Logistic Postponement as a Risk Management Tool: A Real Options Valuation (ROV) Approach to Evaluate the Effectiveness of a Logistic Postponement Strategy in Mitigating the Demand Variability Risk in Global Supply Chains

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ABSTRACT

Logistic Postponement as a Risk Management Tool: A Real Options Valuation (ROV) Approach to Evaluate the Effectiveness of a Logistic Postponement Strategy in Mitigating the Demand Variability Risk in Global Supply Chains

Dylan MacDonald

Recent world events such as the coronavirus pandemic and the war in Ukraine have caused increases in supply chain disruptions along global supply chains. The resulting supply chain challenges necessitate an increased effort in improving supply chain risk management for companies around the world. One source of uncertainty that is increasingly difficult to deal with is demand variability. With both supply and demand becoming increasingly difficult to predict, companies need tools to manage demand variability. Our work evaluates a logistic postponement solution to demand variability where safety stock is shipped from an overseas supplier to a distribution center instead of being shipped directly to retailers. By taking advantage of risk pooling, the proposed strategy aims at reducing stockouts at retailers well also reducing the present value of total costs incurring along the supply chain. A real options valuation (ROV) approach is used in this thesis to present both a theoretical model and a computational model. The theoretical model aims to provide an approach for supply chain practitioners to compare the logistic postponement strategy to their current strategy using historical data. On the other hand, the computational model incorporates some simplifications in the theoretical model to avail it for simulation. Sensitivity analyses conducted aim to provide an analysis on the potential cost savings and stockout reductions a logistic postponement strategy can provide.

Keywords: Logistic postponement · Real Options Valuation · Supply Chain Risk Management · Demand Variability · Global Procurement · Stochastic Modelling ·Simulation ·Sensitivity Analyses

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Chapter 1: Introduction

In recent years, we have experienced wars, pandemics, and other disruption, resulting in a dire need for supply chain risk mitigation strategies. A study done by Wagner and Simon (2023), found through a survey of over 300 companies that due to the war in Ukraine and the Coronavirus pandemic, supply chains, in particular demand uncertainty, have been challenged and proved to be viewed as a top priority by 58% of companies surveyed. As such, when goods are shipped from overseas and orders need to be placed several weeks in advance, there is bound to be some sort of mismatch between supply and demand.

This is what ultimately inspired this thesis. A focus will be laid on the mitigating risk associated with demand variability by delaying the decision of the final stocking location of goods, through the usage of a logistic postponement strategy, as referenced below.

1.1 Postponement strategy

Supply chain operations such as manufacturing, procurement, and transportation are typically carried out in anticipation of customer orders. The decisions associated with these activities, such as determining how much of a product to produce or order, which products to produce or order, and where to stock these goods tend to rely on lower levels of uncertainty as we approach the point where demand becomes known. Therefore, it is advantageous to delay these decisions as much as possible to obtain more accurate forecasts and reduce costs. However, it is not feasible to postpone all decisions until the demand is known because this would result in long delays in filling customer orders which will result in lost sales and unhappy customers. Companies must therefore find the optimal trade off between delaying activities to improve forecasts and reducing lead times to customers.

The postponement strategy is used to help optimize this trade off. Since not all supply chain activities have the same level of uncertainty, the postponement strategy seeks to delay activities, or portions of an activity, with high levels of uncertainty until additional information, such as customer orders, are received and perform activities with lower levels of uncertainty in advance.

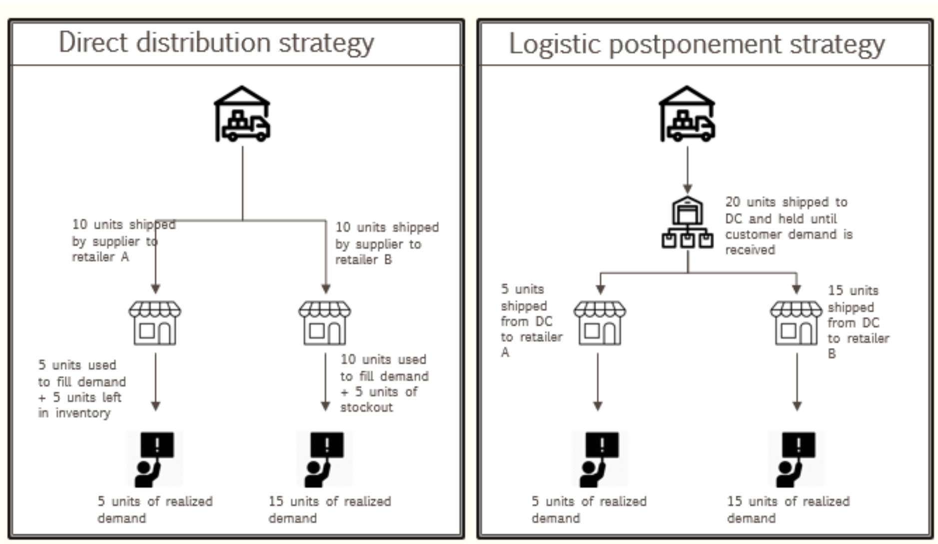
Carbonara and Pallegrino (2018), provide an example of Dell computers to help explain the postponement strategy. It is explained that Dell computers offers their customers with high levels of customization to the base model their computer, without requiring excessive wait times. This is done through a postponement strategy which works by building the base portion of the computer before customer orders are received and then customizing other aspects of the computer to customer preferences after customer orders are received. This is an example of manufacturing postponement where the final form of a product is delayed until customer orders are received. Although, this is the most common type of postponement in both research and real-world applications, there are several other types of postponement that vary based on the type of supply chain activity that is postponed.

1.2 Logistic postponement strategy

The focus of this thesis is on the logistic postponement strategy which refers to delaying the decision on the final stocking location of goods. The strategy works by shipping goods a portion of the way in anticipation of customer orders and then waiting for more demand information to be received before deciding on the final location to ship these goods.

This strategy is most commonly conducted using a distribution center to which suppliers ship goods for all retailers based on aggregate forecasts. The distribution center then waits until additional customer demand information is received before shipping the goods to retailers. The benefit of this strategy is that it allows for stock to be pooled among the retailers to decrease the risk of stockouts under varying demand by avoiding stoking goods in the wrong location. An example of this is shown in Figure 1 where one product is sourced by retailer A and retailer B who both have a forecasted demand of ten units and retailer A has a realized demand of five units and retailer B has a realized demand of fifteen units.

Figure 1 Logistic postponement inventory example:



As seen in Figure 1, under a direct distribution strategy with decentralized inventory Retailer A would have five additional units while retailer B would have a stockout of five units. However, under a logistic postponement's strategy an aggregated forecast of twenty units would be made and sent to the distribution center. Once the demand information became known a shipment of 5 units would be made to retailer A and a shipment of 15 units would be made to retailer B resulting in zero stockouts for retailer A and retailer B.

The most common way to mitigate the risk of demand variability is to carry safety stock. Since the cost of carrying additional stock is usually less than the cost of stockouts companies carry extra stock to prevent stockouts when demand peaks beyond their forecast. The logistic postponement strategy increases the benefits of holding safety stock as it allows this stock to be pooled among the different retailers and used as needed. For example, if there is one product sourced by retailer A and retailer B who both have a forecasted demand of ten units per period and carry an additional two units of safety stock. If retailer A had a demand of fifteen units in period one and ten units in period two and retailer B had a demand of ten units in period one and fifteen units in period two there would be a total stockout of six units over the two periods. However, if a logistic postponement strategy was used where the ten forecasted units and two units of safety stock for each retailer (a total of twenty-four units) were sent to the distribution center until demand for each retailer became known there would be a total stockout of only two units over the two periods.

Although, a logistic postponement strategy can be a very useful tool for mitigating demand variability and reducing stockout costs there are additional costs to consider before implementing a logistic postponement strategy. The first cost is the additional facility cost of building and running the distribution center. The second cost is the additional transportation cost of sending shipments from the supplier to the DC and from the DC to the retailers. This points to a need for supply chain practitioners to have a modeling technique to compare the costs of a proposed logistic postponement strategy to their current strategy.

1.3 Real options valuation (ROV) approach

To determine whether a logistic postponement strategy should be pursued from an expected total cost perspective we would need to determine how the costs of setting up this strategy, such as building a distribution center, compares to the monthly cost savings brought by the logistic postponement strategy. However, since the expected monthly costs are uncertain and depend on managerial decisions, such as when to send a shipment from the distribution center to the retailers, we need a modeling technique with the ability to evaluate an investment while incorporating managerial flexibility under uncertain conditions.

The real options valuation approach has been shown in past literature to incorporate managerial flexibility under uncertainty (Guthrie, 2013) (Costantino and Pellegrino, 2010) (Huchzermeier and Loch, 2001). The strategy comes from financial options, such as American call options which allows you to pay a premium for the right but not the obligation to buy a security at a given price for a specified period of time. The holder of this option then has the flexibility to exercise the option at any time before it expires if the option becomes profitable. Before buying a financial option, the buyer must determine if the cost paid to acquire the option is worth the expected future profit of the option. This resembles logistic postponement strategy where a premium needs to be paid at time zero to have the ability to exercise the option of shipping from the DC to the retailers when it proves profitable.

1.4 Purpose of this thesis

There are three main goals of this thesis. The first is to provide an overview on the current research which will be presented in section 2 of this thesis. The second is to provide a theoretical model that can be adapted and used by practitioners using their own historical data to decide if a distribution center should be built to pursue a logistic postponement strategy. This will be presented in section 3.4 of this thesis. The final goal of this thesis is to provide a computational model to compare the proposed logistic postponement strategy where safety stock for one product that is sourced from overseas is pooled among three retailers and shipped to a distribution center until customer demand becomes known to a base case where all three retailers hold safety stock independently from each other without the use of a distribution center.

Chapter 2: Literature Review

2.1 Introduction to literature review:

The literature review section will use a top-down approach starting broadly with a brief analysis on procurement risk management (PRM) in section 2.2, before proceeding to more specific concepts of PRM that will effectively set the stage for the focus of this research.
The analysis of PRM will start in subsection 2.2.1 where a definition for PRM will be provided. It will then proceed to subsection 2.2.2 where the main sources of procurement risk and the typical strategies used to mitigate these risks will be discussed. Finally, in subsection 2.2.3, a proposed outline for managing procurement risks will be presented.

After providing an overview of PRM this thesis will move onto evaluating a specific strategy used in procurement risk management: Postponement. Starting in subsection 2.3.1, postponement will be defined and the strategy as a whole will be discussed. Next, in subsection 2.3.2 the advantages and disadvantages of the postponement strategy as whole will be provided. Subsection 2.3.3 will focus on the various forms of postponement by providing a definition for these forms, presenting their advantages and disadvantages, and discussing situations where these strategies are favourable. The final two section will explore articles that are more specific to how postponement will be used in this article. Subsection 2.3.4 will look at past research done on logistic postponement and subsection 2.3.5 will look at past research done on postponement in a global setting.

The literature review will then move on to section 2.4 where the focus shifts to inventory policies and the optimization of the placement of safety stock. Specifically, this section will provide an overview of the current research on the optimizing the placement of inventory in the supply chain.

We will then move on section 2.5 which explores the method this thesis will use to evaluate the proposed logistic postponement strategy- real options valuation or ROV. Starting in subsection 2.5.1 a definition and brief description of ROV will be provided. We will then move on to subsection 2.3.2 where the advantages and disadvantages of the ROV strategy will be discussed.

Section 2.6 will then address the current research on how ROV is used to evaluate postponement. Since our research only found one article that uses a real options approach to evaluate postponement, we will give an overview of the methods used in this article and the relevant findings.

The literature review section will conclude in section 2.7 where the gaps in literature that provide the motivation for this research will be discussed.

2.2 An overview of procurement risk management

The overview of procurement risk management (or PRM) will rely on a literature review article on procurement risk management presented by Hong et al. (2018). This article does a good job of capturing the existing literature on the topic and provides us with a good starting point for our analysis.

2.2.1 What is procurement risk management?

Hong et al. (2018), provide the following definition for PRM: "PRM is the management of procurement risk through reducing the exposure and uncertainty in price, lead time and demand so as to ensure continue flow of supply (material, skills, capabilities, facilities) with minimum disruption". It is explained that procurement risk and risk in general are a growing concern in supply chain management as the uncertainty of occurrence of an event at one stage of the supply chain can have a significant negative effect on another stage of the supply chain.

2.2.2 Main Sources of procurement risk and how they are managed:

Hong et al. (2018) classified procurement risks into two broad categories: operational risks and disruption risks. Operational risks are caused by lack of coordination of supply chain activities among different parties in the supply chain. While disruption risks are caused by unexpected events such as natural disasters or political instability. The focus of this paper is on mitigating operational risks rather than mitigating disruption risks. Therefore, only operational risks will be explored in this section.

Hong et al. (2018), discuss four main sources of operational procurement risks: uncertain demand, uncertain price, uncertain yield, and uncertain lead time. The main approaches proposed in previous literature for mitigating each of these risk sources are then discussed.

Four strategies for handling demand risk are presented. The first approach is to frequently update demand information. When demand information, such as orders from customers, macroeconomic factors that could influence future demand of products, changes in customers future buying habits etc., change demand forecasts must be updated quickly to reflect these changes and improve the forecast. The second approach is to integrate sourcing and inventory decisions. This is done by collaborating with customers to create a production or procurement plan that fits the customers needs. This collaboration allows companies to better predict future customer orders thus allowing them to improve their demand forecast. The third approach is the use of a backup supply channel. The benefit of this approach is that when demand is realized the purchasing team has multiple ways to fill this demand thereby decreasing the chance of stockouts. The final approach is the use of financial products such as options or futures. A call option (glossary) is a useful way to mitigate demand risk by giving the buyer the right, but not the obligation, to execute the contract. Therefore, if the demand is realized the contract would be executed and if the demand is not realized the contract would not be exercised.

Hong et al. (2018), then move on to present three strategies for handling price risk. The first strategy is to integrate sourcing and inventory decisions. It is explained that procurement time and quantity affect the holding cost and inventory level. So, these factors should be considered simultaneously to minimize the total price of the inventory; this concept will be explored in more detail in section 2.4. The second strategy is the use of a flexible contract. This involves locking in a price for a quantity of products during a period of time instead of having to predetermine the exact time and quantity of an order, like in an inflexible contract. The third strategy suggested is again the use of financial instruments. Companies can hedge against price risk through the use of options and futures contracts. A call option for example is a great way to hedge against price risk as it allows the buyer the right but not the obligation to buy a predetermined amount of goods at a predetermined price. Therefore, if the market price is above the predetermined strike price the buyer can exercise their option by paying the predetermined strike price for the goods instead of having to pay the market price.

Two strategies are then discussed for managing uncertain yield (glossary). The first strategy is supplier diversification. By using multiple suppliers, buyers can source from a backup supplier if the goods are not available to be bought from their main supplier thus decreasing default risk. The second strategy discussed is collaboration with a supplier. This could involve investing to improve the supplier's operations. It could also involve sharing your demand information with your supplier, so they are better prepared to handle changes in demand. By investing in your suppliers, you are improving the likelihood that they will be able to fill your order which decreases yield uncertainty.

Hong et al. (2018), then presents three strategies for managing lead time uncertainty (glossary). The first strategy discussed is to improve demand forecasting. Studies have shown that as the demand forecast updating process becomes more efficient firms become less sensitive to lead time uncertainty. The second strategy proposed is a dynamic emergency response plan. This involves creating a plan for managing longer than expected lead times. The third strategy discussed is the use of safety stock (glossary) which involves holding excess stock that can be released when facing longer than expected lead times.

2.2.3 PRM strategies and modeling method:

Hong et al. (2018), propose an outline to be used by buyers to handle procurement risks. This outline is made up of four sections for buyers to use for their risk management strategy. The first section requires buyers to review their purchasing requirements, the second section requires buyers to identify procurement risks, the third section requires buyers to decide on risk management strategies, and the final section requires buyers to evaluate their risk management strategy.

As Hong et al. (2018) point out, in order to effectively decide on a risk management strategy and to properly evaluate the effectiveness of this strategy a review of the existing strategies is required. Buyers need access to information on the latest strategies and a way to evaluate whether these strategies fit their needs. We will now move on to looking at the current research on one strategy that can be used to manage risk: "Postponement."

2.3 Postponement and its various forms:

2.3.1 What is postponement?

Several articles have attempted to define and explain postponement. One explanation is that of Xiaoxun et al. (2016) who explained that postponement can be understood as a way to change the form, identity, or location of products at the latest possible point in time. The logic behind this delay is that it leads to the availability of more information, which can be used to reduce risk and uncertainty. As time passes, we get a better understanding of customer needs. This includes the customers demand, the location of the customer, the form the customer needs the product to be in etc. Therefore, the longer we can postpone the decision of where to store the products, how to customize the products, or the quantity of the products to be ordered the more likely we are to make decisions that correspond to our customers needs.

Following Xiaoxun et al. (2016)'s definition of postponement, under the postponement strategy all decisions would be made as late as possible. However, in general this is not what the concept of postponement is understood to be. As Carbonara et al. (2018) explain, postponement has come to be understood as an organizational concept where a portion of supply chain activities are delayed until precise customer order information is available. Most literature on postponement has followed this idea that not all supply chain activities need to be or should be postponed and the ones that are postponed don't need to be postponed to the latest possible point in time as suggested by Xioxun et al. (2016). Therefore, although Xioxun et al. (2016) provide a solid definition of postponement, our research suggests that postponement does not involve postponing supply chain activities as long as possible. This then presents two important considerations when implementing a postponement strategy: which supply chain activities should be postponed and how long should these activities be postponed?

To answer these two questions, the postponement strategy follows the logic that supply chain activities that are executed early on are associated with cheaper cost and/or shorter lead times while activities that are executed later on are associated with a reduction in risk and uncertainty. Therefore, supply chain activities that are associated with high levels of uncertainty should be postponed while supply chain activities that are associated with low levels of uncertainty should not be postponed. This presents what is known as a decoupling point where activities with low levels of uncertainty are positioned before the decoupling point (made early) and decisions with high levels of uncertainty are positioned after the decoupling point (made late). The decoupling point represents the point where more information is received by the company and usually occurs when customer order information becomes available.

