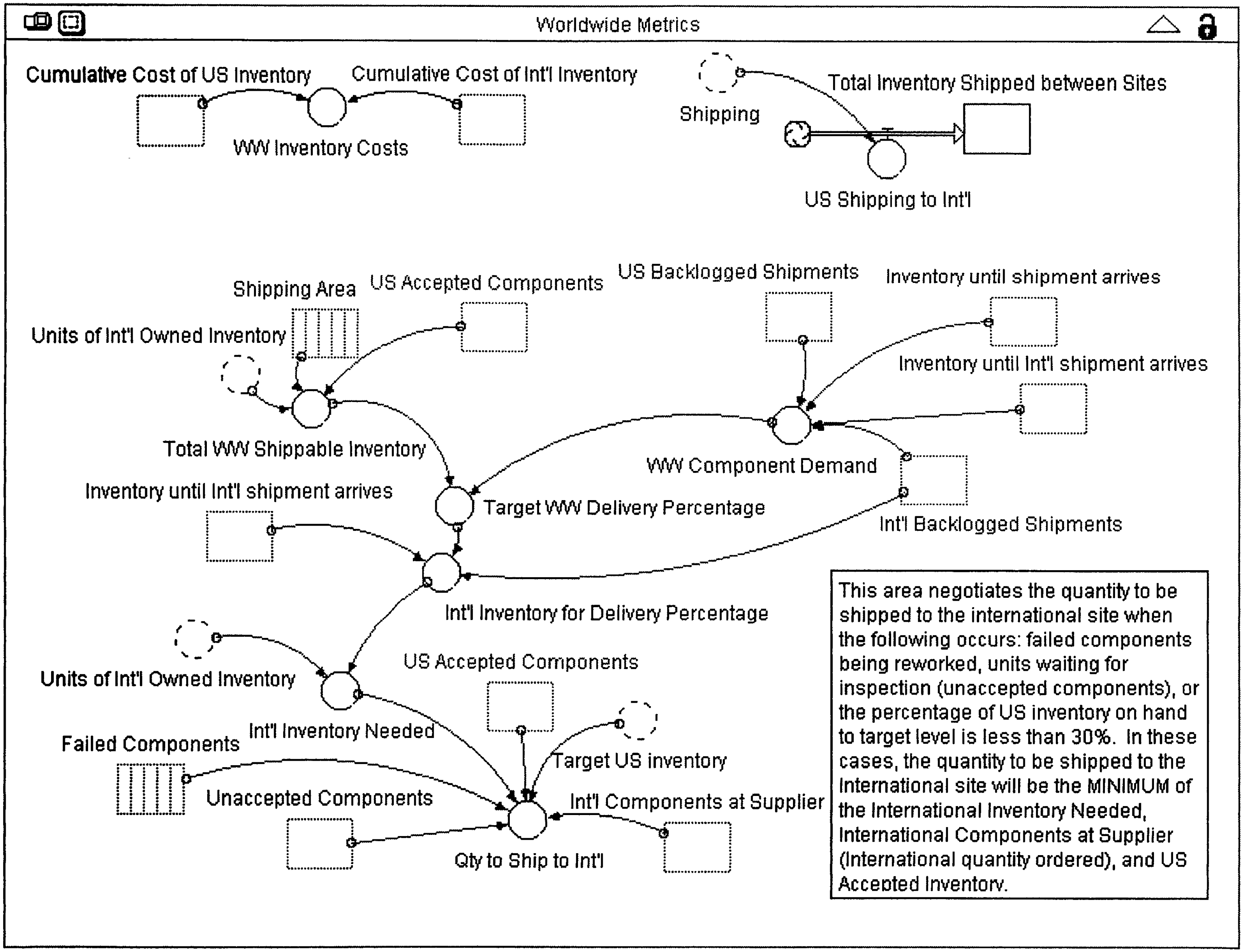

International Ordering/Shipping 1
Components In Internal Transit
Units on Order with Int'l Supplier
Int'l Backlogged Shipments
Target Int'l Inventory
Int'l Inventory Gap
Unaccepted Int'l Components
Failed Int'l Components
Total Int'l Inventory
Int'l Accepted Inventory
Int'l Inventory Adjustment Period
Units of Int'l Owned Inventory
Int'l Inventory Correction
Int'l Inventory Correction
Int'l Order Qty
Int'l Safety Stock Gap
Int'l Order Trigger
Forecast of Int'l Inventory Needed for next shipping period
Int'l ForecastReOrderPeriod


