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Measuring the Effect of Transportation Uncertainty in the Postponement Strategy

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Transportation Uncertainty and

Postponement Strategy

THESIS

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Abstract

A manufacturing company can postpone production and logistics processes in its supply chain system. The delaying of manufacturing and logistics can eliminate the burden of accurate forecasting of demand and thereby reduce inventory carrying cost. Identical postponement processes cannot be generally implemented because every product has its own characteristics in reference to demand and every company has its own individual production environment. A company needs to find its best postponement strategy to minimize its costs for any certain product. This study applies Pagh and Cooper (1998)'s typology of supply chain postponement/speculation strategies to find the best postponement strategy for a global 500 company which has factories in Europe and the U.S. The total cost of the example product may be affected by holding cost rate, customer service level, exchange rate, and transportation uncertainty while the product moves through each supply chain. This study will simulate the supply chain system and apply these factors in each postponement strategy. The simulated data will be used to analyze the effect of parameters and discuss the result.

To my Father and my Mother

Acknowledgments

I would like to express my sincere appreciation to my faculty advisor, Lt. Col. Ned Sandlin, for his guidance and support throughout the course of this thesis effort. His insight and experience were certainly appreciated. I would, also, like to thank my reader, Dr. Alan Johnson, for both the support and latitude provided to me in this endeavor.

Chang-Sung Kim

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I. Introduction

Background, Motivation, & Problem Statement

Accurate demand forecasting is important to achieve a high customer satisfaction and to maximize profit. If demand forecasting is lower than actual demand, customer service suffers. Conversely, company profit decreases due to excess products when forecasted demand is higher than actual demand. Most companies try to predict demand as accurately as possible, but no forecast is perfect.

Managers can mitigate problems created by inaccurate forecasting by using the right supply chain strategy. If they change their supply chain strategy from speculation to postponement, companies can meet customer demand with fewer shortages or surplus product. For instance, postponing the shipment of appliances to Sears until a customer order is received, allowed Whirlpool to realize a significant reduction in inventory and transportation cost (Waller et al., 2000).

However, not every company can use this 'postponed' supply chain strategy because of the characteristics of the product or the company's manufacturing system. Some products must be on hand for customers to instantly get items when they need them. Some companies may have lead times which are prohibitively long. Finding the appropriate supply chain strategy for each product and company is important to increase the profitability of companies.

This study is focused on finding an effective supply chain strategy for a global 500 company. The case company uses a both a speculation and postponement strategy. These kinds of methods have various benefits and limitations from the perspective of lead time and inventory level. The location of manufacturing factories and warehouses affects supply chain efficiency, too. Deciding the best supply chain strategy among those logistics and manufacturing activities considering cost-effectiveness and customer satisfaction is the purpose of the study. The competition no longer takes place between individual businesses, but between supply chains (Yang et al., 2004). The study will compare four supply chain strategies with example products and decide which strategy is the most appropriate one. This study will conduct a discrete event simulation that uses a total cost model based on the inventory theoretic approach to test for supply chain strategy. The data consist of example product's 2008 shipment, actual demand, and fixed and variable cost of manufacturing.

Methodology

The research will compare the cost of the four supply chain strategies considering transportation uncertainty. Arena software will be used to conduct a simulation to compare the total cost of constant and variable Lead Time. By applying transportation uncertainty factor to logistics supply chain strategies, companies may get more accurate cost estimates and recognize possible savings. This will allow companies to build or change their manufacturing and logistics system in a more cost-effective way. The company can choose the best supply chain strategy and location for their manufacturing facilities and warehouses. The parent company of the manufacturer, which provides some components, is located in Sweden, Europe. The manufacturer's warehouses and assembly factories are located in Koping, Sweden and Lexington, Tennessee.

Statistical Analysis

One year of data (2008) was analyzed in order to answer the questions being investigated. The data consist of its 2008 shipment, actual demand, and both fixed and variable costs of manufacturing. The study will also compare transportation, fixed, and variable cost. Variable costs will be divided into inventory carrying costs and transportation costs, which will attempt to assess which of these costs most affect total cost. Identification of distribution, estimate of parameters, and goodness of fits tests will be conducted. Verification and validation steps which are provided by Banks et al. will be used to check the validity of the model. The scenarios of full speculation, logistics postponement, manufacturing postponement and full postponement will be tested to find the most appropriate strategy.

Thesis Organization

In this chapter the main focus is to provide background about the postponement strategy in the supply chain process. Chapter 2 presents a literature review about postponement concept and background. Chapter 3 give details about modeling the real system by using Arena. Chapter 4 presents the outcomes of the simulation and the analysis. Chapter 5 summarizes all the phases of this research, contributions and recommendations for future research.

II. Literature Review

Concept of the Postponement

The postponement concept was first introduced in the literature by Alderson (1950), who noted that delaying activities until the latest possible point in time can promote the efficiency of a marketing system. Alderson's concept of postponement would not be tested for a long time since the long lead time in production and distribution made it difficult to rely on postponement (Yang et. al, 2004). The development of manufacturing, transportation and inventory managing technology made it possible to investigate postponement strategy. The postponement is considered as one of the most beneficial strategic mechanisms to manage the risk associated with a variety of products and sales in uncertainty (Avive and Federgruen, 2001).

The concept can be divided into three types: time postponement, place postponement and form postponement (Bucklin, 1965). Delaying the manufacturing or logistics activity until a customer order is received is time postponement; keeping the product at the central warehouse until the customer's order is received is place postponement, and delaying product customization until the customer order received is form postponement (Bowersox and Closs, 1996). These three types of postponement are closely related to the cost of uncertainty during the manufacturing and logistics operations. The risk of uncertainty is reduced by applying postponement strategy to the time, place and form factors. The postponed manufacturing system combines these three basic forms within one operating system (Van Hoek et al, 1998).

Time and place postponement can be regarded as logistics postponement which including transportation, inventory and etc. Companies may intentionally delay manufacturing process until the latest point possible to maintain the material at upstream level because of higher inventory cost of material at the downstream level. The delayed increases of a product's variety, volume, value and weight by postponing logistics activity reduces inventory holding and carrying costs, obsolescence costs and transportation costs (Yang et. al, 2004). In the logistics postponement strategy, differentiated products are stocked at a strategically central location to achieve a balance between inventory costs and responsiveness (Bowersox and Closs, 1996). Reducing the logistics costs is one of the primary goals of a company, considering the portion of logistics costs of a product. Logistics costs consist of 10 percent or more of the total price of a product (Davis and Sasser, 1995).

Zinn and Bowersox (1988) categorized four different types of form postponement as alternatives to anticipatory distribution: labeling, packaging, assembly and manufacturing. These four types of postponement constitute five types of postponement when combined with time postponement. These types provide flexibility in deciding product content, package size, product version, material and amount to manufacturer. Keeping the product in the upstream process as long as possible increases the flexibility in the circumstance of market uncertainty (Lee, 1996). By changing or delaying the sequence of manufacturing activity, a product can meet the customer's requirements in the perspective of design, function and amount. It can be more effectively conducted by moving the point of product differentiation closer to the market and end customer (Mason-Jones and Towill, 1999).

Intentionally delaying activities for as long as possible and delaying the differentiation of products in terms of form, identity and place is time-based postponement. This does not include changing the sequence of activities (Garcia-Dastugue and Lambert, 2007). Implementation of postponement by changing the sequence of activity is conducted by using standardization, modularization and process restructuring (Lee and Tang, 1997). Standardization is using common components or processes so that they can be used in multiple finished products, even though applying too much commonality can reduce product differentiation and lead to a cannibalization effect (Swanminathan, 2001). Modularization is decomposing the product into sub-modules and delaying assembly of product-specific modules. The modularity breaks down the whole production process into sub-processes that can be performed simultaneously or in a different sequential order (Lee, 1998). Process restructuring is re-sequencing some manufacturing steps in order to delay the assembly of the product-specific components which can create the greatest diversity for later stage in the supply chain (Lee and Tang, 1998).

Study of Postponement

Some researchers conducted theoretical work on the postponement concept and strategy. As mentioned above, Alderson (1950) established the concept which is focused on the role of postponement in positioning inventory in the distribution system. Shapiro (1984) theoretically contributed, from a logistics perspective, the concept of positioning postponement in various logistical structures and the logistics capabilities of companies. Zinn and Levy (1988) built a theoretical analysis about what would be the most effective for a speculative inventory in marketing channels, including economic and marketing theories such as transaction costs and the role of power in positioning inventories. Cooper (1993) conducted theoretical work which examined the postponement application of supply chain and assessed the effects of market-product characteristics and logistics strategies. Pagh and Cooper (1998) established a theoretical overview of the postponement concept within a diagnostic and normative framework to recognize the most appropriate strategy for each business case.

Several researchers conducted modeling studies to assess the benefits of postponement application in specific cases. Zinn and Bowersox (1988) conducted a modeling study under various operating circumstances to assess the relevance of certain postponement applications in the supply chain system. Zinn (1990) expended the study of Zinn and Bowersox (1988) by using heuristic analysis. Lee et al. (1993) conducted modeling study on Hewlett Packard to assess the effect of postponement application in a manufacturing system compared to a manufacturing process without postponement application. Garg and Tang (1997) compared the application of point of differentiation in the supply chain for two types of products model. Sandlin (2010) considered pipeline stock costs which can form a large part of total logistics costs, through a modeling study.

Investigations utilizing case study and survey data are also used to identify the effects of implementing postponement. Chiou et al. (2002) conducted a survey with 102 Taiwanese IT firms to empirically examine the four types of form postponements: labeling, packaging, assembly and manufacturing. Sanchez and Perez (2005) used survey data from 126 automotive suppliers to explore the relationship between the dimensions of supply chain flexibility and firm performance. Yang et al. (2005) conducted a survey with British manufacturing companies to investigate the growing importance and implementation of postponement in the current business environment. They sought to identify which factors hinder the adoption and implementation of postponement in other literature. Krajewski et al. (2005) conducted a case study of a computer manufacturer in Taiwan and recognized that postponement was used to reduce uncertainty in responding to short-term fluctuation of demand.

Theoretical Framework

Speculation is the opposite concept from that of postponement in that speculation is the making of decision about manufacturing or product delivery before demand based on forecasting demand. Speculation makes it possible to gain economies of scale in manufacturing and logistics operations, and reduce the number of stock outs (Pagh and Cooper, 1998). Postponement and speculation are supply chain strategies offering opportunities for achieving cost-effectiveness and customer satisfaction by adjusting the logistics and manufacturing point of a product. Pagh and Cooper (1998) identified four different supply chain postponement strategies for a generic supply chain. These are the full speculation strategy, the logistics postponement strategy, the manufacturing postponement strategy, and the full postponement strategy.

The full speculation strategy is predicting demand before production; the retailer/customer order point is positioned at the lowest level downstream in the supply chain. This strategy is most widely used in a traditional supply chain strategy (Bucklin, 1965). The logistics postponement strategy is manufacturing based on speculation and performing logistics activity based on the postponement strategy. This strategy reduces the risk of placing products in the wrong time and/or place by allowing a company to keep its options open as to where to deploy their inventory until the last minute (Bowersox et al., 1993). In the manufacturing postponement strategy, the final manufacturing operation with prepared sub-assembly parts is performed at some point downstream in the supply chain. The implementation of manufacturing postponement, combined with the shift of manufacturing locations closer to the downstream process, results in a more cost-efficient manufacturing process while reducing transportation and logistics cost (Feitzinger and Lee, 1997). The full postponement strategy's manufacturing and logistics operations are customer order initiated. A product manufacturer needs to apply one of the above supply chain strategies depending on the characteristics of the product or material in order to earn the maximum profit. The study will be conducted based on these four supply chain strategies.

