YAŞAR UNIVERSITY
GRADUATE SCHOOL

MASTER THESIS

DESIGN OF LATERAL INVENTORY SHARE POLICIES IN AN OMNI-CHANNEL SUPPLY CHAIN NETWORK

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PRESENTATION DATE: 29.01.2021

BORNOVA / İZMİR
JANUARY 2021

ABSTRACT

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January 2021

Today, with the spread use of internet and communication technologies, customer needs and expectations have changed towards decreased volume order profile with high variety. Hence, these changes and developments have also affected the way of marketing for companies. When competition between companies increase drastically and customer expectations are changing, the concept of e-commerce has gained importance. Companies tend to utilize different combination of distribution channels for that purpose. With the omni-channel marketing, customers can easily switch between shopping channels and interactively benefit from all channels. With the recent order profile, inventory management has become a critical issue in order to overcome inventory uncertainty and cost increase. By the high integration of channels in omni-channel concept, inventory management becomes critical issue for customer satisfaction. In this study, lateral inventory share policies among same echelon companies are studied to reduce unavailability of stocks and demand uncertainty in an omni-channel network. Simulation models are developed in order to compare different lateral inventory share polcies under different connectedness scenarios in omni-channel networks. Total network costs are optimized by considering s, S inventory control policies. The results show that, considering any pre-defined inventory share policy in the system provides better results than considering non-inventory share policy.

Key Words: omni-channel, lateral inventory share, e-commerce, (s, S) inventory policy, inventory control

ÖZ

BÜTÜNCÜL KANAL TEDARIK ZİNCİRİ AĞINDA YANAL ENVANTER PAYLAŞIM POLİTİKALARI

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Ocak 2021

Günümüzde internet ve iletişim teknolojilerinin yaygınlaşması ile müşteri ihtiyaç ve beklentileri, yüksek çeşitlilik ile azalan hacimli sipariş profiline doğru değişmiştir. Dolayısıyla bu değişiklik ve gelişmeler, şirketlerin pazarlama şeklini de etkilemiştir. Firmalar arası rekabet büyük ölçüde arttığında ve müşteri beklentileri değiştiğinde e-ticaret kavramı önem kazanmıştır. Şirketler bu amaçla farklı dağıtım kanalları kombinasyonlarını kullanma eğilimindedir. Bütüncül kanal pazarlama ile müşteriler alışveriş kanalları arasında kolaylıkla geçiş yapabilir ve tüm kanallardan interaktif olarak faydalanabilir. Son sipariş profiliyle birlikte, stok belirsizliği ve maliyet artışının üstesinden gelmek için envanter yönetimi kritik bir konu haline gelmiştir.Bütüncül kanal konseptinde kanalların yüksek entegrasyonu ile envanter yönetimi, müşteri memnuniyeti için kritik bir konu haline geliyor. Bu çalışmada, aynı kademeli şirketler arasındaki yanal envanter paylaşım politikaları, çok kanallı bir ağda stokların yetersizliğini ve talep belirsizliğini azaltmak için incelenmiştir. Bütüncül kanallı ağlarda farklı bağlılık senaryoları altında farklı yanal envanter paylaşım poliçelerini karşılaştırmak için simülasyon modelleri geliştirilmiştir. Toplam ağ maliyetleri, (*s, S*) envanter kontrol politikaları dikkate alınarak optimize edilir. Sonuçlar, sistemdeki herhangi bir önceden tanımlanmış envanter paylaşım politikasının dikkate alınmasının, envanter dışı paylaşım politikasını dikkate almaktan daha iyi sonuçlar verdiğini göstermektedir.

Anahtar Kelimeler: bütüncül kanal, yanal aktarım, e-ticaret, (*s, S*) envanter politikası, envanter kontrolü

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ABBREVIATIONS

ABBREVIATIONS:

B2B Business to Business

IoT Internet of Things

UTAUT2 Unified Theory of Acceptance and Use of Technology 2

MILP Mixed Integer Linear Programming

SLA Service Level Agreement

CSL Customer Service Level

LIS Lateral Inventory Share

.

CHAPTER 1
INTRODUCTION

Digitalization has led to significant changes in customer expectations as well as retailing. Firms sought new channels to meet customer expectations and provide better service. For instance, they are evolving from single-channel to multi-channel, cross-channel and omni-channel commerce (Piotrowicz & Cuthbertson, 2014). E-commerce is one of the most important channels in marketing providing uninterrupted and fast service experiences. By the rapid increase in competitive environment, e-commerce has gained importance as a new sale and marketing concept ensuring customer expectations and satisfaction. With the concept of e-commerce, supply chain networks have become more connected and management of those complex systems has become an important issue to increase the competitiveness of companies.

With the increased connectedness and disappearance of boundaries between the channels, redesign of business relationships considering integrated operating policies has become critical. Omni-channel marketing is a recent marketing policy integrating physical and online channels, enabling consumers to shop from any channel by reaching real time information on product availability (Mosquera et al., 2017). That increased integration in supply networks has also increased the complexity in efficiently management of those networks. Hence, design and analysis of such supply networks for both cost effective and responsive performance metrics is an emerging topic.

Business-to-Business (B2B) models are considered to be one of the building blocks for omni-channel system designs. They enable business applications within the company or between companies in the network. They do not only provide market and economic advantages to businesses but also provide customer sustainability. Due to recent demand profile towards increased variability with low volume, enterprises seek good inventory management policies and practices for their supply chains. Inventory sharing between chain members in the network may be an option providing flexibility and profitability in a supply chain system. By an optimal inventory share policy, total inventory holding costs can be decreased and the customer service level can be increased by the transfer of excess stock between locations. By the recent technological and IoT-based developments, real time communication and active coordination of supply chain members have become possible. Hence, efficiently management of inventory share implementations among locations can contribute the network efficiency and responsiveness, significantly.

An omni-channel system concept is the channel integration not limited to channels bu also channel integration of retail, brand and customer (Juaneda-Ayensa et al., 2016). Hence, issues such as technological equipment, big data and database integration are of great importance in an omni-channel system. Especially, thanks to IoT, it allows the information sharing and integration of online and physical stores, making the omni-channel concept applicable. By that lateral inventory share can be realized enabling fast and low cost response to customer demands in uncertain demand situations (Ekren & Heragu, 2008). In networks, when lateral inventory share is applied at a cost effective way, then customer satisfaction may increase by having products ready all the time. Thanks to Industry 4.0 and its most basic technology, IoT, which has increased the communication between processes in the supply chain and contributed to active coordination (Glazebrook et al., 2014).

In this thesis, we aim to explore the impact of inventory share policies for a multi-channel supply network with interconnected online and offline stores in an IoT environment. By a well designed inventory share policy, our aim is to reduce total network cost by ensuring customer satisfaction and sustainability in the system by reducing total transportation frequency from upper echelons. We consider three online and offline stores and optimize their re-order and order-up-to inventory levels (s, S) under several pre-defined inventory share policies. Due to the complexity of the system, to solve the problem, we utilize a simulation-based optimization procedure. The performance of pre-defined inventory share policies results are compared with each other under their optimized results.

The flow of the thesis is as follows: We define channel types in marketing, multi-channel, cross-channel and omni-channel concepts in Chapter 1. The literature review is summarized in Chapter 2. Methodology, problem definition, simulation models and details of the pre-determined inventory share policies are explained in Chapter 3.

Results are sumamrized in Chapter 4. In Chapter 5, we conclude the work and suggest some future works.

1.1. Multi-channel Strategy

Developing technology has caused great changes in customers' shopping experiences and retailing. In order to achieve success in today's competitive environment and to increase quality of service they provide, companies tend to search for new channels. One of recent approaches in retailing is interaction of companies with customers through multiple channel. Rangaswamy and Van Bruggen (2005) define it as a multi-channel strategy for companies to reach customers and provide services through more than one channel. Many companies mostly reach their customers through television commercials and social media by applying the multi-channel marketing strategies. Similar to customer's purchase through website, they can also buy from a physical store where they are connected. Companies reaching their customers through more than one channel may increase both their profitability and responsiveness. Multi-channel system can provide services through many channels. However, these channels work independently from each other. In other words, it does not allow customers to move between the channels. The multi-channel strategy is not enough to meet today's customer expectations and has caused retailers to search for other new ways (Beck & Rygl, 2015).

1.2. Cross-channel Strategy

Cross-channel has emerged right after the multi-channel concept. In this concept, customer interaction increases by the integration between channels. Although multi-channel and cross-channel serve through the same channels, the biggest difference between them is that cross-channel provides partial integration between channels. Channels can record information among themselves and those information can be transmitted to each other. The company perceives the customer as a single user, even it reaches through different channels or it has more than one information during the shopping process. It allows the customers purchase by switching between channels. For example, a product advertised on social media can be purchased online or in a physical store.

In cross-channel, integration is partially provided, meaning that the transition of customers between channels is limited. Multi-channel and cross-channel do not provide customers with a truly seamless shopping experience. Consumers' uninterrupted shopping and service expectation has revealed by omni-chanel strategy.

1.3. Omni-channel Strategy

By the recent digitalization trend and increased use of internet, customer and retail business behaviors are affected significantly. For instance, companies tend to communicate with customers and provide service through various channels in order not to lose them and gain the new ones so that they can increase their profitability. The current implementation providing this strategy is omni-chanel strategy being implemented by many retailers nowadays.

Omni-channel can be defined as all marketing and distribution channels working together and integrated without interruption (Lazaris & Vrechopoulos, 2014). With this current strategy, the borders between physical and online stores have all disappeared. In the omni-channel concept, customers use all channels and switch between channels without interruption, while in the multi-channel strategy, customers cannot switch between channels. Hence, they may experience interruptions (Melero et al., 2016).

In the following chapter, we discuss the current works in literature including all these concepts in marketing.

CHAPTER 2
LITERATURE REVIEW

Changes in customer behavior due to recent technological developments have also created increased competition between retailers. Thus, they are eager to adapt digitalization faster. Digital channels emerging by the ease of internet access and the spread of mobile devices create customers expect uninterrupted shopping. For instance, e-commerce has experienced significant developments through brick and click channel system.

Digitalization in retail affects consumer behavior and changes consumers' expectations (Rigby, 2011). Lazaris and Vrechopoulos (2014) conduct a comprehensive literature review on retailing, emphasizing that multi-channel retailing has evolved through omni-channel concept. In their study, they define the concept of omni-channel as it integrates all channels and provides uninterrupted use by removing the boundaries between channels. Beck and Rygl (2015) suggest a third form as the hybrid form, in their study. Hybrid form is simply defined as fulfilling a retailer or customer integration or interaction criteria. With today's technological developments and the widespread use of mobile devices, retailers have driven the concept of omni-channel to provide consumers with an uninterrupted shopping experience (Rodríguez-Torrico et al., 2017).

As mentioned previously, multi-channel and omni-channel systems are very similar concepts. The main difference is that customers cannot transit between online and offline channels in the multi-channel. However, in the omni-channel concept, it allows the customers transit between channels without restrictions (Melero et al., 2016). Juaneda-Ayensa et al. (2016) develop an omni-channel understanding and observe consumer behavior. They develop a model based on personal innovativeness and perceived security factors and variables used in a model called UTAUT2. They discuss the concept of omni-channel by developing and expanding multi-channel system. It is stated that it is to provide an integrated customer experience and especially to prepare an efficient technological infrastructure for successfully management of omni-channel applications.

Changing customer expectations with digitalization and technology and different channel conflicts force companies to determine the most appropriate omni-channel strategies. Hosseini et al. (2018) state that the studies of the omni-channel concept mostly have a descriptive perspective and emphasize the high practical need for an efficient omni-channel strategy. In their study, they develop an economic decision model guiding companies to evaluate and choose omni-channel strategies. In this economic decision model, they consider online channels, offline channels, opening and closing channels, non-sequential journeys and channel preferences of customers. They use data from a bank to validate their economic decision model. According the results of the study, it was suggested that companies choose the best contributing omni-channel strategy.