A classic example that is often used to describe the concept of postponement is that of Dell computers. Dell assembles a portion of a computer before customer order information is received and then allows the customers to decide how the rest of the computer will be assembled. The decoupling point here is the customer's order. Dell is able to make the portion the computer that is standard across all (or most) models, and therefore has a low level of uncertainty, before the customer order information is available. It is then able to allow the customer to customize the computer based on their needs, for example the amount of storage or the size of the screen, and then finish the production of computer after these decisions have been made.

2.3.2 Advantages and disadvantages of postponement and when it should be used:

Before deciding which supply chain activities should be postponed and for how long these activities should be postponed, decision makers must first decide whether they should even implement the postponement strategy at all. By exploring the advantages and disadvantages of the postponement strategy decision makers are in a better position to decide whether the postponement strategy fits their needs.

Graman (2010), described two main benefits of the postponement strategy. The first benefit is the reduction of costs by pushing upstream inventory (glossary) to less costly stages of production. This benefit refers to activities performed before the decoupling point. An example of where this benefit could be realized is by producing a portion of a product overseas where production and labour costs are reduced. The second benefit discussed is improvements in customer service levels through reduced lead times and broad product offerings. The reduced lead times are a result of the decisions made before the decoupling point. Since a portion of the work is done beforehand, it leaves less work to be done when customer demand information becomes available thus reducing the lead time. The broad product offerings are a result of the decisions made after the decoupling point which allow for customizations to be made after customer information becomes available.

Graman et al. (2010), also pointed out two potential disadvantages of the postponement strategy. The first is that the marginal benefit diminishes as more of the product is postponed. This makes sense because as more activities are pushed beyond the decoupling point, less activities can benefit from the cost savings of pushing inventory to less costly stages of production. The second disadvantage discussed is that the strategy is only useful when some portion of the demand for a specific final configuration is known with certainty in advance. This disadvantage is particularly interesting as it not only suggests that postponing all activities is not necessary for postponement but actually suggests that postponement is only useful when not all activities are postponed.

2.3.3 Various forms of postponement and their advantages and disadvantages:

The postponement strategy can further be broken down into various forms depending on the supply chain activities that are being postponed. There are four commonly used and studied forms of postponement: logistic postponement, manufacturing postponement, purchasing postponement and product development postponement. This section will aid decision makers in deciding on the form(s) of postponement to implement in their postponement strategy by providing the advantages and disadvantages as well as a description of the most commonly used forms of postponement.

Logistic Postponement:

Although the research is limited, several researchers have provided explanations for the logistic postponement strategy. Yang et al. (2007) explain that logistic postponement seeks postponement opportunities in the movement of products to customers. It is further explained that unlike other forms of postponement, these products have already taken their final form in advance of customer orders. Pagh and Cooper (1998) also addressed logistic postponement. It is explained that the logistic postponement strategy involves performing manufacturing operations based on speculation and performing logistic operations based on postponement. It is further explained that logistic postponement usually involves direct distribution of fully finalized products from centralized inventory to final retailers/ customers. Following the description of postponement taken in this article, we can interpret “operations based on speculation” as operations performed before the decoupling point and “operations based on postponement” as operations performed after the decoupling point.

Past research has also explored the advantages and disadvantages of this strategy which can be used to determine when it should be used. Pagh and Cooper (1998) compared the logistic postponement strategy to what they referred to as the “full speculation strategy” which involves performing all supply chain activities before the decoupling point. Through this comparison, they found that logistic postponement tends to increase on-time deliveries of complete orders, provide shorter and more reliable lead times, reduce inventory costs, and provide a faster introduction of new products. Additionally, it is explained that centralized inventories reduce the amount of stock required to offer high-in stock availability. However, they also note that shiping costs may increase due to the smaller shipment sizes and faster modes required to ship products directly to customers only after customer order information has been received.

Yang et al. (2004) also addressed advantages and disadvantages of the logistic postponement strategy when focusing on postponement as a method for managing uncertainty. The first advantage mentioned is that logistic postponement reduces obsolete inventories (glossary) and improves customer responsiveness by avoiding the wrong time and place utility of products. Additionally, they point out that, due to the uncertain nature of customer demand, logistic postponement reduces the amount of inventory that needs to be stocked at various locations thus reducing inventory holding costs. This is done by stocking inventory at a central distribution center and shipping this inventory directly to their customers or retailers as demand becomes known. The main disadvantage noted, once again, is the significant increase in transportation costs that is associated with this strategy. Yang et al (2004) therefore suggest that logistic postponement is best suited for products that are more sensitive to inventory costs than transportation costs.

Manufacturing Postponement:

Manufacturing postponement is the most commonly used, and studied form of postponement. We will look at several descriptions of the strategy before moving on to its advantages and disadvantages. Yang et al. (2007) described manufacturing postponement as a strategy where semi-finished goods are kept and differentiated based on customer preferences. Pagh and Cooper (1998) described the manufacturing postponement strategy as a strategy where a portion of manufacturing operations are performed after customer order information is received, while logistic operations are performed in anticipation of customer orders.

Several advantages and disadvantages of this strategy have been noted in past research. Again, by comparing the manufacturing postponement strategy to what they referred to as "the full speculation strategy", Pagh and Cooper (1998) pointed out that this strategy allows for a reduction in the number of differentiated products held before customer order information is received, while still providing a full assortment of products. This results in a reduction of the total value of inventory and a simplification of the inventory planning and management. However, they also point out that manufacturing postponement results in an increase in the cost and complexity of customer order processing, a reduction in economies of scale for operations performed after the decoupling point, and a reliance on the coordination between the separate manufacturing stages.

When addressing manufacturing postponement as a tool for managing uncertainty, Yang et al. (2004) found that manufacturing postponement reduces the risk associated with holding finished goods inventory by producing generic semifinished products and retaining the generic status until information about customer preferences becomes available. This makes sense if we assume that forecasts are more accurate at the component level than at the finished product level which is a fair assumption since components can usually be differentiated into several different finished products. Additionally, retaining products in a generic status and waiting for customer information to become available before differentiating the product allows for a broader product offering as there is less risk associated with this differentiation. However, Yang et al. (2004) also points out that to implement manufacturing postponement certain levels of capacity and resources are required to be reserved for postponed manufacturing which results in increased cost. Additionally, by offering a wider selection of products the manufacturer will forgo the economies of scale associated with mass production of finished products which can result in increased production costs. It can also result in increased lead times as customers will have to wait for the customizations to be done before receiving their product. Yang et al. (2004) mention that manufacturing postponement should only be considered for attributes that can better be decided when exact customer demand information becomes available. This consideration becomes a trade off between the potential sacrifice the customer is willing to make in the form of increased lead times and increased production costs and the company's ability to produce individualized products within an acceptable time and cost frame.

Purchasing Postponement:

Another form of postponement is purchasing postponement which involves postponing the purchase of raw materials. As Xiaoxun and Jiajun (2016) explain, basic demand can be produced by relying on long term forecasts while product quantities for surge demands can be delayed until further information on market demand is available. This idea presents a differentiation point similar to that in manufacturing postponement. The raw materials required to serve the basic demand can be purchased in advance when customer demand information is still unknown (before the decoupling point) while raw materials required to serve the surge demand can be purchased after the customer demand information becomes available (after the decoupling point).

Xiaoxun and Jiajun (2016) point out that this strategy results in higher production costs but lower inventory holding costs. Therefore, they recommend using this strategy when demand is highly uncertain, raw material has high obsolescence cost (glossary) and represents a high percentage of the total production cost resulting either from the cost of the raw material themselves or the cost of the working capital required to convert the raw materials into finished goods.

Yang et al. (2004) looked at the advantages and disadvantages of this strategy for the supply chain as a whole. The main advantage found is that this strategy leads to raw materials or components spending more time in the supply chain as opposed to finished goods which leads to lower total inventory holding costs. There are two main reasons why raw materials are associated with lower inventory holding costs. The first is due to the shelf life of raw materials generally being greater than that of finished goods since raw materials are less prone to deterioration. The second reason is that raw materials generally have a lower obsolescence cost (glossary) than finished goods because they can be used to produce a wider range of products. The main disadvantage mentioned is that this strategy requires a high level of collaboration with suppliers and can result in simply shifting the risk to the supplier as they will need to have raw materials readily available to meet the short lead time required when the point of purchase is pushed close to the point where the products need to be manufactured. This leads to increased cost for suppliers and can increase the risk of stockouts or long lead times if the suppliers are not able to provide the raw materials or components in time. Yang et al. (2004) found that purchasing postponement is best suited for raw materials and components that are expensive and fragile and come in many shapes and sizes as these characteristics increase the holding cost and the cost of obsolescence.

Product development postponement:

The final form of postponement we will explore is product development postponement which is considered the most extreme form of postponement. As Xiaoxun and Jiajun (2016) explain product development postponement as postponing all activities of the value chain, including product design, until customer order information is received. As Yang et al. (2007) explain that this strategy involves no inventory until the customer order information is received. Since the customers are involved in the design of the product the company cannot hold any inventory in anticipation of customer orders, regardless of the form the inventory is held. The advantage of this approach is a reduction in uncertainty as the product is designed based on the customers needs. However, it can result in long lead times as the customer has to wait for the product to be designed and manufactured before receiving it and can result in high production and product design costs as the product is manufactured specifically to meet the customers needs and therefore cannot be mass produced. It also results in high obsolescence costs if the product is customized for a specific customer and does not fit the needs of other customers. Due to these high product costs this strategy is reserved for expensive products or products that the customer will be ordering repeatedly that would usually involve a contract between the manufacturer and the customer to avoid designing and producing the product for nothing if the customer doesn't follow through with an order after production is complete.

Yang et al. (2004) take a slightly different perspective on product development postponement where the product is designed in stages as customer preferences become known. This involves designing the portion of the product with low levels of uncertainty early on and the portion of the product with higher levels of uncertainty later on. This results in a reduction in lead times compared to the approach where the customer is involved in the entire design process as the portion of the product design with low levels of uncertainty can be designed and produced in advance. One form of product development postponement that Yang et al. (2004) have observed in practice is the "make a little, sell a little" strategy where a small quantity of products is produced to gauge the interest and preference of the market. The product is then adapted based on customer preferences before mass production of the product takes place. This strategy has the advantage of reducing the risk of designing and mass producing a product that does not meet customer needs but has the disadvantage of the additional costs of designing the product and testing the markets interest in the product before mass producing the product.

2.3.4 Previous research on logistic postponement:

Since the focus of this paper is on logistic postponement, we will now move on to address logistic postponement in more detail. Although the research is limited when compared to other forms of postponement, such as manufacturing postponement, several past researchers have addressed logistic postponement directly.

García-Dastugue and Lambert (2007), addressed logistic postponement through an optimization model which seeks to optimize the location of safety stock across the entire supply chain with the objective of minimizing the products lead time. They focused on minimizing the lead time for the entire supply chain by taking an interorganizational approach where each member of the supply chain took into account the effects their inventory decisions had on the entire supply chain. The logic behind their model is that for logistic postponement to work the upstream member of the supply chain (glossary) must hold safety stock in order to quickly move the products to the downstream member of the supply chain (glossary) when customer demand information becomes available. Following this logic, all members of the supply chain cannot postpone the decision of which products to hold in anticipation of customer orders without causing very long lead times for the product to move from the manufacturer to the final consumer. García-Dastugue and Lambert (2007) compared this approach to the approach where each member of the supply chain determined inventory levels based only on local information. Through this comparison they found that the strategy where safety stock is held by downstream members of the supply chain led to an overall reduction in lead time and supply chain costs. It was then concluded that the use of postponement needs to be a supply-chain-wide initiative focused on decreasing the lead time for the final customer and decreasing the total supply chain costs.

Bucklin (1965) also argued that not all members of the supply chain can postpone decisions to the latest possible moment without simply shifting risks to another member in the supply chain. This idea caused Bucklin (1965) to explore what they called the combined principle of postponement where inventory held in anticipation of customer orders will appear at each point in a distribution channel whenever its costs are less than the net savings to both the buyer and seller from postponement. This inventory, held as safety stock, allows downstream members of the supply chain to delay the decision of when to place their order and to what location they should place their order without drastically increasing the lead time for the final customer.

Lee and Whang (2001), take a different approach looking at logistic postponement from the perspective of direct shipments to customers through the use of e commerce. It is explained that if companies can replace the physical flow of products with information flows they can wait to ship products till they have more accurate order information. This strategy results in higher transportation costs and longer lead times. Two strategies that use the logic of logistic postponement are proposed to help reduce these long lead times. On strategy is called merge in transit and involves components being picked up at different locations and delivered straight to the customer without having to warehouse the products at a distribution center. The other strategy is called the rolling warehouse where quantities for individual delivery are not predetermined. The quantity delivered may change from the time the driver leaves the warehouse to the time the delivery is made based on based on updated customer demand information. This allows some customers to increase their order quantity and some to decrease their order quantity while the products are in transit.

Jafari et al. (2016) use a case study approach looking at the logistic processes of three large Swedish retailers: Jysk, Lidl and Media Markt. The goal was to dig into their logistic processes to understand how they apply the principle of postponement and to evaluate their flexibility in relation to applying postponement. Several important findings were mentioned with regards to how the retailers use logistic flexibility (glossary) to optimize processes and reduce uncertainty. One option that was seen as appealing for tackling uncertainty was to postpone the point of differentiation or to consider a base level of predictable demand for products and to postpone the production and distribution of the demand above the base level. One retailer, Lidl, was able to ensure high on-shelf availability of products through a logistic postponement strategy that involved central planning and forecasting. It was explained that the stock out rates for centrally planned forecasts are lower than when forecasts are made at each individual retailer. This makes sense as the variance of the forecasted demand can be evened out if one retailer provides a forecast that is higher than the actual realized demand while another retailer provides a forecast that is too low. Media Markt was also seen to use logistic postponement by holding bulkier items at the distribution center and pulling it to individual retailers when customer demand information becomes known. One main finding of this case study was that retailers with limited control over upstream activities saw logistic postponement as the prevalent type of postponement employed.

2.4 Global postponement:

When sourcing products from overseas the effects of postponement vary. This is specifically true when sourcing from a country where the cost to produce and hold inventory are significantly different than that of the home country. Past literature has looked at postponement on a global scale and presented some important findings that are relevant to our research.

Prataviera et al. (2020) looked to develop an original framework that conceptualizes postponement for global downstream supply chains. It is explained that there are two potential stems of research for postponement in global supply chains. The first focuses on the benefits of applying postponement in a global setting which come in the form of reduced holding costs and transportation costs. The second stem of literature focuses on the additional considerations that need to be made when applying postponement in a global setting. These additional considerations include custom duties and tariffs, trade barriers and cross-boarder trade processes, transfer prices and corporate tax rates, government regulations and local content requirements, different transportation modes, and the fluctuating costs of production factors. It is explained that when considering postponement on a global setting the consideration of where to perform supply chain activities needs to be taken into account. In a domestic setting postponement refers to when specific manufacturing and/or logistic operations are to be executed. However, in a global setting the place of manufacturing and/or the place in which the inventory is held also have a major impact on the company's overall performance. The decision on where to perform supply chain activities presents what is known as the postponement boundary problem. The postponement boundary problem can be defined as the issue of how to select operations to be performed within the international distribution network rather than in the centralized factories. When referring specifically to the distribution of finished products the "when" in the postponement boundary problem refers to the choice between logistic speculation and logistic postponement. Specifically, it refers to the decision of distributing end products before the customer order information becomes available (logistic speculation) or after the customer order information becomes available (logistic speculation).

Choi et al. (2012) addressed global postponement by addressing the allocation of production activities in a global supply chain based on differences in production costs, custom tariffs, transportation costs and required foreign capital investments in overseas facilities. The results of this simulation style study show that total costs with a strategy involving an earlier decoupling point are higher at the earlier stage of investment but significantly decrease as production expands. As the study looked at manufacturing products in developing countries where the manufacturing costs would be lower, this result makes sense as the total cost of investment in developing countries is relatively high at the initial stage when costs such as assembly line set up are high, but declines significantly when cheaper production costs, due to factors such as cheaper labour, materialize. Choi et al. (2012) also found that the choice of the optimal decoupling point and postponement timing have a significant effect in determining overall cost efficiency when national characteristics differ. The results of this study point to the importance of taking into account differences in national characteristics, such as the cost of labour, when deciding on a postponement strategy for global supply chains.

2.5 Inventory policies and safety stock placement optimization:

As seen through the analysis of logistic postponement and global postponement, the placement of inventory, and in particular the placement of safety stock, along the supply chain is crucial for the success of the logistic postponement strategy in a global setting. This section will go over past research on the topic of inventory policies and the optimization of the placement of safety stock.

Brunaud et al. (2019) provided a solid overview of the traditional inventory policies. The purpose of their research is to provide an overview on how inventory policies are used in practice, the parameters to consider in these policies and the shortcomings of these policies. Specifically, Brunaud et al. (2019) evaluate two commonly used inventory policies, the continuous review policy, and the periodic review policy, under uncertain demand. It is explained that the continuous review policy works by placing an order of Q units when inventory reaches a predetermined reorder point; while the periodic review policy by placing orders at predefined periods to bring inventory that is below the predetermined level back up to this predetermined level.

Brunaud et al. (2019)'s model also considers four safety stock formulations: (1) proportional to throughput, (2) proportional to throughput with risk pooling, (3) explicit risk pooling and (4) guaranteed service time. The "proportional to throughput" approach involves holding an amount of safety stock that is proportional to this item's throughput. The "proportional to throughput with risk pooling" approach builds off the "proportional to throughput" approach while taking into account the risk pooling effect where an unexpected increase in demand for one customer can be offset by an unexpected decrease in demand for another customer. Therefore, as throughput increases, and the likelihood of serving more customers increases, the proportion of safety stock relative to the throughput can decrease. This approach relies on the key assumption that the throughput level is related to the number of customers served. The "explicit risk pooling" approach does not rely on this assumption and instead looks at the throughput and the portion of standard deviation effecting each customer to determine the level of safety stock needed. The "guaranteed service time" approach assigns safety stock based on the guaranteed service time (glossary) by taking into account the lead time and the variation of demand.

A mixed integer linear programming model is used to model the inventory policies based on historical lead times. This model is then tested using a simulation approach with a target service level of 95%. Brunaud et al. (2019)'s simulation results favor the continuous review policy because continuously reviewing the inventory allows companies to react faster to changes in demand. With regards to safety stock optimization, Brunaud et al. (2019) found that the "proportional throughput" and the "piece wise linear with risk pooling" both gave good results; while the "explicit risk pooling" and "guaranteed service time" methods gave conservative solutions and took a long time to solve. It was therefore recommended to use either one of the first two methods with the "piecewise linear with risk pooling" approach being preferred when the risk pooling effect is specified.