Table 1. The P/S-Matrix and strategies (Pagh and Cooper, 1998)

		Logistics	
Manufacturing		**Speculation** Decentralized inventories	**Postponement** Centralized inventories and direct distribution
	Speculation Make to inventory	**The full speculation strategy**	**The logistics postponement strategy**
	Postponement Make to order	**The manufacturing postponement strategy**	**The full postponement strategy**

As Boone, Craighead and Hanna (2007) suggested, more research about further development of postponement as a response to uncertainty needs to be conducted. The supply chain has been affected enormously by uncertainty in recent market circumstances (Geary, 2002). Ignoring transportation uncertainty can underestimate the costs of postponement strategy and lead to choosing a more expensive supply chain strategy (Sandlin, 2010). Assuming a constant lead time is possibly an error because of the time variations which exist in the real system. Uncertainty of transportation may cause delayed supply to both manufacturer and customer. Implementation of postponement resulted in an improvement of responsiveness, but not delivery reliability in one case study (Skipworth and Harrison, 2004). Accounting for transportation uncertainty is not a well-developed aspect of postponement strategy research. Especially, it is not standard to implement various lead time uncertainty factors in the total cost model. From the perspective of total cost framework and lead time, a more proper supply chain strategy can be found by applying transportation uncertainty (risk). Postponement strategy can help a company to reduce inventory levels while maintaining customer service (Brown et al., 2000) and as a result, improve cash flow. This research uses total cost to compare supply chain strategies.

III. Methodology

Introduction

This chapter describes the general process of methodology used to conduct the research of postponement strategy. This chapter begins with the scope of the research, followed by the four possible scenarios of postponement strategy for the example company. This chapter will then proceed into the assumptions, building the model and defining basic processes, and covers a building process of the Arena model which will represent the four postponement scenarios. Experimental design conducted to check the effect of parameter change will discussed, too. Finally, this chapter will discuss validation and verification of the model.

Scope

Every component of manufacturing process is affected by existing manufacturing, transportation and inventory operation and might be changed by newly transformed processes. It is important to narrow the scope of analysis by limiting products and processes of operation. The research will analyze the total cost of designated example products of designated company by examining supply cost of sub-components, manufacturing process, inventory carrying activity and transportation lead time. While calculating the changing inventory costs of a product, this study used only class A items among the total sub-assembly parts in order to avoid creating an overly complex simulation model which can be caused by simulating too many processes. After that, how the changing parameters in the postponement scenario affect the total cost will be examined. The postponement scenario is based on Pagh and Copper (1998)'s typology of supply chain strategies. The example company is ranked among global 200 which make marine parts. The data used in this research are identical with the data used in the study by Sandlin (2010).

Four Postponement Scenarios

The first scenario for the postponement strategy is full speculation (making to stock). The company manufactures their product at the factory located in Europe. The factory keeps raw materials in storage to build product. Supplier lead times of parts are generally less than for the manufacturing postponement scenario because most parts suppliers are located in Europe. After manufacturing, the products are shipped to the U.S. and stored at a warehouse which is located in Tennessee. When the company receives an order from a customer, they ship it to the customers the U.S. If the stock level of the warehouse hits the reorder point, the company asks the factory to ship more products to the warehouse, a process which takes approximately 45 days. The reorder point of the warehouse is decided based on past data and customer service levels. The company pays for transportation costs, inventory carrying costs (at warehouse and in pipeline), customs and the fixed and variable costs of manufacturing.

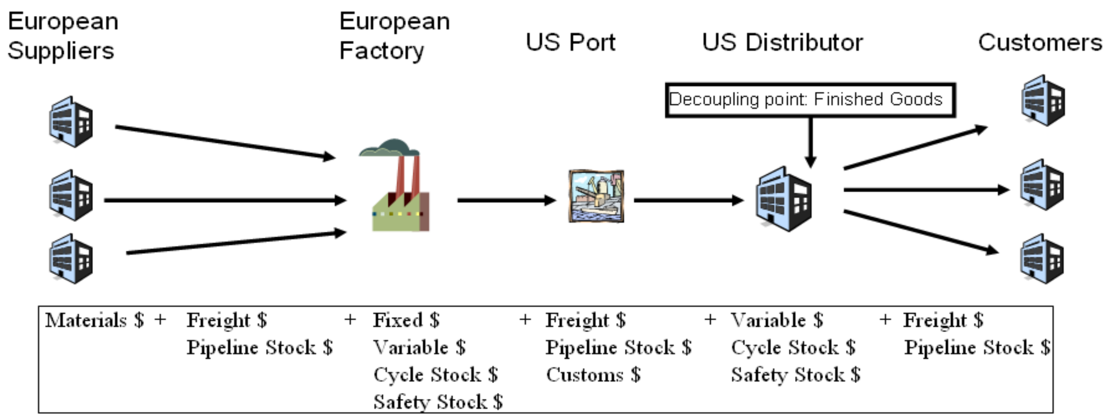


Figure 1. Speculation (Sandlin, 2010)

The second scenario is manufacturing postponement (assemble to order). The company stores sub-assembly parts of their product at the factory/warehouse. When they receive an order from a customer, the sub-assembly parts are assembled to complete the product which is then shipped to customers. The sub-assembly parts are provided by suppliers in Europe. The factory/warehouse tries to maintain a proper number of sub-assembly parts by initiating an order when the stock level of parts hits the reorder point. In this case, order fulfillment of some parts would take more time (approximately 90 days because of the geographical distance between factory and supplier). Inventory carrying costs can be decreased by minimizing the in-stock period of valuable product (completed product).

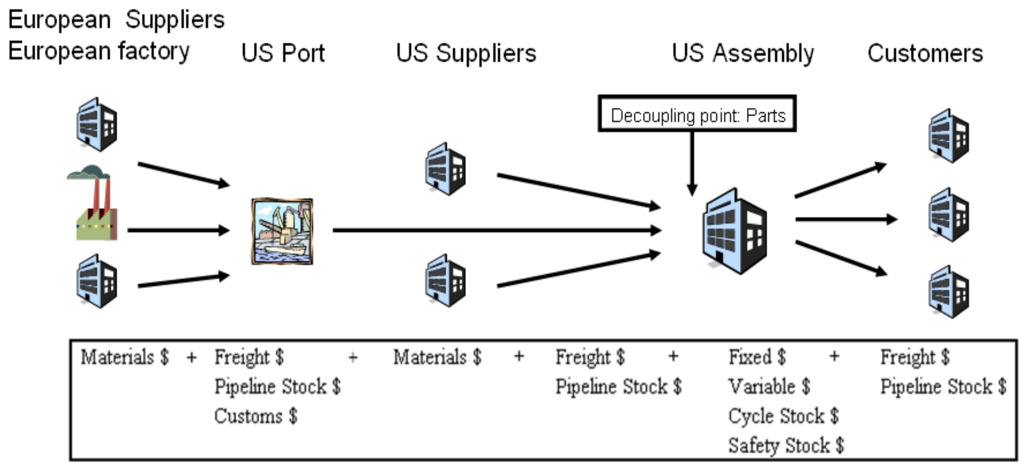


Figure 2. Manufacturing postponement (Sandlin, 2010)

The next scenario is logistics postponement (ship to order). The company manufactures the product and stores it at the warehouse. When they receive orders from their customers, they ship the product from their Europe warehouse to customers in the US. The factory and warehouse are both located in Europe. The warehouse tries to maintain a proper amount of stock (completed product) by requesting the product from the factory when the stock level hits the reorder point. In this case, the period of transporting finished goods (completed product) is increased (a shipping timeframe of approximately 45days from the warehouse in Europe to customers in the U.S.) which resulted in an increase in inventory carrying costs compared to the previous scenarios.

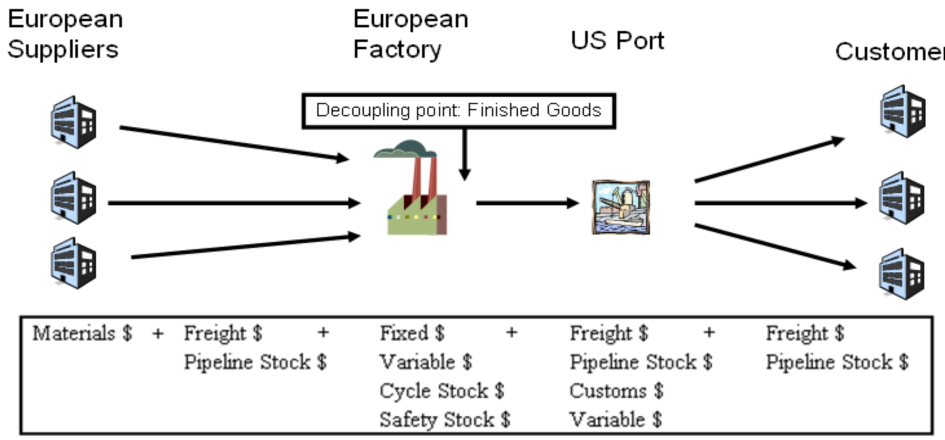


Figure 3. Logistics postponement (Sandlin, 2010)

The final scenario is full postponement. The company initiates the manufacturing process when they receive orders from customers. They ship the product to customers right after the manufacturing process; therefore, no warehouse stock keeping activity is needed. All of the production processes are finished in Europe. Only transportation costs are generated between the factory in Europe and customers in the U.S. In this case, the transportation cost remains high, and inventory carrying costs are reduced because the company keeps only sub-assembly parts as stock, not the completed product.

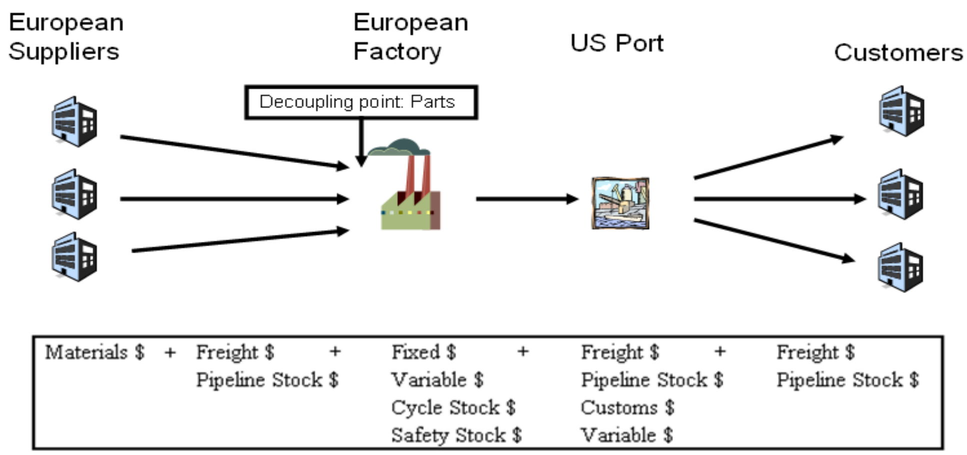


Figure 4. Full postponement (Sandlin, 2010)

Assumptions

Although much of the analysis utilized real-world inputs, several assumptions are still required. The key assumptions for the model are as follows:

1. Class A items' inventory cost change represents a product's inventory cost change.
2. Orders for sub-assembly parts at factory and completed product at warehouse are initiated as soon as they hit the reorder point.
3. Customer demand occurs only on company working days.
4. The company does not operate on weekends and holidays.
5. Neither fixed costs nor variable costs change during the simulation period.
6. No demurrage cost.
7. No damage of product occurs during manufacturing or transporting.

These assumptions were reviewed by a former researcher who is familiar with the manufacturing system of the company and who deemed them to be plausible assumptions for the purpose of this study.