Yadav et al. (2017) propose a mathematical MILP model in an omni-environment. The objectives of this developed model are considered to be maximization of sustainability and minimization of total cost for the studied supply chain. They aim to show the applicability of the suggested model by designing different scenarios. First, the model is solved for a single product and time period. Then, a traditional supply chain network is solved in an environment with similar conditions and the results are compared. The model is coded in GAMS and CPLEX. It is observed that the model developed at the end of the study is much more efficient than the classical supply chain network. However, it cannot be ignored that besides the advantages of this omni-channel strategy, it creates some difficulties for retailers. It is necessary to manage online and offline stores together for an uninterrupted shopping experience, but the different operations of these channels create administrative and financial difficulties. Hübner et al. (2016) emphasize that uncertain customer demands and order, stock, storage and distribution processes of physical and online stores should be synchronized. Pereira et al. (2018) offer a predictive and adaptive omni-channel retail supply chain management approach with machine learning and simulation-based optimization in order to minimize the uncertainty factors created in omni-channel. They propose a clustering method and an artificial neural network method in machine learning for information flow. It is emphasized that artificial neural network can reduce uncertainty in demand forecasting while analyzing consumer behaviors reached by big data by a clustering method. They optimize costs and lead times by using simulation-based optimization and pull/push flows. Using simulation-based optimization and machine learning, they propose a reference model in which the integration and analysis of material, financial and information flows can be achieved and the needs can be determined.

The most critical factors affecting efficiency of a supply chain network are inventory and logistics management. Inventory control should be more flexible in order to minimize negative effects of increased integration and increased demand uncertainties in the omni-channel strategy and to ensure customer satisfaction. With an efficient inventory management, optimum stock levels can be determined and customer demand can be met on time. Lateral inventory share allows stock share of locations at the same echelon helping to reduce costs while increasing customer satisfaction (Lee et al., 2007). However, some difficulties arise in transition from a traditional supply chain to an omni-channel one. In an omni-channel concept, implementation of previously planned logistics operations may become impossible. Integration of shipments for customers who shop from the physical and online stores and, timely delivery of those orders can only be achieved by a successful logistics management. For instance, while designing the logistics operations, physical distribution for virtual and physical customers should be satisfied at the desired service levels (Ishfaq et al., 2016).

Lateral transshipment can be defined to be share of products between stock positions by physically transshipping the products at the same echelon levels in a supply chain. This concept is implemented when there is possibility that demand cannot be fully satisfied by a stocking location. There are many studies in the literature on lateral transshipment. Mostly, studies aim to decide the effect of lateral transshipment on total network cost and how it will occur between stocking locations. Cohen and Lee (1990) find that service levels result well in supply chain as a result of their two case studies in the automobile and computer industries. Axsäter (2003) develops a single-echelon system consisting of several warehouses encountering compound poisson demand. He proposes a new decision rule for lateral transshipment, and this proposed decision is tested by simulation models. He observes that the proposed decision rule performs well.

Lateral transshipment implementations are divided into two main concepts: reactive and proactive, in which the realization differs based on their timing. Banerjee et al.

(2003) observe the effects of lateral transshipment according to some criteria determined in a two-echelon network that includes a single supplier and multiple retailers. In the TBA (lateral transshipments based on availability) approach, the warehouse whose inventory level falls below the stock level is shared from warehouses with excess stock and lateral transshipment occurs. In the TIE (lateral transshipments for inventory equalization) approach, product sharing takes place from the dealers with equal stocks. In terms of statistics, it has been observed that the TBA policy is more effective than the TIE policy in terms of preventing the lack of stock, that is, the inability to meet the demand. In addition, it has been found that in many cases, the TIE policy can provide improvement in transfer costs depending on the actual shipping cost structure. Lee et al. (2007), develop a hybrid lateral transshipment policy called SLA by integrating reactive and proactive sharing approaches. SLA determines the amount of lateral transshipment according to the level of service. It has been observed that this proposed new policy costs less than previous policies of lateral transshipment with a simulation study with a two-echelon supply chain. Olsson (2009) develops a single-echelon inventory system with two stock locations where lateral transshipment is performed when there is a stock shortage in one of stock locations while the other stock location has excess stock. He studies the performance of the (R, Q) policy, by concluding that it is a reasonable policy when the rate of demand is not high.

Heuristic methods are used to determine the appropriate lateral transshipment policy for multi-echelon, multi-stock location supply networks where analytical approaches are not sufficient. Lau et al. (2009) examine the minimization of the cost of a supply chain network, taking into account both a single-purpose and a multi-purpose approach involving three decisions using both vertical and preventive lateral transshipments. They design a decision model integrating supplier selection, vehicle routing and horizontal sharing decisions depending on genetic algorithm and fuzzy logic. As a result of their studies, it is determined that FLGA (fuzzy logic guided genetic algorithms) performs better for scenarios determined in both single-purpose and multi-purpose approaches. Alvarez et al. (2014) develop a model that can only use lateral transshipment for priority customers in two customer classes and multiple warehouses models.They suggest an intuitive approach in determining stock levels. Cost savings have been observed when selective lateral transshipment are used with selective emergency shipping. Glazebrook et al. (2014) propose a hybrid policy that takes economies of scale into account, unlike reactive horizontal sharing policies in a system that is periodically reviewed. By developing a quasi-myopic heuristic method, they determine how to make hybrid transmissions. Zhi and Keskin (2018) investigate the design of a multi-product, lateral transshipment and direct transport capability and three-stage network system to minimize total fixed facility and transportation costs. In their work, they propose two solution algorithms, simulated annealing and GRASP heuristics. As a result of their experiment, it is seen that the two solution algorithms they propose are better than the present heuristic method in the literature related to dispersion search for large-scale problems with capacity constraints, solution quality and duration.

One of the most critical issues in supply chain performance and efficiency is to determine the most accurate reorder point and safety stock level. Ekren and Örnek (2015), (*s, S*) study an inventory control problem using simulation optimization. Amiri-Aref et al. (2018) aim to optimize the position and inventory in a two-echelon supply chain network with uncertain demand and multi-source characteristics. They optimize the (*s, S*) inventory policy they use to avoid demand uncertainty and control inventory with a linear approach. In addition, it is aimed to produce near-optimal solutions by using the average approximation approach. As a result of their studies, they observe that the proposed modeling approach is provided to manage practical situations efficiently and to produce more effective solutions in uncertain situations. Ekren and Arslan (2019) compare different lateral transshipment policies. They model an (*s, S*) inventory control policy by minimizing the network cost by simulation optimization. Their results show that lateral transshipment applications are effective in decreasing total network cost.

There are several works considering the Physical Internet (PI) concept aiming to increase the integration of lateral transshipment and logistics networks. Pan et al. (2015) aim to bring research questions to inventory management with PI and to reveal its effect on traditional inventory control. They aim to show the advantages and importance of PI with the model they develop by (*Q*, *R*) stock policy. Results show that PI performs well in reducing inventory levels and logistics costs. Similarly, Yang et al. (2016a) compare the classical inventory models and PI with each other through the models they developed. Their models are on simulation-based optimization procedures in order to determine the inventory levels in their models. Their results show that logistics costs decrease while maintaining high service level. It is also presented that PI performs better than traditional inventory models. Yang et al. (2016b) observes how PI copes with outages by examining an inventory model with uncertain demand and disruptions caused by stochastic supply. It has been found to be more efficient than traditional inventory models in terms of flexibility and durability.

With Industry 4.0, radical changes take place in supply chains. Increasing and changing customer expectations with e-commerce require supply chain to be more transparent, more integrated and faster. It has made a great contribution to the creation of increased volatility, uncertainty and risks by increasing the integration between the customers supplied in the Industry 4.0 and IoT supply chain. Ben-Daya et al. (2019), present a literature review on relationship between IoT and supply chains. In their literature review, many studies have tried to determine IoT with analytical models and observational experiments. In addition, issues related to food and production chain in marketing have also been focused. Ekren et al. (2020) develop a business model aiming to minimize food waste while ensuring customer satisfaction in a digitalized food supply chain network. In their proposed model, online markets are allowed to send directly to the customers without performing a physical lateral transshipment. Using a simulation-based optimization approach, they determine the (*s, S*) inventory levels for online grocery stores. In their results, they observe that the policies with lateral inventory share performes better than the policy without lateral inventory share in terms of food waste and carried inventory.

E-commerce has become widespread as a result of increasing digitalization. Apart from the integration of online and offline warehouses, there might be a need for integration between channels of different companies. However, this complex structure forces the supply chain to be more visible, more flexible and more integrated in order to cope with costs and to ensure customer sustainability. In the literature, there are studies in which the concept of lateral transshipment is applied to solve these problems. Zhao et al. (2015) conduct a study using lateral transshipment to reduce the risk of demand uncertainty from offline to online (OTO) that is a new trading model. The supply chain model they develop is from a manufacturer, e-store and a retailer. In order to reduce the risks arising from demand uncertainty, lateral transshipment application between the e-store and the retailer is allowed. As a result of their analysis, it has been seen that transshipment is beneficial for OTO, the new trade model. Yu and Wei (2018) propose an inventory control strategy to increase the efficiency of a multi-location e-commerce supply chain network. The inventory control system is developed to improve the performance of the e-commerce supply chain including a combination of quick response and lateral transshipment. The results of this new strategy they proposed show that the lateral transshipment can have a performance-improving effect on the supply chain. İzmirli et al. (2020) develop an omni-channel system aiming to increase customer satisfaction while minimizing total network cost. The online and offline stocking locations of each store are separate from each other and the optimization of (*s, S*) values for each stocking location is determined with a simulation-based optimization approach. They propose a lateral inventory share as a solution and, explore a good one in the studied omni-channel system.

The main motivation of this thesis is to explore a good lateral inventory share in omni-channel supply network preventing cost increase, customer dissatisfaction, excess shipping caused by uncertain inventory level and uncertain demand in an omni-channel supply network. For this reason, we propose five different lateral inventory share policies and optimize the (*s*, *S*) levels under those policies. Then, we compare each policy's performance under its optimal results. In addition to lateral inventory share policies, we also propose a 6th policy where there is no lateral inventory share policy in the system.

CHAPTER 3
SYSTEM DYNAMICS

3.1. Problem Definition

The rapid development of the internet by technological developments resulted with wide use of e-commerce marketing by the retailers. Although the online stores seem to be competitors with physical stores, these two channels are mostly completing each other. Usage of both online and offline marketing strategies forces companies to be more connected and more integrated. This is also mainly because in today's increasingly competitive environment, being accessible from several channels and providing uninterrupted service have gained great importance. Initially, companies implemented multi-channel and cross-channel concepts. However by the increased customer expectations as well as digitalization concept, they are forced to adopt omni-channel concept for more channel integration and seamless customer experience.

Issues such as demand uncertainty and logistics management also brought the implementation of omni-channel strategy to perform efficiently in the supply chain. Channels must be integrated and visible in real time for successful management of both physical and online stores. So, companies look for ways in which they can achieve customer satisfaction and reduce total cost while managing complex supply networks. For example, lateral inventory share applications are one of important applications in reducing total costs, meeting customer demands efficiently with integrated network designs and real-time visibility. Since there cannot be a physical product transshipment in the developed omni-channel system, in this work, instead of lateral transshipment we refer it as lateral inventory share.

In this thesis, an omni-channel strategy serving in an IoT environment where customer demands and inventories have real-time visibility is evaluated. In this system, we examine a multi-channel supply chain network with separate stocking locations for both online and offline demands connected to each other and, to a main warehouse assumed to have infinite inventory capacity. As an inventory control policy, an inventory policy with a continuous review method (s, S) is implemented. This policy, also called the min-max system, increasing the inventory level to S (order up to level) by re-ordering when the inventory level falls below the s (order level) value. When the customer orders the product from the online or offline store, lateral inventory share takes place if there is not enough product in the stock place. Inventory share takes place not only between stocking locations of the same company's store, but also between different companies. This inventory sharing policy among businesses, also known as B2B, aims to reduce cost while customer sustainability is increased.