Graves and Williams (2000) used a different approach to find the optimal placement of safety stock inventory in the supply chain: the minimum spanning tree approach. Their model seeks to minimize inventory holding costs while maintaining a guaranteed service level under uncertain demand with a predetermined upper bound. The multi period model was tested through a case study of Kodak company. Through the application of their model, Kodak optimized the placement of their safety stock inventory by creating a few strategic locations to hold safety stock inventory rather than spreading the safety stock across the entire supply chain.

2.6 Real options valuation:

In order for a company to employ a new strategy an initial capital investment is often required. To decide whether or not to employ this strategy the future benefits must be weighed against this initial capital investment. One approach that has been used in past literature to make this comparison is the real options valuation, or ROV, approach. ROV fits well with the focus of this research as it allows for managerial flexibility to be incorporated in the model. This section will provide an overview of ROV before discussing its benefits and showing how it has been used to model managerial flexibility in past research.

2.6.1 What is real options valuation?

As Carbonara and Pellegrino (2018) explain, the real option approach is based on financial call options which give the holder the right but not the obligation to by an asset at a predetermined price (known as the exercise price), in the future, whenever they prove valuable, by paying a predetermined cost (known as the option premium) to maintain such a right. The main difference in the ROV approach when compared to other approaches, such as the net present value approach or the cost-benefit analysis approach, is their ability to capture the value of projects/assets when further options exist, whose exercise is not certain and depends on the evolution of uncertainty. The value of these further options is incorporated in the ROV approach by taking into account the managerial flexibility of exercising these options or letting them expire if they do not provide additional value.

These real options can take various forms. When looking at valuing R and D projects under risk, Huchzermeier and Loch (2001) address six potential options managers can exercise based on future market information. The first option is to defer which refers to the possibility of waiting till more information becomes available before making a decision. The second option is to abandon which refers to the possibility to abandon a project that no longer seems profitable. The third is the expansion option which refers to the possibility oaf investment to expand the scale or scope of the project. The fourth option is the contraction option which refers to the possibility of reducing the scale or scope of the project. The fourth option is the switching option which refers to the possibility of changing the mode of operation (for example switching suppliers). The final option the improvement option refers to a midcourse operational improvement.

2.6.2 Advantages and disadvantages of the ROV approach:

The benefits of the ROV approach stem from its ability to incorporate managerial flexibility. Huchzermeier and Loch (2001) show the benefits of the ROV approach when compared to a simple net present value approach when looking at valuing R and D projects under risk. Huchzermeier and Loch (2001) found that NPV approach underestimates the value of a project, when compared to the ROV approach, by failing to incorporate managerial flexibility. Additionally, Huchzermeier and Loch (2001) show how the variability of various drivers of uncertainty can increase the value of managerial flexibility. The first driver addressed is market payoff variability which refers to variability of potential profits in the target market which are caused by changes in the market demand and the price consumers are willing to pay. The second driver addressed is budget variability which refers to the fact that the running development of the project costs of are not entirely foreseeable. The third driver is performance variability which refers the uncertainty in the performance of what is being developed. The fourth driver is market requirement variability which refers to uncertainty about the performance level required by the market. The final driver discussed is schedule variability which refers to the project finishing unpredictably ahead or behind schedule. Huchzermeier and Loch (2001) showed that for each driver discussed above, one or more of the options discussed in the previous section can be used to mitigate risks or capitalize on opportunities. Therefore, the value of managerial flexibility and the value of a model that incorporates managerial flexibility, like the ROV approach, increases as uncertainty increases.

Pellegrino et al. (2013) look at the ROV approach as method for addressing risk. It is explained that risk mitigation approaches can be deployed as various risks present themselves. Recall the various risk and risk mitigation approaches discussed in the 2.1 of this article. The real option approach allows these approaches to be deployed to a varying degree as risks and uncertainties present themselves and are gradually resolved.

Costantino and Pellegrino (2010), also note that the ROV approach has the advantage of capturing managerial flexibility. It is explained that traditional methods for evaluating the suitability of adopting a strategy are often unable to capture the management's ability to react to new market events. These traditional models are often based on discounted cash flows that rely on the limiting assumption that once the firm commits to a strategy or project the strategy's outcome will not be affected by future decisions of the firm. However, it is noted that, despite its potential of capturing managerial flexibility, the real option approach is not widely used in corporate decision making. Costantino and Pellegrino (2010), point to three reasons why current models for evaluating real options are not used in practice. The first reason is that these models are often difficult for managers or practitioners to understand. The second is the methods for these models often build on assumptions that are too "narrow" and do not reflect industrial practice. An example of a narrow assumption is that most traditional models assume that only one/two financial inputs are uncertain when in reality there are often many more uncertain inputs. Therefore, these narrow assumptions usually limit these models to evaluating only price uncertainty. The third reason is that these models are mathematically very complex. Which results in their application to the industrial context requiring a series of simplifying assumptions that limit the reliability of the results.

Consistent with other researchers, Guthrie (2013) also note the ability for ROV to value projects while recognizing the flexibility available to managers and allows managers to determine the best way to exercise this flexibility. However, Guthrie (2013) also points out two disadvantages of the ROV approach. The first is that real options analysis is often implemented using mathematical tools that are complex and unavailable to many managers and practitioners. The second is that many different approaches to valuing a project using ROV exist, and no single approach has become standard practice.

2.6.3 How has real options valuation been used to model managerial flexibility?

Past research has used the Real Options Valuation method to model managerial flexibility in both optimization and simulation models. Various approaches have been used in these studies. This section will give an overview of the approaches with the goal of helping managers decide which approach best fits their needs and capabilities. Specifically, we will look at how ROV was used in one simulation study and how it was used in one optimization study.

One approach for modeling managerial flexibility using ROV can be seen in Costantino and Pellegrino (2010)'s evaluation of the benefits created by the managerial flexibility of multiple sourcing to react to a supplier default. The main benefit of sourcing from multiple suppliers, from the perspective of minimizing default risk (glossary), is that if one supplier is not able to fill the buyers order the buyer can turn to another supplier to fill this order. Costantino and Pellegrino (2010) model this using ROV. It is explained that the flexibility granted by multiple sourcing is acquired at a "cost premium". This cost premium represents the additional costs of using a multiple sourcing strategy instead of a single sourcing strategy. In terms of real options, the cost of this flexibility is considered as the option premium while the cost switching the order to another supplier if needed is the exercise price. The value of the real option is evaluated using a Monte Carlo simulation (glossary). It is explained that the Monte Carlo simulation can account for the disadvantages of traditional models used to value real options. Costantino and Pellegrino (2010) mention two main advantages of using Monte Carlo simulation to value real options. The first is that the Monte Carlo simulation can typically consider several different uncertainty sources in evaluation and decision making. The second is that a probability distribution, resulting from managers' experience, is assigned to each uncertain variable input. When compared to traditional deterministic models the Monte Carlo simulation gives a more realistic probabilistic representation of the model outputs. Additionally, a probabilistic representation of outputs is less mathematically complex and easier for managers to understand.

Another approach would be that of Alvarez and Stenbacka (2007) who present an optimization model, using the real options approach, which can be used by managers to determine the optimal proportion of production to produce in house and the optimal proportion of production to outsource. The study assumes that a firm can only benefit from the cost savings associated with outsourcing by making an initial irreversible investment. This initial investment would be the cost implementing a system which makes it possible to design and monitor contracts with subcontractors. The decision whether to make this initial investment becomes a trade off between this initial investment and the marginal cost benefits of outsourcing production. In the ROV model the initial investment becomes the option premium while the benefits of outsourcing production make up the exercise price. These benefits are influenced by uncertain factors such as changes in market conditions that effect the marginal cost savings of outsourced product. Since the optimal proportion of production that should be outsourced is uncertain at future dates the ability to alter this proportion based on changes in market conditions becomes valuable. Alvarez and Stenbacka (2007)'s optimization model was able to capture this value through the use of a real options valuation approach.

2.7 Postponement and real options valuation:

Since the purpose of postponement is to allow for managerial flexibility in changing future decision when unknown information becomes know, to effectively evaluate postponement this flexibility needs to be addressed. As seen in our analysis of ROV its main advantage is its ability to incorporate managerial flexibility. Therefore, it would be a useful tool for managers to decide whether or not they should pursue a postponement strategy. However, there has been limited research providing ROV models to value postponement strategies. Our research only found one article that uses an ROV model to value the postponement strategy. The purpose of this section will be to give an overview on the methods used in this article and its findings.

Carbonara and Pallegrino (2018) used a ROV model to quantify the value associated to manufacturing postponement as a risk management strategy. Specifically, they looked at using postponement to capture the value of the managerial flexibility of differentiating a product when a disruption occurs. For the case of valuing the manufacturing postponement strategy through ROV, Carbonara and Pallegrino (2018) explain that there are two main decision that managers need to make. The first decision is whether they should pay the initial cost of making a product standard so they it can be differentiated if needed. This cost can be seen as the option premium. The second decision is whether they differentiate a product or not when a disruption occurs. This decision is based on the switching cost which represents the time and costs associated with differentiating a product which can be seen as the exercise price of the option. Similar to how financial call options should only be exercised if the stock price exceeds the exercise price; in this case the option to differentiate the product should only be exercised if the net benefits of created by this differentiation exceed the switching cost. Additionally, also like financial call options, the decision maker must also decide whether the option would have more value if it was exercised at a later date (postponed). Therefore, the option to differentiate the product should only be exercised if the associated payoff is maximized compared to projected payoffs of exercising the option at a later date.

Carbonara and Pallegrino (2018) used a Monte Carlo simulation approach to value the option described above. They explain that the Monte Carlo approach is suitable in dealing with complicated cases, like this one, as opposed to analytical methods that are applicable in limited cases. Several parameters are estimated based on probability, including the likelihood that a supplier defaults the likelihood that an alternative supplier is available, the likelihood that there would be demand for the postponed product etc. The simulation is then run many times to see whether manufacturing postponement would be a viable strategy to deal with disruptions. Additionally, a sensitivity analysis is conducted where changes are made to the probabilities of occurrence for the estimated parameters to see how they would affect the results.

Based on the results of the simulation and the sensitivity analysis two relevant findings were presented. The first is that the numerical experiments show the importance of incorporating an option valuation method when pricing the value of postponement. It is explained that this provides decision makers a method for valuating postponement allowing them to only implement postponement when it is valuable. This is important because it allows companies to avoid the initial sunk costs of the strategy if it does not prove to be valuable and allows companies to benefit from it if it proves to be valuable. The second finding is that postponement proves more valuable in risky contexts as it provides companies with a tool to manage disruptions. However, Carbonara and Pallegrino (2018) found that the value of the postponement strategy to manage supply chain disruptions depends not only on the probability of having a disruption, but also on the characteristics of the supply chain, specifically, the company's customers and suppliers.

2.8 Gaps in literature:

During our literature review, we found several relevant gaps in literature which became the basis of this research. This section will look at relevant gaps pointed out by past researchers while also pointing out the gaps found in our own analysis of the current research.

When addressing postponement strategies as a method for reducing supply chain risk, Xiaoxun and Jiajun (2016) pointed to two main gaps in literature that are relevant to this research. The first is that there is a need for empirical tools to value postponement. This gap was also seen in our literature review. We found that the majority of research articles published on the topic of postponement were theoretical articles and there seemed to be a lack of empirical models. The second gap in literature noted was a lack of research on the impact of supply chain structure and relationships of adopting different forms of postponement. Most research, in particular empirical research, focused on manufacturing postponement resulting in a lack of research focused on the other forms of postponement.

Our literature review also found a lack of research on postponement in a global setting. Specifically, Pratataviera et al (2020) noted that there is a lack of research on what is know as the postponement boundary problem and on the conceptualization of postponement strategies in a global context. We also noticed a lack of research, again particularly empirical, on logistic postponement in a global setting. Since a benefit of logistic postponement is the ability to benefit from cheaper production costs offered by third world countries overseas, we believe that this is an important gap to fill.

We also noticed a gap in literature in the use of ROV to value postponement. The managerial flexibility offered by postponement and ROV's ability to capture this flexibility makes it a useful tool for valuing postponement. However, we only found one article (Carbonara and Pallegrino, 2018) that used ROV to value a postponement strategy.

When addressing logistic postponement in general, we observed a gap in research in general and specifically a lack of research in providing an empirical tool to this end. Furthermore, we found a lack of recent articles on the topic of logistic postponement where most articles on the topic being published before 2010.

Chapter 3: Methodology

3.1 Introduction to methodology section

The methodology section of this thesis will begin by providing a description of the supply chain members, in subsection 3.2. The problem which will be evaluated using the proposed logistic postponement strategy, is presented, in subsection 3.3. Next, in subsection 3.4 a theoretical model will be presented. This theoretical model represents the ideal way of evaluating the proposed problem to see whether the proposed logistic postponement solution should be used to minimize the total expected costs. Then, in subsection 3.5, we will discuss the simplified computational model that is used in this thesis to evaluate the proposed logistic postponement. The computational model is used due to constraints in the modeling software that prohibits modeling of the theoretical model and requires a simplified version of this model. The results of this computational model will then be analysed in the section 4 under 'Results and Discussion'.

3.2 Description of the supply chain members

In our example, the supply chain consists of the following members: the central decision maker, three retailers, and the overseas supplier. The central decision maker has ownership over the retailers which grants them the right to decide on the quantity to supply to each retailer. However, the central decision maker does not have ownership over the overseas supplier.

3.3 Problem

Currently the same product is sourced from the overseas supplier to each of the retailers. The decision on the quantity of the product to order from the overseas supplier to each retailer is made by the central decision maker. This is done through a periodic review policy where orders are placed monthly to the overseas supplier.

A logistic postponement strategy is proposed with the objective of minimizing the total expected procurement costs. Using a real options valuation (ROV) model, we will determine whether a logistic postponement strategy should be pursued. This strategy involves shipping products from the overseas supplier to a distribution center (as a buffer) and shipping this stock to retailers as needed to avoid stockouts at the retailer.

The decision-making process associated with the logistic postponement strategy, can be characterized by two key decisions. The first is to implement or ignore the logistic postponement strategy. The cost of this decision can be seen as the cost of building the distribution center and keeping it stocked with the product to provide the flexibility of implementing the logistic postponement strategy. Once this flexibility has been granted, the second key decision is about implementing the postponement strategy. This decision is the decision of making a shipment to a retailer from the central DC to avoid stockout at this retailer.

3.4 Theoretical model

The theoretical model can be used by practitioners to evaluate the proposed logistic postponement strategy. The model described in this section serves as a good starting point for an example on how this evaluation should be conducted. However, the approach should be altered to reflect the companies' network. Practitioners should use historical data and their demand forecast to compare their current strategy to a logistic postponement strategy. They should also use historical data for the value of all the variables used such as prices and lead time. For simplicity we used average monthly demand as our forecast.

3.4.1 Description of the model

The model will consist of the base case which represents a continuation of the current operations where the supplier ships directly to each retailer and an alternative case which represents the logistic postponement strategy. The logistic postponement strategy will involve shipping a portion of the product to the central distribution center. The logic behind shipping a portion of goods to a central distribution center is that it allows the central decision maker to delay the decision of the final location of the product. This delay decreases the likelihood that the product will be stocked at the wrong retailer thus allowing for a more efficient use of inventory.

The base case and the proposed logistic postponement alternative will be modeled using Monte Carlo simulation. The proposed logistic postponement alternative will follow the ROV approach to take into account the managerial flexibility of the central decision maker to change the quantity shipped to each retailer. The results of the simulation will be analysed through sensitivity analysis. Based on this analysis, recommendations as to the strategy the central decision maker should implement will be proposed for each set of parameters used in the sensitivity analysis.

Both the base case and the logistic postponement alternative will be optimized with the objective of minimizing the expected value of the total discounted value of costs on a before-tax basis. This analysis seeks to focus on the effects of logistic postponement and real options valuation without over-complicating the analysis with tax rate considerations.

3.4.2 Model parameters and decision variables

Decision variables:

Figure 2 provides an overview of the decision variables and when they occur. Our simulation model will optimize these variables with the goal of minimizing the objective function. In our case, the objective function is cost minimization on a before tax basis. The model will seek to minimize the expected value of the present value of the total expected costs for each simulation run.

The first two decision variables are binary variables which represent the ROV decision-making process outlined in "The problem" section of this thesis:

Opt^1: decision to build the distribution center or not

Opt^2_{rt}: Decision to implement the logistic postponement strategy by sending a shipment from the central distribution center to one of the three retailers.

There are additional decision variables that will be optimized to minimize the expected value of discounted costs for each simulation run:

Q_{rt}: quantity shipped from the overseas supplier for retailer r in month t (r=1, 2, 3) (t=1,…,120).

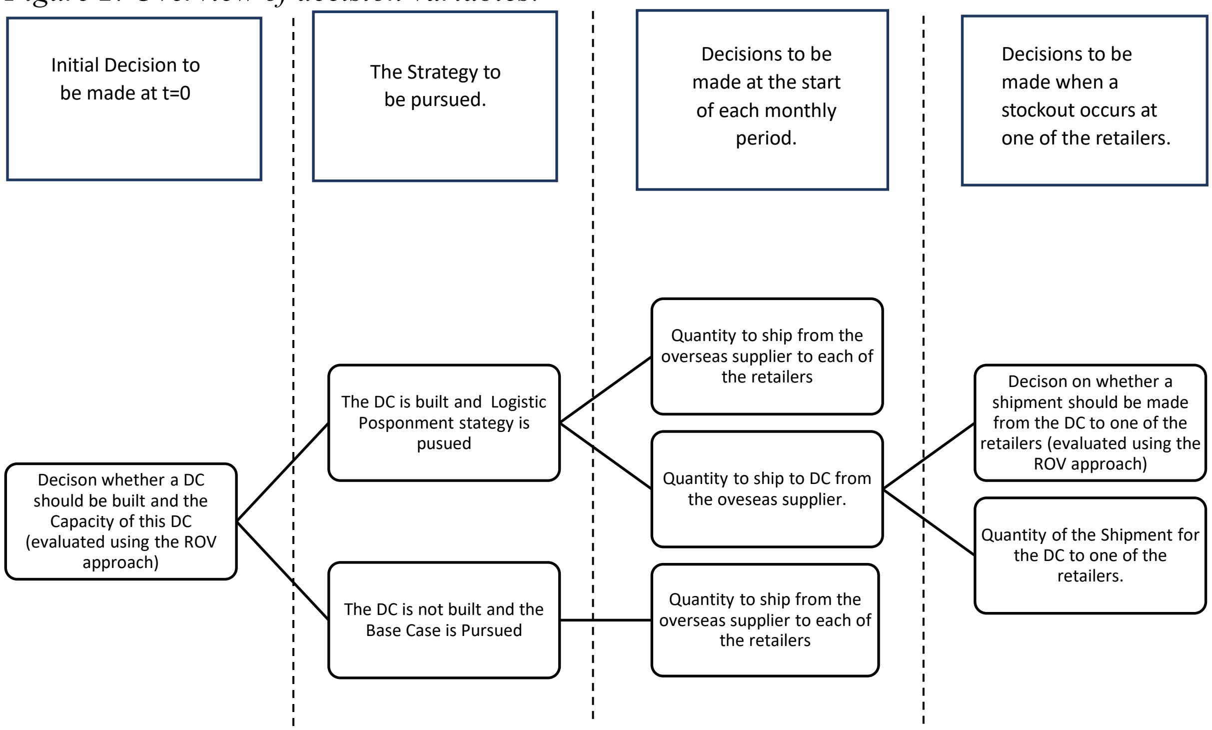
Only for the logistic postponement alternative

CDC: capacity of the distribution center

Q_{dt}: quantity ordered from the overseas supplier to the distribution center d in period t (t=1,…,120).

