THE JOINT LOCATION-DISTRIBUTION-INVENTORY MODEL FOR A MULTI-ECHELON SUPPLY CHAIN NETWORK CONSIDERING MULTI-SOURCING, DROP SHIPPING, AND LATERAL TRANSSHIPMENTS

BY

MS. DIEP THI THAO LY

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE
(ENGINEERING AND TECHNOLOGY)
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Thesis Title	THE JOINT LOCATION-DISTRIBUTION-INVENTORY MODEL FOR A MULTI-ECHELON SUPPLY CHAIN NETWORK CONSIDERING MULTI-SOURCING, DROP SHIPPING, AND LATERAL TRANSSHIPMENTS
Author	Ms. Diep Thi Thao Ly
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ABSTRACT

Competitive pressure in the global marketplace inquires enterprises to establish efficiently distribution planning and inventory management in supply chain. This study proposes a framework to optimize distribution and inventory decisions integrating decisions of opening or closing facilities in multi-echelon supply chain network under non-stationary demand. The model adopts distribution requirements planning (DRP) technique and considers flexible distribution strategies, including multiple sourcing, drop shipping, and lateral transshipments to minimize the expected total cost. The original stochastic model has been simplified into the equivalent deterministic mixed-integer linear programming by following the sample average approximation (SAA) technique.

Besides, the numerical experiments are conducted to validate the model and its practical application. The results indicate the model adopting multiple flexible distribution strategies outperforms the models adopting single distribution strategy. The study is applied for enterprises who sell products through their both physical stores and online stores on e-commerce platforms or the company's private website.

Keywords: Multi-echelon supply chain network, Distribution requirement planning, Multi-sourcing, Drop shipping, Lateral transshipments, Demand uncertainty, Opening or closing facility

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Symbols/Abbreviations	**Terms**
DRP	Distribution requirements planning
ROP	Reorder point
SAA	Sample average approximation
MILP	Mixed integer linear programming
MINLP	Mixed integer non-linear programming
CAP	Capacity
D	Deterministic
S	Stochastic
NS	Non-stationary
LT	Lateral transshipments
MS	Multi-sourcing
DS	Drop shipping
AC	Allocation cost
PC	Procurement cost
HC	Holding cost
BC	Backorder cost
RTC	Regular transportation cost
DSC	Drop shipping cost
TC	Transshipment cost

CHAPTER 1

INTRODUCTION

1.1 Context and motivations

In accompany with the development of information technology and logistics industry, supply chain uncertainty factors require executives to operate the distribution and inventory system efficiently. Adopting the flexibility sourcing and distribution strategies helps a company to quickly respond to uncertainty factors in terms of supply disruptions, lead time and demand uncertainty. Particularly, companies use several sourcing and distribution policies simultaneously such as multiple sourcing, drop shipping, lateral transshipments with the aim of enhancing customer service and reducing stockout risk and inventory cost as well.

1.1.1 Flexibility sourcing and distribution

Many relevant researches have discussed multiple sourcing, drop shipping and lateral transshipments as flexible sourcing and distribution strategies in large-scale supply chain. However, most of them consider these strategies separately.

Lateral transshipment is defined as exchanging inventory between warehouses at the same echelon level of multi-echelon supply chain (Axsäter, 2015; Axsäter, Howard, & Marklund, 2013; Jin-Hong, Rui-Xuan, & Gui, 2015; Min, 2008; F. Zhao, Wu, Liang, & Dolgui, 2016).

Multi-sourcing is a strategy using two or many suppliers to tackle and decrease the supply disruption risk (Glock & Ries, 2013; Ho, 1990; Silbermayr & Minner, 2014, 2016; Wang, Jiang, Li, & Liu, 2008).

Drop shipping is defined that the demand of an echelon is forwarded to a supplier or its upper echelons, who fulfil the orders by shipping the products directly to the customers on its behalf. For regular distribution channel, the inventory of a stocking point is fed by upper echelon stocking point and each stocking point keeps inventory to satisfy its demand. Even so, the lost sales problem occurs when the inventory of a stocking point is out of stock. While the advantage of traditional system is that upper facilities have full control of supply process to their lower echelon, drop shipping can be used as a backup strategy in case of stockout (Dennis, Cheong, & Sun, 2017).

Combining between traditional and drop shipping distributions is called dual distribution channel. Dual channel can help to balance service level and inventory cost under demand uncertainty (Khouja & Stylianou, 2009; J. Zhao, Duan, Wang, & Huo, 2012).

The benefit of the combination of these sourcing and distribution strategies will be evaluated in this study.

1.1.2 Network design

According to Cardona-Valdés, Álvarez, and Ozdemir (2011), the strategic decisions of network design determine the supply chain configuration, which have long-term impacts on the performance of supply chain. Making decision basically bases on the trade-off analysis between the total costs and the responsiveness. Specifically, the number of facilities is directly proportional to the responsiveness to customer. The facility cost is a large financial burden on businesses because of a large amount of cost to open or close a facility or move a facility to another location. Over time, many parameters such as demand, replenishment lead time, and costs of supply chain network can have huge fluctuations. Many approaches have been being applied for supply chain network design under uncertainty over recent year such as fuzzy approach (Ramezani, Kimiagari, Karimi, & Hejazi, 2014), stochastic approach (Subulan, Baykasoğlu, Özsoydan, Taşan, & Selim, 2015), mathematical modelling (Kumar et al., 2017; Prakash, Soni, & Rathore, 2017), robust optimization (Prakash, Kumar, Soni, Jain, & Rathore, 2020), and so on.

Moreover, location decisions impact significantly on inventory and distribution costs, so solutions can be sub-optimality if there is not the incorporation between them. The joint location-distribution-inventory models have been being extensively studied (Ahmadi-Javid & Seddighi, 2012; Miranda & Garrido, 2008).

1.1.3 Supply chain distribution and inventory management

Although multi-echelon supply chain distribution and inventory problems have attracted many recent researches (Amiri-Aref, Klibi, & Babai, 2018; Firoozi, 2018; Martel, 2003; Yang, Pan, & Ballot, 2017), there is not any research combining traditional distribution with flexible distributions satisfying both online and offline markets in the integration into network design problem. Most of researches of multi-echelon supply chain only concentrate on offline channel (Alawneh & Zhang, 2018; Ayanso, Diaby, & Nair, 2006; Bailey & Rabinovich, 2005; Chen, Chen, Parlar, & Xiao, 2011). Recently, Firoozi, Babai, Klibi, and Ducq (2020) proposed a multi-echelon supply chain distribution and inventory model considering multi-sourcing and lateral transshipments under demand uncertainty.

In issues of distribution and inventory management, demand uncertainty is one of the critical and practical issues in planning models (Gupta & Maranas, 2003). Without considering demand fluctuations, the unintended consequences could happen such as lost sales or high holding costs (Petkov & Maranas, 1997). The approach to deal with this problem is presented in methodology section.