International Ordering/Shipping 2
Safety Stock after Next Int'l Delivery
Forecasting SafetyStock after Int'l delivery
Reducing Safety Stock after Int'l Deliver
Days of Int'l Safety Stock
Days in a month
Mean Int'l Delivery Delay
Int'l for target ss after delivery
Int'l ForecastReOrderPeriod
Forecast of Int'l Inventory Needed for next shipping period
Expected Int'l Supplier Leadtime
Reordering Int'l Forecast
Inventory for Int'l Shipments
Mean US Delivery Delay
Days in a month
Int'l Forecast for remaining shipping period
Expected Internal Shipping Time
Mean Int'l Delivery Delay
Probability of Int'l Acceptance
Mean Int'l Delivery Delay
US Reorder Period
Int'l Forecast for next shipping period
Expected Rework Time
Int'l ForecastReOrderPeriod

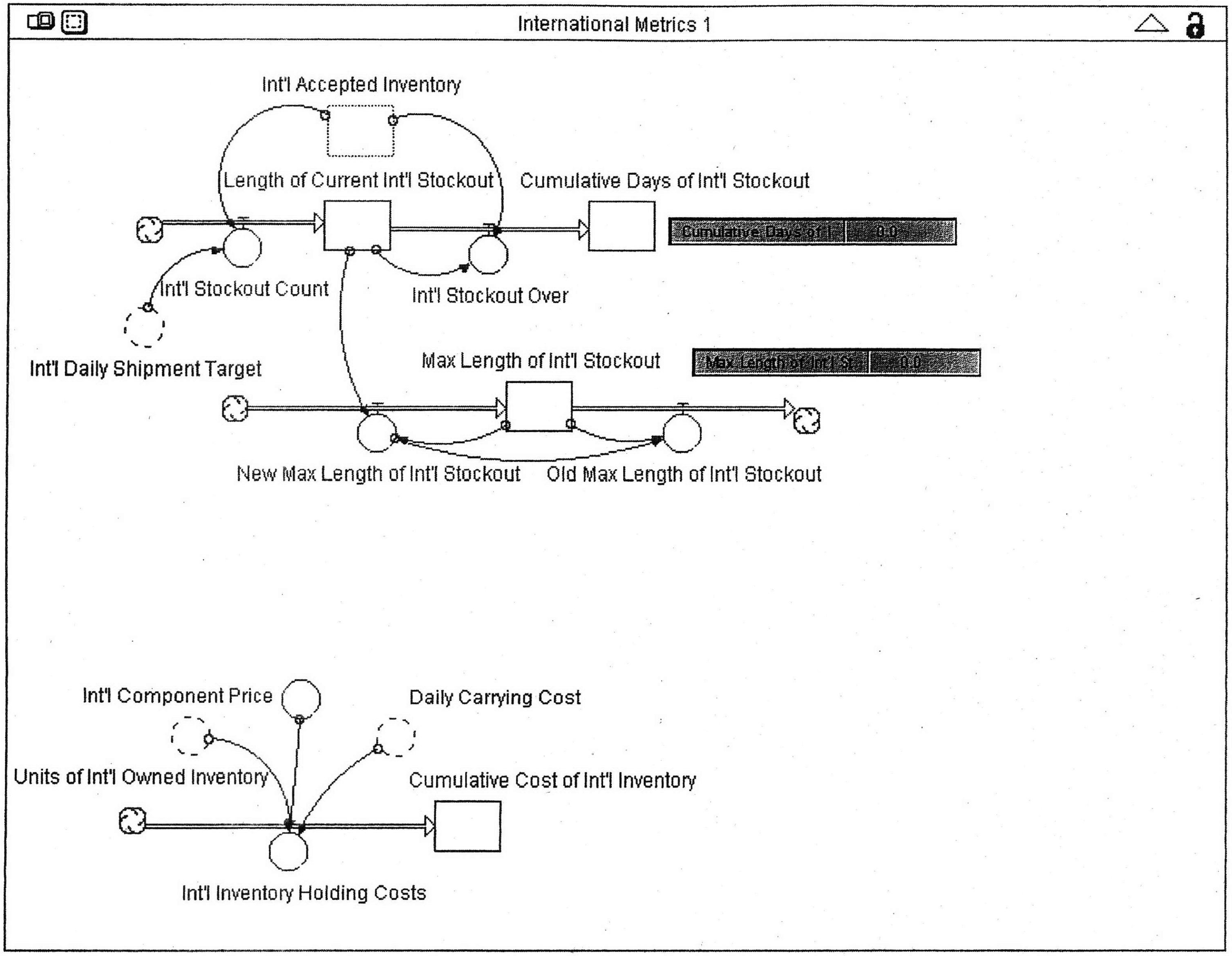

International Ordering/Shipping 3
Int'l ForecastReOrderPeriod
Days of Int'l Safety Stock
Days in a month
Forecast for Int'l target safety stock
Int'l Forecast for Inv 'til next arrival
Target Int'l Safety Stock
Forecasting Int'l Safety Stock
Reducing Int'l Safety Stock
Target Int'l Inventory
Int'l Safety Stock Gap
Safety Stock after Next Int'l Delivery
Inventory until Int'l shipment arrives
Forecasting Int'l shipment needs
Reducing Int'l forecast to current
Int'l Order Trigger
Days in a month
Int'l Daily Forecast
Forecast of Int'l Inventory Needed for next shipping period
Int'l Forecast