QSL_{rt}: quantity shipped from the distribution center to retailer r during period t (r=1, 2, 3) (t=1,…,120).

Figure 2: Overview of decision variables:



Parameters:

The optimal value for the decision variables defined above will depend on various model parameters. These parameters may be fixed, or they may follow a distribution over the long term. However, it is assumed that they are fixed for a given period and that their values do not depend on decisions made by the central decision maker.

The parameters have been classified under the following headings: demand, lead time, shipping costs, ordering costs, holding costs, cost of stockouts, cost of distribution center, discount rate, total costs, and ROV.

Demand:

D_t: aggregate realized demand for all three retailers in period t (t=1,…,120)

$\overline{D}$: mean of the aggregate monthly demand for all three retailers

d_{rt}: realized monthly demand for retailer r in period t (r=1, 2, 3) (t=1,…,120)

$\overline{d_r}$: mean monthly demand for the retailer r (r=1, 2, 3)

σ: standard deviation of the aggregate monthly demand for all three retailers

σ_{dr}: standard deviation of monthly demand for retailer r (r=1, 2, 3)

w: percentage of total demand for retailer r (r=1, 2, 3)

ρ_{12}: correlation between demand for retailer 1 and retailer 2

ρ_{13}: correlation between demand for retailer 1 and retailer 3

ρ_{23}: correlation between demand for retailer 2 and retailer 3

Lead time:

$\overline{LT}$: average lead time to ship from the overseas supplier.

σ_{LT}: standard deviation of lead time to ship from the overseas supplier.

Shipping costs:

OTC_{rt}: total overseas shipping cost incurred by retailer r in period t (r=1, 2, 3) (t=1,…,120)

OTC_{dt}: total overseas shipping cost incurred by distribution center d in period t (t=1,…,120)

LTC_{rt}: total local shipping cost incurred by retailer r in period t (r=1, 2, 3) (t=1,…,120)

$\overline{FOSC}$: mean fixed overseas shipping cost charged per order placed

σ_{FOSC}: standard deviation of the fixed overseas shipping cost charged per order placed

$FOSC_t$: realized fixed overseas shipping cost

FLSC: fixed local shipping cost

$\overline{VOSC}$: mean overseas variable shipping cost charged per unit ordered

σ_{VOSC}: standard deviation of the variable overseas shipping cost charged per unit ordered

$VOSC_t$: realized variable overseas shipping cost

VLSC: variable local shipping cost charged per unit ordered

LTC_{rt}: total local shipping cost incurred by retailer r in period t (r=1, 2, 3) (t=1,…,120)

$TOSC_t$: total expected overseas shipping cost incurred during period t (t=1,…,120)

Ordering costs:

UC: unit cost of the product

FORD: ordering cost charged by the overseas supplier for each order placed

$TORD_{rt}$: total ordering cost for the order placed by retailer r in period t (r=1, 2, 3) (t=1,…,120)

$VORD_{rt}$: variable ordering cost for the order placed by the retailer r in period t (r=1, 2, 3) (t=1,…,120)

$VORD_{dt}$: variable ordering cost for the order placed by the distribution center d in period t (t=1,…,120)

$TORD_{t}$: total expected overseas ordering cost incurred during period t (t=1,…,120)

Holding costs:

QA_{rt}= The quantity available (current inventory) at retailer r during period t (r=1, 2, 3) (t=1,…,120)

QA_{dt}= The quantity available (current inventory) at the distribution center during period t (t=1,…,120)

$AvgInv_{dt}$= The average inventory held at the distribution centre during period t (t=1,…,120)

$AvgInv_{dt}$= The average inventory held at retailer r (r= 1.2.3) during period t (t=1,…,120)

h_{r}: monthly holding cost per unit for retailers

h_{d}: monthly holding cost per unit for the central distribution center

HC_{r}: total expected holding cost incurred during period t at retailer r (r=1,2,3) (t=1,…,120)

HC_{t}: total expected holding cost incurred at the DC during period t (t=1,…,120)

HC_{t}: total expected holding cost incurred during period t (t=1,…,120)

Cost of stockouts:

$TSTK_{rt}$: total cost of stockouts at retailer r in period t (r=1, 2, 3) (t=1,…,120)

$TSTK_{t}$: total cost of stockouts in period t (t=1,…,120)

STK: per unit cost of a stockout

Cost of the distribution center:

SDC: one time cost of setting up the distribution center

FDC: fixed cost of setting up the distribution center

VDC: variable cost of setting up the distribution center

TCDC: total cost of the distribution center

Discount rate:

dr: monthly discount rate

Total Costs

TC_{rt}: total cost for retailer r in period t (r=1, 2, 3) (t=1,…,120)

TC_{dt}: total cost for the distribution center d in period t (t=1,…,120)

TDC: total discounted cost of the base case

TDC_{LP}: total discounted cost of the logistic postponement strategy

ROV options valuation parameters

OV^1: value provided by the logistic postponement strategy.

OV_{rt}^2: value provided by shipping goods from the distribution center to retailer r during period t (r=1, 2, 3) (t=1,…,120)

3.4.3 Base case model formulation

As explained above the base case will involve a continuation of the current operations where the product is supplied directly to the three retailers from the overseas supplier. This strategy involves a demand forecast to be made by the central decision maker for each of the retailers independently. Based on this demand forecast, an order will be placed for each retailer to the overseas supplier.

The cost of the base case will be measured by the sum of the discounted value of the costs incurred during each order cycle at each retailer. These costs include transportation costs from the overseas supplier to the retailers, fixed ordering cost charged by the overseas supplier for each order placed, cost of the product ordered, cost of holding the goods at the retailer, and opportunity cost resulting from stockouts.

Base case decisions:

For each period, the central decision maker must decide the quantity for order to each of the retailers.

Based on the quantity ordered, we can calculate the cost at each retailer (r) for during each period (t).

Shipping costs:

When deciding the quantity to order for each retailer the central decision maker must take into account the overseas transportation costs (OTC_{rt}). Since the procurement process follows a periodic review policy each period will incur an ordering cost for each retailer. The transportation cost for each retailer during each period (Equation 1) is simply the realized fixed overseas shipping cost ($FOSC_t$) plus the quantity ordered (Q_{rt}) for the period multiplied by the variable realized overseas shipping cost ($VOSC_t$). Both the fixed and variable overseas shipping costs follow a normal distribution and will therefore change each period but will be constant for all three retailers in each period respectively.

$$OTC_{rt} = FOSC_t + VOSC_t * Q_{rt} \qquad (1)$$

Ordering costs:

The next cost to consider when deciding on the quantity to order to each retailer during each period is the ordering cost ($TORD_{rt}$)**.** It consists of a fixed ordering cost ($FORD$) that is paid for each order placed to the overseas supplier as well as a variable ordering cost which is the cost of each unit ordered. Therefore, the ordering cost can be calculated using Equation 2.

$$TORD_{rt} = FORD + UC * Q_{rt} \qquad (2)$$

Holding costs:

Another important consideration when deciding the quantity to order is the holding cost. Each unit ordered incurs costs when stocked at one of the retailers. This cost is estimated as a fixed rate for every unit stocked at the retailer for each period. Therefore, to calculate the holding cost for period (t) at retailer (r) we must determine the average inventory held retailer during this period ($AvgInv_{rt}$). We can then simply multiply the average inventory held at the retailer for this period by our estimated per unit holding cost to get the total holding cost for retailer r during period t as given in Equation 3.

$$HC_{rt} = h_r * (AvgInv_{rt}) \qquad (3)$$

Stockouts costs:

The final cost that the central decision maker must consider when deciding on the quantity to order for each retailer is the cost of stockouts (STK_{rt}). For this study, this cost is kept simple as a fixed cost (STK) for each unit of demand that is not met by the retailer. This cost represents both the opportunity cost lost when demand is not filled, and the cost associated with weakened customer relationships resulting from the stockout. Based on this per unit cost we can calculate the total stockout cost at each retailer during each period by subtracting the quantity available from the quantity demanded. If this value is positive, we multiple it by the per unit cost of a stockout (STK) to get the total stockout cost. If the value is negative, it means that there were no stockouts for the period and therefore the stockout cost would simply be zero. The total stockout cost at each retailer is given by Equation 4.

$$STK_{rt}\text{= MAX }((d_{rt}\text{-}QA_{rt}))\text{ *(STK),0)} \qquad (4)$$

Total expected cost:

To determine the present value of the costs explained above it is important that we take into account when in each period cost are incurred. Since costs transportation costs and ordering costs are assumed to occur at the beginning of the period and stockout costs and holding costs are assumed to occur at the end of the period they must be discounted differently. Taking into account the difference in when various costs occur, we can calculate the net present value of the total costs incurred for the base case using Equation 6.

By using the cost formulas described above, we can calculate the total cost at each retailer for each period using Equation 5.

$$TDC_{BC} = \sum_r \sum_t \left(\frac{(OTC_{rt} + TORD)}{(1+dr)^t}\right) + \sum_r \sum_t \left(\frac{(HC_{rt} + STK_{rt})}{(1+dr)^t}\right) \quad (5)$$

3.4.4 Logistic postponement strategy model formulation

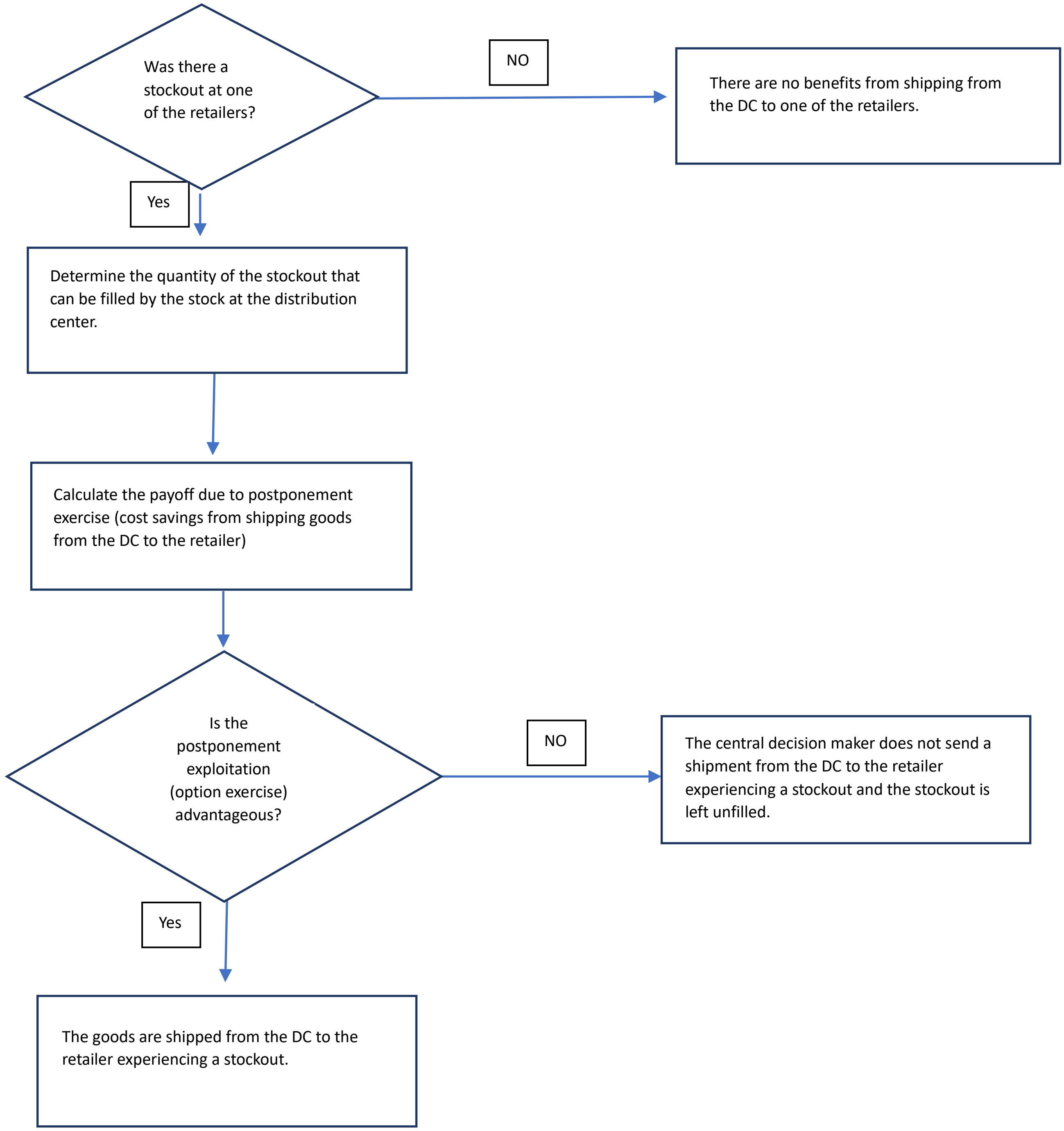
The ROV model for the decision to place an order for the DC each period:

Shipping goods from the overseas supplier to the distribution center allows for these goods to be shipped to the retailers from the distribution center later in the period with significantly reduced lead times. The benefit of the reduced lead times is that it allows for the decision on which retailer to ship these goods to be delayed until customer demand information becomes available. The stockout costs will be reduced by allowing these goods to be used to fill shortages at the retailers. However, since we are concerned with total costs rather than just stockout costs we will need to evaluate the difference in total costs if we allow for goods to be shipped from the DC to the retailers with the total costs if goods are shipped directly to the retailers.

The decision to exercise the logistic postponement option:

During each period the central decision maker should determine whether a shipment should be made from the central distribution center to each of the retailers. Figure 3 below shows the decision-making process used to determine if a shipment should be made from the central DC to each of the retailers.

Figure 3: Decision making process when a stockout occurs at one of the retailers.



Assuming that the distribution center has been built, each time there is a stockout at a retailer the option to exercise the logistic postponement must be evaluated. If there is no stockouts during the period, there is no value in exercising the logistic postponement option and the stockouts at the retailer(s) are left unfulfilled. However, in the event that a stockout occurred during the period the logistic postponement option must be evaluated.

The first step in evaluating the logistic postponement strategy is to determine the extend of the stockout. In a real-life scenario, the central decision maker would have to evaluate the extent of the stockout by projecting demand for the remainder of the period when a stockout occurs. However, this would complicate our model as we would have to look at demand on a daily basis rather than the approach used in this thesis which is to look at demand on a monthly basis. We will therefore rely on the simplifying assumption that retailer demand will be known with certainty halfway through each period. Therefore, the extent of a stockout will be known with certainty halfway through each period when the retailers demand is revealed. This assumption allows us to continue to look at costs at a monthly level and the extent of the stockout for each period would be the quantity available at the retailer less the quantity demanded. We can then allow the quantity shipped from the DC to each of the retailers to become decision variables that will be optimized by our model (QSL_{rt}). However, the quantity shipped from the DC to all three of the retailers in a given period would have to be less than the quantity available at the DC, as shown by Equation 6.

$$\sum_r QSL_{r=1,2,3t} \leq QA_{dt} \tag{6}$$

To determine if a shipment should be made from the DC to one of the retailers to fill a stockout, we must take into account the differences in cost occurrences between the stockout costs (which are assumed to occur at the end of the period), and the local transportation costs (which are assumed to occur halfway through the period). To did this we will multiply the local transportation cost incurred each period by discount rate to the power of 0.5, as shown by Equation 8.

$$LTC_{rt} = [(FLSC_t + VLSC_t) * \ QSL_{rt}] * (1 + dr)^{0.5} \tag{7}$$

We can then determine if the option is advantageous at each retailer during each period by adding a binary variable (Opt_{rt}^2) that will be 1 if a shipment is made to retailer ‘r’ in period ‘t’ and zero otherwise. Using this binary variable, the payoff of the option can be determined using Equation 8.

$$OV_{rt}^2 = Opt_{rt}^2 * (QSL_{rt} * (\mathrm{STK}) - LTC_{rt}) \tag{8}$$

The total option value payoff for all three retailers during a period Equation 9.

$$OV_t^2 = \sum_r (OV_{rt}^2) \tag{9}$$

Value of the logistic postponement strategy:

To calculate the value of the logistic postponement strategy, we must determine if the total discounted value of the postponement exploitation outweighs the additional costs of implementing this strategy. To do this we will calculate the total discounted costs if the logistic postponement strategy is pursued less the total discounted costs if the base case is pursued.

Shipping costs:

The first cost we consider is the transportation cost. When employing the logistic postponement strategy, the transportation cost is expected to increase in comparison to the base case. This is because the proposed logistic postponement strategy not only incurs transportation costs from the overseas supplier to each of the retailers but also from the overseas supplier to the distribution center and from the distribution center to each of the retailers.