Model Setting

Based on the system employed by the example company, the model used the continuous review (s, Q) inventory system. The equation (1) provides an intuitive description of the estimated logistics cost (ELC) for a sub-assembly part used in the model.

$$ELC_i = (\frac{Q_i}{2} + SS_i)V_i H_1 \frac{1}{T_i} + \frac{P_i Q_i}{O} V_i H_2 \frac{1}{T_i} \qquad (1)$$

Where:

i = index for a sub-assembly part of a product

P = pipeline period during the operation period

Q = order quantity

O = operation period

SS = safety stock

V = value of a sub-assembly part

H_1 = holding cost factor for warehouse (%/$/yr)

H_2 = holding cost factor for pipeline (%/$/yr)

T = total amount of ordered sub-assembly parts

The first part in the equation is the cycle stock cost ($V_i \cdot H_1 \cdot [Q_i/2]$) of a sub-assembly part. The second part is the safety stock cost ($V_i \cdot H_1 \cdot SS_i$) and the third part is the pipeline cost ($V_i \cdot H_2 \cdot P_i \cdot [Q_i/O]$). The safety stock amount is simulated in the model and depends on the reorder point, calculated by s = $\hat{x}_L$ +SS. The initial value of safety stock is calculated by the safety factor (customer service level) k multiplied by the standard deviation of demand during lead time. The standard deviation of demand during lead time σ_x is calculated by $\sigma_x = \sqrt{\sigma_D^2 \mu_L + \sigma_L^2 \mu_D^2}$. The total cost of a product is calculated from the ELC of each sub-assembly part. The equation (2) provides a description of the total cost (TC) of a product in the model.

$$TC_j = FC_j + VC_j + \sum_i^k ELC + F_j \qquad (2)$$

Where:

j =	index for different types of product
FC =	fixed costs of manufacturing
VC =	variable costs of manufacturing
F =	total door-to-door transportation related costs ($/unit)
i ~k =	every sub-assembly part (i+…+k) of a completed product j

The door-to-door transportation related costs F include freight rate, customs and handling fees during shipping.

Model Building

While the company receives orders and manufactures products, the factory tries to maintain at least certain number of sub-assembly parts as a safety stock to maintain appropriate customer service levels. The reorder point is variable, as it depends on the customer service level that the company wants to maintain. If the sub-assembly parts stock level hits the reorder point, the factory asks suppliers in Europe (or, in some cases, local suppliers in the U.S.) to supply more products. After piling up the ordered amount of the product, they are shipped to destinations spread across the U.S. These are basic process of manufacturing and transporting of the example company as shown in Figure 5. The location of factories and warehouses can be in Europe or the U.S., depending on the scenario. The costs of sub-assembly parts are different between Europe and the U.S. because the costs of parts increase during the transportation process. At the same time, the transportation costs of completed products also vary widely, depending on the scenario (affected by transportation distance, product handling process).

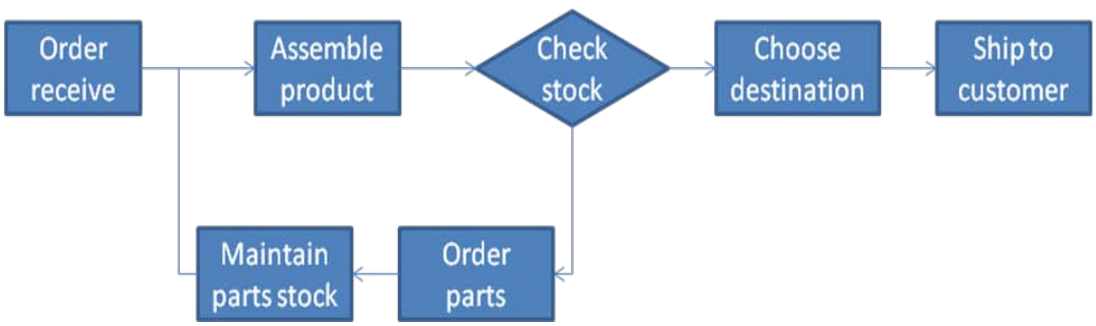


Figure 5. Basic process of supply chain

The company sells 12 products and each product is consists of 90 components. To avoid too much complexity, the model deals with class A items for the 10 highest selling products of the example company (the amount of selling 11^{th} or 12^{th} products are not significant). These 10 products were sold in different amounts during the 2008 and each has its own demand distribution. The distribution of demand was calculated by Input Analyzer of Arena (See Table 2).

Table 2. Order Amount and Distribution

	Distribution	Selling amount	Chi-square p-value
Product 1	LOGN(0.272,0.221)	933	< 0.005
Product 2	ERLA(0.086, 1)	2897	< 0.005
Product 3	ERLA(0.181, 1)	1364	< 0.005
Product 4	ERLA(0.0961, 1)	2633	< 0.005
Product 5	EXPO(1.72)	144	< 0.005
Product 6	ERLA(0.103, 1)	2389	< 0.005
Product 7	LOGN(0.543,0.344)	472	< 0.005
Product 8	ERLA(0.14, 1)	1790	< 0.005
Product 9	ERLA(0.0379, 1)	6591	< 0.005
Product 10	13 * BETA(0.155, 2.52)	332	= 0.00565

The p-value of chi-square test for each distribution recommends not to use the fitted distributions. However, this rejection of fitted distribution can be considered as the fallacy of the goodness-of-fit test when a large real-world data set is fitted. A large data set can be fitted to many classical distributions and all can be rejected because the large sample size yields large power and the error in the model is indeed statistically significant (Schmeiser, 1999). The 10 product's demand distributions were used in the research model because they shows visually and conceptually adequate fit (See appendix E).

These 10 different types of products have a high degree of commonality. By choosing several different components while assembling 13 class A items, the model divided the products into 10 products. The model expressed this process by letting each entity of the 10 products choose its own items through the manufacturing process. Every entity of products is assigned its name at the first step and chooses its own item at the point of differentiation while going through the shared items as shown in Figure 6. The total number of class A items for 10 the different types of products is 23 items. The inventory carrying costs, pipeline costs and transportation costs of these class A items will be simulated in the model and the average cost of each product will be calculated as a result.

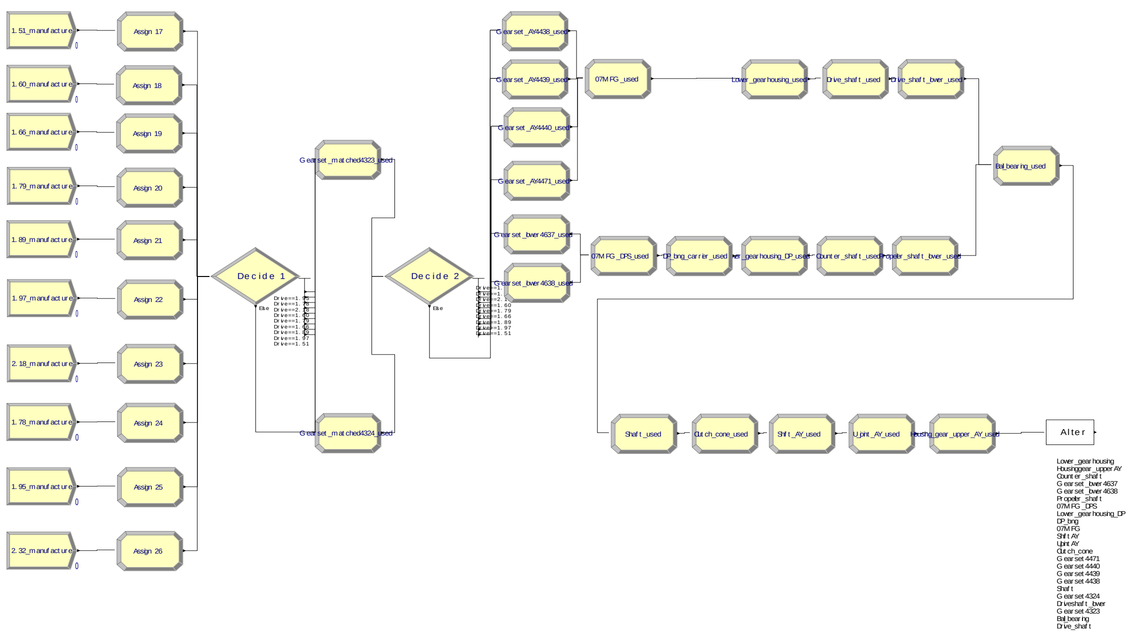


Figure 6. Assembly process of 10 products

The model assumes one year to be 250 working days by subtracting weekends and holidays. The order amount and frequency of each product is expressed in the model through distribution of received orders. The time between the arrival of orders for each product initiates orders in the model. After the order initiation, each entity of the order subtracts the parts count from the stock level. The model continuously checks the stock level of 23 items and initiate orders to the suppliers as soon as the stock level hits the reorder point. The model has a review cycle for class A items stock level every minute and reorders parts when the inventory amount is not higher than reorder point. The model gets the safety stock level by checking inventory amounts right before the factory receives ordered parts after supplier lead time as shown in figure 7. After one year (250 days) of inventory level checking, the model calculates the average safety stock, cycle stock and pipeline stock.

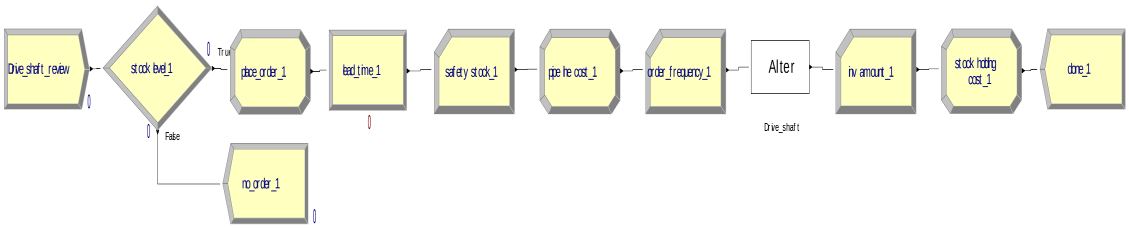


Figure 7. Inventory checking of a part

In case of logistics postponement and making to stock scenarios, the warehouse tries to maintain a certain amount of completed product stock. The model simulates this process by checking the stock level in the warehouse and initiating order for 32 products, a number which equals full container load (minimum order quantity). While conducting this process, the model calculates the average inventory amount that the warehouse maintains for the operating period and the total lead time that the factory uses to supply product to warehouse. These processes are simulated in the model as shown at Figure 8.

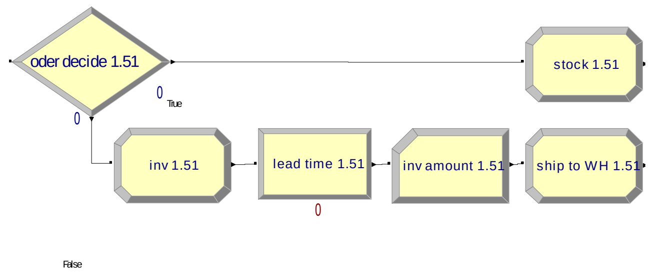


Figure 8. Inventory checking of a product

If the entity completed the assembly process, it piled up to 32 products (transportation unit) and shipped to customers. The delivery destination is decided by the past selling record (percentage of 2008 selling record) of each customer. There are 13 customers in the U.S. and each customer has a different freight rate and distance. The model expresses the transportation process as shown at Figure 9.

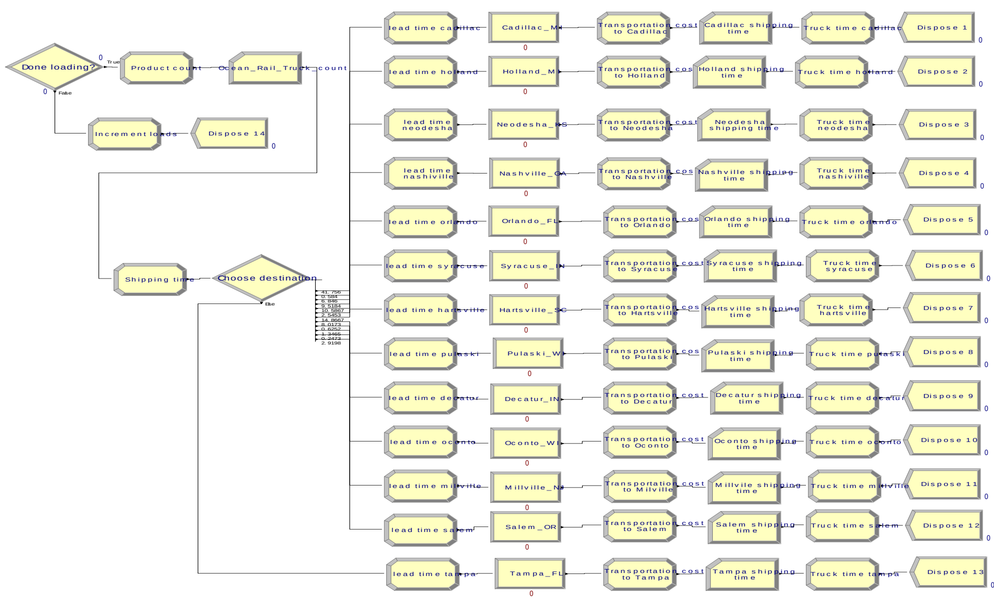


Figure 9. Transportation process

The model assumes the transportation of product that is conducted by truck has a maximum 11 hours of delivery time per day based on the federal government regulation. The model applied reasonable trucking time based on distance and regulation (See Table 3).