In this work, it is assumed that there are three different companies having both their online and offline stores. It is also assumed that there is single type of product. Each stocking location is assumed to have its own demand distribution. When the required demand cannot be met from the regarding stocking location, inventory share takes place based-on the pre-defined policy. In the studied system, inventory share can take place not only between online and offline stocking locations of a single store, but also between online and offline stocking locations between different companies. Figure 3.1 shows the studied omni-channel network. In that figure, dashed arrows show information flow while solid lines show product flows.

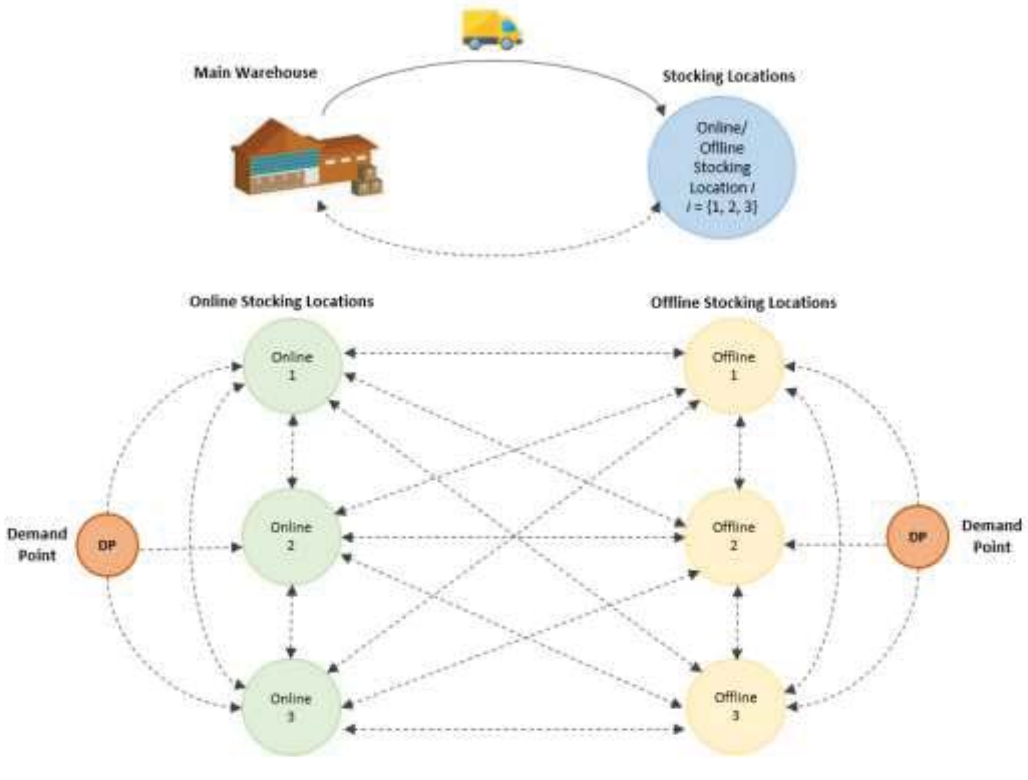


Figure 3.1. Omni-Channel Network with Lateral Inventory Share

The aim of this work is to minimize total network cost by optimizing the (*s, S*) inventory levels at each stocking location. It is significant to determine the optimal (*s, S*) levels in order to increase efficiency and the responsiveness in supply chains. The considered models are simulated in Arena 16.0 commercial software, and the (*s, S*) levels are optimized by the OptQuest optimization tool provided with this software. The performance metrics that are considered to be optimized are total network cost while satisfying the desired fill rate. The details of the simulation models along with the assumptions are summarized in Section 3.2.

3.2. Simulation Model Assumptions

The inventory share policies and the assumptions of the studied omni-channel network are summarized below:

- There are three stores and, each store has a separate online and offline store marketing its products. Hence, there is a total of six stocking locations in the same echelon.
- The network processes single type of product.
- Each depot has its separate demand distribution where online depots have higher mean demand distributions than offline depots.
- The mean inter-arivals of demand follows Exponential distribution with mean one day.
- Demand amounts follow normal distribution for the stocking locations. They are: Normal (70, 20), Normal (50, 20), Normal (90, 20) for online store 1, 2 and 3, respectively. They are: Normal (35, 20), Normal (25, 20), Normal (45, 20) for offline store 1, 2 and 3, respectively.
- There is a main depot at the upper echelon providing products with infinite capacity.
- There is lead time from main depot to the depots that is UNIF (1, 2) days.
- The amount of replenishment (Q_{it}) for stocking location *i* at time *t* is counted as on hand even it has not arrived yet when re-ordering from the main depot.
- There is a truck capacity from the main warehouse considered to be 100 products/truck.
- There is no number of trucks constraint in the system.

- For the demand that offline stores cannot meet, it is assumed that with 75% probability the customers accept to supply them from another store.
- (s, S) levels are optimized for each store individually under 95% fill rate constraint of the network.
- For offline depots by assuming that there might be a tighter capacity constraint in storing the products, order up to levels, S_i, are considered to be 200 products. For online stores, no capacity is considered.
- All simulation models are run for one year.
- Ten independent replications are performed for each simulation model.
- Warm-up periods are 60 days for each model.
- Total cost includes holding, ordering, transportation, lateral inventory share and lost sale costs.
- Common Random Numbers (CRN) technique has been used in simulation models. Thanks to this technique, it has been ensured that the random numbers are consistent with each other in all scenarios.
- Verification and validation of the models are done by animating and debugging the models, respectively.

Besides the simulation model assumptions, we summarize the notations that are used in modelling in Section 3.3.

3.3. Notations Considered in the Simulation Models

The notations that are used for simulation models are summarized below:

s_i: safety stock level of stocking location i, $i = \{1, 2, 3, 4, 5, 6\}$.

S_i: up-to-level of stocking location i, $i = \{1, 2, 3, 4, 5, 6\}$.

k: the number of total stocking locations (i.e., $k = 6$).

d_{it}: incoming demand amount to the online / offline store i, $i = \{1, 2, 3, 4, 5, 6\}$, at time t.

TD_i: total demand for stocking location i, $i = \{1, 2, 3, 4, 5, 6\}$.

C_T: truck capacity from main depot (i.e 100 per truck).

I_{it}: inventory level at stocking location *i*, at time *t*.

IS_{ji}: inventory share cost per product from stocking location *j* to *i*, *i* = {1, 2, 3, 4, 5, 6}, *j* = {1, 2, 3, 4, 5, 6}.

L_{jit}: stock amount sent from stocking location *j* to *i* with lateral inventory share at time *t*.

LF_{ji}: frequency of lateral inventory share from stock location *j* to stocking location *i*, *i* = {1, 2, 3, 4, 5, 6}, *j* = {1, 2, 3, 4, 5, 6}.

T_C: total fixed transportation cost for a single truck send from the main depot to any storage location (i.e., $100 per truck).

LS_{it}: total amount of lost sales at stocking location *i, i* = {1, 2, 3, 4, 5, 6}, at time *t*.

Q_{it}: product amount sent from the main depot to stocking location *i*, *i* = {1, 2, 3, 4, 5, 6}, at time *t*.

A_{it}: available amount of inventory at stocking location *i*, at time *t*.

q_{ijt}: amount of product sent from stocking location *i* to stocking *j* with lateral inventory share at time *t*, *i* = {1, 2, 3, 4, 5, 6}, *j* = {1, 2, 3, 4, 5, 6}.

nt_{it}: number of trucks shipped from the main depot to the stocking location *i* at time t, *i* = {1, 2, 3, 4, 5, 6}.

sr_{it}: stock ratio among all for online stocking location *i*, *i* = {1, 2, 3} at time *t*.

tr_i: total sr_{it} amount for online stocking location *i*, *i* = {1, 2, 3}.

ra_{jt}: ratio of available product at online stocking location *i* at time *t*, *i* = {1, 2, 3}.

DT: total amount of demand arrived at the network at the end of simulation run.

QR_{it}: amount of products on road from the main depot to the stocking location *i*, *i* = {1, 2, 3, 4, 5, 6}, at time *t*.

C_o: ordering cost per product.

C_{LS}: lost sale cost per product.

C_h: holding cost per product.

I_t: time based carried inventory on hand.

TQ: total amount of order from the main depot.

I_{DAVG}: daily average inventory carried in the network.

I_{AAVG}: yearly average inventory carried in the network.

TLS_C: total lost sale cost in the network.

TO_C: total order cost in the network.

TT_C: total transporatation cost in the network.

TIS_C: total inventory share cost in the network.

TH_C: total holding cost in the network.

CSL_i: customer service level for stocking location i, $i = \{1, 2, 3, 4, 5, 6\}$.

IS_{ji} is set to \$1/product if product share occurs between stocking locations of the same company, and \$1.5/product if product share occurs between different company stocking locations. C_o is set as \$1.5/product. Inventory levels at stocking locations are checked in real time. If the inventory level of stocking location i is less than s_i, Q_{it} amount of products are ordered from the main warehouse calculated by (1).

$$Q_{it} = \begin{cases} S_i - I_{it} & if\ I_{it} \leq s_i\ and\ QR_{it} = 0, \\ S_i - I_{it} - QR_{it} & if\ I_{it} \leq s_i\ and\ QR_{it} > 0, \\ 0 & otherwise \end{cases} \quad (1)$$

TQ value is computed by (2) when k represents the number of stocking loacations (i.e $k = 6$) and T represents the simulation run time (i.e 365 days):

$$\sum_{t=1}^{T} \sum_{i=1}^{k} Q_{it} \quad (2)$$

At the end of the simulation run, we calculate a customer service level at stocking location i (CSL_i) by (3):

$$CSL_i = 1 - LS_i / TD_i \quad (3)$$

(4) shows the calculation of total amount of inventory in the network. Daily average inventory carried (I_{DAVG}) and yearly average inventory carried (I_{AAVG})calculations are shown by (5) and (6), respectively. Here, k represents the number of stores in the network (i.e $k = 6$) and T represents the simulation run time (i.e 365 days).

$$I_t = \sum_{t=1}^{T} \sum_{i=1}^{k} I_{it} \tag{4}$$

$$I_{DAVG} = \int_{0}^{T} I_t dt \Big/ T \tag{5}$$

$$I_{AAVG} = I_{DAVG} \times 365 \tag{6}$$

nt_{it} value is computed by (7) and the value found is rounded to the next integer value:

$$nt_{it} = Q_{it} \,/\, C_T \tag{7}$$

Total cost calculations for different performance metrics considered in the simulation model are shown by (8) – (12).

$$TLS_C = \sum_{i=1}^{k} \sum_{t=1}^{T} (LS_{it} \times C_{LS}) \tag{8}$$

$$TO_C = \sum_{i=1}^{k} \sum_{t=1}^{T} (Q_{it} \times C_O) \tag{9}$$

$$TT_C = \sum_{i=1}^{k} \sum_{t=1}^{T} (nt_{it} \times T_C) \tag{10}$$

$$TIS_C = \sum_{j \neq i}^{k} \sum_{i=1}^{k} \sum_{t=1}^{T} \left(L_{jit} \times IS_{ji}\right) \tag{11}$$

$$TH_C = I_{AAVG} \; x \; 20\% \; x \; \left[\frac{TO_C + TT_C}{TQ}\right] \tag{12}$$

In (12), 20% is considered to be yearly interest rate. In (13), we show the total network cost calculation. Here, *k* represents the number of stores in the network (i.e *k* = 6) and *T* represents the simulation run time (i.e 365 days).

$$TC = TLS_C + TO_C + TT_C + TIS_C + TH_C \quad (13)$$

3.4. Policies of Lateral Inventory Share

In a network where lateral inventory share strategy is implemented, it can also be observed how the frequency and quantity of lateral transshipment, order frequency and quantity from the main warehouse and costs are affected. In order to compare how those impacts change, we define six lateral inventory share policies applied between three companies at the same echelon level of stocking locations. The considered scenarios are based on how those stocking locations are connected and hence whether or not they can to share their inventory products. In addition to the lateral share-based scenarios, a policy without lateral inventory share policies is also modeled for the comparison purpose. There are three different demand arrival scenarios at the online stocking locations. All policies modeled are individually optimized under three different lost sale per product costs (i.e., \$5, \$10, \$20). This thesis aims to determine the most efficient inventory share policy in terms of several performance metrics.