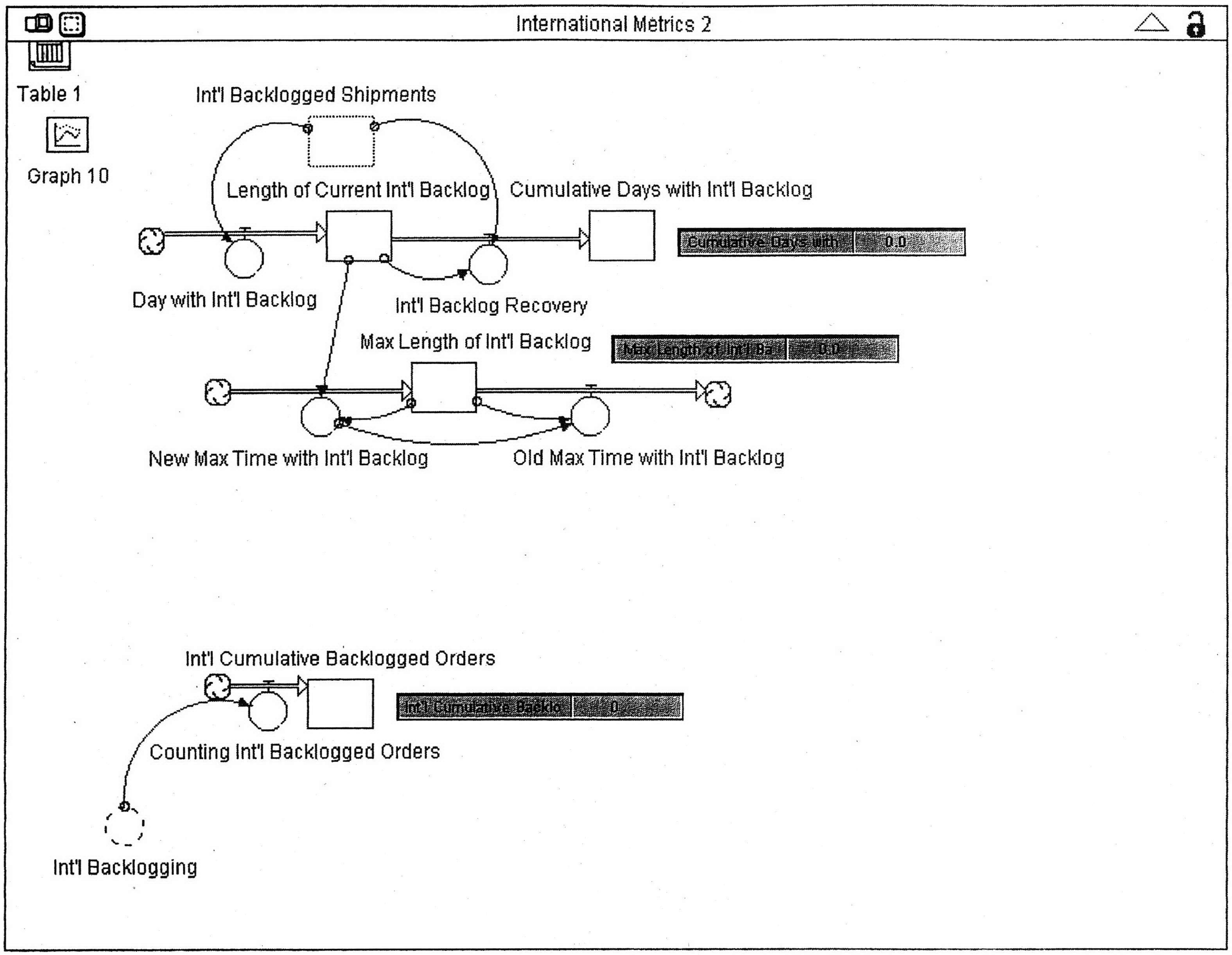

US Metrics 1
This tracks the cumulative days with a stockout (no accepted inventory) in the US. It also tracks the Maximum length of any stockout that may occur.
US Accepted Components
Length of Current US Stockout
Cumulative Days of US Stockout
US Stockout Count
US Stockout Over
US Daily Shipment Target
Max Length of US Stockout
New Max Length of US Stockout
Old Max Length of US Stockout
US Component Price
Daily Carrying Cost
Units of Owned Inventory in US
Cumulative Cost of US Inventory
This determines the cumulative cost of the US Inventory. It takes a constant component price and a daily carrying cost to determine the daily costs and then sums over the period.
US Inventory Holding Costs


US Metrics 2
Graph 6
US Backlogged Shipments
This determines the total number of days with backlogged inventory, as well as the maximum length of any period with a backlog.
Length of Current US Backlog
Cumulative Days with US Backlog
Cumulative Days with
0.0
Day with US Backlog
US Backlog Recovery
Max Length of US Backlog
Max Length of US Ba
0.0
New Max Time with US Backlog
Old Max Time with US Backlog
This tells how many orders were backlogged during the period. This may be an indicator of how many customers are impacted, but the real answer is a function of Master Scheduling.
US Cumulative Backlogged Orders
US Cumulative Backlo