Table 3.Transportation Rate and Hours

Destination	**Rate**	Distance	Drive Time 1*	Drive Time 2**
Cadillac, MI	975	783	16.6	29.6
Holland, MI	775	661	14.1	27.1
Neodesha, KS	700	609	12.9	25.9
Nashville, GA	960	569	12.1	25.1
Orlando, FL	1485	797	16.9	29.9
Syracuse, IN	650	559	11.9	24.9
Hartsville, SC	875	621	13.2	26.2
Pulaski, WI	1025	715	15.2	28.2
Decatur, IN	650	515	10.9	10.9
Oconto, WI	1025	730	15.5	28.5
Millville, NJ	1875	927	19.7	32.7
Salem, OR	3000	2377	50.5	102.5
Tampa, FL	1492	811	17.2	30.2

* Distance/Proper Speed (47m/h)
** Each 11 hours considered as 24 hours based on the federal government regulation

Total transportation cost and delivery time is calculated through the process above. The model calculates each parts' pipeline period during the supplier lead time, the total amount that the factory bought, the average inventory amount that factory carried and safety stock that the factory maintained. Each product's selling amount, transportation time to the warehouse and inventory amount at the warehouse are calculated in the model, as well. The calculated values are recorded in the excel file through the read/write module as shown at Figure 10.

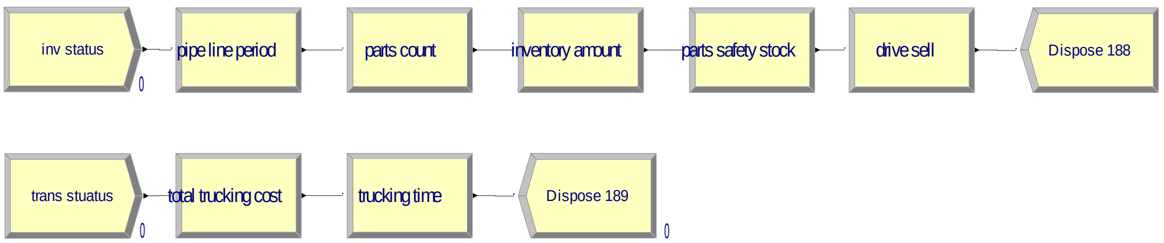


Figure 10. Read/Write module of inventory and transportation

Each product's manufacturing cost at factory, inventory cost at warehouse and pipeline can be calculated through the simulated amount of parts count, lead time, and inventory amount and safety stock. The total supply chain cost for a product can be calculated through the inventory carrying period, the transportation period and the rate. This study compares the effect of holding cost rate and customer service level to the total cost of a product. From 0.07 to 0.13 of holding cost rate (0.01 gaps) and five levels of customer service level (0.99, 0.98, 0.95, 0.90 and 0.85) were used to compare the effect. The compared values of these variables are expressed on the excel file through the Process Analyzer tool of Arena. To compare the effect of transportation uncertainty, three random distributions (Gamma, Exponential and normal distribution) were used for supplier lead time of parts and product delivery time to customers.

Verification and Validation of the Model

To check the verification and validation of the model, the steps suggested by Banks et al. (2005) were used. One step of verification is to have someone familiar with the actual system review the model. Dr. Sandlin, who studied the example company's supply chain system, reviewed the four scenarios' simulation models respectively and checked the logic of the model. The equations used in the simulation process to calculate total inventory costs were examined, as well. Based upon feedback from the review, the model was modified accordingly. The animation feature in Arena was also used to verify the model. The animation features of each entity were checked to determine if it imitates the actual system or not. No entities disappeared or passed through one another during the simulation. Every entity showed intended movement through the simulation process. Input parameters were checked before conducting experimental design method by using a Process Analyzer and checked at the end of the simulation, to be sure that these parameter values have not been changed inadvertently. The reasonableness of output was examined by comparing the results of various settings of the input parameter that was implemented in the Process Analyzer.

Validation of model was checked through sensitivity analysis. Some variables in the model were changed intentionally for the purpose of sensitivity analysis and they showed expected results (manufacturing amount, parts count, transportation period and frequency). The structural assumptions and data assumptions of the model were reviewed by Dr. Sandlin. The results of the simulation model were compared with the analytical approach results conducted by Dr. Sandlin. The simulation of each scenario showed similar results to the analytical approach, which is considered reasonable.

IV. Analysis and Result

Introduction

This chapter describes the simulation output and what the resulting information from the data implies. The statistical analysis process was employed after sufficient data were gathered from simulation runs. Performance metrics were calculated and recorded for the operation period and for each scenario. The process analyzer tool of Arena made it possible to have multiple simulation runs with various variable changes. The data imported into an Excel spreadsheet through the Read/Write module were used for charting and statistically analyzed by JMP. The experimental design results were compared and evaluated concerning the effect of parameter changes.

Input Data for Analysis

The example product has 10 products. Each different product has a different customer demand (See Table 4). For the purpose of comparing each postponement strategy, the total cost of the ten different types products of a postponement strategy are transformed to one average value. While getting the average value, the cost of each product type is multiplied by ratio of demand and summed up as one average value. Each scenario runs 20 replications to get sample groups of values. The study used this value for comparing each postponement strategy and the effect of parameter changes.

Table 4. Demand Data of Each Type (2008)

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9	Type10
Total demand	933	2897	1364	2633	144	2389	472	1790	6591	332
Avg demand /day	3.73	11.59	5.46	10.53	0.58	9.56	1.89	7.16	26.36	1.33
Std of daily demand	4.92	12.57	8.18	11.35	3.28	12.95	3.54	7.20	24.42	2.44
% of total demand	0.05	0.15	0.07	0.13	0.01	0.12	0.02	0.09	0.34	0.02
Coefficient of variation	1.32	1.08	1.50	1.08	5.70	1.35	1.87	1.01	0.93	1.84

Sensitivity Analysis for Holding Cost Rate

The holding cost can be defined as the cost of capital plus the cost of insurance. In the changing economic situation, the rate of holding cost is not constant. The total logistics cost is affected by the holding cost rate change. The sensitivity of the holding cost rate can be analyzed by comparing the changing total cost of each postponement strategy. Figure 11 shows each postponement strategy's total cost change depends on the holding cost rate. The lowest total logistics cost among the four scenarios is Assemble-to-order and the highest total logistics cost scenario is Making-to-stock. There is no line crossing during the changing of the holding cost rate which means that the total logistics cost cannot be reversed through a change in holding cost rate. The line slope of the four scenarios shows different sensitivity for different postponement strategies.

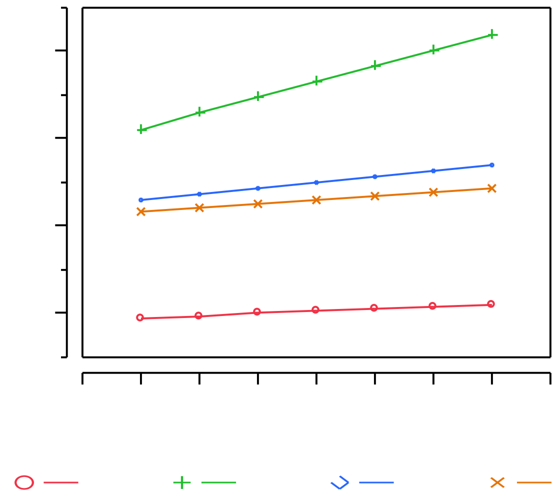


Figure 11. Overlay Plot by Holding Cost Rate

The line slope was analyzed by getting the linear fit of each postponement strategy's logistics costs (See Table 5). The linear fit of each scenario shows how sensitive the strategy is to changes in the holding cost rate. The linear fit equation received from JMP shows the most sensitive scenario for the holding cost rate is Making-to-stock and the least sensitive scenario is Assemble-to-order. The independent variable of each linear fit shows definite differences.

Table 5. Holding Cost Rate Linear Fit for Each Scenario

	Linear fit	P-value
ATO	1337.705 + 136.94066*HOLDING COST	<.0001
MTS	1391.8042 + 908.23834*HOLDING COST	<.0001
LP	1390.9545 + 339.70389*HOLDING COST	<.0001
FP	1391.8662 + 233.11987*HOLDING COST	<.0001

Sensitivity Analysis for Customer Service Level

The stock keeping level of parts in factories and completed products of warehouse are affected by the customer service level. If the company wants to maintain a high customer service level, the company maintains a high reorder point in order to retain high stock level. High stock keeping levels cause high inventory carrying costs which will increase the total logistics cost. Figure 12 shows that the total cost changes for each scenario depend on customer service level. The rank of total costs for each postponement strategy is the same as in the case of holding cost rate change. The slope of each line shows gentle change.

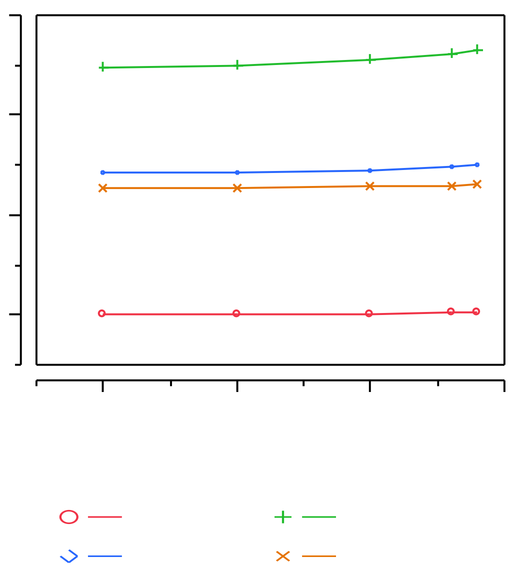


Figure 12. Overlay Plot by Customer Service Level

The linear fit of each postponement strategy shows more precisely how sensitive the total cost is to customer service level. Even though they show less sensitivity than holding cost rate changes, the independent variables show that the Making-to-stock strategy is the most sensitive one and the Assemble-to-order strategy is the least sensitive among the four (See Table 6).

Table 6. Customer Service Level Linear Fit for Each Scenario

	Linear fit	P-value
ATO	1341.3423 + 9.9477729*CSL	<.0094
MTS	1420.2471 + 61.776162*CSL	<.0075
LP	1397.2777 + 27.303329*CSL	<.0146
FP	1404.8632 + 10.201256*CSL	<.0094

Sensitivity Analysis for Exchange Rate

The example company buys its product's sub-assembly parts from Europe. In the case of Making-to-stock, Logistics postponement and Full postponement, fixed cost, variable cost and some of the inventory carrying cost are paid in Europe. Some of the transportation costs are paid in Europe for some strategies, too. The portion of costs paid in Europe and the exchange rate between the Krona (Swedish currency) and the Dollar affect the total cost of a product. Figure 13 shows us that the fluctuations in the exchange rate affected the total cost of a production in a significant manner. The slope shows stiff changes result from the exchange rate.