The transportation cost of shipping the goods from the overseas supplier to each of the retailers is calculated the same way as in the base case as given by Equation 10.

$$OTC_{rt} = FOSC_t + VOSC_t * Q_{rt} \tag{10}$$

If the logistic postponement strategy is pursued, the cost of shipping goods from the overseas supplier to the DC will also need to be considered. This means an extra decision variable (Q_{dt}) will be added to represent the quantity ordered from the overseas supplier to the DC. The overseas transportation cost can then be calculated using Equation 11.

$$OTC_{dt} = FOSC_t + VOSC_t * Q_{dt} \tag{11}$$

The total overseas transportation cost incurred for each period is given by Equation 12.

$$OTC_t = \sum_r (OTC_{rt}) + OTC_{dt} \tag{12}$$

When the logistic postponement strategy is pursued transportation costs will be incurred when shipping goods from the DC to the retailers. However, since this has already been accounted for when evaluating the option value of exercising the logistic postponement strategy, this cost will not be considered here.

Ordering costs:

Next, we will consider the ordering cost. When the logistic postponement strategy is used, we need to consider the ordering costs of sourcing goods from the overseas supplier to the retailers and to the distribution center.

The ordering costs incurred when ordering goods from the overseas supplier to the retailers can be calculated the same way as in the base case as given in Equation 13.

$$TORD_{rt} = FORD + UC * Q_{rt} \tag{13}$$

Similarly, for the calculation of the transportation costs from the overseas supplier to the distribution center, the cost of shipping goods from the overseas supplier to the DC will also need to be considered for orders placed from the distribution center to the overseas supplier as given in Equation 14.

$$TORD_{dt} = FORD + UC * Q_{dt} \tag{14}$$

It is also important to note that in this study we will not take into account the ordering cost when an order is placed from one of the retailers to the distribution center. This is because the retailers and the central distribution center are all owned by the central decision maker. Therefore, the per unit ordering costs would have already been calculated when the order was placed from the central distribution center to the overseas supplier.

The total overseas ordering cost incurred for each period is given by Equation 15.

$$OTC_t = \sum_r (TORD_{rt}) + TORD_{dt} \tag{15}$$

Holding costs:

The next cost to consider is the holding cost. When calculating the option value, we must take into account both the holding costs associated with stocking goods at each of the three retailers and the holding costs associated with stocking goods at the distribution center.

The holding costs incurred at each of the three retailers can be calculated the same way as in the base case retailer using Equation 16.

$$HC_{rt} = h_r * (AvgInv_{rt}) \tag{16}$$

We do not have to consider the holding cost at the retailers for the goods shipped from the distribution center to the retailers because it is assumed that these goods will be used to fill stockouts and will therefore only be held at the retailers for a very short period of time.

A similar procedure can be followed when calculating the holding costs at the distribution center, as seen by Equation 17.

$$HC_{dt} = h_r * (AvgInv_{dt}) \tag{17}$$

The total holding cost incurred for each period is given by Equation 18.

$$HC_t = \sum_r (HC_{rt}) + HC_{dt} \tag{18}$$

Stockouts costs:

When calculating the option value for the proposed logistic postponement strategy the central decision maker must also consider stockout costs. The stockout costs at each retailer can be calculated using Equation 19.

$$STK_{rt} = \text{MAX } [(d_{rt} - QA_{rt}) * (\text{STK}), 0] \tag{19}$$

This formula is the same as that used in the base case and does not take into account the reduction of stockouts caused by goods shipped from the DC to the retailers. This is to avoid double counting because this reduction is taken into account in the calculation of the value of exercising the logistic postponement strategy.

The total stockout cost incurred for all three retailers each period is given by Equation 20.

$$STK_t = \sum_r (STK_{rt}) \tag{20}$$

Total cost of the logistic postponement strategy:

To find the total cost of the logistic postponement strategy we must add the discounted value of the total cost for each period with the cost of setting up the distribution center. The cost of setting up the distribution center (TCDC) has a fixed cost (FDC) and a variable cost (VDC) component. The variable cost component is dependent on the capacity of the distribution center (CDC) which is a decision variable that is left to be optimized by the model. The cost of setting up the distribution center is a one-time cost that occurs at t=0 and can be calculated using Equation 21.

$$TCDC = FDC + VDC * CDC \tag{21}$$

Next, we must look at the discounted value of total costs. Similar to as in the base case, costs occur at different point in a period and therefore must be discounted differently to account for these differences in cost occurrences. Again, transportation costs and ordering costs occur at the beginning of the period while holding costs and stockout costs occur at the end of the period. Taking this into account the total expected cost of the logistic postponement strategy can be calculated using Equation 22.

$$TDC_{LP} = \text{TCDC} + \sum_t \left(\frac{OTC_t + TORD_t}{(1+dr)^t}\right) + \sum_t \left(\frac{HC_t + HC_{dt} + (STK_t - OV_t^2)}{(1+dr)^{t+1}}\right) \quad (22)$$

The value of the logistic postponement strategy:

Following the ROV model, the central decision maker will only choose to implement the logistic postponement strategy if the discounted value of additional benefits provided by the strategy outweigh the discounted value of the additional costs of the strategy. The total discounted value of the logistic postponement strategy can be shown by Equation 23.

$$OV^1 = Opt^1 * (TDC_{BC} - TDC_{LP}) \quad (23)$$

Where Opt^1 is a binary variable that represents the central decision maker's decision to pursue the base case. If the total discounted cost of the logistic postponement strategy is less than that of the base case this will take the value of "1" and will otherwise take the value of "0".

3.5 Computational model:

3.5.1 Description of the computational model:

The purpose of this section is to provide a simplified computational model of the problem discuss in the previous section. The computational model will use the academic version of Arena software to model the logistic postponement strategy and the base case described in the previous section. However, due to constraints associated with the academic version of the Arena simulation software some simplifying assumptions are required. Two main assumptions are used in our Arena model to both simplify the understanding of the model and the results, as well as, to isolate the effect the proposed logistic postponement strategy has on mitigating demand uncertainty.

The first simplifying assumption our model will rely on is that prices will remain constant throughout the simulation period. Although this assumption is not realistic as transportation, holding cost etc. vary over time, it allows us to focus on the logistic postponement strategy's ability to handle uncertain demand at constant prices.

The second simplifying assumption our model will rely on is that the demand at each retailer is exponentially distributed with a fixed mean. This means that there is no growth or seasonality factors in our model. This assumption is used to simplify the model and to clarify the effects the logistic postponement strategy has on managing demand uncertainty.

The remainder of this section will be organized as follows. We will begin by presenting the inputs used in our model in subsection 3.5.2. Subsection 3.5.3 will discuss how the model is set up to run. Finally, subsection 3.5.4 will explain the equations used to evaluate the logistic postponement and base case models before presenting and analyzing the results in the section 4. A full description on how the model is set up in Arena can be found in the appendix section.

3.5.2 Inputs for the Arena model:

This section will focus on explaining the model inputs that were used in out computational example. The computational example consists of two Arena models one representing the base case and one representing the logistic postponement strategy. We will begin by discussing the demand distribution used at each retailer, which will stay constant for both the base case and the logistic postponement strategy. We will then move on to provide the model inputs for the static variables used in the logistic postponement strategy before concluding the subsection by showing which inputs change for the base case model.

Relying on our first simplifying assumption, the only variable factor in our model is the demand of the three retailers. It is assumed that each arrival at the retailer represents one unit of demand. The demand at each retailer is then represented by a exponential distribution that dictates the time between orders. Retailer A is assumed to have the highest demand with a mean time between arrivals of one day and a standard deviation of one and a half days. Retailer B has the lowest demand with a mean time between arrivals of five days and a standard deviation of three days. Retailer C is assumed to have a mean time between customer arrivals of three days and a standard deviation of four days.

Along with defining demand, there are several other static variables that need to be defined before running our Arena model. These input variables are defined in Table 1 below.

Table 1: Logistic postponement model inputs

Variable	Retailer A	Retailer B	Retailer C	DC
Backordering cost per day	$3	$3	$3	N/A
Holding Cost per day	$0.25	$0.25	$0.25	$0.25
Ordering Cost	$200	$200	$200	$200
Fixed Transportation Cost DC	$15	$15	$15	N/A
Variable transportation cost overseas	$25/unit	$25/unit	$25/unit	$25/unit
DC to retailer lead time	1 day	1 day	1 day	1 day
Supplier lead time	30 days	30 days	30 days	30 days
Max level	30 units	8 units	10 units	N/A
Reorder level	15 units	4 units	5 units	N/A
Reorder quantity DC	N/A	N/A	N/A	10
Reorder point DC	N/A	N/A	N/A	5
Critical Backorder Level	5 units backordered	5 units backordered	5 units backordered	N/A

The costs shown in the Table 1 were chosen arbitrarily and are assumed to be fixed throughout the duration of the simulation. The lead times are also assumed to be fixed with the lead time from the overseas supplier set at thirty days and the lead time from the DC set at one day. The DC is assumed to follow a continuous review policy with a reorder point of five units and a reorder quantity of ten units.

The remaining input variables are not chosen arbitrarily, relying on some logic to come up with their variables. The retailers are assumed to follow a periodic review policy where an order is placed every thirty days if the inventory the retailer has on hand is less than the predetermined reorder level. If an order is made the quantity of this order is assumed to be equal to the mean monthly demand of the retailer (as shown by the "Max level" in the table above). For the purpose of our simulation, the reorder level is assumed to be half of this Max level.

The final variable to be defined is the critical backorder level. This variable is used to represent the decision to send a shipment from the DC to fill a backorder at one of the retailers and its value represents the optimal trade off between transportation, holding and stockout costs. Since the costs are assumed to be fixed throughout the simulation this critical backorder level can also remain fixed. Given the costs shown in Table 1, the backorder level where the cost of sending a shipment from the DC outweighs the daily stockout costs plus the costs of holding goods at the DC is 5 units.

For the base case only two adjustments are to be made from the input variables shown in Table 1. The first adjustment is the removal of all variables related to the DC and the removal of the critical backorder level. The second adjustment is to add a 15% to the Max level at each retailer to represent a safety stock buffer as it is assumed in the base case that each retailer carries its own safety stock rather than polling safety stock at the DCs. Additionally, since the reorder level is assumed to be half of the max level for each retailer this value will also be adjusted. These adjustments are shown in Table 2 below.

Table 2: Base case inventory policy adjustments

Variable	Retailer A	Retailer B	Retailer C
Max Level	35 units	9 units	12 units
Reorder Level	18 units	5 units	6 units

3.5.3 Running the Arena model:

Both the logistic postponement and base case models are set up to run for ten years. It is assumed that the distribution center will last for ten years so this gives us the required time period to evaluate the logistic postponement strategy against the base case. This ten-year run period will be replicated for 100 simulation runs. At the end of each simulation run statistics will be captured from the model. The total cost and backorder statistics will be shown in the "Results and Discussion" section of this thesis. For a full breakdown of the statistics captured please refer to Appendix 2.

3.5.4 Equations used to evaluate the logistic postponement strategy:

To determine whether the logistic postponement strategy should be pursued instead of the base case, we must compare the discounted value of the estimated costs for both strategies. Relying on our first simplifying assumption, we can treat average monthly costs as payments and use an annuity formula to calculate the expected present value of costs for both the logistic postponement strategy and the base case. The annuity formula is given in Equation 24.

$$PV = PMT * \frac{1-\left(\frac{1}{(1+(r))^{n}}\right)}{(r)} \tag{24}$$

In the annuity formula above "PMT" represents the payments for each period, "r" represents the discount rate and "n" represents the number of periods in which payments will be made. Relying on our first simplifying assumption, we can treat average monthly costs as payments. We used the Canadian prime rate as of January 2023 of 6.7% as our discount rate. However, since this is an annual rate, and we are dealing with monthly costs we must divide this number by 12. Finally, since our simulation runs over ten years (or 120 months) we can use 120 as the number of periods in our annuity formula. Based on these inputs we can calculate the expected present value of future costs for both the base case and the logistic postponement strategy using Equation 25.

$$PVTotalCosts = AvgMonthlyCost_{LP} * \frac{1-\left(\frac{1}{\left(1+\left(\frac{0.067}{12}\right)\right)^{120}}\right)}{\left(\frac{0.067}{12}\right)} \tag{25}$$

Once the PV of monthly costs are computed, we can find the value of the logistic postponement strategy by taking the sum of the cost of building the DC and the present value of the total cost incurred using the logistic postponement strategy and then subtracting the value of the base case. If this value is positive, it would represent the additional costs of pursuing the logistic postponement strategy. If the value is negative, it would represent the cost savings of the logistic postponement strategy, as shown by Equation 26.

$$LPPremium = Cost\ of\ DC + PVTotalCost_{LP} - PVTotalCost_{BC} \tag{26}$$

Chapter 4: Results and discussion

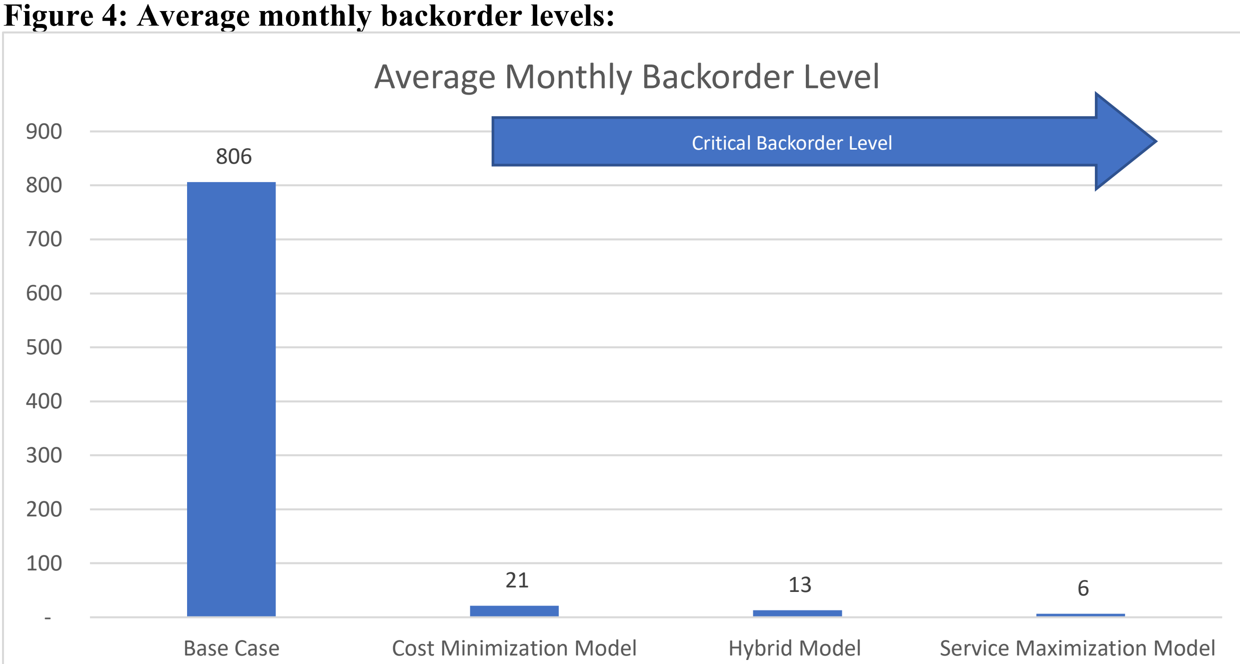
The results of the Arena models discussed in the methodology section of this thesis are presented here. Subsection 4.1 will address the service level provided by each model. Subsection 4.2 will provide brief discussion of the monthly costs obtained from the Arena models. Subsection 4.3 will compare the discounted present value of the base case against that of the logistic postponement strategies to explore which model should be pursued from a cost and service perspective. Finally, subsection 4.4 will provide a sensitivity analysis.

There are three logistic postponement strategies Evaluated using Arena simulation. These strategies vary only in the critical backorder used. The fist strategy is the cost minimization strategy where a shipment is sent only if the outbound shipping costs are less than the cost of not sending the order (the sum of the stockout and holding costs for the quantity backordered). The critical backorder level that represents the cost minimization model is 5 units. However, since higher service levels may be preferred to lower cost by some decision makers two additional models are presented. One of these models is the service maximization model where a shipment will be sent from the DC to a retailer experiencing a stockout regardless of the size of this stockout. The critical backorder level that represents this decision-making process is 1 unit. The final model is the hybrid model that seeks to capture the preference of decision makers who are willing to sacrifice some cost savings for improved service but also value lower costs. This model simply takes the average of the two critical backorder levels of, which is three units.

4.1 Comparison of the average monthly backorder quantity:

The goal of the logistic postponement strategy is decrease stockouts and costs by delaying the final decision of where goods should be stocked. The monthly backorder level provides a good proxy to determine whether the model is working as intended to decrease stockouts. Figure 4 presents the average monthly costs for the base case and the three logistic postponement models.

Figure 4: Average monthly backorder levels:



As seen in Figure 4, the base case has considerably higher monthly backorder levels than any of the logistic postponement models. This provides support for the logistic postponement strategy in that it is effectively reducing stockouts by delaying the decision on the final stocking location of goods.

As the critical backorder level decreases and shipments are made more frequently from the DC to the retailers, the monthly backorder levels, as expected, reduce significantly. This makes sense because when smaller more frequent shipments are sent from the DC to the retailers, backorders are filled quicker.

4.2 Comparison of monthly costs:

Table 3 provides a summary of the costs of the three logistic postponement models, described previously, and the base case. These costs include holding costs, stockout out costs, and transportation costs.

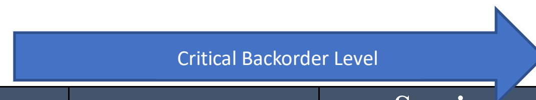


Table 3: Average monthly costs:

	Base Case	Cost Minimization Model	Hybrid Model	Service Maximization Model
Retailer A Cost	**$ 1,683.59**	**$ 451.09**	**$ 467.65**	**$ 537.28**
Retailer B Cost	**$ 515.13**	**$ 270.13**	**$ 276.21**	**$ 295.72**
Retailer C Cost	**$ 667.69**	**$ 291.64**	**$ 305.76**	**$ 337.13**
Retailer A Holding Cost	**$ 5.53**	**$ 211.44**	**$ 238.17**	**$ 320.34**
Retailer B Holding Cost	**$ 4.03**	**$ 66.77**	**$ 81.09**	**$ 104.93**
Retailer C Holding Cost	**$ 3.97**	**$ 83.35**	**$ 103.32**	**$ 138.45**
Retailer A stockout Cost	**$ 1,526.44**	**$ 38.15**	**$ 27.97**	**$ 15.78**
Retailer B Stockout Cost	**$ 365.61**	**$ 13.42**	**$ 5.18**	**$ 1.05**
Retailer C Stockout Cost	**$ 525.90**	**$ 11.71**	**$ 5.84**	**$ 2.32**
DC Cost	**$ 0**	**$ 396.52**	**$ 564.49**	**$ 1,615.50**
Transportation Cost from DC	**$ 0**	**$ 1.60**	**$ 2.75**	**$ 7.35**
Variable Transportation Cost overseas	**$ 1,259.99**	**$ 1,195.50**	**$ 1,190.84**	**$ 1,222.69**
Average Units Shipped from Overseas	**50.40**	**47.82**	**47.63**	**48.91**
Total Cost	**$ 4,126.39**	**$ 2,606.48**	**$ 2,807.70**	**$ 4,015.67**

One key difference between the base case and the logistic postponement strategies is that the costs at each of the retailers for the base case are significantly greater. The key driver for this is the number of backorders that occur during the base case. The reason for this is two-fold. Firstly, the amount of safety stock required to provide the same level of service decreases if retailers are able to combine safety stock through the DC. Secondly, since the DC is assumed to be very close to the retailers the logistic postponement models can become much more responsive to unexpected demand patterns.