1.2 Problem statement and research methodology

1.2.1 The scopes and purposes

Our study is aim to extend the research of Firoozi et al. (2020) to apply for multi-echelon pull supply chain considering multi-sourcing, drop shipping, and lateral transshipments between retailers in company 's supply chain. Beside inventory and distribution management problems, the decisions of opening and closing facilities are taken into account to adjust the strategic decisions of location and capacity according to actual situation under uncertainty factors in supply chain.

The purpose of this study includes the following items:

- Use the flexible sourcing and distribution policies to reduce cost while increasing customer service.
- Analysis sensitivity how lateral transshipments impacts on total cost and the other component costs when changing unit lateral transshipment cost.
- Analysis sensitivity how drop shipping impacts on total cost and the other component costs when changing unit drop shipping cost.
- Incorporate the decisions of opening or closing facilities into the inventory and distribution management problems, which helps companies’ executives to react quickly to uncertainty factors in supply chain.

1.2.2 Contributions

The study integrates network design problem into supply chain distribution and inventory management to choose opening or closing facilities from the predefined facilities in a planning horizon.

Additionally, as mentioned, the model considers simultaneously the sourcing and distribution strategies. Particularly, drop shipping is used when a stocking point is stockout and forwards its demand to the upper echelons, lateral transshipment is to share inventory between stocking points at the same echelons to reduce holding cost, and multiple sources is to avoid supply risks.

Especially, drop shipping is applied extensively in the e-commerce and online retail industry. In the context of the ecommerce development, even small and medium-sized enterprises normally own at least a webshop besides their physically stores. Our work is proposed for enterprises which sell products through their brick and mortar stores along with online stores on e-commerce platforms or the company's private website.

1.2.3 Methodology

Although the joint location-distribution-inventory model considering the flexible sourcing and distribution policies under uncertainty demand has a practical significance in supply chain management, this integration makes the complexity of model. Multi-echelon distribution and inventory management problems have been being extensively studied over the past decades. Ross (2015) synthesized that in multi-echelon network under pull system, an enterprise can manage resupply policy by choosing one of two possible replenishment techniques: reorder point (ROP) and distribution requirements planning (DRP). There are two main factors to distinguish between DRP and ROP. The first is the homogeneity and the length of the replenishment lead time. The second is how items enter the supply chain. Particularly, planners choose ROP when the lead time to replenish items is short and homogeneous. Normally, DRP works in the environment that the supply source is an internal company production plant or an outside make-to-order supplier and the replenishment lead time between facilities is non-homogeneity. This study uses distribution requirements planning (DRP) approach in multi-echelon network under pull system. DRP technique is adopted to create a time-based inventory replenishment plan to minimize the holding cost while enhancing customer service levels.

To deal with uncertainty in supply chain, the two-stage stochastic programming framework is taken into consideration as one of the most common planning approaches (Firoozi, 2018; Gupta & Maranas, 2003; McDonald & Karimi, 1997; Schneeweiss, 2012). The decision-making process are classified into two levels. The first level is of the here-and-now problem, which variables are determined before the uncertain parameters are observed. This means the decision variables in this stage do not depend on uncertain factors. Then, the second level is of the wait-and-see problem, which wait to make decisions until uncertain parameters are known. In this study, the first stage decides the problem of opening or closing retailers and the allocation of customer zones to opening retailers. Subsequently, after the demand is revealed, distribution and inventory decisions are made.

According to Gupta and Maranas (2003), there are two distinct methodologies to represent uncertain parameters. The first one is the scenario-based approach, which a set of discrete scenarios are generated to depict how the uncertainty may take place in the future. The probability of each scenario corresponds to how much the decision maker expects its occurrence. Even so, this approach requires to define all possible situations. In case decision makers only can predict the continuous range of potential outcomes of uncertainty parameter, distribution-based approach is adopted. This technique specifies the mean and the standard deviation of demand. This study uses the scenario-based approach. The planning model become more complicated due to the large number of distinct scenarios. The sample average approximation (SAA) technique is applied to simplify the original stochastic model into the equivalent deterministic mixed-integer linear programming (MILP) (Shapiro, 2008). Many recent researches used SAA method to find near-optimal solutions for stochastic problems in the supply chain (Amiri-Aref et al., 2018; Benyoucef, Xie, & Tanonkou, 2013; Klibi, Lasalle, Martel, & Ichoua, 2010; Özdemir, Yücesan, & Herer, 2013).

1.3 The organization of the research

The thesis is organized into 5 chapters. This chapter presents context and motivations to conduct this research. Then, research scope, methodology and contributions are presented in detail. Chapter 2 conducts literature reviews on the integration network design into inventory and distribution management, the flexible soucing and distribution strategies. Next, chapter 3 refers to a detailed description of the model assumptions and proposes a scenario-based model using distribution requirements planning (DRP) approach. Chapter 4 presents the numerical experiments and then analysis the sensitivity of using drop shipping, lateral transshipments in the model. Finally, chapter 5 summarizes the results to give concluding remarks and future directions as well.

CHAPTER 2
REVIEW OF LITERATURE

Many considerable researches studied the distribution planning and inventory optimization problems for a multi-stage supply chain network. This study will review three streams of relevant researches, consisting of the multi-echelon inventory and distribution optimization problems under DRP and other replenishment techniques, the flexible and responsive supply strategies, and the supply chain network design under uncertainty problem.

2.1 Multi-echelon inventory and distribution optimization problems

There are many considerable researches of multi-echelon distribution and inventory problems over the past decades. Ho (1990) carried out delivery scheduling for a multi-echelon logistics system considering multi-sourcing by adopting DRP technique. This study was analyzed under deterministic demand. Martel (2003) and Yoo, Kim, and Rhee (1997) proposed the models with stochastic demand based on DRP approach. The former study applied the concept of reorder point installation-stock, whereas the latter one used a DRP-decomposition approach. Then, the findings indicated the improvement of these studies in comparison to the traditional DRP approach by using simulation experiments. However, both considered networks with single sourcing. Besides DRP replenishment technique, ROP is also attracted many researches. The studies of Amiri-Aref et al. (2018) and Yang et al. (2017) are typical works for this technique. It is worth pointing out that they analysed a multi-echelon network with taking demand allocation into account. Besides, while the first one proposed a model with continuous review policy (R, Q) to handle stochastic demand pattern, the second one consider a two-stage model in a periodic review (s, S) with multiple source strategy to apply for non-stationary demand. As aforementioned, the work done by Firoozi et al. (2020) is the closest to our study. They applied DRP approach to analyze a multi-echelon distribution network and adopted multiple sources and lateral transshipment to decrease the risk of demand uncertainty. By considering drop shipping strategy, we propose a model applied for dual channel warehouse, which fulfils both online and offline orders.