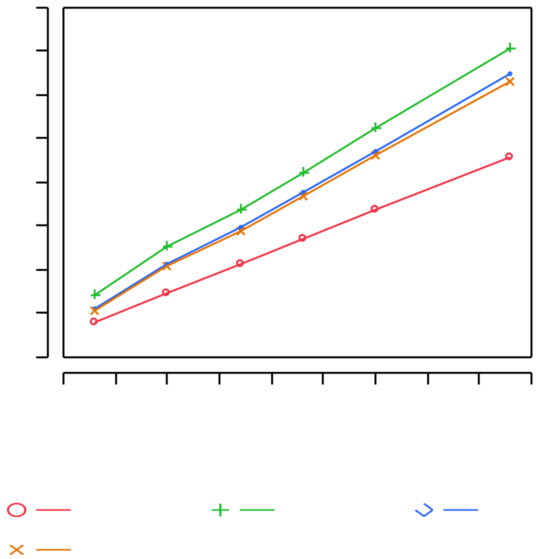


Figure 13. Overlay Plot by Exchange Rate

The linear fit of each strategy shows great independent variables. As is the true for the holding cost rate and the customer service level, Making-to-stock has the largest sensitivity and Assemble-to-order has the lowest sensitivity. The total cost change during the experiment was enormous compared to experiments described above. As mentioned earlier, fixed costs, variable costs, inventory carrying costs and transportation costs paid in Europe affect the total costs more than do those paid in the U.S. when it comes to exchange rate.

Table 7. Exchange Rate Linear Fit for Each Scenario

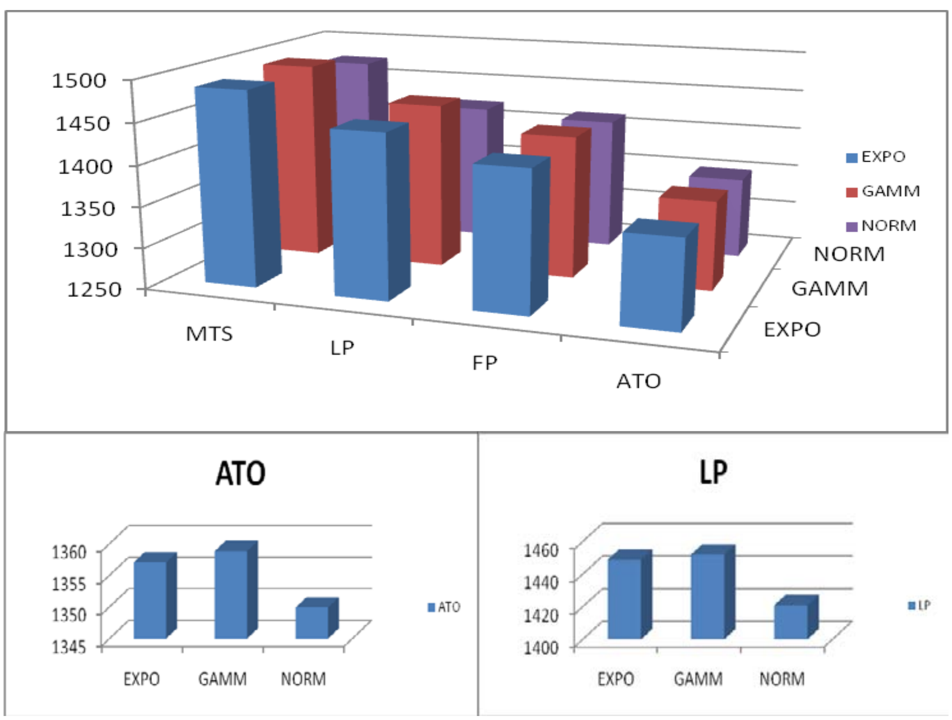
	Linear fit	P-value
ATO	395.56419 + 950.69758*Exchange Rate	<.0001
MTS	52.202332 + 1392.7678*Exchange Rate	<.0001
LP	72.386017 + 1334.5721*Exchange Rate	<.0001
FP	103.32766 + 1298.3637*Exchange Rate	<.0001

Sensitivity Analysis for Transportation Uncertainty

The example product's supply chain process has three general transportation periods: supplier lead time, the transportation times from the factory to the warehouse and from the warehouse to the customer. The four scenarios cannot apply the same transportation period for supplier lead time because the location of the factory is different in each scenario. The transportation periods from the factory to the warehouse and from the warehouse to the customer, likewise, are different in each scenario. To analyze the effect of transportation uncertainty, the model applied the transportation uncertainty factor to supplier lead time, transportation time from the factory to the warehouse and transportation time from the warehouse to the customer.

As mentioned earlier, three random distributions (Gamma, Exponential and normal distribution) were used to obtain the results for various transportation uncertainty environments. Using different distribution of transportation period represents the unpredictable transportation time situations; this will lead to comparing factor of transportation uncertainty. The same numbers were used for the mean value of the exponential and normal distributions. The gamma distribution used $\alpha = \mu_x^2/\sigma_x^2$ and $\beta = \sigma_x^2/\mu_x$ as parameter values. To conduct the simulation, 99% of the customer service level, a holding cost rate of 1, and 1 exchange rate were used.

The rank of postponement strategy total costs does not change according to changes in the transportation uncertainty (See Figure 14). This is consistent with the previous holding costs, customer service level, and exchange rate analysis. The total costs of a product might be affected by the transportation uncertainty factor but the uncertainty does not cause so large a change that the rank of each postponement strategy's total costs can be reversed in this example company's example product. Normal distribution consistently represents the lowest cost among the three random distributions. Gamma distribution seems to have the highest cost among the four postponement scenarios. However, the differences in sample mean total costs among the exponential, gamma, and normal distribution is not significant with charts checking.



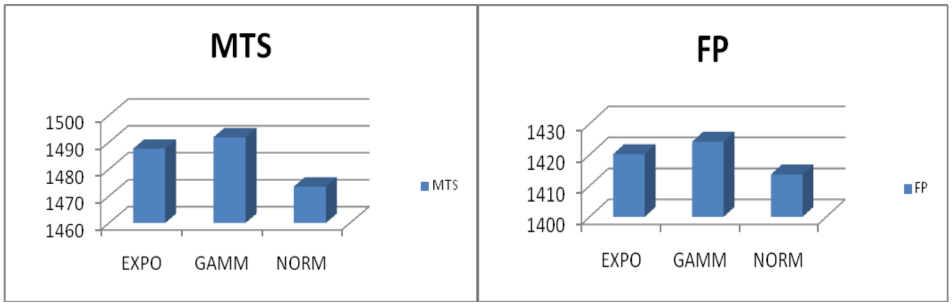


Figure 14. Total cost by strategy and random distribution

Analysis of Variance (ANOVA) and Tukey's HSD (Honestly Significant Difference) test are implemented via JMP statistical package to conduct more specific comparisons. ANOVA tested 20 values replicated in the model to compare the sample mean difference among the three random distributions. Upper and lower levels for the mean of three random distributions do not overlap with a 95% confidence interval in the Assemble-to-Order scenario. Tukey's HSD test shows each pair's means are significantly different (See Table 8).

Table 8. Comparison for ATO transportation scenarios

Comparison		Difference	Std Err Dif	Lower CL	Upper CL	p-Value
GAMM	NORM	8.937774	0.2954421	8.161708	9.713842	<0.0001
EXPO	NORM	1.748322	0.2954421	6.372256	7.924389	<0.0001
GAMM	EXPO	1.789452	0.2954421	1.013385	2.565519	<0.0001

The mean comparisons show similar results in the Making-to-Stock scenario (See Table 9). The normal distribution shows a significant mean difference with gamma, and exponential distribution. The exponential distribution, also, shows a significant mean difference with gamma distribution with 95% confidence interval. ANOVA test shows mean upper and lower levels of the three distribution cases do not overlap each other. The logistics postponement and full postponement scenarios show the same result for sample mean comparison (See Table 10 and Table 11).

Table 9. Comparison for MTS transportation scenarios

Comparison		Difference	Std Err Dif	Lower CL	Upper CL	p-Value
GAMM	NORM	18.32073	0.7089991	16.61458	20.02689	<0.0001
EXPO	NORM	14.06633	0.7089991	12.36018	15.77248	<0.0001
GAMM	EXPO	4.25440	0.7089991	2.54825	5.96056	<0.0001

Table 10. Comparison for LP transportation scenarios

Comparison		Difference	Std Err Dif	Lower CL	Upper CL	p-Value
GAMM	NORM	31.12202	0.3389677	30.30632	31.93772	<0.0001
EXPO	NORM	28.00214	0.3389677	27.18644	27.18644	<0.0001
GAMM	EXPO	3.11987	0.3389677	2.30418	3.93557	<0.0001

Table 11. Comparison for FP transportation uncertainty scenarios

Comparison		Difference	Std Err Dif	Lower CL	Upper CL	p-Value
GAMM	NORM	10.52506	0.4130290	9.531141	11.51899	<0.0001
EXPO	NORM	6.56843	0.4130290	5.574511	7.56236	<0.0001
GAMM	EXPO	3.95663	0.4130290	2.962707	4.95055	<0.0001

Overall, sample mean total costs in the three random distribution cases show significant differences from each other in all the four postponement scenarios. The upper and lower levels of 95% confidence interval do not overlap with the other distribution cases' upper and lower levels based on ANOVA test. Tukey's HSD test shows significant p-value in the mean comparison with the other distribution case as well. Each of the three distribution cases has its own cost range in its provided supply chain environment. From this, it can be recognized that lead time distribution settings in transportation factors have a significant effect on the total cost of a product. The transportation uncertainty factor, which is expressed as certain random distribution has a significant difference in the aspect of costs when compared to different lead time distribution cases and transportation certainty situations.

Compared to the other transportation distributions, normal distribution case's total mean costs show a consistently low value. Standard deviation of sample groups also shows the lowest value in normal distribution cases in all of the four postponement scenarios. (See Table 12). The exponential and gamma distribution cases can be inspected for their relative level of robustness by comparing them to normal distribution cases.

Standard deviation of exponential and gamma distribution cases are almost twice or more compared to normal distribution case. The gamma distribution case shows the largest standard deviation of all the four postponement strategies while having largest sample mean. It can be recognized that gamma distribution in transportation lead time shows unstableness and a lack of robustness. The exponential distribution case shows the second largest sample mean and standard deviation among the three cases, which represents a lack of robustness compared to normal distribution case.

Table 12. Standard deviation of total cost for each distribution

	ATO	MTS	LP	FP
NORM	0.4794	0.6887	0.7145	0.7734
EXPO	1.0010	2.5869	1.1714	1.5890
GAMM	1.3978	2.8132	1.2507	1.4123

In summary, this analysis showed transportation uncertainty, expressed by using various random distributions, does not change the rank of postponement strategy's total costs for a product in the given environment. However, each distribution case has significant sample mean differences in all the four postponement scenarios. The three random distributions, exponential, gamma, and normal, affect the total cost significantly with different levels in supply chain of a product. Gamma distribution and exponential distribution show instability with large sample mean cost and standard deviation while normal distribution, which has the lowest sample mean cost and standard deviation, is shown to be the most robustness.

Conclusion

This chapter presented the data produced by simulation model runs. It was run through various levels of statistical scrutiny under various model conditions. The total costs of a product are analyzed with holding cost rate, customer service level, and exchange rate in the four postponement scenarios. The effect of lead time uncertainty in the four postponement scenarios, was also, analyzed by implementing several random distributions in the transportation period.

V. Conclusions and Recommendations

Research and Conclusion

This study simulated the example company's supply chain system to investigate the total cost of a product in the four postponement strategies: full postponement, logistics postponement, manufacturing postponement, and full speculation. The simulation model checked reliability by extending the results with previously conducted analytical study for identical products belong to the same company. There are several parameters that affect the total cost of a product and the parameters keep changing depending on market and manufacturing situations. The simulation model conducted experimental design research by changing those parameters to assess the effect on total cost in each postponement scenario.