0.0
Counting US Backlogged Orders
US Backlogging



This area negotiates the quantity to be shipped to the international site when the following occurs: failed components being reworked, units waiting for inspection (unaccepted components), or the percentage of US inventory on hand to target level is less than 30%. In these cases, the quantity to be shipped to the International site will be the MINIMUM of the International Inventory Needed, International Components at Supplier (International quantity ordered), and US Accepted Inventory.


International Metrics 1
Int'l Accepted Inventory
Length of Current Int'l Stockout
Cumulative Days of Int'l Stockout
Int'l Stockout Count
Int'l Stockout Over
Int'l Daily Shipment Target
Max Length of Int'l Stockout
New Max Length of Int'l Stockout
Old Max Length of Int'l Stockout
Int'l Component Price
Daily Carrying Cost
Units of Int'l Owned Inventory
Cumulative Cost of Int'l Inventory
Int'l Inventory Holding Costs


International Metrics 2
Table 1
Graph 10
Int'l Backlogged Shipments
Length of Current Int'l Backlog
Cumulative Days with Int'l Backlog
Day with Int'l Backlog
Int'l Backlog Recovery
Max Length of Int'l Backlog
New Max Time with Int'l Backlog
Old Max Time with Int'l Backlog
Int'l Cumulative Backlogged Orders
Counting Int'l Backlogged Orders
Int'l Backlogging

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