2.2 The flexible sourcing and distribution strategies

This study considers 3 flexible and responsive resupply strategies within distribution and inventory systems, including multi-sourcing, drop shipping and lateral transshipments.

2.2.1 Drop shipping

Drop shipping is a common delivery practice as a backup strategy to satisfy demand in the case a stocking point runs out of stock. Another terms to describe drop shipping is direct shipping. Dumrongsiri, Fan, Jain, and Moinzadeh (2008) proposed a model which a customer can receive products from a retailer or directly from a manufacturer. They suggested conditions under which the manufacturer and the retailer share the market in equilibrium. The findings show that using dual channel help to improve the overall profit. Khouja and Stylianou (2009) explored the (Q, R) inventory models in dual-channel supply chain. Their study showed the drawback of this strategy in forwarding orders to the upper echelons or manufacturers is that it leads longer delivery lead time, higher unit order processing cost. However, the findings indicated that drop shipping policy can help to enhance customer satisfaction and decrease the total cost. Alawneh and Zhang (2018) and Chen et al. (2011) explored an inventory policy serving both online and offline customers. While the former study proposed a model to divide the warehouse into the storage area for satisfying online order and the other area for offline order, the latter analyzed scenarios by assuming the priority of a retailer to satisfy online demand. Both studies was set up under stochastic demand. Ly and Rujira (2019) proposed an analytical study of dual channel distribution for online retailers, which is combined between traditional distribution as a primary fulfilment channel and drop shipping distribution as a backup in case of stockout. This study considered multiple suppliers in supply chain network.

2.2.2 Multi-sourcing

Multi-sourcing means a buyer can originate from more than one supplier to protect against supply disruption risk. Glock and Ries (2013) analyzed a supply chain with single customer and multiple suppliers under stochastic demand. The study showed that multiple sourcing can help to reduce the risk of stockout when considering stochastic demand and a deterministic lead time. Silbermayr and Minner (2014) also analyzed the same supply chain facing Poison demand. They evaluated the trade-offs between using only one source and many supply sources, holding stock and using a back-up supplier.

2.2.3 Lateral transshipments

Lateral transshipments are stock movements between members within an echelon level of supply chain network to enable to not only decrease shortages but also enhance service levels. Paterson, Kiesmüller, Teunter, and Glazebrook (2011) synthesized many researches of inventory models with the lateral shipments over the past decades (Axsäter, 2003; Dong & Rudi, 2004; Grahovac & Chakravarty, 2001). While proactive transshipment occurs at predetermined moments in time (Lee, Jung, & Jeon, 2007), reactive transshipment can happen randomly (Nakandala, Lau, & Shum, 2017; Paterson, Teunter, & Glazebrook, 2012; F. Zhao et al., 2016). Besides, this article provided literatures classified by the inventory system (Axsäter, 1990) and the ordering policy (Olsson, 2009; Wee & Dada, 2005). Grahovac and Chakravarty (2001) focused on a replenishment model based on one-for-one ordering policy under complete pooling style of lateral transshipment, whereas Axsäter (2003) considered partial pooling by a continuous review (R, Q). Besides, the latter study derived decision rule of the number of transshipped units, basing on the complete state of the system. In the same problem, Wee and Dada (2005) conducted study by combination alternatives of transshipment, including: (1) only transshipment at retailer level, (2) movements within retailers first and replenishment from warehouses in the of stock out at all retailers, (3) Only transshipment within retailers when warehouses are out of stock, (4) No transshipment at retailer level, and (5) No pooling system, each retailer acts independently.

2.3 Supply chain network design

Many approaches have been being applied for supply chain network design (SCND) under uncertainty over recent years such as fuzzy approach (Ramezani et al., 2014), stochastic approach (Subulan et al., 2015), mathematical modelling (Kumar et al., 2017; Prakash et al., 2017), robust optimization (Prakash et al., 2020), and so on.

Recently, the integration of network design problem into supply chain distribution and inventory management have been being extensively studied. Miranda and Garrido (2008) presented Lagrangian relaxation to solve the joint location-distribution-inventory problem under stochastic capacity for a three-echelon network. Ahmadi-Javid and Seddighi (2012) addressed a location-routing-inventory model by developing a mixed-integer programming and a three-phase heuristic.

2.4 The summary of the most relevant researches

The most relevant researches related to this study is indicated in Table 2.1. The contributions are classified by methodology, replenishment polices (reorder point – ROP, and distribution requirements planning – DRP), demand type (deterministic – D, stochastic – S, and non-stationary – NS), flexible sourcing and distribution strategies (lateral transshipment – LT, multi-sourcing – MS, and drop shipping – DS), and solution approach. Besides, the studies are considered whether they include demand allocation constraints, capacity constraints, and multiple period (MP).

Table 2.1 The most relevant researches.

Paper	Methodology	Replenishment technique	SCND	Demand allocation	CAP	MP	Demand			LT	MS	DS	Solution approach
							D	S	NS				
Ho (1990)	Conceptual	DRP					*				*		Analytics
Yoo, Kim and Rhee (1997)	MILP	DRP						*					Simulation
Martel (2003)	MILP	DRP						*					Simulation
Miranda and Garrido (2008)	MINLP	EOQ	*	*	*			*					Heuristic
Khouja and Stylianou (2009)	Conceptual	(R, Q)						*				*	Analytics
Ahmadi and Seddighi (2012)	MINLP	EOQ	*		*			*			*		Heuristic
Yang, Pan and Ballot (2017)	MINLP	(R, Q)		*		*		*		*			Heuristic
Alawneh and Zhang (2018)	MINLP	(R, Q)			*			*				*	Metaheuristic
Amiri-Aref et al (2018)	MILP	(s, S)		*	*	*	*	*	*		*		CPLEX/ SAA
Friroozi et al (2020)	MILP	DRP		*	*	*	*	*	*	*	*		CPLEX/ SAA
This research	MILP	DRP		*	*	*	*	*	*	*	*	*	CPLEX/ SAA

CHAPTER 3
MODELLING AND SOLUTION APPROACH

3.1 Problem statement

This research considers three-echelon supply chain network. The first stage includes multiple potential suppliers. The second stage is central warehouses. The third stage is a set of retailers, which work as outlets and receive both online and offline orders. It is assumed that this model considers uncapacitated suppliers, but capacity problem is taken into consideration at central warehouse and retailer echelons. This research develops a multi-stage inventory optimization model using DRP approach. The model is applied to a product family or a product under periodic review policy. Demand at consumption points is stochastic and follows a non-stationary process over the planning horizon. In the context of demand uncertainty, the model is set up to choose the potential retailers from the predefined retailers.