The first parameter that was implemented in the research is the holding cost rate. Based on a holding cost rate change from 7% to 13%, each postponement strategy shows a level of sensitivity to the holding cost rate. The Making-to-stock scenario shows the most sensitivity and the Assemble-to-Order scenario shows the least sensitivity. The rank of postponement scenarios for total cost does not change in the experimented holding cost rate range. The second parameter, customer service level, implemented from 85% to 99% and the third parameter, exchange rate, implemented from 93% to 133% showed the same results for the holding cost rate in the experiment range. From the perspective of a business manager, the Assemble-to-Order scenarios would be the best strategy because it shows the most reliability and the least cost.

The transportation uncertainty parameter does not cause enormous change to reverse the rank of postponement scenarios for total cost. However, the random distributions applied in the model showed significant differences from one other for the total cost of a product. Every distribution has its own range of sample groups for the total cost of a product and its mean showed significant difference with other distributions. The ANOVA test showed that each distribution case's total cost has an upper and lower level which are different each other with a 95% confidence interval. Tukey's HSD test even shows the sample groups in each distribution case are significantly different with more than 99% p-value. These differences in each distribution case are applied in all the four postponement scenarios.

Standard deviation of total cost within a sample group shows a specific pattern for each distribution case in the four postponement scenarios. Normal distribution case shows the lowest standard deviation among the three random distributions and gamma distribution case shows the largest standard deviation. Exponential and gamma distribution case can estimate their robustness because normal approximation of lead time demand in a distribution setting shows robustness with respect to cost. Each transportation uncertainty situation, which is expressed with several random distributions, affects the total cost of a product with different levels.

Limitations

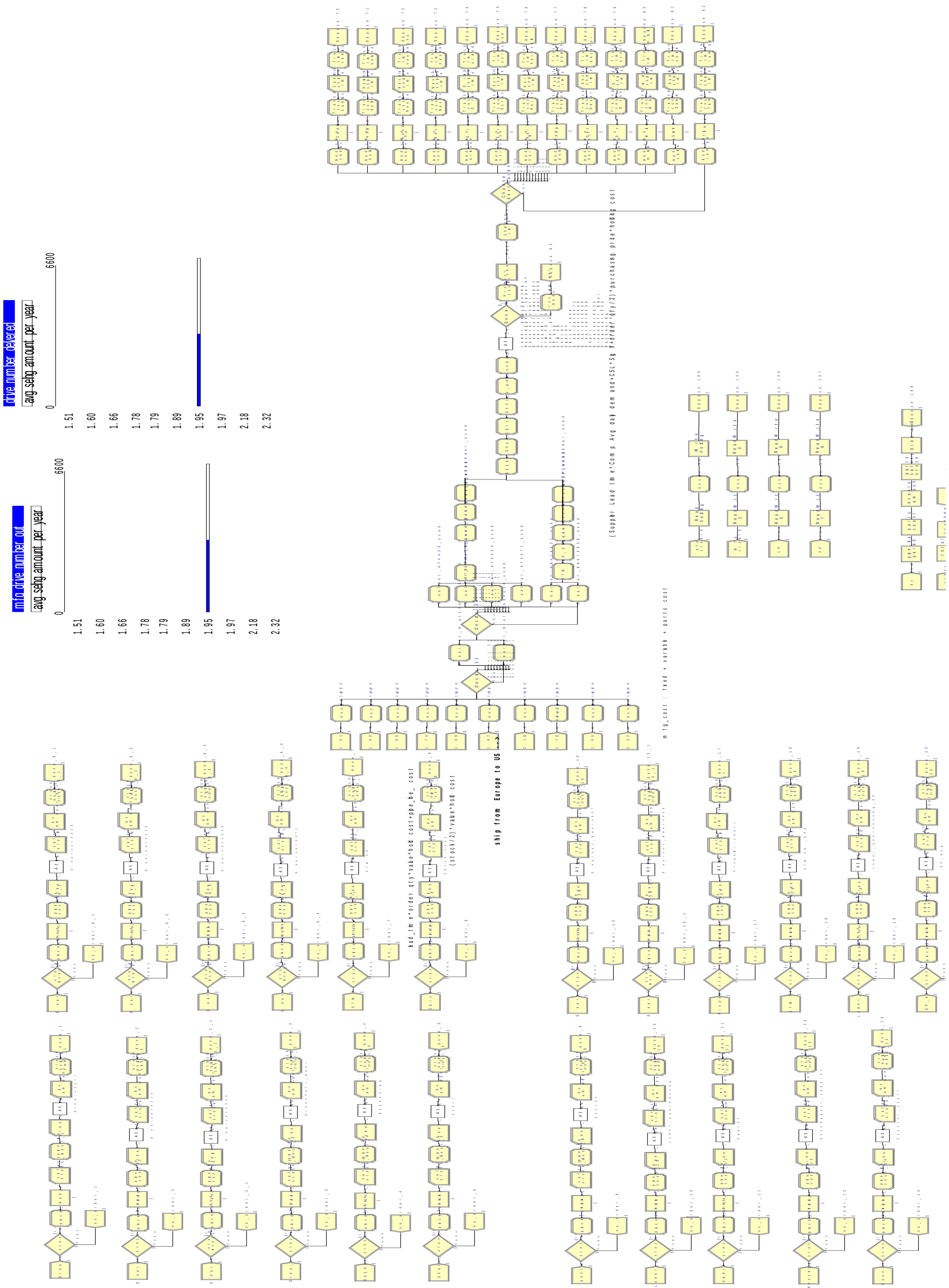
The model applied one lead time distribution while conducting lead time distribution case tests to check the effect of the certain distribution. In the real supply chain environment, the lead time distribution can be different in every phase of transportation (supplier lead time, transportation time from the factory to the warehouse and from the warehouse to the customer). The effect of lead time distribution can be examined by applying several different lead time distributions in one scenario. This can test the effect of a mixture of variable transportation uncertainty.

Future Research

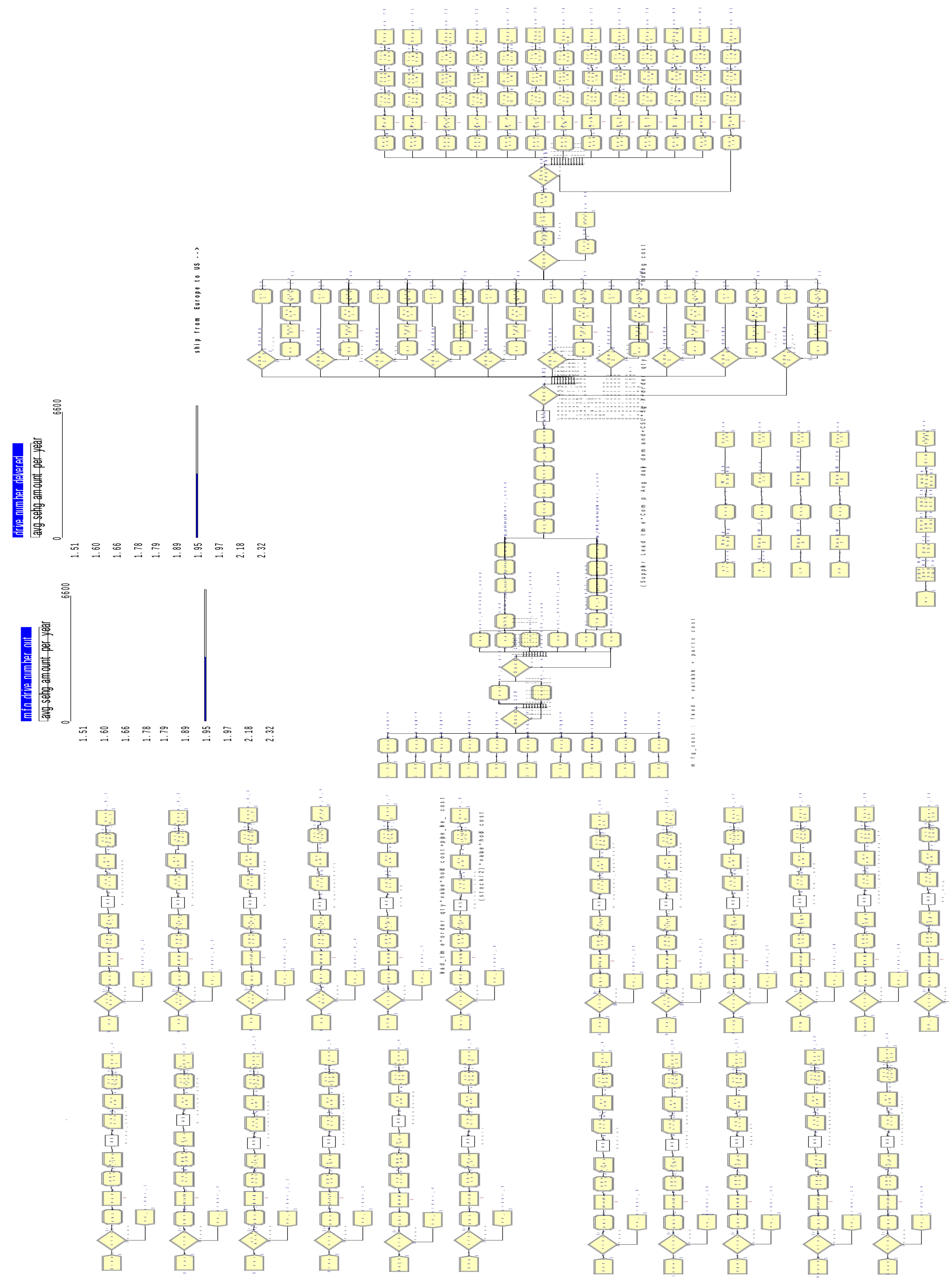
The simulation model can be improved by adding the cost of defective products during the manufacturing and by including return management cost. In the current model, all of the products manufactured in the factory have no defects and no product that is delivered downstream in the supply chain is returned upstream. The returned and defective product values that are embedded into the simulation model may provide more accurate cost analysis depend on postponement manufacturing strategies.

The study can achieve greater reliability by conducting research for various supply chain cases. This research implemented the transportation uncertainty factor as in the case of a company's example product which has a specific supply chain process. The effects of lead time distribution can be changed or limited depending on the portion of the transportation period within the whole supply chain. For that reason, the effect of transportation uncertainty can be generally recognized, by applying those lead time distributions to various supply chain processes.