Another indication that the DC provides more efficient utilization of safety stock is the average units shipped from the overseas supplier. We can see a minimal difference in the average units shipped from overseas for the base case and the three logistic postponement strategies. This means the the number of units entering the system each period is relatively constant. This result paired with the high stockout costs for the base provides support that the logistic postponement strategy helps avoid the wrong timing and wrong location of goods by delaying the decision on the final stocking location.

Another key difference between the base case and the logistic postponement models is the holding cost incurred. We see that under the base case the holding cost is very low and increases significantly under the three logistic postponement models. The explanation for this is that since backorder are carried over from one period to another, under the base case all stock is used to fill backorders from previous periods whereas under the logistic postponement strategies stock is carried over from low demand periods to higher demand periods.

When addressing the three logistic postponement models we see that total costs increase as the service level (represented by the average monthly backorder level) provided also increases. There are two reasons for this. The first is that the cost minimization model presents the optimal trade off between stockout costs and local transportation costs thus minimizing total retailer costs. The second reason is that since less shipments will be sent from the distribution center and the distribution center follows a periodic review policy, the DC will be stocked less frequently from the overseas supplier.

4.3 Comparison of the three strategies' present values:

From purely a cost perspective, the central decision maker would only choose to pursue a logistic postponement strategy if the present value of expected costs is less than that of the base case. If we assume that the cost of the distribution center is equal to $50,000, the present value of expected costs for all models can be calculated using Equation 25 from the methodology section of this thesis. Table 4 shows the present value of the total costs and the savings/premium of the logistic postponement models when compared to the base.

Table 4: Expected present value of total costs:

	Base Case	Cost Minimization Model	Hybrid Model	Service Maximization Model
PV of Monthly Costs	$360,169	$227,504	$245,068	$350,505
Cost of DC	$0	$50, 000	$50, 000	$50, 000
PV of Total Costs	$360,169	$277,504	$295,068	$400,505
Premium	NA	NA	NA	$ 40, 336
Cost Savings	NA	$ 82, 665	$ 65, 101	NA

As seen in Table 4 the cost minimization model represents a present value of total cost savings of $82, 665 and the hybrid model represents a cost savings of $65,101, when compared to the base case. Since both models provide both and service reductions (represented by the avg. monthly backorder level) compared to the base case, the DC would be built to pursue one of the three logistic postponement models.

When examining the service maximization model, we see a cost premium of $40,336. In this case the decision to pursue the logistic postponement strategy would depend on whether the central decision maker is willing to incur the additional cost in order to increase the service level.

When examining the results as a whole, it is clear that, given the model inputs, the logistic postponement strategy is more favourable than the base case. However, the decision on which logistic postponement model should be pursued would depend on the central decision makers preference towards either cost minimization, service maximization, or a trade-off in the form of a hybrid model.

4.4 Sensitivity analysis:

Sensitivity analysis was performed to test the robustness of the results found. Eight such analyses were performed testing the effect that changes in stockout cost and transportation costs had on the cost savings that the cost minimization model had in comparison to the base case (LP cost savings). The variables used in all eight analyses can be found in the Appendix 2 of this thesis. These sensitivity analyses included singles factor analysis which looked at the transportation and stockout costs independently as well as two factor analysis to see if there were any interaction between the two costs. To isolate the effect the stockout and transportation costs had on the model, the critical backorder level was kept constant at 5 units for all sensitivity analyses. Table 5 provides a breakdown of the variables impacted by each sensitivity analysis.

Table 5: Variables impacted by each sensitivity analysis:

Sensitivity	Backordering Cost Per Day	Fixed DC Transportation Cost	Ordering Cost
S1. Stockout cost increase	$3.60	$15	$200
S2. Stockout cost decrease	$2.40	$15	$200
S3. Transportation cost increase	$3.00	$18	$240
S4. Transportation cost decrease	$3.00	$12	$160
S5. Stockout increase + TC increase	$3.60	$18	$240
S6. Stockout increase + TC decrease	$3.60	$12	$160
S7. Stockout decrease + TC increase	$2.40	$18	$240
S8. Stockout decrease + TC decrease	$2.40	$12	$160

As seen in Table 5, each sensitivity analyses either decreases or increases the transportation cost, stockout cost or combination of the two by 20%. To represent an increase or decrease in stockout costs the average daily backordering cost is altered in the Arena model and to represent an increase or decrease in transportation costs
both the cost of ordering from the overseas supplier and the cost of shipping from the DC to the retailers are altered. After altering the variables for each sensitivity as shown in table 5, both the base case and the cost minimization logistic postponement arena models are re-run for 100 replications.

Table 6 shows the results of these simulation runs. The average of the cost savings of the cost minimization logistic postponement model compared to the base case is shown in column one of the Table 6. This is calculated by subtracting the present value of total costs of the cost minimization logistic postponement model from that of the base case for each replication and finding the average. The second column shows the difference from the control (where no changes are made to any input variables). This is calculated by subtracting the average LP cost savings from the cost savings of the sensitivity.

Table 6: Results of the sensitivity analysis:

Sensitivity	Avg. LP Cost Savings	Difference from control
Control	$82, 664.75	NA
S1. Stockout Cost Increase	$123,770	$41,105
S2. Stockout Cost Decrease	$41,560	-$41,105
S3. Transportation Cost Increase	$79,599	-$3,066
S4. Transportation Cost Decrease	$85,730	$3,066
S5. Stockout Increase + TC Increase	$120,703	$38,039
S6. Stockout Increase + TC Decrease	$126,836	$44,171.38
S7. Stockout Decrease + TC Increase	$38,493	-$44,171
S8. Stockout Decrease + TC Decrease	$44,626	-$38,039

The first main takeaway from the sensitivity analysis is that there is a strong positive correlation between stockout costs and LP cost savings. If we look at sensitivity 1 (where stockout out costs were increased by 20%) we see a $41,105 increase in LP cost savings compared to the control case. Similarly, it we look at S2 (where stockout costs were decreased by 20%) we see a -$41,105 decrease in LP cost savings. Also, for both of these sensitivities, we see large enough F-values to reject the null hypothesis that there is no significant difference between the sensitivities and the control with 95% confidence. These results show that there is a significant positive correlation between stockout cost increases and LP cost savings which is in line with expectations.

The second main takeaway is that there is a minor negative correlation between transportation cost increases and LP cost savings. If we look at S3 (where transportation costs were increased by 20%) we see a slight decrease in LP cost savings when compared to the control case. Similarly, if we look at S3(where transportation costs were decreased by 20%) we see a slight increase in LP cost savings. However, if we look at the F-values for each of these sensitivities, we see that the null hypothesis that there is no difference between the control and the sensitivities cannot be rejected with 95 % confidence. These results show that although there may be a slight negative correlation between transportation costs and LP cost savings, transportation cost does not have a large impact on LP cost savings.

The third main takeaway is that changes in stockout costs and transportation costs do not affect flows quantities shipped in the model. We see that the average LP cost savings vary equally from the control case for S1 and S2 as well as for S3 and S4. This implies that the difference in cost savings only affects the costing of goods flowing throughout the model and not the actual flows. Hence, compared to transportation costs, stockout costs account for a larger portion of the difference between the cost of the logistic postponement strategy and the cost of the base case.

The final takeaway is that there is no interaction between stockout and transportation costs. If we look at S5-S8, we see that the difference of the LP cost savings from the control case is simply the sum of the difference of the two corresponding single factor sensitivity analyses.

Chapter 5: Conclusion

5.1 Deliverables:

This work aimed to have both academic and practical merit. This was accomplished through three main deliverables. The first was to provide an introduction to logistic postponement as a demand risk mitigation strategy and an overview of the current research on the topic. This deliverable was covered in the literature review section of this thesis (section 2). Its main takeaways will be summarised in subsection 5.2. The second deliverable was to provide a theoretical model that will serve as a framework for practitioners to use. This deliverable was covered in theoretical model section of this thesis (subsection 3.4) and its main takeaways will be summarised in subsection 5.3. The final deliverable was to provide a simplified model using arena simulation and to analyse the results. This deliverable was covered in computational model (subsection 3.5) and the results and discussion (section 4) of this thesis and its main takeaways will be presented in subsection 5.4. The final subsection of the conclusion section (subsection 3.6) will discuss directions for future research.

5.2 Takeaways from the literature review section:

The first takeaway from the literature review section is that there is limited research on the topic of logistic postponement. Most of the research on the topic of postponement was on manufacturing postponement. When searching specifically for logistic postponement, a limited number of articles were found. Of the articles that were found on the topic very few were recently published with the majority of articles being published before 2010. Additionally, when searching specifically for articles that discussed both logistic postponement and ROV modeling no articles were found. Similarly, limited research has been done on global logistic postponement. This points to a need for conducting research on the global logistic postponement and computational models using the ROV approach to evaluate logistic postponement. Our work addresses all theses gaps in literature.

The second takeaway is that the logistic postponement strategy can be an effective strategy for decreasing customer lead times and decreasing total supply chain costs (García-Dastugue and Lambert, 2007) under demand uncertainty. This is done by stocking products closer to customers to avoid the wrong time and place utility of products (Yang et al., 2004), and by reducing total inventory costs (Yang et al., 2004) (Pagh and Cooper, 1998).

The final takeaway is that the logistic postponement strategy results in increased transportation costs and is therefore best suited for products that are more sensitive to inventory costs than transportation costs (Yang et al. 2004) (Pagh and Cooper, 1998).

5.3 Takeaways from the theoretical model:

The theoretical model section of the thesis provides a framework for practitioners to use to evaluate if the logistic postponement strategy is suitable for their business. It is designed to allow practitioners to use monthly historical demand data to evaluate the benefits a logistic postponement strategy can have for their business. The theoretical model should be adapted to better reflect the practitioner's business specifics but serves as a good starting point to analyze whether the costs of building a DC to pursue to logistic postponement strategy is worth the future cost savings.

5.4 Takeaways from the computational model:

The purpose of the computational model section of this thesis was to provide insights on the benefits of the logistic postponement model. Although the model was simplified for the purpose of this research and no actual company data were used, two main takeaways can be made.

The first takeaway is that the logistic postponement strategy improves service to customers by decreasing retailers' lead times. This was clearly observed when comparing the backorders in the base case to backorders in the proposed logistic postponement strategies.

The second takeaway is that the proposed logistic postponement strategy allows for a more efficient use of inventory by avoiding the wrong time and place utility of safety stock. We see in the results and discussion section of this thesis that, although the quantity shipped from the DC to the three retailers was relatively constant for the base case compared to the logistic postponement strategies, the number of stockouts under the logistic postponement strategies was significantly lower than the number of stockouts in the base case.

5.5 Directions for future research:

The most obvious future direction for research is to modify and run the theoretical model using historical company data. It would be great to see the study of evaluating logistic postponement using the ROV approach applied to real data. By adapting the theoretical model building approach to the studied company, greater insights could be gained to expand the study of logistic postponement.

Furthermore, an evaluation of a company using a similar approach to the proposed logistic postponement strategy would allow the study of additional features that were not considered in this thesis. For example, both the theoretical and computational models presented in this thesis relied on simplifying assumptions to incorporate managerial flexibility. It would be interesting to observe and reflect in the model how companies would handle the real-life decision of sending a shipment from the DC when a stockout occurs.

Finally, an evaluation of a more complex supply chains is needed. For example, looking at incorporating a similar approach to evaluate adding an additional DC to a network that already contains several DCs or using a similar approach to incorporate the benefits of stock pooling under a hub and spoke model would be beneficial.

Appendix A:

A1.0 Description of the Arena model:

The first section of the appendix will provide a detailed description of the Arena model used in this thesis. The logistic postponement model will be described in detail before moving on to describe what changes for the base case model. The description of the logistic postponement Arena model will begin by discussing the demand at each retailer in subsection A1.1. We will then discuss the variables used in the logistic postponement model and their initial values in subsection A1.2. Next, we will look at how entities flow through the model to update the variables in subsection A1.2. We will then look at how the base case is set up in Arena and what varies from how the logistic postponement strategy is set up in subsection A1.3. Next, we will look at the statistics taken from the Arena model in subsection A1.4. Finally, we will look at how the base case Arena model varies from the logistic postponement Arena model in subsection A1.5.

A1.1 Logistic postponement demand:

For simplicity it is assumed that each order is of the same size and the same value. The frequency of these orders follows an exponential distribution that varies depending on the retailers. For Retailer A it is assumed that orders are received on average once every day. For Retailer B it is assumed that orders are received on average once every four days ys. For Retailer C it is assumed that orders are received on average once every three days.

A1.2 Logistic postponement variables:

This section will go over the variables that are used in the logistic postponement Arena model. These variables will be updated as entities flow through the model. These updated variables will then be used to collect statistics that will determine the cost of the logistic postponement strategy. The variables used in the model can be split up into the following two sections: static variables, and continuous variables.

Static variables:

Although, no real-world data will be used in this thesis; initial values for variables will be needed to show how the model can be used. Please note that these values are selected arbitrarily with the goal of providing an example of how ROV modeling can be used to estimate the value of the proposed logistic postponement strategy and should not be taken as a benchmark for current market conditions. The following static variables were used in the logistic postponement model:

vBackorderingCostPerDay: This variable assigns a daily cost for each unit that is backordered at the retailers. It is assumed that customers will wait as long as it takes for their order to be filled when stockouts occur, therefore orders will stay in the system as long as it takes for them to be filled. The daily per unit backorder cost is assumed to be $3 for all three retailers.

vHoldingCostPerDay: This variable assigns a daily cost for each unit held. The daily per unit holding cost is assumed to be $0.25 for all three retailers and the distribution center.

vOrderingCost: This variable assigns a fixed cost for each order sent to the overseas supplier. The ordering cost is assumed to be $200 for an order sent from the DC or any of the retailers. This ordering cost accounts for the fixed transportation cost and the cost charged by the supplier to take an order.

vDCtoRetailerLeadTimeThis variable assigns a lead time for orders sent from the distribution center to one of the retailers. This value is assumed to be one day for each retailer.

vSuppliertoRetailerLeadTime: This variable assigns a lead time for orders sent from the overseas supplier to the DC or one of the retailers. This value is assumed to be 30 days for each retailer and the DC.

vReorderLevel(A, B, C): A reorder level is assigned to each of the retailers. This value dictates if an order will be placed to the overseas supplier when a new period begins. The reorder level is assumed to be half of the Max level for all three retailers.

vReorderPointDC: This variable assigns a reorder point for the DC. Since the DC follows a continuous review policy once the inventory level at the DC falls below the reorder point an order is sent to the overseas supplier. The reorder point is assumed to be five for the DC.

vMaxLevel(A, B, C): The Max level variables are used to determine how much needs to be ordered from the retailer to the overseas supplier each period. This is done by taking the difference between the inventory position and this max level variable. The max level is set to the average monthly demand for all three retailers (rounded to the closest integer). Since orders are received at Retailer A on average once a day and the order cycle is thirty days the Max level is set to 30. Since orders are received at Retailer B on average once over four days and the order cycle is thirty days the Max level is set to 8. Since orders are received at Retailer C on average once every 3 days and the order cycle is thirty days the Max level is set to 10.

vReorderQtyDC: The reorder level determines the order quantity that is sent from the DC to the overseas supplier when an order is triggered. The reorder quantity is assumed to be ten for the DC.

TCFixedDC: This variable keeps a tally of the transportation costs for orders placed from the DC to the overseas supplier. The initial transportation cost of sending goods from the DC to a retailer is assumed to be $15.

TCVariableCostOverseas: This variable assigns a per unit cost for transporting orders from the overseas supplier to either the DC or one of the retailers. The variable overseas transportation cost is assumed to be $25 per unit shipped.

vCriticalBackorderLevel(A, B, C): The critical backorder variables are used in the logistic postponement strategy to determine when a shipment is sent from the DC to a retailer to fill backorders. The logistic postponement strategy will be run with three model variations, where the only difference will be the value of the critical backorder level. For the Cost Minimization Model, the critical backorder levels will all be set to five. Since the cost of sending a shipment from the DC to one of the retailers is $15, the daily stockout cost is $3 and the cost of holding units at the DC is $0.05; the minimum shipment value where the stockout cost plus the cost of holding goods at the DC is greater than the local transportation cost is five units. The Service Maximization Model sets the critical backorder level to one to represent the maximum service that can be provided through the option to send goods from the DC to the retailers when stockouts occur. The Hybrid Model will show a balance to the other two variations by setting the critical backorder levels to the average of the Cost Minimization Model and the Service Maximization Model, which is three.

Continuous variables:

The next set of variables in the model is continuous variables. The continuous variables are updated as entities flow through the model. A description of the entities and how they flow through the model updating continuous variables is provided in the next section of this theis.

vOnHand (DC, A, B, C): These variables are used to represent the quantity of product the DC and retailers currently have in stock. The initial value for the quantity each of the retailers has on hand is assumed to be equal to the retailer max level and the DCs reorder quantity. The reason for assigning an initial value is to reduce the number of backorders the DC and retailers would experience before an order is received from the overseas supplier.

vBackorder (DC, A, B, C): These variables are used to represent the quantity of the product the DC and retailers currently have on backorder. It is assumed that there are no outstanding backorders at the start of the simulation. Therefore, the initial value for the backorder variable is assumed to be zero for the DC and all three retailers.

vOnOrder (DC, A, B, C): These variables are used to represent the quantity of the product the DC and retailers have ordered to either the overseas supplier or the DC but has not yet received. It is assumed that there are no outstanding orders at the beginning of the simulation. Therefore, the initial value for the OnOrderValue is assumed to be zero for the DC and all three retailers.

vInvpos (DC, A, B, C): These variables are used to represent the DC and retailers inventory positions. The inventory position can be calculated by the sum of the quantity the retailer has on order and on hand less the quantity it has backordered. Since the inventory position will be calculated as entities begin to flow throughout the model there is no need to assign an initial value.