Beside each stage is supplied products by the upper stage and feeds the ones below as usual, multiple sourcing, drop shipping, and lateral transshipments are applied in this model (figure 1). For multiple sourcing, each stocking point can be fed from many potential sources, such as a customer zone can be satisfied by more than one stocking point. Lateral transshipments are allowed in the third echelon, which means stock movements between retailers can be performed as a replenishment policy. For drop shipping, the demand from a retailer can be directly shipped from suppliers in case of stockout at a central warehouse. Besides, drop shipping from central warehouses or suppliers to consumption points can occur in case of stockout at a retailer. Besides drop shipping, backorder can be used when demand cannot be satisfied from on hand inventory. To sum up, an order at a warehouse or a retailer can be fulfilled by: (1) on-hand inventory, (2) drop shipping, and/or (3) backorder. It is noted that a straightforward strategy would always be to fulfil demands from the own stocking point if possible, and otherwise via a lateral transshipment or backorder or drop shipping, if possible. However, this strategy will turn out to be suboptimal in certain cases, which mainly depends on the cost parameters.

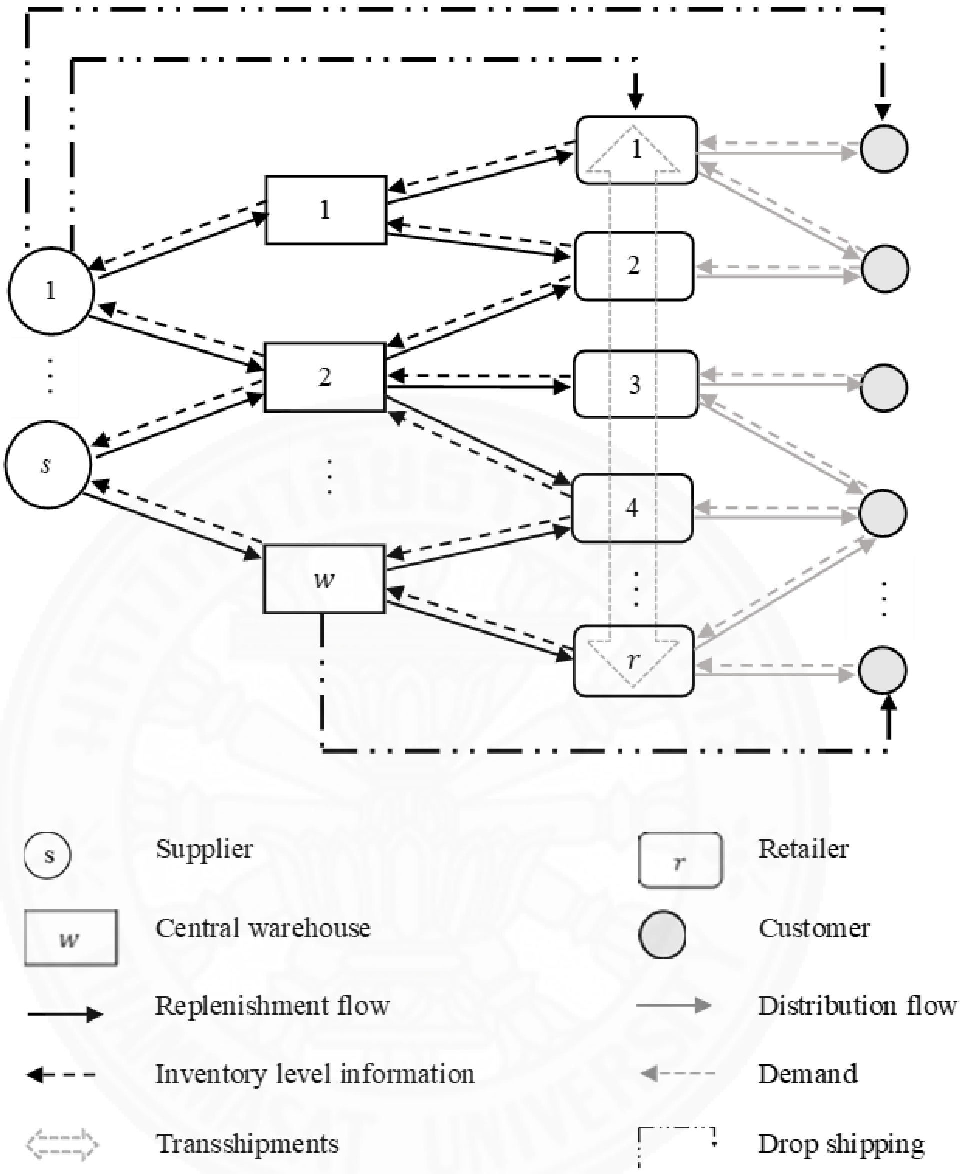

Figure 3.1 A multi-stage supply chain network with multiple sourcing, drop shipping, and lateral transshipments.

3.2 Mathematical model

3.2.1 Notation

3.2.1.1 Sets

S : Set of suppliers, s ϵ S.

W : Set of central warehouses, w ϵ W.

R : Set of retailers, r ϵ R.

Z : Set of consumption points, $z \in Z$.

T : Set of time periods, $t \in T$.

Ω : Set of scenarios, $\omega \in \Omega$.

3.2.1.2 Parameters

$d_{zt\omega}$: Demand at consumption point z at the beginning of period t under scenario ω.

f_r : Facility cost of retailer r.

CAP_n : Throughput capacity of stocking point n at each period t, n = {w, r}.

$L_{nn'}$: Expected lead time (number of periods) between stocking point n' and stocking point n, n = {s, w, r}, n' = {w, r, z}.

c_n^H : Unit holding cost at stocking point n per unit per period, n = {w, r}.

c_n^B : Unit backorder cost for stocking point n, n = {r, z}.

$\tau_{nn'}$: Unit transportation cost between stocking point n and stocking point n', n' = {w, r, z}, n = {s, w, r}.

$c_{nn'}^K$: Ordering cost per one order from stocking point n' to stocking point n, n' = {w, r}, n = {s, w, r}.

a_{rz} : Fixed allocation cost of consumption point z to retailer r.

M : A large positive number.

3.2.1.3 Variables

$I_{nt\omega}^+$: The ending inventory of stocking point n at the end of the period t under scenario ω, n = {w, r}.

$I_{nn't\omega}^-$: The backordered quantity of stocking point n for stocking point n' at the end of the period *t* under scenario ω, n = {w, r}, n' = {r, z}.

$R_{nn't\omega}$: The received quantity of stocking point n' from stocking point n at the beginning of period t under scenario ω, n = {s, w, r}, n' = {w, r, z}.

$R_{nn't\omega}^m$: The received quantity of stocking point n' from stocking point n by drop shipping at the beginning of period t under scenario ω in case of stockout at stocking point m, n = {s, w}, n' = {r, z}, m = {w, r}.

$D_{rzt\omega}$: Demand of consumption point z assigned to retailer r at the beginning of period t under scenario ω.

$Y_{nn't\omega}$: Binary variable. If stocking point n' is sourced by stocking point n under scenario ω ($R_{nn't\omega} > 0$), it takes value 1, n = {s, w, r}, n' = {w, r, z}. Otherwise, it takes value 0.