In Figure 3.2, a general flow chart diagram independent from a specific lateral inventory share is shown. In that figure, if demand is larger than the current inventory level at its arriving location, then lateral inventory share takes place according to the pre-defined policy.

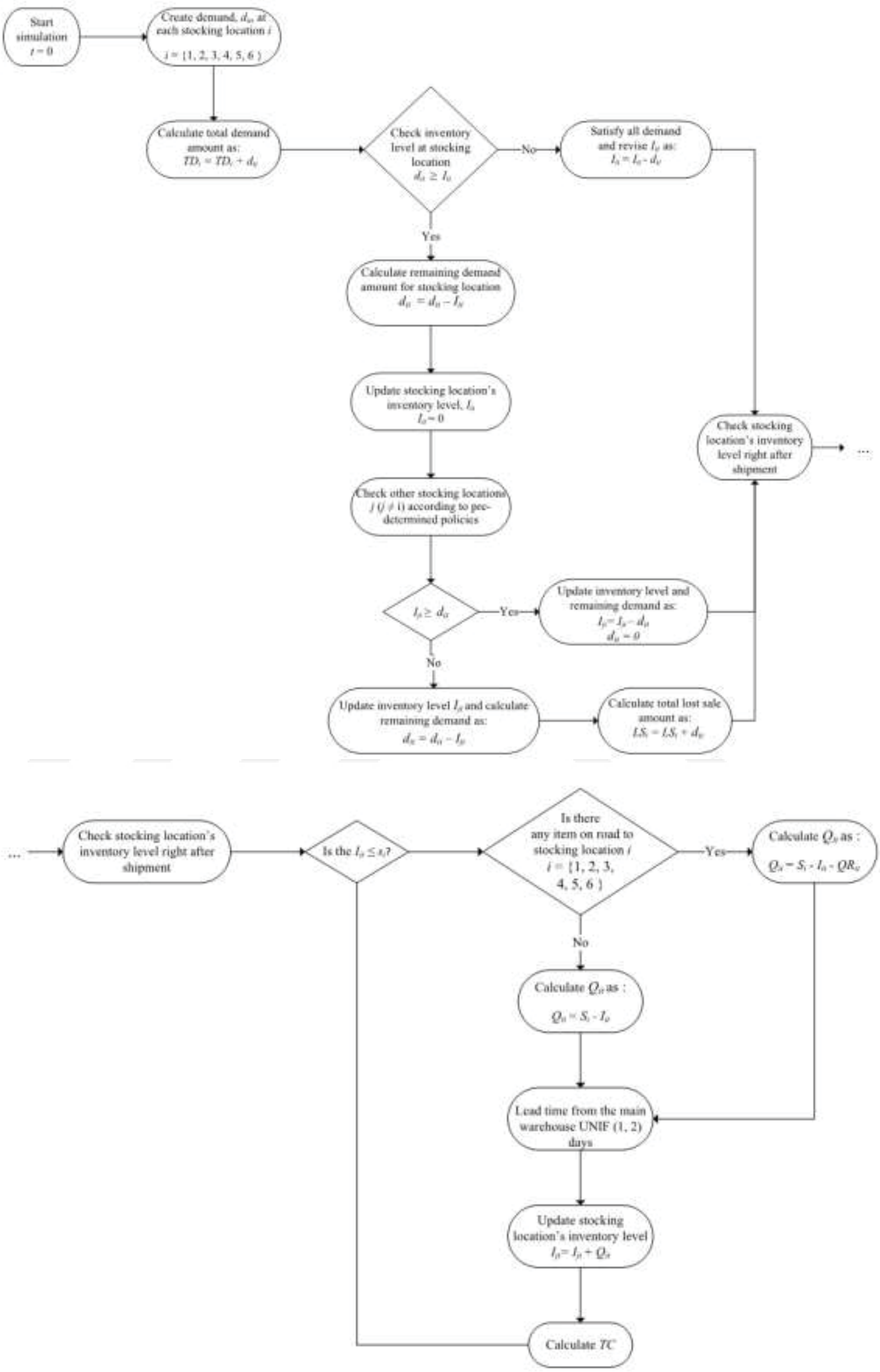


Figure 3.2. Lateral Inventory Share Applied in Simulation Model

Figure 3.3 shows the general flow diagram of the system without lateral inventory share.

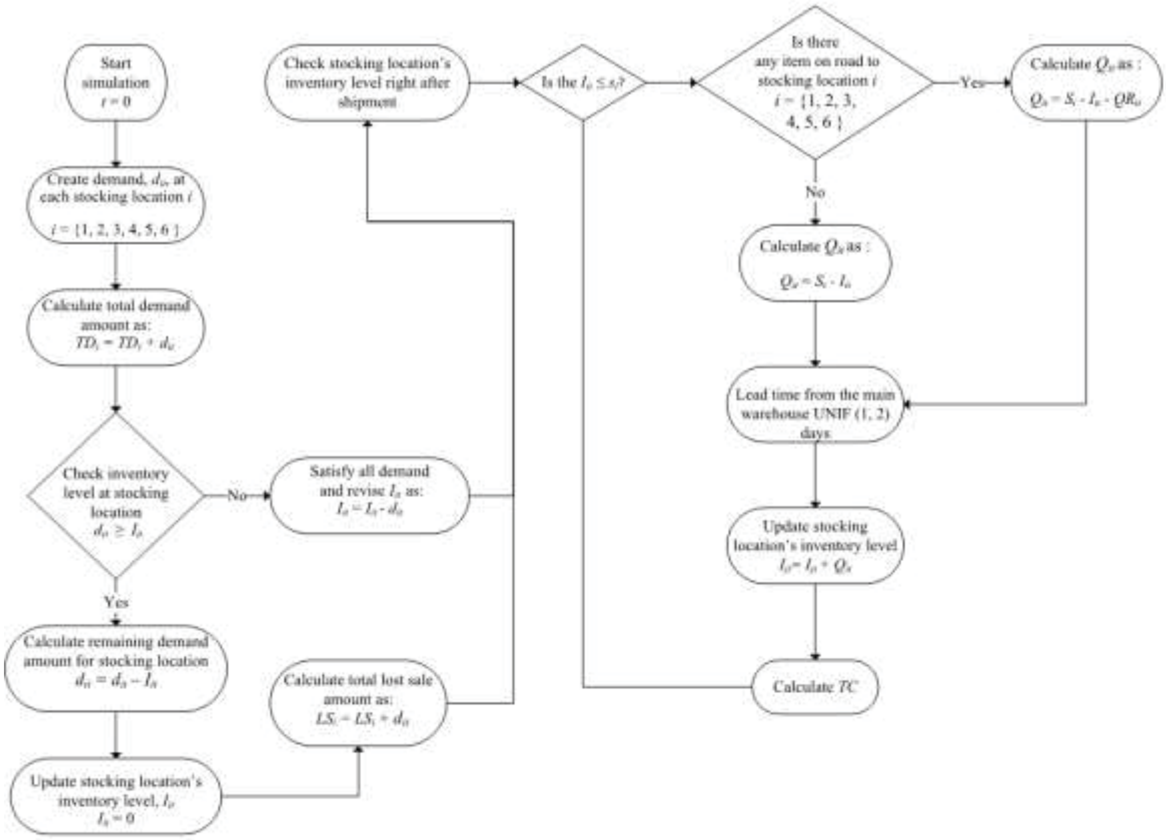


Figure 3.3. Simulation Model without Lateral Inventory Share

In Figure 3.4 pseudo-codes showing how we calculate the amount of order (i.e., replenishment amount) to be sent from the main warehouse to the stocking i presented.

```
Start
    i = 1                        // stocking locations
    while i <= 6
                    if  I_it ≤ s_i and QR_it = 0 then
                            Q_it = S_i - I_it
                            Delay with UNIF (1, 2) day
                            TQ_it = TQ_it + Q_it
                    else if  I_it ≤ s_i and QR_it > 0
                            Q_it = S_i - I_it - QR_it
                            Delay with UNIF (1, 2) day
                            TQ_it = TQ_it + Q_it
                    else
                            Q_it = 0
                    end if
            i = i+1
    end while
    i = 0
End
```

Figure 3.4. Pseudo-codes for Replenishment Amount Calculations from the Main Warehouse

In the following section, we explain the considered inventory share scenarios.

3.4.1. Policy 1 for Online Stocking Locations with Lateral Inventory Share

Remember that in the studied omni-channel network, there are both online and offline stocking locations of a company. This policy is related with the sharing policy when demand arrives at online stocking locations. In Policy 1, each online stocking location is linked to its offline stocking location (see Figure 3.5). Also, all online stocking locations are connected and can share inventory information and physical product between them. When demand arrives at stocking location *i*, and the amount of demand cannot be fully met then, first this company's offline stocking location is checked whether or not it has the remaining amount of inventory for the unmet demand. If it has the required amount of inventory for the remaining demand, then all are met from that offline stocking location. Otherwise, the available amount is sent to the demand point and, the updated remaining amount is started to be met by the other online stocking locations having the largest stock level. If still not all demand can be met, then the remaining amount will be considered as lost sale. Figure 3.5 shows the considered network and how online and offline stocking locations are connected. In this figure, dashed arrows show information flow while solid lines show product flows.

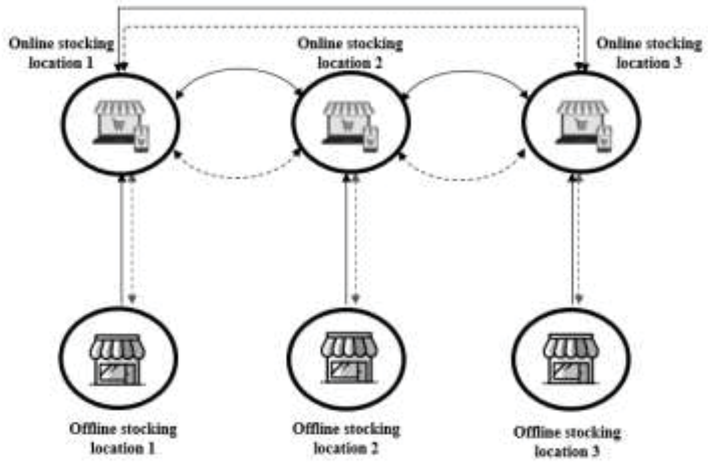


Figure 3.5. Online Storage Location and Relationships between Other Online/Offline Stocking Locations

The steps taking place in Policy 1 are as follows:

Step 1: Demand arrives at online stocking location *i*, if it can be fully met by that online stocking location, then all are sent from stocking location *i*.

Step 2: Otherwise, all available products are sent from that online store and, the remaining demand is attempted to be sent from this company's offline stocking location.

Step 3: If there is not enough amount of product in the offline store then, the remaining amount is started to be met by the online stocking locations with the highest inventory levels.

Step 4: If the demand cannot be fully met, the remaining amount will be lost sale.

In Figure 3.6, we provide the pseudo-codes of this policy.

```
Start
        i = 1    // online stocking locations
        while  i ≤ 3
                TD_i = TD_i + d_it
                if     I_it ≥ d_it     //this if statement part is for the stocking location where the
                incoming demand and the offline storage location of its own store
                                        I_it= I_it - d_it
                                        d_it = 0
                else
                                        d_it= d_it - I_it            // update remaining demand
                                        I_it = 0
                end if
                if     d_it > 0
                                while  j ≤ 2
                                    I_jt = Max (I_jt)  // Determine the online stocking stocking
                        location j with the highest inventory level
                                            if     I_jt ≥ d_it
                                                        I_jt  = I_jt – d_it
                                                        d_it = 0
                                            else
                                                        d_it= d_it – I_jt
                                                        I_jt = 0
                                            end if
                                    j = j + 1
                                end while
                        j = 0
                end if
                if     d_it > 0
                            LS_it = LS_it + d_it          //lost sale amount
                end if
                i = i+1
        end while
        i = 0
End
```

Figure 3.6. Pseudo-codes for Policy 1

3.4.2. Policy 2 for Online Stocking Locations with Lateral Inventory Share

The demand meeting principle in Policy 2 is very similar with Policy 1. Namely, also in Policy 2, as in Policy 1, lateral share takes place in an order of online stocking locations having the highest inventory level. However, this time the sharing stocking location *i*, can send the amount of products that would not cause to decrease its inventory level less than its re-order point, s_i.