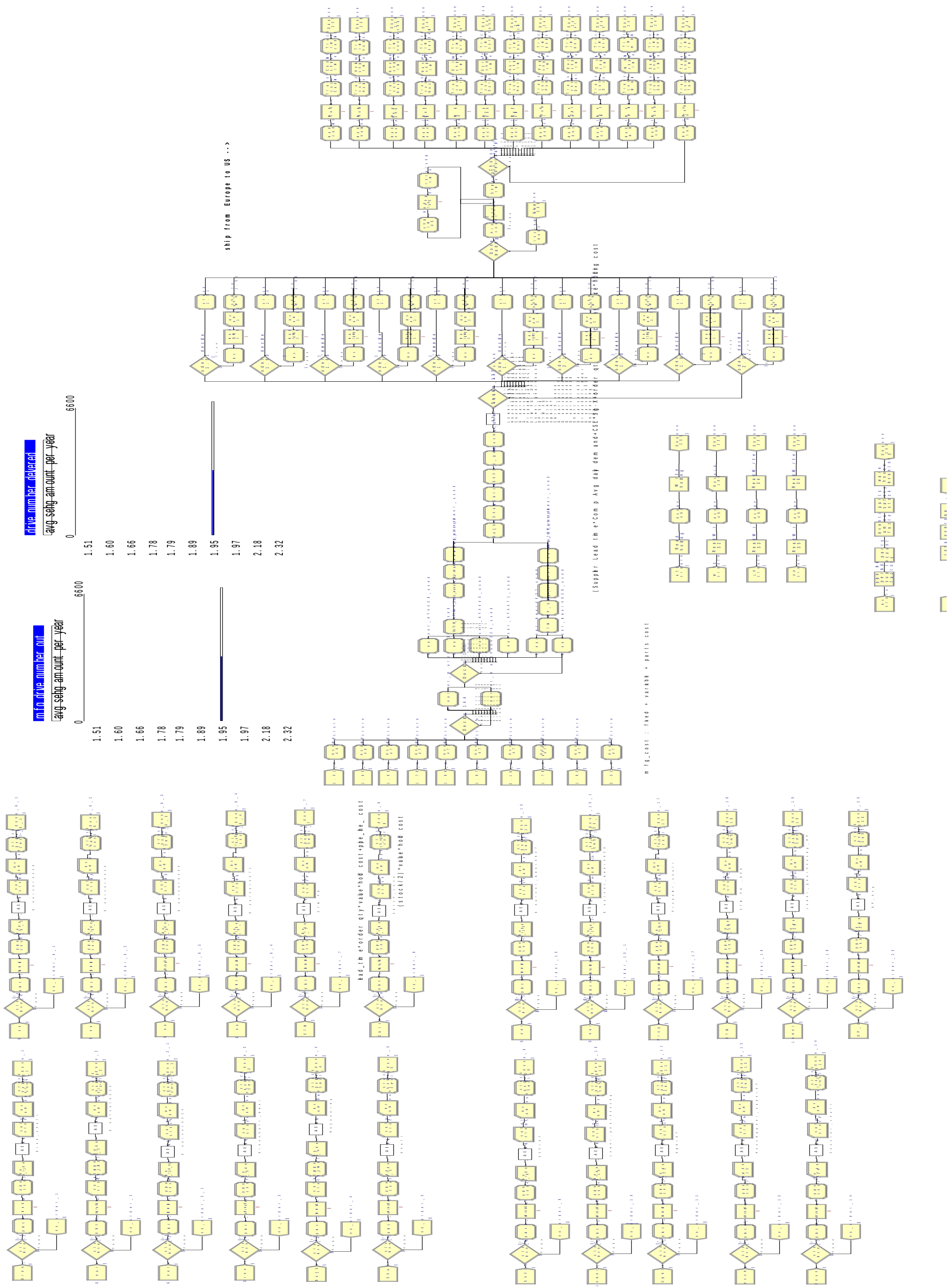
Appendix A. Manufacturing Postponement Model



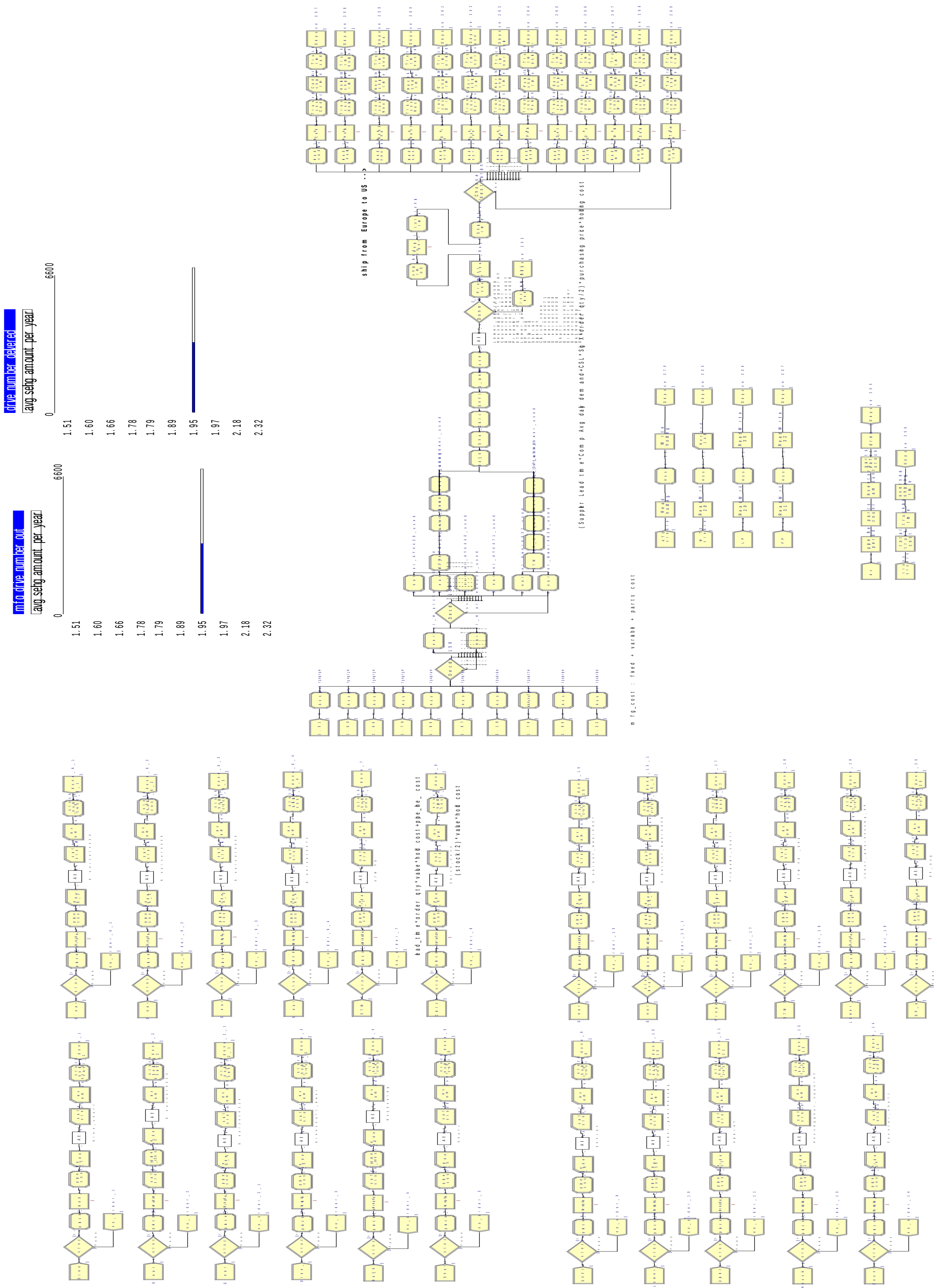
Appendix B. Full Speculation Model



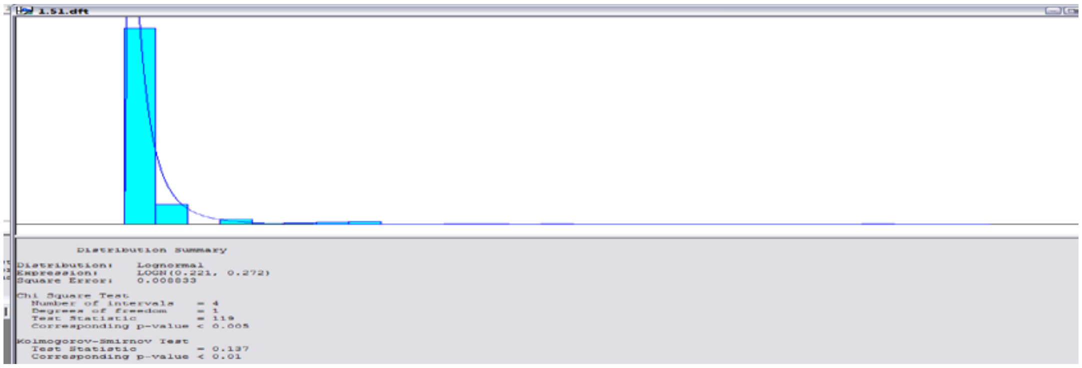
Appendix C. Logistics Postponement Model

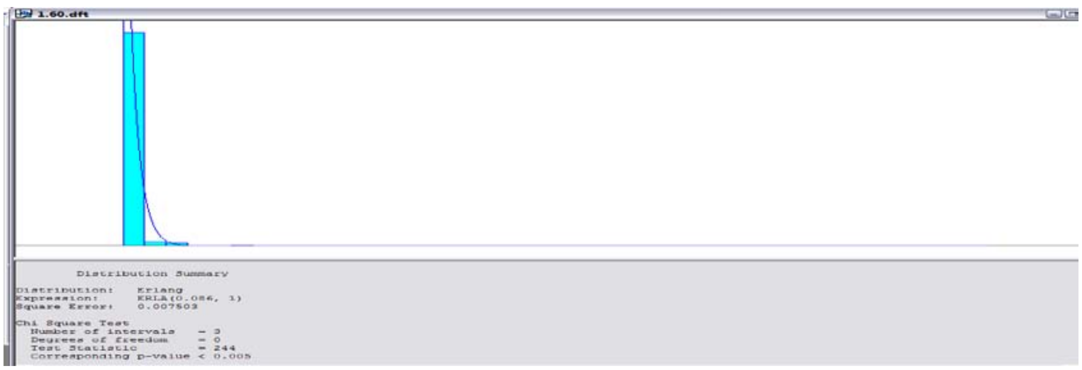


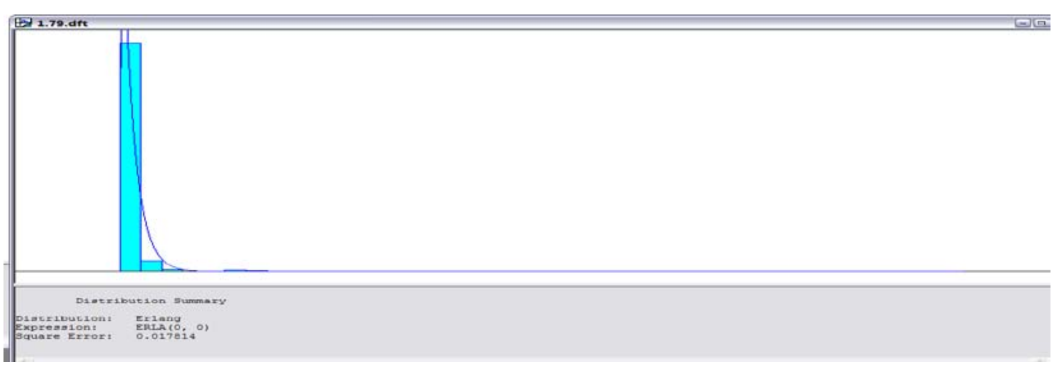
Appendix D. Full Postponement Model

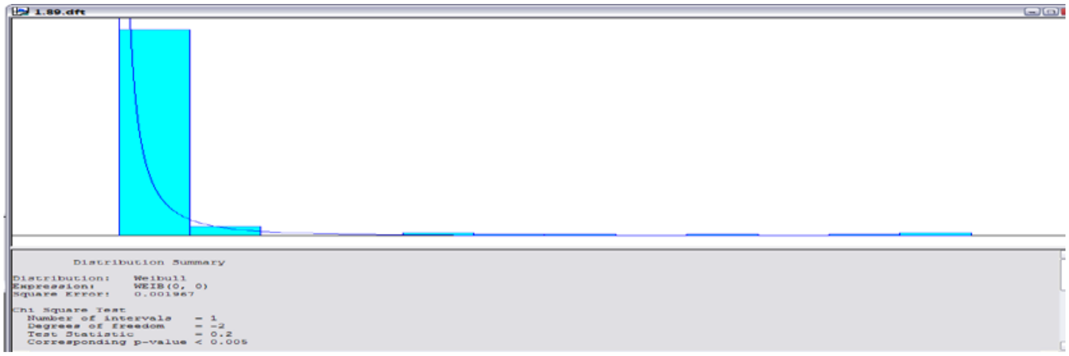


Appendix E. Demand Distribution








1.89.dft
Distribution Summary
Distribution: Weibull
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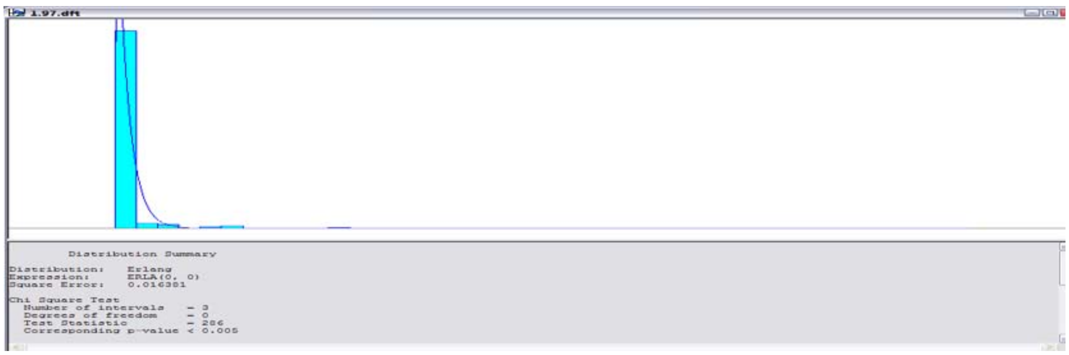
Square Error: 0.001967
Chi Square Test
Number of intervals = 1
Degrees of freedom = -2
Test Statistic = 0.2
Corresponding p-value < 0.005