Transportationfromoverseasto(DC, A, B, C): These variables are used to keep a tally of the overseas transportation cost. This is done through an assign module in the DC and retailer subsections of the model and will be explained in the next section of the thesis.

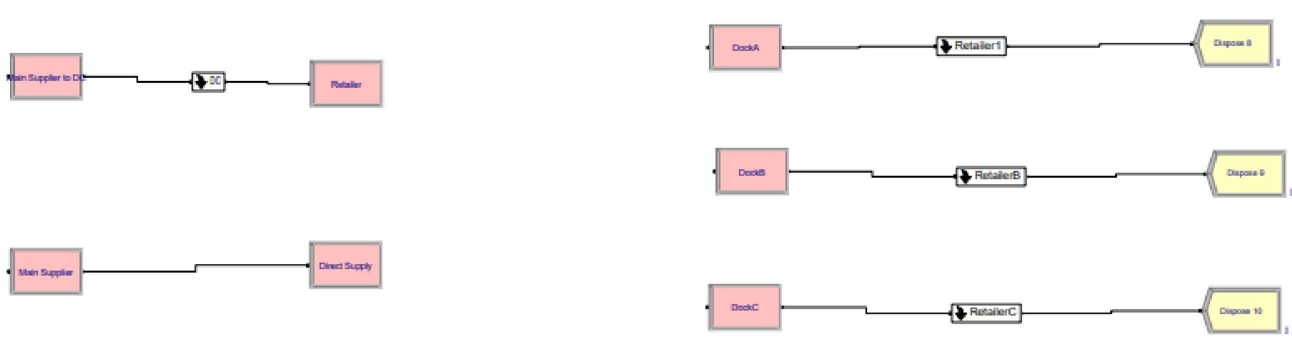
Appendix 1.3 How entities flow through the model:

Entities are used in the model to either represent an order or a unit of demand. This section will look at how these entities flow through the model, updating variables that will later be used to calculate statistics. The model is set using submodels that interact with each other through the top level of the model. This section will begin by addressing this top level before moving on to address the logistic postponement and retailer submodels.

Top level:

The top level of the Arena model provides a link from the overseas supplier to the distribution center, and retailer sub models, along with providing a link from the distribution center sub model to each of the retailer sub models. This is done using station and dock modules as seen in figure A1.

Figure A1: The top level of the arena model



The Top Level of the model defines various paths entities can use to travel within the network. The left side of Figure 1 represents the shipment of goods from the overseas supplier while the right side of Figure 1 represents the reception of goods by the retailers.

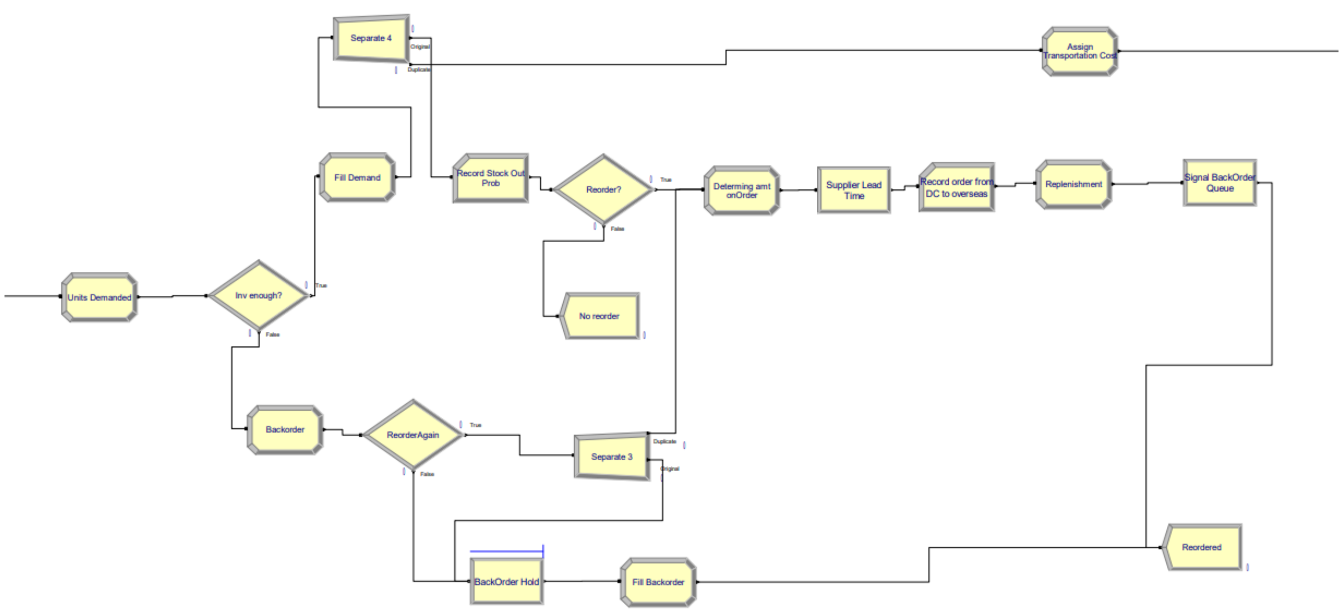
The path found on the bottom left of Figure 1 shows the direct supply from the overseas supplier to the retailers. Since the overseas supplier is assumed to be able to fill all orders from the retailers or the distribution center (DC) there is no need to represent the overseas supplier with a sub model. Instead, the overseas supplier is represented with a station module. This station module is connected to a Route module called “Direct Supply” which delays the shipment by the 30-day lead time assigned to shipments from the overseas supplier to the retailers. Next, through the use of Dock modules, the shipment is assigned to one of the three retailer docks: Dock A, Dock B, or Dock C. This assignment is determined by which of the three retailers sent the order to the overseas supplier. Finally, the goods flow to the corresponding retailer sub model before going through a dispose module (marking the end of the process).

The second path, which is specific to the logistic postponement models, can be found on the top right of Figure 1. This path represents the logistic postponement option where goods are stocked at the DC, as a buffer, and then sent to the retailers in the case of a stockout. Once again, the process starts with the overseas supplier which is represented as a Station module. The goods then flow to the DC sub model as orders are placed from the DC to the overseas supplier. Next, once the DC receives an order from one of the retailers, goods flow from the DC sub model to the “DCtoRetailerRoute” Route module. This Route module then assigns a DC to retailer lead time (which for the purpose of this model is assumed to be zero). The “DCtoRetailerRoute” module then assigns the goods to one of the three retailer sub model with the use of Dock modules as explained above.

DC submodel

The DC submodel follows a continuous review policy where orders are placed to the DC when inventory reaches a predetermined level. The quantity of this order is determined using an order up to approach where the order quantity corresponds to the difference between the predetermined order up to level (represented by the DC MAX Level variable) and the inventory on hand at the DC. Goods flow through the DC sub model as shown by Figure A2.

Figure A2: The DC Arena sub model



The DC sub model starts with an Assign module called “Units Demanded” which interacts with the retailer submodel to tell the DC submodel the retailer’s order quantity. This order becomes the entity flowing through the DC submodel. Next, we reach our first Decide module which determines if the quantity on hand at the DC is greater than the quantity ordered by one of the retailers.

A backorder occurs at the DC:

If there is not enough quantity on hand at the DC to fill the order, the entity will flow to the bottom portion of the sub model into an Assign module called “Backorder”. The “Backorder” module adjusts both the DCs backorder quantity by adding the amount of the order and adjusts the DCs inventory position by subtracting the amount of the order. After the backorder and inventory positions are adjusted the entity flows to a decide module which determines whether an additional order should be placed to the overseas supplier.

Following the continuous review policy, if the supplier’s inventory position (determined by the sum of the quantity on hand at the DC and the quantity on order at the DC less the quantity the DC has on backorder) is less than the predetermined reorder point an order is placed to the DC. If the inventory position is greater than the reorder points an order is not placed to the DC and the entity flows to a Hold module called “Backorder Hold” to wait till an order is received from the overseas supplier. Once an order has been received the entities in the “Backorder Hold” module are released and flow to an Assign module called “Fill Backorder”.

The function of the “Fill Backorder” Assign module is to update the quantity backordered at the DC by subtracting the quantity the retailer has on order that can now be filled with the stock received by the overseas supplier. Once the backorder quantity has been filled the entities exit the submodel through a dispose module.

In order to explore what happens when the inventory position is less than the reorder point and an order is needing to be placed to the overseas supplier, we will return to the “reorder again” Decide module. In this case the entity will flow to a Separate module where it is duplicated. One of the duplicated entities will flow into the “Backorder Hold” module where it will follow the same steps as explained above. The other portion of the entity will flow to an Assign module called “Determining the amt on Order.”

The “Determining the amt on Order” Assign module updates the quantity the DC has on order by adding the supplier’s predetermined reorder quantity to the amount the supplier currently has on order. Additionally, this Assign module updates the number of orders placed from the DC to the overseas supplier by adding one to the current number of orders placed. Once these updates are complete the entity flows to a Delay module called “Supplier Lead Time”.

Since the lead time required for the DC to receive orders from the overseas supplier was not accounted for in the “Top-Level” of the model it must be taken into account here. To do this a Delay module is used to delay the receipt of goods from the overseas supplier by the predetermined supplier to DC lead time. Once this delay is complete the entities flow to an Assign module called “Replenishment”.

The purpose of the “Replenishment” Assign module is to represent the reception of an order by the DC from the overseas supplier by updating both the amount the DC has on order and the amount the DC has on hand. This is done by subtracting the amount the DC has on order by the supplier reorder quantity and then adding this reorder quantity to the amount the DC has on hand. Once this update is complete the entity flows to a Signal module called “Signal Backorder Queue.”

The “Signal Backorder Queue” module then interacts with the “Backorder Hold” module to signal the release of entities waiting for the reception of an order form the overseas supplier. Once this signal has been sent the entities are disposed of by flowing to a Dispose module.

An order received from one of the retailers is filled by the DC:

Circling back to the first Decide module, we will now explore the case where the DC has enough inventory on hand to fill the order received from one of the DCs. In this case the entity flows to an Assign module called "Fill Demand."

The "Fill Demand" module is used to update both the amount the supplier has on hand and the supplier's inventory position. The amount the DC has on hand is updated by subtracting retailer order quantity that was filled by the DC. The DC's inventory position is then adjusted by adding the updated amount the DC has on hand to the amount it has on order less the amount it has backordered. Once these updates are complete the variable flows to a Separate module which duplicates the entity. One of the duplicates flows to another Assign module called "DC to Retailer Transportation Cost"; while the other duplicate flows to a Record module called "Record Stock Out Prob".

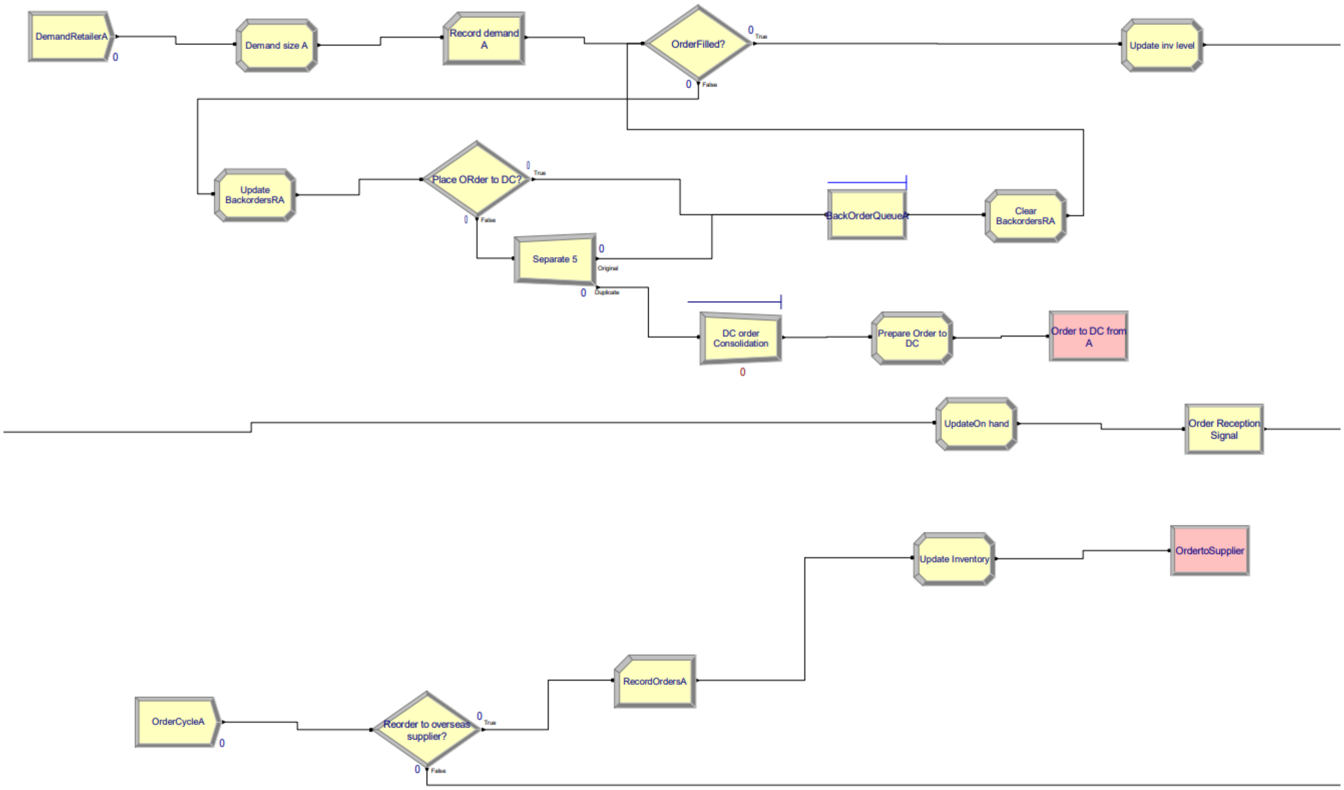
The "DC to Retailer Transportation Cost" Assign module updates the total transportation cost from the DC to the retailers. Since this transportation cost is assumed to be the same for all three retailers the same formula can be used regardless of where the goods will be shipped. The formula works by taking the sum of the current value of the total DC transportation costs, and adding the fixed transportation cost. Once the transportation costs are calculated, the entity exits the DC sub model and flows to the appropriate dock as explained in the "Top-Level" portion of this thesis.

The second duplicate flows to the "Record Stock Out Prob" Record module where a tally for the total quantity backordered is updated. It then flows to a decide module called "Reorder?" which determines if an order should be placed to the overseas supplier. This decision is made by determining if the inventory position at the DC is less than or equal to the reorder point. If the inventory position is greater than the reorder points no order is placed and the entity can exit the model through a dispose module; if the inventory position is less than or equal to the reorder point the entity instead flows to the same "Determining amt on Order" as described previously. The entity will then follow the same procedure as explained above to place and receive an order from the overseas supplier.

Retailer submodels:

All three retailer submodels contain the same modules with the only difference being that the reference variable and attributes (such as demand, inventory position etc.), that are specific to the retailers the submodel corresponds to. Therefore, to avoid redundancy we will only explore the modules an entity would flow through for one of the retailers (Retailer A), as seen in Figure A3.

Figure A3: The retailer Arena sub model



The retailer sub models can be split into three parts: the top part of the sub model represents the logistic postponement option where orders are placed to the DC to fill backorders, the middle portion of the sub model represents the reception of goods from both the DC and the overseas supplier, the bottom portion of the model represents the periodic review policy where orders are placed to the overseas supplier.

Logistic postponement portion:

The top portion of the submodel starts with a "Create" module where demand at the retailers is created. This is where the entities that flow through the model originate from. The entities flowing through this portion of the model represent a customer's demand. To keep the model simple, we assume that one entity arrives per arrival with demand of one unit and that the time between arrivals is defined using a normal distribution with no trend or seasonality factors. Once the demand entity is created it flows to an Assign module called "Demand Size A."

This Assign module assigns the units demanded by each entity that flows through the model. Again, with the goal of keeping the model simple, the demand size for all three retailers is assumed to be one. Meaning each entity that flows through the model represents the single unit of demand. Once the entity is assigned the demand size of one it then flows to a Record module called "Record Demand A".

The "Record Demand A" module keeps a count of the entities flowing through. The purpose of this record module is to keep track of the total demand for the retailer. Since each entity flowing through the model represents one unit of demand, we can simply count the entities flowing through the model to get the total demand. Once the demand has been recorded the entity then flows to a Decide module called "OrderFilled?".

The “OrderFilled?” decide module determines if there is enough inventory on hand to fill the demand. If the inventory on hand is greater than the demand attributed to the entity flowing through the module the entity will then flow to an Assign module called “Update inv level,” otherwise, the entity will flow to a different Assign module named “Update BackOrdersRA.”

The function of the “Update inv level” Assign module is to simulate the fulfillment of a customer order by updating both the inventory on hand at the retailer and the retailers inventory position. The inventory on hand is updated by subtracting the retailer’s current inventory on hand by the demand attributed to the entity flowing through the module. The inventory position is updated by adding the current inventory the retailer has on order with the updated inventory the retailer has on hand and then subtracting the result by the current quantity the retailer has on backorder. Once these updates are complete the entity flows to the “Top-Level” of the model where it is disposed.

The function of the “Update BackordersRA” Assign module is to simulate a stockout at the retailer. When an entity flows through this module the retailer’s backorder position is updated by adding the current back-order position with the demand attributed to the entity flowing through the module. Additionally, the inventory position is updated to reflect the adjusted backorder position by subtracting the sum of the current inventory the retailer has on hand and the current inventory the retailer has on order by the updated backorder position. Following this update the entity flows to a Decide module called “Place Order to DC”.

The “Place Order to DC” Decide module determines if an order should be placed to the DC. This represents the logistic postponement option that determines if a shipment should be sent from the DC to fill the backorder at the retailer. If the quantity the DC has on backorder is less than the predetermined critical back-order level the entity is sent to a queue module called “Backorder Queue”, otherwise, the entity is sent to a separate module.