The steps in Policy 2 are summarized as follows:

Step 1: Demand arrives at online stocking location *i*, if it can be fully met by that online stocking location, then all are sent from stocking location *i*.

Step 2: Otherwise, all available products are sent from that online store and, the remaining demand is attempted to be sent from this company's offline stocking location.

Step 3: If there is not enough amount of product in the offline store then, the remaining amount is started to be met by the online stocking locations with the highest inventory levels. However, it is not allowed for an online stocking location to send the amount of product causing to fall below of its re-order level.

Step 4: If the demand cannot be fully met, the remaining amount will be lost sale.

In Figure 3.7, we provide the pseudo-codes for Policy 2.

```
Start
    i = 1   // online stocking locations
    while  i ≤ 3
        TDi = TDi + dit
        if     Iit ≥ dit    //this if statement part is for the stocking location where the
        incoming demand and the offline storage location of its own store
                        Iit= Iit - dit
                        dit = 0
        else
                        dit= dit - Iit              // update remaining demand
                        Iit = 0
        end if
        if     dit > 0
                while  j ≤ 2
                        Ijt = Max (Ijt)  // Determine the online stocking stocking
            location j with the highest inventory level
                        if    Ijt ≥ sj
                                AIjt  = Ijt − sj
                                if    dit ≥ AIjt
                                        dit = dit − AIjt  //update remaining
                    demand
                                        Ijt = Ijt − AIjt
                                        AIjt = 0
                                else
                                        AIjt = AIjt - dit
                                        Ijt = Ijt − AIjt
                                        dit = 0
                                end if
                        end if
                        j = j + 1
                end while
            j = 0
        end if
        if     dit > 0
                LSit = LSit + dit          //lost sale amount
        end if
        i = i+1
    end while
    i = 0
End
```

Figure 3.7. Pseudo-codes for Policy 2

3.4.3. Policy 3 for Online Stocking Locations with Lateral Inventory Share

In Policy 3, inventory share takes place according to a pre-calculated proportion. In another word, online stocking locations can share their products based on the ratios calculated on their current inventory levels out of all. Except this, the initial principle of demand meeting rule is same as in Policies 1 and 2.

The steps in Policy 3 are as follows:

Step 1: Demand arrives at online stocking location i, if it can be fully met by that online stocking location, then all are sent from stocking location i.

Step 2: Otherwise, all available products are sent from that online store and, the remaining demand is attempted to be sent from this company's offline stocking location.

Step 3: If there is not enough amount of product in the offline store then, the remaining amount is distributed among stocking locations based on the pre-defined proportions detailed in Figure 3.8.

Step 4: If the demand cannot be fully met, the remaining amount is counted as lost sale.

In Figure 3.8, we provide the pseudo-codes for Policy 3.

```
Start
        i = 1    // online stocking locations
        while  i ≤ 3
                TD_i = TD_i + d_it
                if      I_it ≥ d_it     //this if statement part is for the stocking location where the
                incoming demand and the offline storage location of its own store
                                I_it= I_it - d_it
                                d_it = 0
                else
                                d_it= d_it - I_it                    // update remaining demand
                                I_it = 0
                end if
                if      d_it > 0
                                while     j ≤ 2
                                                tdj_t = I_jt   + tdj_t // calculate the total inventories of
                                 stoking locations
                                                j = j + 1
                                end while
                                 j = 0
                                while     j ≤ 2
                                                I_jt = Min (I_jt)
                                                sr_jt =  I_jt / Min (I_jt)
                                                tr_jt = tr_jt + sr_jt
                                                j = j + 1
                                end while
                                 j = 0
                                while     j ≤ 2
                                                ra_jt =  td_jt/  tr_jt
                                                j = j + 1
                                end while
                                 j = 0
                                while     j ≤ 2
                                                AI_jt =  I_jt × ra_jt
                                                I_jt =  I_jt – AI_jt
                                                d_it = d_it – AI_jt // update remaining demand
                                                j = j+ 1
                                end while
                                 j = 0
                end if
                if      d_it > 0
                                LS_it = LS_it + d_it          //lost sale amount
                end if
                i = i+1
        end while
        i = 0
End
```

Figure 3.8. Pseudo-code for Policy 3

3.4.4. Policy 4 for Offline Stocking Locations with Lateral Inventory Share

This policy is considered for offline stocking locations. If the arriving demand at offline stocking location *i* cannot be fully met, then we assume that the customer accepts to wait to meet his/her demand from another store with 75% probability. Here, the offline store's unmet demand can only be met from the same company's online stocking location. Figure 3.9 shows how offline and online stocking locations are connected.

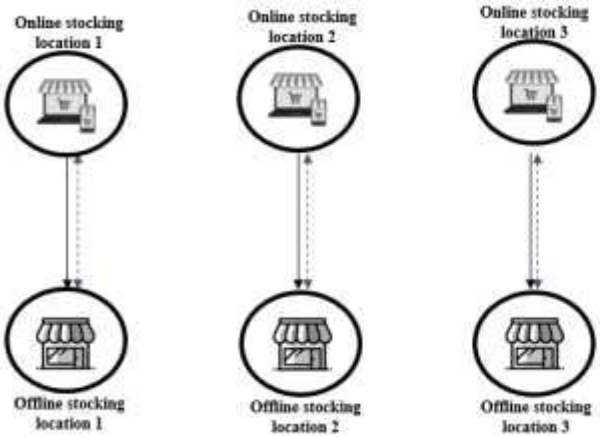


Figure 3.9. Connection Structure for Online and Offline Stores for Policy 4

The steps in Policy 4 respectively are as follows:

Step 1: Demand arrives at offline stocking location *i*. If it can be fully met by that offline stocking location, then all are met by location *i*.

Step 2: Otherwise, the remaining demand is met by the same company's online stocking location. However, it is assumed that with 75% probability, the customer accepts its remaining demand to be met by its online store.

Step 3: If the demand cannot be fully met, the remaining amount is counted as lost sale.

In Figure 3.10, we provide the pseudo-codes for Policy 4.

```
Start
        i = 1    // offline stocking locations
        while  i ≤ 3
                TDi = TDi + dit
                if      Iit ≥ dit      //this if statement part is for the stocking location where the
                incoming demand and the offline storage location of its own store
                                Iit= Iit - dit
                                dit = 0
                else
                                dit= dit - Iit                  // update remaining demand
                                Iit = 0
                end if
                if      dit > 0
                        if      (if customer accepts with 75% probability, stocking location can
                        product shipment from online stocking location of own store)
                                if      Ijt ≥ dit
                                                Ijt= Ijt - dit
                                                dit = 0
                                else
                                                dit= dit – Ijt   // update remaining demand
                                                Ijt = 0
                                end if
                        end if
                end if
                if      dit > 0
                                LSit = LSit + dit          //lost sale amount
                end if
                i = i+1
        end while
        i = 0
End
```

Figure 3.10. Pseudo-codes for Policy 4

3.4.5. Policy 5 for Offline Stocking Locations with Lateral Inventory Share

As in Policy 4, also in this policy, in the case where offline stocking location *i* cannot meet the demand fully, with 75% probability the customers accept to meet the demand from online stocking location. However, this time, the remaining demand is met from online stocking locations having largest inventory levels. Figure 3.11 shows the connection structure of offline and online stocking locations in this policy.

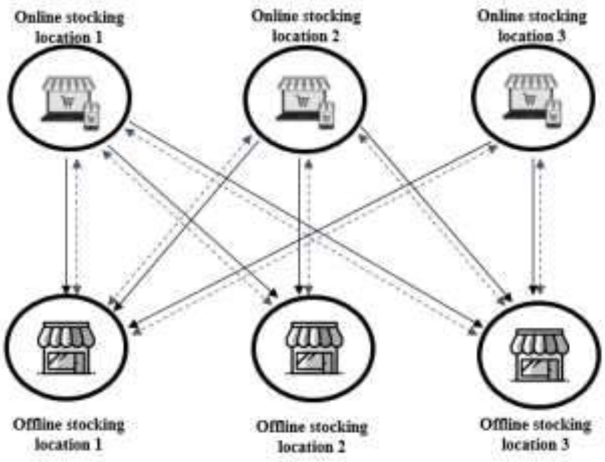


Figure 3.11. Connection Structure For Online and Offline Stores for Policy 5

The steps in Policy 5 are as follows:

Step 1: Demand arrives at offline stocking location *i*. If it can be fully met by that offline stocking location, then all are met by location *i*.

Step 2: Otherwise, remaining demand is met, starting with online stock locations from the largest stock levels.

Step 3: If the demand cannot be fully met, the remaining amount is counted as lost sale.

In Figure 3.12, we provide the pseudo-codes for Policy 5.

```
Start
        i = 1    // offline stocking locations
        while  i ≤ 3
                TD_i = TD_i + d_it
                if      I_it ≥ d_it      //this if statement part is for the stocking location where the
                incoming demand and the offline storage location of its own store
                                I_it= I_it - d_it
                                d_it = 0
                else
                                d_it= d_it - I_it                   // update remaining demand
                                I_it = 0
                end if
                if      d_it > 0
                        if      (if customer accepts with 75% probability, stocking location can
                        product shipment from online stocking locations)
                                        while   j ≤ 3
                                                I_jt = Max (I_jt) // Determine the online stocking
                                stocking location j with the highest inventory level
                                                        if      I_jt ≥ d_it
                                                                I_jt = I_jt - d_it
                                                                d_it = 0
                                                        else
                                                                d_it= d_it – I_jt
                                                                I_jt = 0
                                                        end if
                                                j = j + 1
                                        end while
                                j = 0
                        end if
                end if
                if      d_it > 0
                                LS_it = LS_it + d_it          //lost sale amount
                end if
                i = i+1
        end while
        i = 0
End
```

Figure 3.12. Pseudo-codes for Policy 5

3.4.6. Policy 6 without Lateral Inventory Share

Besides the inventory share-based policies, we also study no inventory share policy and consider this policy in the comparison procedure as well. In this policy, the arriving demand at a stocking location can only be met by this location. In another word, no lateral inventory share takes place under the unmet demand condition.

In Figure 3.13, we present the pseudo codes for Policy 6.

```
Start
        i = 1    // stocking locations
        while  i ≤ 6
                TDi = TDi + dit
                if        Iit ≥ dit
                          Iit= Iit - dit
                          dit = 0
                else
                          dit= dit - Iit              // update remaining demand
                          Iit = 0
                end if
                if        dit > 0
                              LSit = LSit + dit          //lost sale amount
                end if
                i = i+1
        end while
        i = 0
End
```

Figure 3.13. Pseudo-code for Policy 6

3.5. OptQuest Optimizer

Simulation modelling approach is widely utilized for policy or strategy optimization. It is usually hard to optimize complex systems by a mathematical model. OptQuest optimizer tool provided the by the Arena software, makes it easier to reach the optimal results by heuristically searching for alternatives. This tool uses combinations of three different metaheuristic heuristics: tabu search, neural networks, and scatter search (Kleijnen and Wan, 2007). It basically searches for the optimal results depending on the objective function, constraints and variables. OptQuest initiates the search procedure based on the lower, suggested, and the upper values decision variables specified by the user. The suggested value entered in the variables section is the starting point of the search procedure (Kleijnen and Wan, 2007). OptQuest tries to achieve the best result by minimizing or maximizing the entered objective function by running the simulations more than once depending on the replication determined (Kleijnen and Wan, 2007). In this thesis, the decision variables are considered to be the (*s, S*) values of stocking locations.

3.6. Warm-up Period Determination

We do a steady-state analysis. Hence, we determine a proper warm-up period for each scenario. To do that we utilize the output analyzer in Arena software. The Output Analyzer analyzes the output statistics obtained from the simulation runs. By output analyzer, understanding of outputs becomes easier with graphical representations and comparison of outputs.