$Y^{m}_{nn't\omega}$: Binary variable. If stocking point n' is sourced by stocking point n by drop shipping at the beginning of period t under scenario ω in case of stockout at stocking point m ($R^{m}_{nn't\omega} > 0$), it takes value 1, n = {s, w}, n' = {r, z}, m = {w, r}. Otherwise, it takes value 0.

x_{rz} : Binary variable. If consumption point z is allocated to retailer r, it takes value 1. Otherwise, it takes value 0.

y_r : Binary variable. If retailer r is open, it takes value 1. Otherwise, it takes value 0.

3.2.2 Mathematical model

The two-stage stochastic programming framework divides the decisions and the constraints into two sets. The first level decides the problem of opening or closing retailers and the allocation of customer zones to opening retailers. These decisions are independent of the demand scenarios. Subsequently, the second makes distribution and inventory decisions after the demand is observed.

This model supports decisions of the inventory optimization and distribution policy between stocking points and between stocking points to consumption points in supply chain at each period as well as choosing opening or closing facilities from a set of given retailers. The decision-making process of supply chain activities is transformed into the model formulation as follows.

$$Min \left\{ A + B + \sum_{\omega \in \Omega} p(\omega) \, [\, C + D + E + F + G + H \,] \right\} \tag{3.1}$$

Where:

$$A = \sum_{r \in R} \sum_{z \in Z} a_{rz} x_{rz}$$

$$B = \sum_{r \in R} f_r y_r$$

$$C = \sum_{t\in T}\left(\sum_{s\in S}\sum_{w\in W}\tau_{sw}R_{swt\omega} + \sum_{w\in W}\sum_{r\in R}\tau_{wr}R_{wrt\omega} + \sum_{r\in R}\sum_{z\in Z}\tau_{rz}R_{rzt\omega}\right)$$

$$D = \sum_{t\in T}\sum_{r\in R}\sum_{r'\in R\setminus\{r\}}\tau_{rr'}R_{rr't\omega}$$

$$E = \sum_{t\in T}\left(\sum_{s\in S}\sum_{w\in W}\sum_{r\in R}\tau_{sr}R^{w}_{srt\omega} + \sum_{s\in S}\sum_{r\in R}\sum_{z\in Z}\tau_{sz}R^{r}_{szt\omega} + \sum_{w\in W}\sum_{r\in R}\sum_{z\in Z}\tau_{wz}R^{r}_{wzt\omega}\right)$$

$$F = \sum_{t\in T}\left[\begin{aligned}&\sum_{s\in S}\sum_{w\in W}c^{K}_{sw}\left(Y_{swt\omega} + \sum_{r\in R}Y^{w}_{srt\omega}\right) + \sum_{w\in W}\sum_{r\in R}c^{K}_{wr}\left(Y_{wrt\omega} + \sum_{z\in Z}Y^{r}_{wzt\omega}\right)\\ &\qquad + \sum_{r\in R}\sum_{r'\in R\setminus\{r\}}c^{K}_{rr'}Y_{rr't\omega} + \sum_{s\in S}\sum_{r\in R}\sum_{z\in Z}c^{K}_{sr}Y^{r}_{szt\omega}\end{aligned}\right]$$

$$G = \sum_{t\in T}\left(\sum_{w\in W}\sum_{r\in R}c^{B}_{r}I^{-}_{wrt\omega} + \sum_{r\in R}\sum_{z\in Z}c^{B}_{z}I^{-}_{rzt\omega}\right)$$

$$H = \sum_{t\in T}\left(\sum_{w\in W}c^{H}_{w}I^{+}_{wt\omega} + \sum_{r\in R}c^{H}_{r}I^{+}_{rt\omega}\right)$$

The model aims to minimize the total cost of supply chain. Therefore, the objective function is the sum of the deterministic costs in the first stage (allocation cost and facility cost) and the expected costs in the second stage (transportation cost, procurement cost and backorder cost). Equation A represents the allocation cost between retailer and consumption point. Equation B calculates facility costs for the open retailers. Equation C, D, E capture terms of transportation, which include regular transportation costs, transshipment costs, and drop shipping costs, respectively. Next, equation F refers the procurement costs. Then, equation G is about the backorder costs. Finally, the holding costs are computed by equation H.

It is noted that unit transportation flow cost between stocking point n and stocking point n' is a linear function of the travelled distance between locations in supply chain network: $\tau_{nn'} = C^{T}_{nn'} + c^{T}_{nn'}.x_{nn'}$. Where $C^{T}_{nn'}$, $c^{T}_{nn'}$, $x_{nn'}$ are fixed transportation cost, variable transportation cost and distance from stocking point n to stocking point n', respectively. The augmented factor γ is added into this function for unit lateral transshipment cost to compare to the regular transportation flows for the same distance: $\tau_{nn'} = \gamma\ (C^{T}_{nn'} + c^{T}_{nn'}.x_{nn'})$.

As mentioned, the allocation decisions are made in the first stage, independently from the scenarios. Therefore, constraints (3.2) and (3.3) are considered as a set of constraint in the first stage.

$$\sum_{r \in R} x_{rz} \geq 1 \qquad \forall\, z \in Z \qquad (3.2)$$

Constraint (3.2) guarantees a customer z can be allocated to at least one retailer r. This means multiple sourcing is allowed and single sourcing is also feasible for some customer z when the left side of the constraint is equal to 1.

$$y_r \geq x_{rz} \qquad \forall\, r \in R, z \in Z \qquad (3.3)$$

Constraint (3.3) defines that only when a retailer r is open, it is considered whether a customer z is allocated to a retailer r.

$$R_{nrt\omega} \leq M.y_r \qquad n = \{w, r'\}, \forall\, w \in W, r \in R, r' \in R \setminus \{r\}, t \in T, \omega \in \Omega \qquad (3.4)$$

$$R^{w}_{srt\omega} \leq M.y_r \qquad \forall\, s \in S, w \in W, r \in R, t \in T, \omega \in \Omega \qquad (3.5)$$

$$I^{-}_{wrt\omega} \leq M.y_r \qquad \forall\, w \in W, r \in R, t \in T, \omega \in \Omega \qquad (3.6)$$

Constraints (3.4), (3.5) and (3.6) make sure that only when a retailer r is open, it is considered whether the retailer r can receive products from the other stocking points (suppliers, central warehouses, and the other retailers) for each period and each scenario.

$$D_{rzt\omega} \leq M.x_{rz} \qquad \forall\, r \in R, z \in Z, t \in T, \omega \in \Omega \qquad (3.7)$$

$$d_{zt\omega} = \sum_{r \in R} D_{rzt\omega} \qquad \forall\, z \in Z, t \in T, \omega \in \Omega \qquad (3.8)$$

Constraint (3.7) ensures that a retailer r can serve a customer z only when there is an allocation between them. Equation (3.8) check that the total demand of each customer z is entirely assigned to the allocated retailers for each scenario and each period.