The function of the backorder queue is to hold the entities that were backordered until an order has been received from either the DC or the overseas supplier. Once the signal is sent that an order has been received the entities held in this queue flow to an Assign module called “Clear Backorders RA.”

The function of the “Clear BackordersRA” Assign module is to update the quantity the retailer has on backorder and the retailer’s inventory position. The backorder level is updated by subtracting the current backorder level by the demand attributed to the entity flowing through the module. Additionally, the inventory position is updated by subtracting the sum of the current inventory on hand and on order by the updated backorder quantity. Once these updates are complete the entity flows back to the “Order Filled?” Decide module described above.

When the DCs backorder level exceeds the entity flows from the “Place order to DC” Decide module to a Separate module where the entity is duplicated. One of these duplicates flows the “BackOrderQueue” Hold module where it follows the same process explained above. The other duplicate flows to a Batch module called “DC order consolidation.”

The “DC order consolidation” batch module works by consolidating a predetermined number of entities that are sent out as a group to the next module. The purpose of this consolidation is to capitalize on economies of scale by sending an order with multiple units to the DC instead of sending single unit orders. Since the service level provided depends significantly on the size of this consolidation three sizes will be tested and presented in the results section of this thesis. After the predetermined batch level is reached the entities are merged and sent to an Assign module called “Prepare order to DC.”

The “Prepare order to DC” Assign module assigns the order quantity to be sent to the DC. This is done by attributing the current backorder level as the order quantity. Additionally, the dock that the order is to be sent to is updated so the DC knows which retailer to send the order to. Once this update is complete the merged entity flows to a Route module that sends the entity to the DC submodel.

Middle portion of the retailer sub model

The middle portion of the retailer sub model represents the reception of goods from the DC and the overseas supplier. If we look back at the "Top-Level" we see that each retailer is connected to the DC and the overseas supplier through docks. Entities, representing shipments, flow to the middle portion of the retailer submodel into an Assign module called "Update on Hand."

The purpose of the "Update on Hand" module is to adjust the inventory position of the retailer to represent the reception of an order. The first variable that is adjusted is the inventory the retailer has on hand. The adjustment is to add the order quantity received to the current quantity the retailer has on hand. The second adjustment is to subtract the order quantity to the inventory the retailer has on order since this quantity has now been received. The final adjustment is to the retailer's inventory position. This is done by adding the adjusted inventory the retailer has on hand and the adjusted inventory the retailer has on order and then subtracting this value by the quantity the retailer currently has on backorder. Once these adjustments are made the entity flows to a signal module called "Order Reception Signal."

The order reception signal sends a signal to the "BackorderQueue" so that the entities in this queue can be released as explained earlier. Once this signal has been sent the entities flow to the top level of the model where they are disposed.

Bottom portion:

The bottom portion of the retailer sub model represents the ordering cycle to the overseas supplier. This section starts with a create module called "OrderCycleA." Entities are created every thirty days to represent the periodic review policy the retailer follows for orders placed to the overseas supplier. Once an entity is created it flows to a Decide module called "Reorder to Overseas Supplier?"

The "Reorder to Overseas Supplier?" Decide module determines if an order should be sent to the overseas supplier. This is done by evaluating the retailer's inventory position to determine if it is less than or equal to the retailer's reorder point. If the inventory position is less than or equal to the reorder point the entity is sent to a Record module called "RecordOrdersA", otherwise, the entity is sent to the top-level of the model where it is disposed.

The "RecordOrdersA" module records the total order the retailer has placed to the overseas supplier by simply adding one to the current value of total orders sent to the overseas supplier. Once the order has been recorded the entity flows to an Assign module called "Update Inventory."

The purpose of the "Update inventory" Assign module is to update the retailers inventory variables to reflect the order. The first variable that is updated is the order quantity variable. This update is done by subtracting the MaxLevelA variable (which represents the retailer's order up to level) by the retailer's current inventory position. Next the amount the retailer has on order is updated to reflect the new order. This is done by adding the order quantity calculated to the quantity the retailer has on order. The next update is to adjust the retailers inventory position. This is done by taking the sum of the quantity the retailer has on hand and the adjusted quantity the retailer has on order and then subtracting this value by the quantity the retailer has on backorder. Once these updates have been completed the entity flows to Route module named "OrdertoSupplier" this route interacts with the "MainSupplier" Station, found on the top-level of the Arena model, to communicate the order quantity to the main supplier.

A1.4 Statistics:

The total costs of the logistic postponement strategy consist of the holding cost at each of the retailers, the holding cost at the distribution center, the distribution costs of shipping goods from the overseas supplier to the retailers, the distribution costs of shipping goods from the overseas supplier to the distribution center, the distribution costs of shipping goods from the distribution center to the retailers, and the stockout costs at each of the retailers.

Since there are no trend or seasonality factors in the model, the average daily costs can be taken from the model. These average daily costs can then be used to find the total discounted costs for the 10-year duration that will be compared against the base case. The costs considered in the model are the costs of holding goods at the DC, the costs of holding goods at the retailers, the cost of stockouts, the cost of ordering goods to the DC, the costs of ordering goods to the retailers, and the costs of transporting goods from the DC to the three retailers.

Holding costs:

The first cost we will consider is the daily cost of holding goods at the distribution center. Since the vOnHandDC variable represents the quantity, we can use the DAVG function in Arena to find the average daily inventory the DC has on hand. This value can then be multiplied by the daily holding cost to find the DCs average daily holding cost, as shown by Equation A1.

AvgDCHoldingCost = DAVG (vOnHandDC) * vHoldingCostPerday (A1)

The next costs we will consider are the average daily holding costs for each of the three retailers. Since it is assumed that the daily holding cost is the same for all three retailers and the DC, the average daily holding cost for the DC and each retailer can be calculated the same way as shown in Equation 1, with the only difference being that the on-hand variable will be specific to each retailer. The average daily holding costs for the DC and each of three retailers are calculated using Equations A2, A3, and A4, A5 respectively.

AvgHoldingCostPerDayDC = DAVG (vOnHandDC value) * vHoldingCostPerDay (A2)

AvgHoldingCostPerDayA = DAVG (vOnHandA value) * vHoldingCostPerDay (A3)

AvgHoldingCostPerDayB = DAVG (vOnHandB value) * vHoldingCostPerDay (A4)

AvgHoldingCostPerDayC = DAVG (vOnHandC value) * vHoldingCostPerDay (A5)

The Stockout Costs:

Since no orders are placed by customers directly to the DC, we only need to consider the stockout costs for the retailers. The stockout costs are calculated in a very similar way as the holding costs. The DAVG function is used here to calculate the average quantity the retailer has on backorder. This value is then multiplied by the daily backordering cost. The average daily stockout costs for Retailer A, Retailer B, and Retailer C are calculated using Equation A6, A7, and A8 respectively.

AvgStockoutCostPerDayA= DAVG (vBackOrderA value) * vBackorderingCostPerday (A6)

AvgStockoutCostPerDayB= DAVG (vBackOrderB value) * vBackorderingCostPerday (A7)

AvgStockoutCostPerDayC= DAVG (vBackOrderC value) * vBackorderingCostPerday (A8)

Ordering costs:

The next cost that needs to be determined is the ordering cost. The ordering cost is assumed to be made up of both the fixed transportation cost and the cost of placing an order to the overseas supplier. To calculate the average daily ordering costs, we need to first determine the average daily orders. The DC and all the retailer modules contain a record module that counts the number of orders placed to the overseas DC. Since our simulation runs for ten years, we can simply divide the number of orders placed by 3650 to get the average daily orders as shown by Equations A9, A10, A11, and A12.

AvgOrdersPerDayDC= (TotalOrdersDC)/3650 (A9)

AvgOrdersPerDayA= (TotalOrdersA)/3650 (A10)

AvgOrdersPerDayB= (TotalOrdersB)/3650 (A11)

AvgOrdersPerDayC= (TotalOrdersC)/3650 (A12)

Once we have the average orders per day, we can compute the average daily ordering cost by multiplying the average orders per day by the ordering cost as shown in Equations A13, A14, A15, and A16.

AvgDailyOrderingCostDC = AvgOrdersPerDayDC * vOrderingCost (A13)

AvgDailyOrderingCostA = AvgOrdersPerDayA * vOrderingCost (A14)

AvgDailyOrderingCostB = AvgOrdersPerDayB * vOrderingCost (A15)

AvgDailyOrderingCostC = AvgOrdersPerDayC * vOrderingCost (A16)

Transportation costs:

The next costs we will look at are the transportation costs. The transportation costs can be broken up into overseas transportation costs and local transportation costs, with overseas transportation costs representing the costs of shipments sent from the overseas supplier and local transportation costs representing costs of shipments sent from the DC.

Since the ordering costs take into account all the fixed costs associated with an order placed to the overseas supplier the overseas transportation cost statistics will only take into account variable costs. These variable costs are tallied in the model as orders are received at either the DC or one of the retailers. This tally value is then used to calculate the average daily overseas transportation costs as shown by Equations A17, A18, A19, and A20.

AvgTCfromOverseastoDC= TransportionCostfromoverseastoDC/3650 (A17)

AvgTCfromOverseastoA= TransportionCostfromoverseastoA/3650 (A18)

AvgTCfromOverseastoB= TransportionCostfromoverseastoB/3650 (A19)

AvgTCfromOverseastoC= TransportionCostfromoverseastoC/3650 (A20)

The local transportation cost is computed through a tally variable in the DC subsection that is updated as units are shipped from the DC to one of the retailers. In this case one variable is used to represent all shipments sent to retailers. This variable is then used to compute the average daily local transportation cost as shown in Equation 21.

AvgTCfromDC= TransportationCostFromDC/3650 (A21)

Total cost:

To calculate the total costs, we simply need to take the sum of all the average daily costs. However, since it would be interesting to see the costs at the DC and the three retailers, we will first compute the average daily costs at each of these supply chain members.

The average daily cost at the DC can be calculated by taking the sum of the average daily cost of holding goods at the DC, the average daily cost of ordering goods to the DC and the average daily cost of shipping goods from the overseas supplier to the DC, as shown by Equation 22.

AvgDailyCostDC = DCHoldingCost + AvgDailyOrderingCost + DCAvgTCfromDC (A22)

As the local transportation cost is calculated for all three DC together, it is not included in the average daily cost for the retailers. The average daily cost for each retailer is made up of the cost of holding goods at the retailer, the stockout cost at each retailer, the cost of ordering goods from the overseas supplier, and the cost of transporting goods from the overseas supplier to the retailers, as shown by Equations A23, A24, and A25.

$$AvgDailyCostA = AvgHoldingCostPerDayA + AvgStockoutCostPerDayA + AvgDailyOrderingCostA + AvgTCfromOverseastoA \quad A23)$$

$$AvgDailyCostB = AvgHoldingCostPerDayB + AvgStockoutCostPerDayB + AvgDailyOrderingCostB + AvgTCfromOverseastoB \quad (A24)$$

$$AvgDailyCostC = AvgHoldingCostPerDayC + AvgStockoutCostPerDayC + AvgDailyOrderingCostC + AvgTCfromOverseastoC \quad (A25)$$

The total daily cost can then be computed by taking the sum of the average daily cost at the DC, the average daily cost at each retailer and the local transportation cost, as shown by Equation 26.

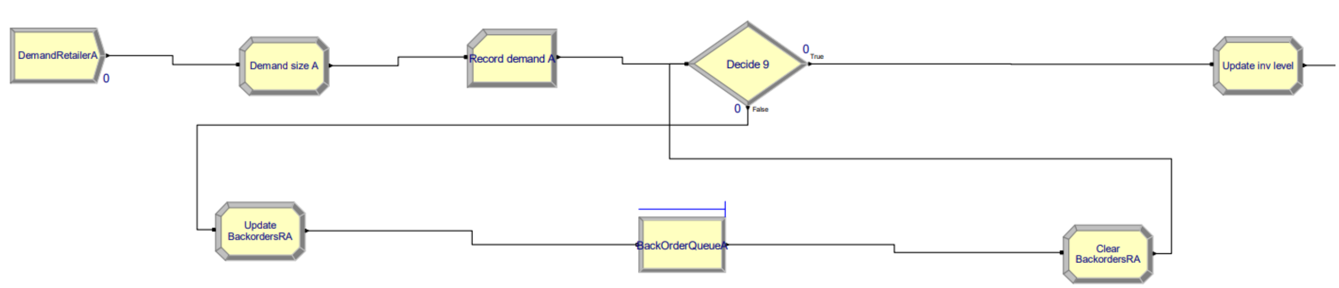
$$AvgDailyCost_{LP} = AvgDailyCostDC + AvgDailyCostA + AvgDailyCostB + AvgDailyCostC + AvgTCfromDC \quad (A26)$$

A1.5 How the base case is set up in Arena:

It is assumed that in the base case the three retailers follow the same periodic review policy as discussed in the logistic postponement strategy, however, there will be no distribution center available to fill backorders.

The first major change between the base case and the logistic postponement strategy is the removal of the DC. In Arena the DC submodel is removed. Additionally, the link between the overseas supplier, the DC and the retailers is removed from the top level of the model. All variables and statistics specific to the DC, such as the vDConhand variable, are also removed from the model. The final step in removing the DC from the Arena model is to update the top portion of the retailer submodels to remove modules related to placing to the DC and receiving orders from the DC. This changes the backorder process at the retailers where the backorders wait in the backorder queue module until a signal, representing the reception of an order from the overseas supplier, is received. Figure 4 shows the modules that are left in the top portion of the retailer submodel after this removal has been completed.

Figure A4: The top portion of the base case retailer submodel



The final adjustment that is made to the Base Case is to update the Max levels at each retailer. Since in the logistic postponement strategy the DC holds excess stock for all three retailers there is no need to hold excess stock at the retailers. However, when the DC is removed, we can assume that some level of safety stock will be held at the retailers. To represent this safety stock, we will add an additional fifteen percent to the average order cycle demand (rounded to the nearest integer) for each of the retailers to determine the Max Level variables. This means that the Max Level variable for Retailer A will be set to 35, the Max Level variable for Retailer B will be set to 9, and the Max Level variable for Retailer C will be set to 12.

Appendix B

Input Variables for the computational model

The second section of the appendix provides the input variables for each of the eight sensitivity models.

Sensitivity 1: LP 20% stockout cost Increase:

Variable	Retailer A	Retailer B	Retailer C	DC
Backordering cost per day	$3.60	$3.60	$3.60	N/A
Holding Cost per day	$0.25	$0.25	$0.25	$0.25
Ordering Cost	$200	$200	$200	$200
Fixed Transportation Cost DC	$15	$15	$15	N/A
Variable transportation cost overseas	$25/unit	$25/unit	$25/unit	$25/unit
Critical Backorder Level	5 units backordered	5 units backordered	5 units backordered	N/A

Sensitivity 2: LP 20% stockout cost decrease:

Variable	Retailer A	Retailer B	Retailer C	DC
Backordering cost per day	$2.4	$2.4	$2.4	N/A
Holding Cost per day	$0.25	$0.25	$0.25	$0.25
Ordering Cost	$200	$200	$200	$200
Fixed Transportation Cost DC	$15	$15	$15	N/A
Variable transportation cost overseas	$25/unit	$25/unit	$25/unit	$25/unit
Critical Backorder Level	5 units backordered	5 units backordered	5 units backordered	N/A

Sensitivity 3: LP 20% transportation cost increase:

Variable	Retailer A	Retailer B	Retailer C	DC
Backordering cost per day	$3	$3	$3	N/A
Holding Cost per day	$0.25	$0.25	$0.25	$0.25
Ordering Cost	$240	240	240	240
Fixed Transportation Cost DC	$18	18	18	N/A
Variable transportation	$25/unit	$25/unit	$25/unit	$25/unit

cost overseas				
Critical Backorder Level	5 units backordered	5 units backordered	5 units backordered	N/A

Sensitivity 4: LP 20% transportation cost reduction:

Variable	Retailer A	Retailer B	Retailer C	DC
Backordering cost per day	$3	$3	$3	N/A
Holding Cost per day	$0.25	$0.25	$0.25	$0.25
Ordering Cost	$160	160	160	160
Fixed Transportation Cost DC	$12	12	12	N/A
Variable transportation cost overseas	$25/unit	$25/unit	$25/unit	$25/unit
Critical Backorder Level	5 units backordered	5 units backordered	5 units backordered	N/A

Sensitivity 5: Stockout increase + TC Increase

Variable	Retailer A	Retailer B	Retailer C	DC
Backordering cost per day	$3.60	$3.60	$3.60	N/A
Holding Cost per day	$0.25	$0.25	$0.25	$0.25
Ordering Cost	$240	240	240	240
Fixed Transportation Cost DC	$18	18	18	N/A
Variable transportation cost overseas	$25/unit	$25/unit	$25/unit	$25/unit
Critical Backorder Level	5 units backordered	5 units backordered	5 units backordered	N/A

Sensitivity 6: Stockout increase + TC Decrease

Variable	Retailer A	Retailer B	Retailer C	DC
Backordering cost per day	$3.60	$3.60	$3.60	N/A
Holding Cost per day	$0.25	$0.25	$0.25	$0.25
Ordering Cost	$160	160	160	160
Fixed Transportation Cost DC	$12	12	12	N/A
Variable transportation	$25/unit	$25/unit	$25/unit	$25/unit

cost overseas				
Critical Backorder Level	5 units backordered	5 units backordered	5 units backordered	N/A

Sensitivity 7: Stockout Decrease + TC Increase

Variable	Retailer A	Retailer B	Retailer C	DC
Backordering cost per day	$2.4	$2.4	$2.4	N/A
Holding Cost per day	$0.25	$0.25	$0.25	$0.25
Ordering Cost	$240	240	240	240
Fixed Transportation Cost DC	$18	18	18	N/A
Variable transportation cost overseas	$25/unit	$25/unit	$25/unit	$25/unit
Critical Backorder Level	7 units backordered	7 units backordered	7 units backordered	N/A

Sensitivity 8: Stockout Decrease + TC Decrease

Variable	Retailer A	Retailer B	Retailer C	DC
Backordering cost per day	2.4	2.4	2.4	N/A
Holding Cost per day	$0.25	$0.25	$0.25	$0.25
Ordering Cost	$160	160	160	160
Fixed Transportation Cost DC	$12	12	12	N/A
Variable transportation cost overseas	$25/unit	$25/unit	$25/unit	$25/unit
Critical Backorder Level	5 units backordered	5 units backordered	5 units backordered	N/A

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