In warm-up period determination, we utilize the cost per demand product as the main output. In Equation (5), we show how we calculate this output in simulation model. Then, we draw its time-persistent graph so that we observe when the system reaches the steady state condition.

$$TC \,/\, DT \tag{14}$$

Figure 3.14 shows the graph drawn by the output analyzer. We consider the longest period among the multiple replications. Here, we define the time as 42 days where the system reaches to steady-state state condition. However, to be more precise, the warm-up period is determined to be 60 days. We integrate this in the run information and add this amount to the desired total run length.

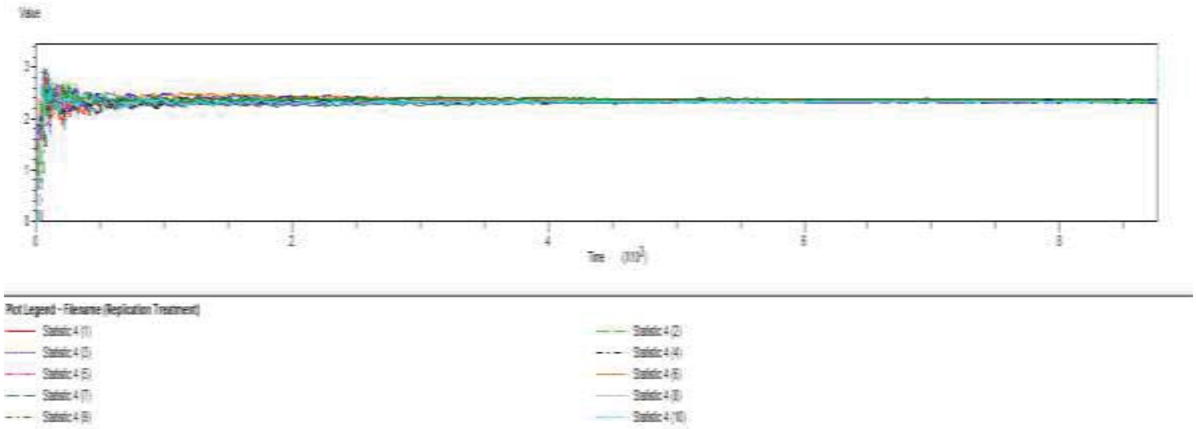


Figure 3.14. Warm-up Period

CHAPTER 4
SIMULATION RESULTS

In this chapter, we summarize the results from Arena simulation and OptQuest runs. As mentioned before, seven different scenarios, six of which are based on lateral inventory share policies, are applied in the omni-channel system. Besides, a model without lateral inventory share is also examined. The results of these scenarios are compared in terms of several outputs. While three of the scenarios, Policy 1, Policy 2 and Policy 3, are defined based on incoming demands at online stocking locations; two of them, Policy 4 and Policy 5, are defined based on incoming demands at offline stocking locations. By an experimental design manner, we merge all possible combinations of online and offline share policies so that we obtain six possible lateral share combinations. For instance, Policy 1&5 combines policies 1 and 5, developed for online and offline stores, respectively. Besides, since we also have a non-lateral share scenario, totally seven scenarios are optimized by the OptQuest tool.

We also complete a sensitivity analysis on those seven policies under different lost sale cost assumptions: \$ 5, \$ 10, \$ 20. Namely, each of seven scenario is optimized under those cost parameters. Here, our aim is also to observe how lost sale unit cost affects performance of the studied lateral inventory share policies.

Screenshots from the OptQuest runs and the results for Policy 1&5 are shown in Figure 4.1. Note that, in OptQuest, (*s, S*) levels, re-order and up to the order levels are optimized and determined individually for each stock location. Hence, a total of 12 (2 x 6) decision variables are optimized. The objective function is considered to be the minimization of total network cost. While the total network cost is minimized, which CSL is limited to at least 95% in order to ensure customer satisfaction. The objective function and constraints entered in the OptQuest tool are as shown in Equation (6) - (9).

$$Minimize \quad TC \tag{6}$$

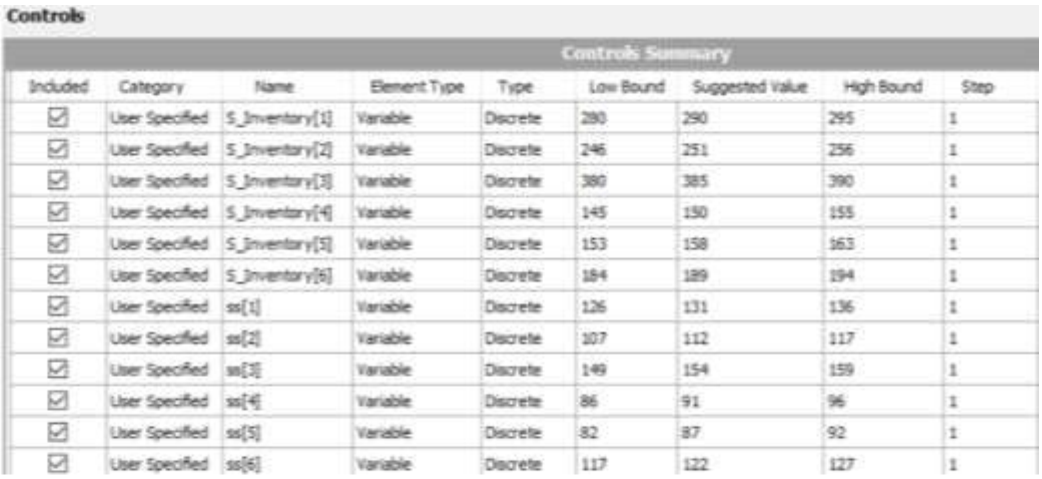
$$\text{s.t.} \quad CSL \geq 0.95 \tag{7}$$

$$S_i \leq 200,\ i = \{4, 5, 6\} \tag{8}$$

$$s_i < S_i,\ \forall i \tag{9}$$

(a)


(b)


(c)


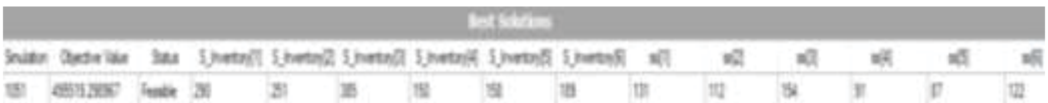
(d)


Figure 4.1. Screenshots from OptQuest: (a) Visualized analysis of values for Policies 1 and 5; (b) Constraints in OptQuest; (c) The control part where bounds are entered for (s, S) values; (d) The part where the best solution is presented with optimized (s, S) values

Tables 4.1 - 4.3 show the (*s*, *S*) values obtained by the Optquest runs.

Table 4.1 (*s*, *S*) Values Obtained by OptQuest When C_{LS} is $5

	Online 1	**Online 2**	**Online 3**	**Offline 1**	**Offline 2**	**Offline 3**
Policy	**(s_1, S_1)**	**(s_2, S_2)**	**(s_3, S_3)**	**(s_4, S_4)**	**(s_5, S_5)**	**(s_6, S_6)**
1&4	(134, 370)	(69, 214)	(142, 390)	(105, 168)	(90, 176)	(106, 180)
2&4	(116, 353)	(87, 295)	(115, 401)	(108, 176)	(98, 160)	(108, 178)
3&4	(121, 334)	(65, 283)	(200, 464)	(115, 174)	(69, 144)	(138, 191)
1&5	(70, 299)	(102, 248)	(170, 334)	(92, 166)	(77, 131)	(68, 198)
2&5	(120, 307)	(106, 341)	(108, 376)	(101, 169)	(86, 163)	(105, 157)
3&5	(110, 365)	(86, 257)	(155, 468)	(101, 185)	(84, 156)	(103, 178)
6	(253, 355)	(200, 292)	(299, 430)	(130, 174)	(127, 181)	(147, 188)

Table 4.2 (*s*, *S*) Values Obtained by OptQuest When C_{LS} is $10

	Online 1	**Online 2**	**Online 3**	**Offline 1**	**Offline 2**	**Offline 3**
Policy	**(s_1, S_1)**	**(s_2, S_2)**	**(s_3, S_3)**	**(s_4, S_4)**	**(s_5, S_5)**	**(s_6, S_6)**
1&4	(114, 388)	(100, 284)	(122, 415)	(99, 172)	(90, 153)	(120, 199)
2&4	(105, 345)	(133, 377)	(138, 395)	(102, 169)	(91, 163)	(114, 185)
3&4	(136, 382)	(40, 227)	(203, 522)	(139, 197)	(59, 116)	(114, 173)
1&5	(132, 291)	(114, 255)	(150, 388)	(94, 153)	(84, 156)	(125, 184)
2&5	(91, 334)	(97, 350)	(141, 384)	(100, 171)	(70, 136)	(125, 191)
3&5	(155, 360)	(108, 254)	(229, 472)	(95, 175)	(80, 155)	(101, 190)
6	(274, 359)	(250, 315)	(311, 427)	(128, 175)	(135, 173)	(150, 192)

Table 4.3. (s, S) Values Obtained by OptQuest When C_{LS} is $20

	Online 1	**Online 2**	**Online 3**	**Offline 1**	**Offline 2**	**Offline 3**
Policy	**(s_1, S_1)**	**(s_2, S_2)**	**(s_3, S_3)**	**(s_4, S_4)**	**(s_5, S_5)**	**(s_6, S_6)**
1&4	(177, 356)	(128, 271)	(152, 419)	(110, 173)	(109, 181)	(123, 188)
2&4	(145, 441)	(77, 328)	(171, 435)	(125, 183)	(99, 164)	(122, 181)
3&4	(158, 415)	(148, 293)	(211, 463)	(100, 171)	(115, 188)	(139, 196)
1&5	(138, 393)	(137, 275)	(142, 363)	(108, 170)	(123, 193)	(144, 199)
2&5	(100, 367)	(110, 397)	(167, 419)	(121, 193)	(89, 162)	(122, 172)
3&5	(146, 392)	(81, 339)	(224, 477)	(77, 140)	(101, 172)	(141, 197)
6	(285, 404)	(250, 371)	(314, 469)	(131, 198)	(145, 168)	(148, 197)

Some findings related to (s, S) values are as follows:

- Generally, the re-order stock levels of models with lateral inventory share policies are lower compared to the model without a lateral inventory share policy. The reason for this is probably that, to assure the fill rate constraint (i.e., >95%) in no lateral inventory share policy (i.e., Policy 6) the network carries more safety inventory than the other scenarios.
- When the lost sale cost per unit increases, the re-order levels mostly tend to increase.

Table 4.4 - 4.6 show results and half-width values at 95% confidence interval results at the optimized (s, S) values for different lost sale per product cases.