$$R_{rz(t+L_{rz})\omega} \ = \ D_{rzt\omega} \ + \ I^{-}_{rz(t-1)\omega} - I^{-}_{rzt\omega} - \sum_{s\in S} R^{r}_{sz(t+L_{sz})\omega} - \sum_{w\in W} R^{r}_{wz(t+L_{wz})\omega}$$

$$\forall\ r \ \epsilon\ R, z\ \epsilon\ Z, t\ \epsilon\ T, \omega\ \epsilon\ \Omega \qquad (3.9)$$

Equation (3.9) calculates the number of products that retailers r fulfills customer z. For each scenario, the shortage that retailer cannot satisfy in a period can be backordered in the next periods or directly shipped from its central warehouses or suppliers.

$$I^{+}_{rt\omega} \ = \ I^{+}_{r(t-1)\omega} + \sum_{s\in S}\sum_{w\in W} R^{w}_{srt\omega} + \sum_{w\in W} R_{wrt\omega} + \sum_{r'\in R\setminus\{r\}} R_{r'rt\omega} - \sum_{z\in Z} R_{rz(t+L_{rz})\omega}$$
$$- \sum_{r'\in R\setminus\{r\}} R_{rr'(t+L_{rr'})\omega}$$

$$\forall\ r \ \epsilon\ R, t\ \epsilon\ T, \omega\ \epsilon\ \Omega \qquad (3.10)$$

$$I^{+}_{wt\omega} \ = \ I^{+}_{w(t-1)\omega} + \sum_{s\in S} R_{swt\omega} + \sum_{r\in R} I^{-}_{wrt\omega} - \sum_{r\in R} I^{-}_{wr(t-1)\omega} - \sum_{r\in R} R_{wr(t+L_{wr})\omega}$$
$$- \sum_{r\in R}\sum_{z\in Z} R^{r}_{wz(t+L_{wz})\omega}$$

$$\forall\ w \ \epsilon\ W, t\ \epsilon\ T, \omega\ \epsilon\ \Omega \qquad (3.11)$$

$$I^{+}_{st\omega} \ = \ I^{+}_{s(t-1)\omega} - \sum_{w\in W} R_{sw(t+L_{sw})\omega} - \sum_{w\in W}\sum_{r\in R} R^{w}_{sr(t+L_{sr})\omega} - \sum_{r\in R}\sum_{z\in Z} R^{r}_{sz(t+L_{sz})\omega}$$

$$\forall\ s \ \epsilon\ S, t\ \epsilon\ T, \omega\ \epsilon\ \Omega \qquad (3.12)$$

Equations (3.10), (3.11) and (3.12) determine the on-hand inventory of a retailer, a central warehouse, and a supplier at the end of the period, respectively.

$$\sum_{w\in W} R_{wrt\omega} + \sum_{r'\in R\setminus\{r\}} R_{r'rt\omega} + \sum_{s\in S}\sum_{w\in W} R^{w}_{srt\omega} \ \leq \ y_r CAP_r$$

$$\forall\ r \ \epsilon\ R, t\ \epsilon\ T, \omega\ \epsilon\ \Omega \qquad (3.13)$$

$$\sum_{s\in S} R_{swt\omega} \ \leq \ CAP_w \qquad \forall\ w \ \epsilon\ W, t\ \epsilon\ T, \omega\ \epsilon\ \Omega \qquad (3.14)$$

Constraints (3.13) and (3.14) indicate the received flows of a stocking point (retailer or central warehouse) do not exceed its throughput capacity limit.

$$R_{nn'tω} \leq M.Y_{nn'tω}$$
$$n = \{s, w, r\}, n' = \{w, r, z\}, \forall\, s \in S, w \in W, r \in R, z \in Z, t \in T, \omega \in \Omega \quad (3.15)$$

$$R^m_{nn'tω} \leq M.Y^m_{nn'tω}$$
$$n = \{s, w\}, n' = \{r, z\}, m = \{w, r\}, \forall\, s \in S, w \in W, r \in R, z \in Z, t \in T, \omega \in \Omega \quad (3.16)$$

Constraints (3.15) and (3.16) ensure when stocking point n' receives products from stocking point n, the procurement incurs between two locations.

$$x_{rz}, y_r, Y_{nn'tω}, Y^m_{nn'tω} = \{0; 1\}$$
$$n = \{s, w, r\}, n' = \{w, r, z\}, m = \{w, r\},$$
$$\forall\, s \in S, w \in W, r \in R, z \in Z, t \in T, \omega \in \Omega \quad (3.17)$$

$$I^+_{ntω}, I^-_{nn'tω}, R_{nn'tω}, R^m_{nn'tω}, D_{rztω} \geq 0$$
$$n = \{s, w, r\}, n' = \{w, r, z\}, m = \{w, r\},$$
$$\forall\, s \in S, w \in W, r \in R, z \in Z, t \in T, \omega \in \Omega \quad (3.18)$$

Constraints (3.17) and (3.18) set binary variables and non-negativity variables.

3.3 Solution approach

The proposal model can give solutions of distribution planning and inventory optimization in multi-echelon supply chain network. However, the problem is intractable to solve due to following reasons. Firstly, the model considers simultaneously many distribution and inventory alternatives to analyze trade-offs between backorder, transshipment, drop shipping or keeping more inventory in multi-echelon supply chain network. Secondly, to validate the practical implications of the research findings, the numerical experiments are conducted with the large number of the plausible demand scenarios.

The combinatorial nature makes the optimization model intractable to solve. To tackle this problem, previous research has simplified the model by transferring the original stochastic model into the equivalent deterministic MILP following SAA technique. A sample of the independent demand scenarios with the occurrence probability p(ω) = 1/N to simplify the original model as follow:

$$Min \left\{A + B + \frac{1}{N}\sum_{\omega\in\Omega^N}\sum_{t\in T}\left[\, C + D + E + F + G + H \,\right]\right\} \tag{3.19}$$

CHAPTER 4
NUMERICAL EXPERIMENTS

4.1 Experiment plan

The proposed model integrates the problem of opening or closing facilities into supply chain distribution and inventory management in a planning horizon. To validate the model, problem cases is designed corresponding to several business contexts.

Firstly, experiments without integration of network design problem are conducted to evaluate the impacts of drop shipping and lateral transshipment strategies. This means the component cost B, so called facility costs, and the constraint 3 to 6 are excluded out of the model. There are 3 sizes of network, including small network (SN), medium network (MN), and large network (LN). For two first type of network, the cases are generated from dimensions: capacity levels of central warehouses and retailers $\{Cap^{low}, Cap^{high}\}$, backorder cost levels $\{B^{low}, B^{high}\}$, inventory holding cost levels $\{H^{low}, H^{high}\}$, and drop shipping $\{D^{low}, D^{without}\}$. For the last type of network, dimensions are the same, except for drop shipping $\{D^{without}, D^{low}, D^{high}\}$ and the augmented factor $\gamma_{rr'}$ = {1, 1.2} of lateral transshipment costs. Next, experiments with the full proposed model is carried out with large network to choose potential facilities from a set of predefined facilities. The setting for parameters is the same as the model without network design problem. This study conducts 88 experiments, consisting of 16 cases for small network (1 – 16), 16 cases for medium network (17 – 32), 48 cases for large network without integration of network problem (33 – 80), and 8 cases of the joint location-distribution-inventory model (81 – 88).