1.97.dft
Distribution Summary
Distribution: Erlang
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Chi Square Test
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Degrees of freedom = 0
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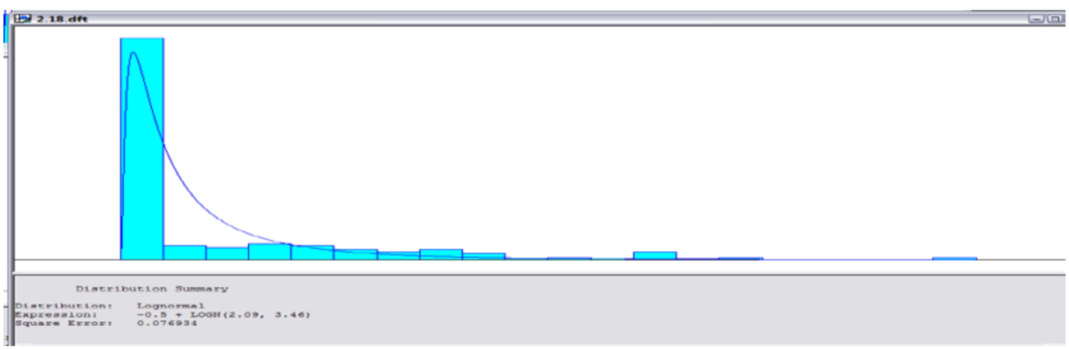
Corresponding p-value < 0.005


2.18.dft
Distribution Summary
Distribution: Lognormal
Expression: -0.5 + LOGN(2.09, 3.46)
Square Error: 0.076934


1.78.dft
Distribution Summary
Distribution: Weibull
Expression: WEIB(0, 0)
Square Error: 0.020047


1.95.dft
Distribution Summary
Distribution: Erlang
Expression: ERLA(0, 0)
Square Error: 0.012428
Chi Square Test
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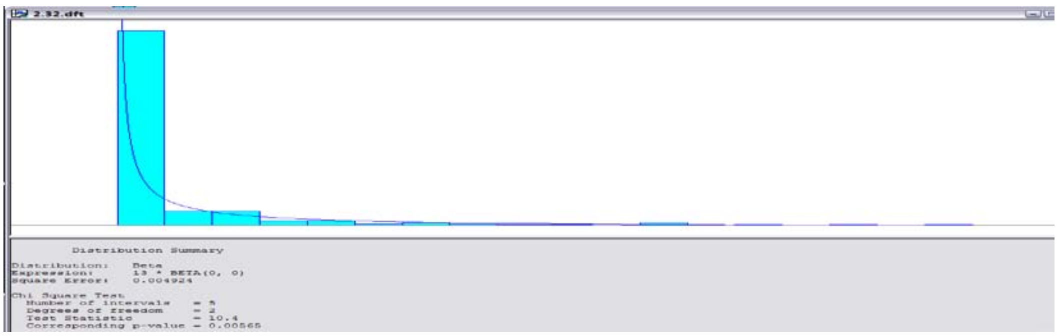
Degrees of freedom = 1
Test Statistic = 596
Corresponding p-value < 0.005


2.32.dft
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Chi Square Test
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Test Statistic = 10.4
Corresponding p-value = 0.00565

Appendix F. Blue Dart

Impact of Transportation Uncertainty on Supply Chain Strategy

Since the detailed empirical description appeared in 1960's, the postponement concept has been developed and researched by many entrepreneurs and researchers. The concept of postponement is attractive enough to change a company's supply chain system to try it. For a company, accurate demand forecasting is important to achieve a high customer satisfaction and to maximize profit. If demand forecasting is lower than actual demand, customer service suffers. Conversely, company profit decreases due to excess products when forecasted demand is higher than actual demand. Therefore, most companies try to predict demand as accurately as possible, but unfortunately no forecast is perfect.

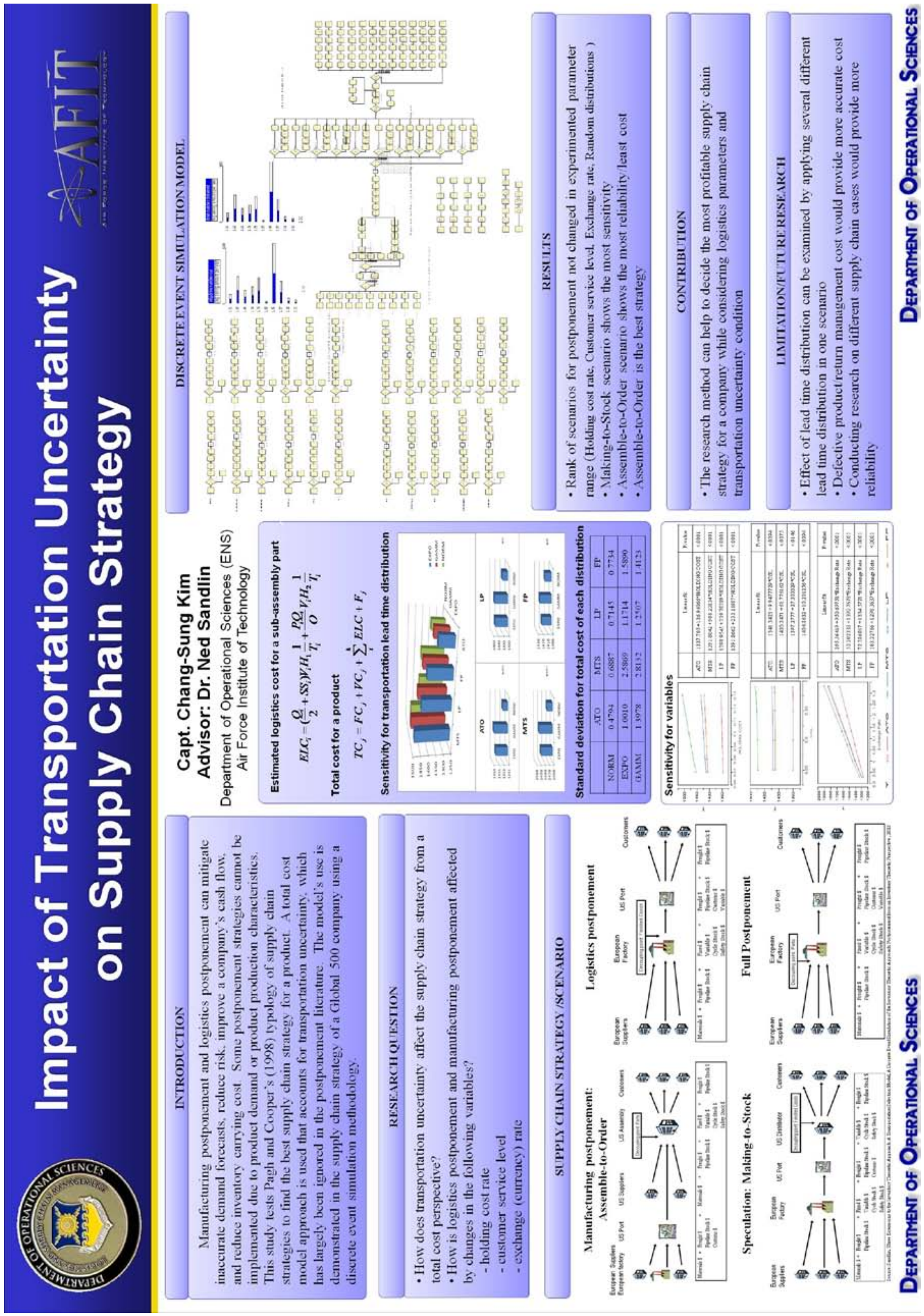
Business managers can mitigate problems created by inaccurate forecasting by using the right supply chain strategy. If they change their supply chain strategy from speculation to postponement, companies can meet customer demand with fewer shortages or surplus product. For instance, as studied by Waller in 2000, postponing the shipment of appliances to Sears until a customer order is received, allowed Whirlpool to realize a significant reduction in inventory and transportation cost. However, not every company can use this 'postponed' supply chain strategy because of the characteristics of the product or the company's manufacturing system. Some products must be on hand for customers to instantly get items when they need them. Some companies may have lead times which are prohibitively long. Finding the appropriate supply chain strategy for each product and company is important to increase the profitability of companies.

The technical breakthrough developed in manufacturing and logistics areas have made it possible to implement more efficient/beneficial postponement to both suppliers and customers. In this competitive business era, many global leading companies using the postponement strategy in their supply chain system. The postponement strategy is becoming the essential component for companies to be on the competitive position in the business area. As mentioned by Yang, the competition no longer takes place between individual businesses, but between supply chains. A company needs to find the best supply chain strategy for itself in the perspective of cost and customer service level to survive in the business.

The best supply chain strategy for a company can be found by comparing the total cost of a product in each possible supply chain strategy through discrete event simulation modeling method. While simulating the supply chain scenarios, there are several variable that need to be considered to get exact cost of a product in the changing economic environment. The holding cost, which is representing capital cost and insurance cost, is changing based on the market situation. A company's inventory level is changing depend on the company's goal of customer service level. The currency exchange rate, which is representing the currency rate difference between two countries, is changing every minute. The supply chain is affected by uncertainty of transportation, too. These variables in the supply chain would have some effect for a cost of a product that produced in each strategy.

The simulation research method found an effective supply chain strategy for a global 500 company in the framework of theoretical postponement supply chain strategy suggested by Pagh and Cooper in 1998. After run through various levels of statistical scrutiny under various model conditions, the variables that experimented in the research proved their effect on each supply chain strategy. The Holding cost rate, customer service level and currency exchange rate variables do not change the preferable supply chain strategy for the case company in the given experimental range, but showed the possibility of preferable strategy change if there is more change of extent in the variable. Transportation uncertainty, expressed with random distributions in the simulation model, shows significant difference of total cost for a product depend on random distributions but does not change the preferable strategy rank. Not only the case company but also the other manufacturing companies can find their best supply chain strategy while considering the logistics variables and transportation uncertainty by using the research method than conducted in this study.

Appendix G. Poster Chart



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Vita

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14. ABSTRACT A manufacturing company can postpone production and logistics process on its supply chain system. Delaying of manufacturing and logistics can eliminate burden of accurate forecasting of demand and reduce inventory carrying cost. Same postponement process cannot be implemented generally because every product has its own characteristic of demand and every company has its own characteristic of production environment. A company needs to find its best postponement strategy to minimize its cost of a product. This study applies Pagh and Cooper (1998)'s typology of supply chain process to find a best postponement strategy for an example company, one of the global 500 company which have factory both in Europe and U.S. Total cost of the example product may be affected by holding cost rate, customer service level, exchange rate, and transportation uncertainty while the product moves through each supply chain. This study will simulate the supply chain system and apply these factors in each postponement strategy. The simulated data will be used to analyze the effect of parameters and discuss the result.							
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