Table 4.4. Performance Results for All Policies When C_{LS} is \$5

Policy	Total Lost Sale Cost	Total Transportation Cost	Total Holding Cost	Total Inventory Share Cost	Total Ordering Cost	Total Cost
1&4	17,280± 2,950.8	140,410± 2,624.4	141,820± 2,209.7	19,649± 1,612.3	167,430± 3,293.9	486,590± 7,113.9
2&4	19,586± 2,207.8	141,180± 2,968.5	151,190± 2,181.5	17,523± 1,118.4	167,850± 3,602.8	497,330± 3,602.8
3&4	23,006± 2,589.7	144,440± 2,434.4	155,420± 2,595.6	16,274± 1,379.4	169,860± 2,967.2	509,000± 6,539.3
1&5	15,435± 1,444.3	140,770± 2,606.2	122,160± 1,766.2	28,880± 1,448.9	168,470± 3,097.7	475,720± 5,963.2
2&5	18,327± 2,412.5	141,220± 2,536.5	143,840± 1,652.7	21,446± 1,168.6	167,400± 2,847.3	492,230± 2,847.3
3&5	20,042± 1,891.4	139,470± 3,231.3	152,670± 3,651.9	20,107± 1,337.9	167,840± 3,651.9	500,130± 6,637.7
6	28,356± 3,047.6	159,000± 2,850.8	215,570± 2,412.9	0	166,900± 3,214.9	569,830± 5,862.1

Table 4.5. Performance Results for All Policies When C_{LS} is \$10

Policy	Total Lost Sale Cost	Total Transportation Cost	Total Holding Cost	Total Inventory Share Cost	Total Ordering Cost	Total Cost
1&4	29,221± 3,083.6	141.570± 2,854.6	156,500± 2,192.9	17,636± 1,134.8	167,960± 3,350.3	512.880± 7,447.9

4.5. (cont'd). Performance Results for the Policies When C_{LS} is \$10

Policy	Total Lost Sale Cost	Total Transportation Cost	Total Holding Cost	Total Inventory Share Cost	Total Ordering Cost	Total Cost
2&4	38,577± 4,417.8	137,810± 2,293.8	158,970± 2,012.8	16,067± 1,225.4	167,440± 2,779.2	518.860± 7,827.5
3&4	36,948± 1,851.2	140,540± 2,976.3	161,400± 2,105.6	15,674± 920.05	167,010± 3,681.0	521,570± 6,074.8
1&5	21,976± 3,148.9	144,540± 3,262.6	136,030± 2,197.1	22,936± 1,639.8	170,040± 3,665.8	495,520± 7,775.0
2&5	27,022± 2,140.3	139,590± 2,471.1	147,100± 1,949.6	20,839± 1,476.8	169,250± 3,233.5	503,800± 5,761.9
3&5	28,074± 3,680.1	144,540± 2,977.1	159,720± 2,431.7	16,034± 1,315.1	169,790± 3,523.3	518,160± 7,667.1
6	53,131± 6,222.0	161,490± 2,879.1	227,910± 2,575.6	0	167,470± 2,575.6	610,000± 8,469.3

From Table 4.5 it is observed that there is a negative correlation between lateral inventory share cost and holding cost. When lateral inventory share cost decreases, holding cost tend to increase. In addition, it is observed that when lateral inventory share cost increases, total cost tends to decrease.

Table 4.6. Performance Results for the Policies When C_{LS} is \$20

Policy	Total Lost Sale Cost	Total Transportation Cost	Total Holding Cost	Total Inventory Share Cost	Total Ordering Cost	Total Cost
1&4	41,576± 5,195.3	143,580± 2,538.4	162,200± 2,432.8	15,234± 1,130.0	170,490± 3,253.9	533,080± 7,668.3
2&4	49,086± 4,256.1	141,200± 2,800.1	173,620± 2,052.8	14,161± 1,312.2	170,250± 3,586.2	548,320± 8,717.6
3&4	50,200± 10,586.0	140,940± 1,995.2	182,040± 2,128.6	10,283± 1,057.8	170,060± 2,710.0	553,530± 12.949.0
1&5	25,430± 5,172.7	144,810± 3,359.5	162,270± 2,277.3	17,724± 1,543.9	171,890± 4,179.6	522,130± 8,956.2
2&5	39,930± 7,014.1	142,430± 2,772.2	169,390± 2,037.4	16,796± 618.23	170,000± 3,177.4	538,550± 11,185.0
3&5	41,654± 7,692.9	141,280± 3,756.3	171,830± 3,029.3	14,647± 1,137.3	171,330± 4,703.5	540,740± 12,726.0
6	83,668± 8,498.9	159,560± 2,849.5	247,470± 2,445.9	0	169,080± 3,231.0	659,780± 11,054.0

According to Table 4.6, it is observed that there is a negative correlation between lateral inventory share and lost sale costs. Except for Policy 3&5, total cost decreases as the cost of lateral inventory share increases in all policies.

Tables 4.7 - 4.9 show results and half-width values at 95% confidence intervals for some critical outputs for each policy under optimal results. Frequency of lateral inventory share (LIS) shows how many times lateral inventory share takes place between locations. The relationship between the total amount of product by lateral inventory share and the lateral inventory share cost, total sales amount and total sales cost, ordering frequency from the main warehouse and ordering cost from the main warehouse, and the number of trucks sent from main warehouse and transportation cost given in the table are shown. Besides, it also shows how all these results change fill rate.

Table 4.7. Results of Important Variables When C_{LS} is $5

Policy	LIS Frequency	Amount of Product Shared by LIS	Total Lost Sale Amount	Frequency of Orders Given to the MW	Total Number of Trucks Sent from the MW	Fill Rate
1&4	478.10± 31.546	18,127± 1,417.0	3,456.1± 590.17	839.10± 17.461	1,404.1± 26.244	0.97004± 0.00485
2&4	419.40± 20.838	15,885± 987.49	3,917.3± 441.57	841.80± 17.242	1,411.8± 29.625	0.96622± 0.00320
3&4	458.70± 38.613	15,731± 13.882	4,601.2± 517.95	846.00± 13.882	1,444.4± 24.344	0.96071± 0.00388
1&5	644.40± 29.487	24,540± 1,112.4	3,087.1± 288.97	850.10± 15.723	1,407.7± 26.062	0.97327± 0.00224
2&5	493.30± 28.606	17,905± 964.74	3,665.5± 482.50	868.60± 16.921	1,412.2± 25.365	0.96881± 0.00385
3&5	512.60± 35.872	18,187± 1,287.2	4,008.5± 378.29	771.80± 17.462	1,394.7± 32.313	0.96511± 0.00310
6	0	0	5,671.3± 609.52	1,215.5± 26.143	1,590.0± 28.508	0.95157± 0.00476

Table 4.8. Results of Important Variables When C_{LS} is \$10

Policy	LIS Frequency	Amount of Product Shared by LIS	Total Lost Sale Amount	Frequency of Orders Given to the MW	Total Number of Trucks Sent from the MW	CSL
1&4	417.50± 23.650	16,343± 997.36	2,922.1± 308.36	801.30± 12.657	1,415.7± 28.546	0.97462± 0.00236
2&4	338.50± 23.279	14,431± 18.826	3,857.7± 441.78	807.60± 16.826	1,378.1± 22.938	0.96664± 0.00344
3&4	475.70± 25.981	15,446± 949.43	3,694.8± 185.12	862.30± 14.894	1,405.4± 29.763	0.96773± 0.00163
1&5	528.10± 28.765	19,764± 1,425.9	2,196.6± 314.89	958.70± 15.902	1,445.4± 32.626	0.98100± 0.00256
2&5	476.70± 29.950	17,469± 1,246.5	2,702.2± 214.03	822.00± 15.061	1,395.9± 24.711	0.97660± 0.00181
3&5	432.70± 29.450	13,882± 1,147.8	2,807.4± 368.01	799.50± 15.271	1,445.4± 29.771	0.97572± 0.00297
6	0	0	5,313.1± 622.20	1,344.8± 25.807	1,614.9± 28.791	0.95466± 0.00473

Table 4.9. Results of Important Variables When C_{LS} is \$20

Policy	LIS Frequency	Amount of Product Shared by LIS	Total Lost Sale Amount	Frequency of Orders Given to the MW	Total Number of Trucks Sent from the MW	CSL
1&4	361.10± 23.816	14,149± 962.23	2,078.8± 259.79	912.90± 17.019	1,435.8± 25.854	0.98207± 0.00211
2&4	345.10± 24.603	12,843± 1,118.6	2,454.3± 212.80	857.70± 14.886	1,412.0± 2,309.8	0.97884± 0.00165
3&4	291.60± 25.863	9,850± 1,118.4	2,510.0± 529.30	873.40± 16.273	1,409.4± 19.952	0.97834± 0.00426
1&5	400.80± 27.491	16,081± 1,338.5	1,271.5± 258.63	947.10± 19.50	1,448.1± 33.595	0.98902± 0.00226
2&5	377.50± 15.610	14,019± 482.82	1,996.5± 350.70	846.70± 18.208	1,424.3± 27.722	0.98305± 0.00272
3&5	390.30± 27.578	12,369± 1,024.4	2,082.7± 398.14	844.00± 17.592	1,412.8± 37.563	0.98211± 0.00311
6	0	0	5,671.3± 424.94	1,189.9± 23.820	1,595.6± 28.495	0.95157± 0.00326

According to the results in Tables 4.4 - 4.9, it is observed that lateral inventory share affects the system positively. This is because in Policy 6, the total cost is always the highest one in any of the lost sale cost scenario.

The other findings can be summarized as follows:

- As the cost of lost sale per unit increases, the amount of lost sale decreases and fill rate increases. This is probably because that the locations tend to carry more inventory under high C_{LS} value.
- Lateral inventory share decreases the total network cost and increases fill rate. However, total network cost and fill rate are not directly related to inventory

sharing frequency and lateral inventory cost. Generally, as the lateral inventory share increases, the cost of holding decreases. However, as the cost of lost sales per unit increases, the amount and cost of lateral inventory share decreases.

- In all policies, the total lost sale cost is lower in policies with lateral inventory share compared to policies without lateral inventory share. Policy 1 & 5 provides the lowest total lost sales cost under all lost sale unit cost scenario. This policy allows lateral inventory share and does not impose any restrictions for its implementation.
- The number of trucks sent from the main warehouse and the total transportation cost are reduced by lateral inventory share scenarios, so the total network cost is positively affected.
- The total amount of product by lateral inventory share and total lateral inventory share cost decreases as the lost sale amount per unit increases. Holding cost increases as lost sale cost increases. In other words, in order to prevent the increase of total cost with the increase in lost sales cost, the system holds more inventory instead of making a lateral inventory share.
- The policy that provides the lowest total cost and highest fill rate for all lost sales costs is Policy 1&5.

In the following sections, we summarize the results by graphs to observe how costs distribute under optimal results.

4.1. Total Lost Sale Cost

According to results, it is observed that although the amount of lost sale decreases, lost sale costs increase mostly due to increase in unit cost. Figure 4.2 summarizes total lost sale costs based on policies under the optimal results.

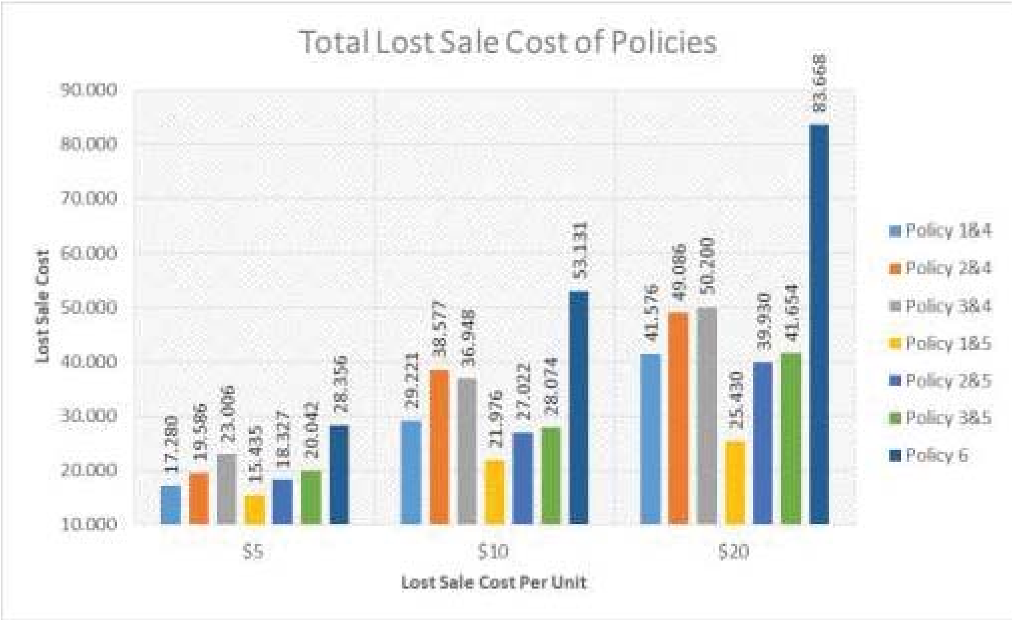


Figure 4.2. Total Lost Sales Cost of the Policies

As seen in Figure 4.2, the highest total lost sale cost is in policies without lateral inventory share (i.e.,Policy 6). Lateral inventory share ensures customer satisfaction and sustainability by reducing the amount of lost sales in all unit lost sales and all policies. Policy 1 & 5 is the policy that has the least lost sales cost among all scenarios. Note that, this policy has the least restrictions on lateral inventory share. Allowing to make lateral inventory share whenever required, regardless of the lateral inventory share amount, gives the most positive result. Although the lateral stock share does not reduce the cost of lost sales, it is definitely observed that it positively affects all models.