The parameters of network, scenario and capacity are showed in table 3.1 and table 3.2. The size of the network impacts on the requirement of computer configuration to gain an optimal solution within an acceptable duration and tolerance. Besides, the increase of the number of scenarios for each instance is in direct proportion to the complexity of calculation. Of course, a higher sample size of scenarios considered can increase the accuracy of optimal solution when demand is stochastic non-stationary. However, finding the optimality for the entire set of scenarios is intractable because of the inherent combinatorial complexity of the proposed model. Therefore, in this research, the sample size of scenarios used for small, medium, and large network is 100, 20 and 5, respectively.

Table 4.1 The network parameters and the number of scenarios in the experiments.

Item	Index	SN	MN	LN
1	No. z	10	60	200
2	No. r	2	8	12
3	No. w	1	2	4
4	No. Ω	100	20	5

Table 4.2 The capacity parameters in the experiments.

Item	Facility	SN		MN		LN	
		Cap^{low}	Cap^{high}	Cap^{low}	Cap^{high}	Cap^{low}	Cap^{high}
1	Retailer	2800	4000	4000	9000	8500	20000
2	Warehouse	4000	9000	7500	17000	12000	30000

The assumption is that the replenishment ability of the supplier echelons is unlimited. The initial inventory of each retailer and each warehouse is the average lead time demand of upper demand. For each period, the unit backorder costs (B^{low}, B^{high}) are (1, 4) and the unit holding costs (H^{low}, H^{high}) are (0.01, 0.1), respectively. The unit transportation flow cost between stocking point n and stocking point n' is a linear function of the travelled distance $\tau_{nn'}$. For regular shipment, the fixed cost $C^{T}_{nn'}$ is 0.0432 and the variable cost $c^{T}_{nn'}$ is 0.0035. In comparison to the regular transportation flows for the same distance, the augmented factor of unit lateral transshipment cost is $\gamma_{rr'}$ = (1, 1.2) and the augmented factor of unit out-bound transportation cost γ_{rz} = 1.5. For drop shipping, the fixed costs between locations $(C^{T}_{sz}, C^{T}_{sr}, C^{T}_{wz})$ are set to (2, 8, 4) and (3, 8, 5) for D^{low} cases and D^{high} cases, respectively. The variable cost is also the same as that of regular transportation cost. For the joint location-distribution-inventory model, the unit facility cost to open a retailer is 10^{5}.

This study is applied for a stochastic non-stationary demand process. A planning horizon includes 90 working days, which is equivalent to 3 season cycles. By following the demand function over planning horizon proposed by Zhao and Xie (2002) and applied by M. Firoozi (2019), the mean demand of consumption point z at each period t is calculated as follows:

$$\mu_{zt} = b^n + slope\,.\,sin\left(\frac{2\pi t}{cycle}\right) + noise\,.\,snormal(\,) \qquad n \,\epsilon\, \{\text{SN, MN, LN}\}$$

It is assumed that season cycle is monthly (season cycle =30). Slope and noise are constant and equal to 40 and 50, respectively. Snormal is a standard normal random number.

These numerical experiments are conducted on a 64-bit operating system server with 112 GB of RAM and 2.1 GHz CPU. The model is generated with OPL Studio 12.10, CPLEX-12.10. The relative mixed integer programming gap tolerance is set to 0.05, which means CPLEX will stop as soon as it has found a feasible integer solution proved to be within 5% of optimal.

4.2 Numerical results

Noticeably, for each network size, the problem instances use the same scenario samples data. The tables 3.3 to 3.8 detail the results about the expected total costs and the component costs for each experiment. The component costs consist of allocation cost (AC), facility cost (FC), procurement cost (PC), holding cost (HC), backorder cost (BC), regular transportation cost (RTC), drop shipping cost (DSC), and transshipment cost (TC). Besides, the relative MIP gap tolerance and the running time of each experiment are shown in detail.

It is necessary to remind that γ means the augmented factor of unit lateral transshipment cost to compare to the unit regular transportation flows. Table 3.3 to table 3.7 represent the experiments without integration of the opening or closing facility problem. When γ equals to 1.0 with the low unit drop cost D^{low} and without drop shipping $D^{without}$, the numerical results of the experiments in small, medium, and large network are presented in table 3.3, 3.4, and 3.5, respectively. In comparison with the experiments in table 3.5, table 3.6 shows the cases γ equals to 1.2. Table 3.7 consists of the experiments with D^{high} for large network. While the cases from 65 to 72 are conducted with γ = 1.0, the others work with γ = 1.2 in this table.

The most comprehensive experiments are presented in table 3.8 by using the full proposed model. Beside the inventory and distribution planning, decisions of opening or closing retailer are carried out in large network with D^{low} and γ = 1.0.

Table 4.3 The numerical results of the experiments in small network.

Experiment	Total cost	AC	PC	HC	BC	Transportation Cost			Gap (%)	Running time (hours)
						RTC	DSC	TC		
1. SN, Cap^{low}B^{low}H^{low}D^{low}, $\gamma = 1.0$	42358	1450	3264	604	6314	29536	1166	23	4.99	4.9
2. SN, Cap^{low}B^{high}H^{low}D^{low}, $\gamma = 1.0$	50618	1450	3989	516	3313	28719	12601	30	3.8	4.1
3. SN, Cap^{low}B^{low}H^{high}D^{low}, $\gamma = 1.0$	44067	1450	5320	236	6308	29529	1173	51	4.21	3
4. SN, Cap^{low}B^{high}H^{high}D^{low}, $\gamma = 1.0$	52120	1450	5910	88	3314	32720	12598	40	4.02	2.1
5. SN, Cap^{high}B^{low}H^{low}D^{low}, $\gamma = 1.0$	41539	1450	2809	704	6825	29723		28	4.93	7.3
6. SN, Cap^{high}B^{high}H^{low}D^{low}, $\gamma = 1.0$	50380	1450	3554	705	3314	28714	12599	44	4.94	5.1
7. SN, Cap^{high}B^{low}H^{high}D^{low}, $\gamma = 1.0$	43653	1450	5415	169	6825	29701		93	4.94	4.8
8. SN, Cap^{high}B^{high}H^{high}D^{low}, $\gamma = 1.0$	52113	1450	5841	107	3314	28694	12599	108	4.93	3
9. SN, Cap^{low}B^{low}H^{low}D^{without}, $\gamma = 1.0$	42269	1450	3178	546	7346	29725		24	4.94	2.7
10. SN, Cap^{low}B^{high}H^{low}D^{without}, $\gamma = 1.0$	65270	1450	4392	294	29383	29724		26	4.77	1.7
11. SN, Cap^{low}B^{low}H^{high}D^{without}, $\gamma = 1.0$	44103	1450	5284	251	7347	29712		59	4.92	2.4
12. SN, Cap^{low}B^{high}H^{high}D^{without}, $\gamma = 1.0$	66245	1450	5597	67	29383	29725		23	4.85	0.9
13. SN, Cap^{high}B^{low}H^{low}D^{without}, $\gamma = 1.0$	41556	1450	2909	621	6825	29724		26	4.95	3.8
14. SN, Cap^{high}B^{high}H^{low}D^{without}, $\gamma = 1.0$	62984	1450	4079	407	27298	29724		26	4.95	2.9
15. SN, Cap^{high}B^{low}H^{high}D^{without}, $\gamma = 1.0$	43625	1450	5377	193	6825	29709		71	4.96	2.6
16. SN, Cap^{high}B^{high}H^{high}D^{without}, $\gamma = 1.0$	64161	1450	5592	65	27298	29721		35	4.95	1.1