4.2. Total Transportation Cost

Figure 4.3 shows total transportation costs based on policies under optimal results. According to that figure, there is no significant difference between the results even unit loss sale cost increase. This is probably because that the amount of demand received is same in all policies. Policy 6 without lateral inventory share has the highest total transportation cost in all lost sale unit costs scenario. It is observed that the lateral inventory share has a positive effect on reducing the total transportation cost.

Figure 4.3. Total Transportation Costs of the Policies

4.3. Total Holding Cost

Figure 4.4 shows holding cost results based on scenarios under optimal results. It is observed that holding cost increases as the lost sale unit cost increases.

Figure 4.4. Total Holding Costs of the Policies

The least holding cost takes place in Policy 1&5. Besides, when no lateral inventory share policy is considered, total holding cost increases drastically. In other words, the stocking locations, reduce the cost of holding by sharing inventory, instead of keeping excess products, and preventing customer loss.

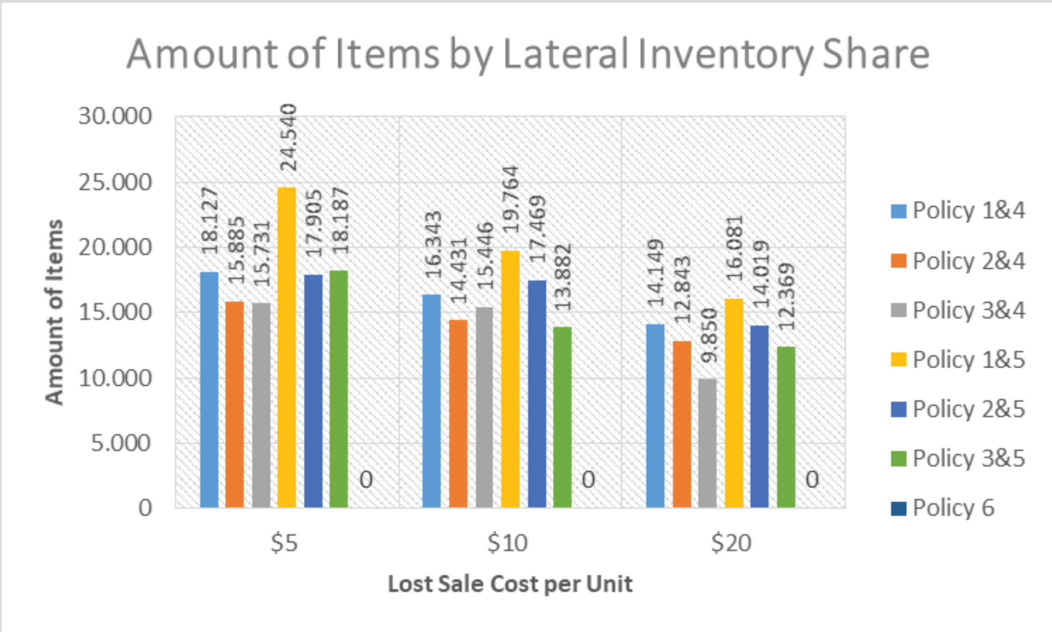


Figure 4.5. Amount of Products by Lateral Inventory Share of the Policies

Figure 4.5 shows amount of products shared by laterally. It is observed that Policy 1&5 has highest amount of products by lateral inventory share in all lost sales cost scenarios.

As the lost sales unit cost increases, the lateral amount tends to decrease. This probably because that with the increase in lost sale unit cost, the systems tends to carry more inventory not to cause lost sale. This results with decreased lateral inventory share.

4.4. Total Lateral Inventory Share Cost

Figure 4.6 shows lateral inventory share cost based on scenarios under optimal results. According to that figure, when cost of unit lost sale increases, the cost of lateral inventory share decreases.

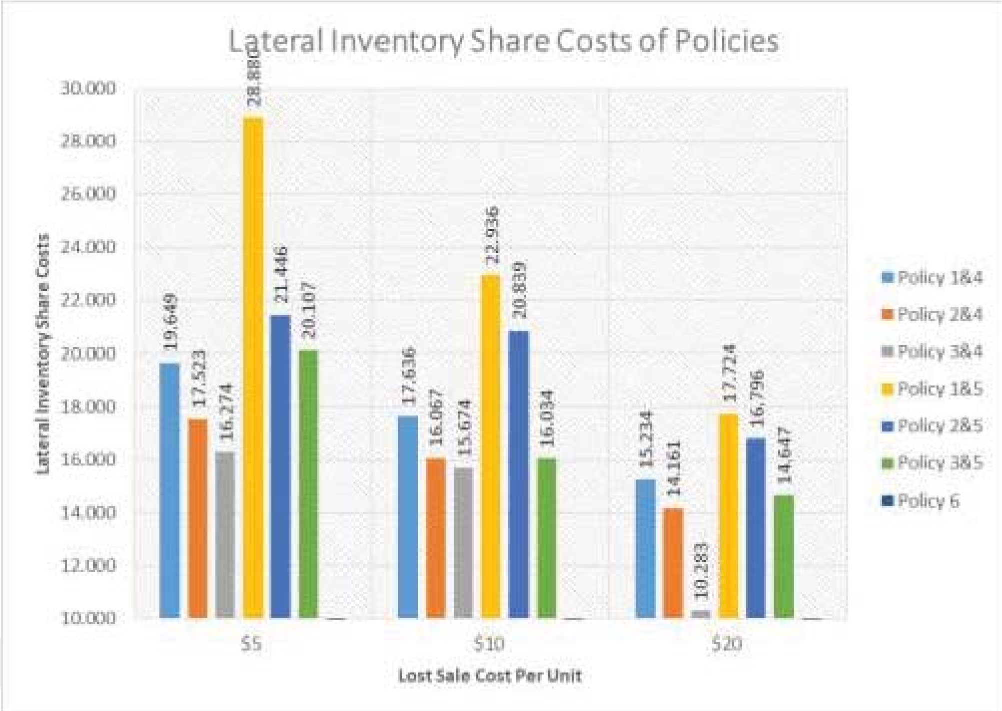


Figure 4.6. Total Lateral Inventory Share Costs of the Policies

As mentioned earlier, as the cost of lost sales increases, the system retains more products to reduce the lost sale risk. Thus, the need for a lateral inventory share is reduced. However, according to the results, policies with lateral inventory share give better results than those without lateral inventory share. For all lost sale unit costs, Policy 1 & 5 has the highest lateral inventory share cost.

4.5. Total Cost

Figure 4.7 shows the total cost of all policies based on all lost sales unit costs. As mentioned previously, the best policy is obtained by Policy 1&5 at all unit lost sale cost scenario. Besides, from Figure 4.7, it is observed that when there is any lateral inventory share policy in the network, it outperforms compared to the policy when there is no lateral inventory share.

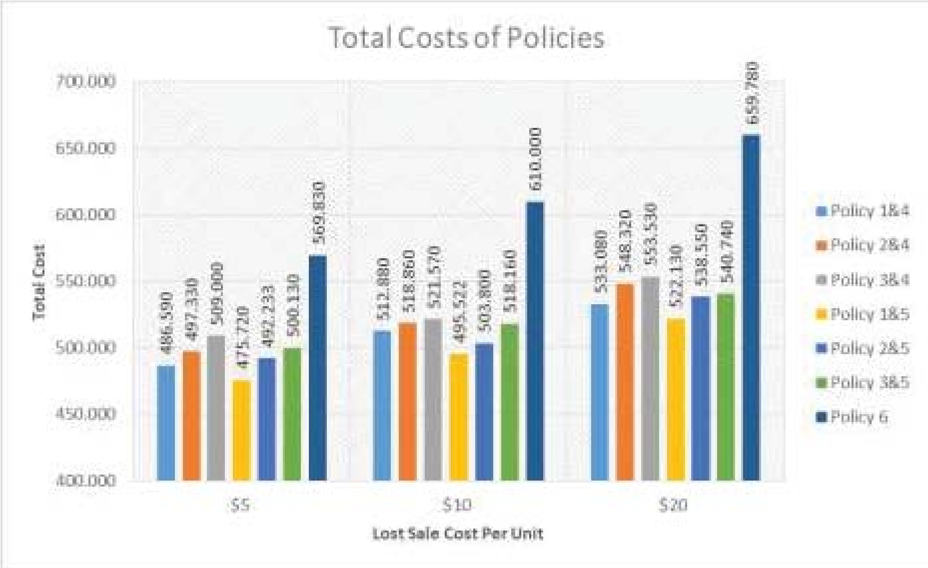


Figure 4.7. Total Cost of the Policies

CHAPTER 5
CONCLUSION AND FUTURE WORK

The rapid improvement of technology and the new economic order have forced companies to seek new marketing strategies to meet customer expectations. Among those strategies, the most common new marketing strategy today is omni-channel marketing strategy. Omni-channel is a customer-centric strategy and aims to provide customer service through all channels. However, it becomes difficult to manage online and offline stocking locations together due to operational differences. The inadequacy of traditional supply chain applications, increasing demand uncertainty and complex logistics management make it difficult to apply this new concept. In an increasingly competitive environment, it is of great importance to be able to respond to customer demands in the fastest way possible. This makes supply chain management a critical one. Thanks to Industry 4.0 components such as IoT and big data, it has become easier to monitor and manage processes such as storage, supply process and stock tracking. This digitalization in the supply chain has enabled real-time tracking of data and information, and this has enabled the implementation of lateral inventory share policies in the supply chain. Therefore, for companies with omni-channel strategy, developing lateral inventory share policies minimizing total cost and ensuring customer satisfaction is of great importance to overcome uncertain demand and difficult logistics management problems.

The aim of this thesis is to observe how the total network cost and customer satisfaction are affected when a lateral inventory share strategy is implemented in an omni-channel system. Also, we aim to seek a good lateral inventory share policy in the studied network. When the studies in the literature about omni-channel are examined, it is observed that there are limited studies. With this study, we aim to shed a light on development of lateral invetory share models for the solution of inventory ready problem for customer demands. A single echelon network having six stocking locations as online and offline stores is developed and the results of six pre-determined sharing policies are compared under optimal network costs. In addition, sensitivity analysis is performed by running the policies for three different lost sale unit cost scenario: \$5, \$10, \$2. In the simulation models, (*s, S*) inventory levels are optimized by using OptQuest optimization tool was provided in Arena 16.0 commercial software.

Results show that, there have been significantly reduced total cost and lost sales when there is a well defined lateral inventory share policy in the network. For instance, Policy 1&5 provides the minimum network cost one, among the pre-defined policies. The results obtained with different unit lost sale costs show that, when the unit cost of lost sale increases, holding cost tends to increase due to increased stock amount. The reason for this is probably that although the lateral inventory share provides increased customer satisfaction while reducing total cost, when the lost sale cost increases, the system increases the amount of products it holds in order to reduce the customer service level. As a result of the models, when there is lateral inventory share in the system, we observe that total lost sale cost, total transportation cost and total holding cost decrease when compared to non-lateral policy applications.

Another finding is that lateral stock share implementation has positive effect on total network cost and customer satisfaction. Policies 1 and 5, the policy with the least restrictions, provide the best cost result. Allowing side stock sharing when necessary, regardless of the amount of side stock share, it provides better results in all models and all lost sales unit cost scenarios. In general, this study shows that if companies implement a well designed multi-channel strategy adapting lateral inventory share policy total network cost can be reduced, sustainability and customer satisfaction can be achieved.

As future works, the effects of lateral inventory share policies on omni-channel networks can be investigated by more different inventory share policies as well as demand distribution scenarios. Besides, more sensitivity analysis can be done based on different cost parameters.

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