Table 4.4 The numerical results of the experiments in medium network.

Experiment	Total cost	AC	PC	HC	BC	Transportation Cost			Gap (%)	Running time (hours)
						RTC	DSC	TC		
17. MN, $Cap^{low}B^{low}H^{low}D^{low}$, $\gamma = 1.0$	394176	9700	18078	209	12542	316793	36854	1	3.15	13.8
18. MN, $Cap^{low}B^{high}H^{low}D^{low}$, $\gamma = 1.0$	420253	11750	19118	210	298	314528	74651		0	9.5
19. MN, $Cap^{low}B^{low}H^{high}D^{low}$, $\gamma = 1.0$	395084	8700	18235		12542	316792	36854	1960	2.91	12.5
20. MN, $Cap^{low}B^{high}H^{high}D^{low}$, $\gamma = 1.0$	418058	9000	19257			314585	73255	1960	3.02	9.2
21. MN, $Cap^{high}B^{low}H^{low}D^{low}$, $\gamma = 1.0$	378358	8900	18034	209	28839	322186	187	2	4.08	21.5
22. MN, $Cap^{high}B^{high}H^{low}D^{low}$, $\gamma = 1.0$	407315	9600	19013	207	51	316518	61947	6	3.7	12.5
23. MN, $Cap^{high}B^{low}H^{high}D^{low}$, $\gamma = 1.0$	378203	9000	16497		28849	322197		1960	3.56	28.2
24. MN, $Cap^{high}B^{high}H^{high}D^{low}$, $\gamma = 1.0$	407961	8700	19189			316262	61850	1960	3.96	4.9
25. MN, $Cap^{low}B^{low}H^{low}D^{without}$, $\gamma = 1.0$	426884	8950	17500	730	77709	321995			2.72	13.3
26. MN, $Cap^{low}B^{high}H^{low}D^{without}$, $\gamma = 1.0$	659651	8700	17920	200	310836	321995			1.67	8.4
27. MN, $Cap^{low}B^{low}H^{high}D^{without}$, $\gamma = 1.0$	428502	8800	18120		77709	321995		1879	2.68	12.1
28. MN, $Cap^{low}B^{high}H^{high}D^{without}$, $\gamma = 1.0$	659282	8800	15770	41	310836	321995		1840	1.38	4.6
29. MN, $Cap^{high}B^{low}H^{low}D^{without}$, $\gamma = 1.0$	378445	8700	17860	200	29700	321995			3.89	18.8
30. MN, $Cap^{high}B^{high}H^{low}D^{without}$, $\gamma = 1.0$	468395	9250	17760	591	118800	321995			3.29	14.3
31. MN, $Cap^{high}B^{low}H^{high}D^{without}$, $\gamma = 1.0$	377243	8800	14860	13	29700	322003		1866	3.15	13
32. MN, $Cap^{high}B^{high}H^{high}D^{without}$, $\gamma = 1.0$	466417	9000	14850		118800	322088		1879	2.58	5.4

Table 4.5 The numerical results of the experiments with $\gamma = 1.0$ in large network when D^{low} (33 – 40) and $D^{without}$ (41 – 48).

Experiment	Total cost	AC	PC	HC	BC	Transportation Cost			Gap (%)	Running time (hours)
						RTC	DSC	TC		
33. LN, $Cap^{low}B^{low}H^{low}D^{low}$, $\gamma = 1.0$	2538860	34150	27360	23200	292640	1665218	496291		0.41	63.5
34. LN, $Cap^{low}B^{high}H^{low}D^{low}$, $\gamma = 1.0$	2813282	31900	39190	23279	23544	1647218	1048152		0.59	30.5
35. LN, $Cap^{low}B^{low}H^{high}D^{low}$, $\gamma = 1.0$	2703549	35000	33700	12322	292908	1658430	542606	128583	0.56	72.3
36. LN, $Cap^{low}B^{high}H^{high}D^{low}$, $\gamma = 1.0$	3034751	71250	47230	12708	23544	1639730	1111146	129143	2.58	14.1
37. LN, $Cap^{high}B^{low}H^{low}D^{low}$, $\gamma = 1.0$	2286355	30600	26320	1856	291440	1703945	232192	1	0.95	64.3
38. LN, $Cap^{high}B^{high}H^{low}D^{low}$, $\gamma = 1.0$	2583109	30700	38270	1400	19232	1682047	811455	5	1.07	14.7
39. LN, $Cap^{high}B^{low}H^{high}D^{low}$, $\gamma = 1.0$	2291092	30850	26590	6101	291414	1703945	232192		1.16	12.6
40. LN, $Cap^{high}B^{high}H^{high}D^{low}$, $\gamma = 1.0$	2584323	29900	39500	54	19652	1681975	812953	289	1.11	10.5
41. LN, $Cap^{low}B^{low}H^{low}D^{without}$, $\gamma = 1.0$	16939141	31700	26070		15215270	1666098		3	0.05	97.4
42. LN, $Cap^{low}B^{high}H^{low}D^{without}$, $\gamma = 1.0$	65638242	32650	27460		63813208	1764924			0.01	80.8
43. LN, $Cap^{low}B^{low}H^{high}D^{without}$, $\gamma = 1.0$	17779176	34250	26700		15953302	1764924			0.06	120.2
44. LN, $Cap^{low}B^{high}H^{high}D^{without}$, $\gamma = 1.0$	62588374	33000	25960	61	60863240	1666113			0.02	66.7
45. LN, $Cap^{high}B^{low}H^{low}D^{without}$, $\gamma = 1.0$	2431653	32000	29230	1071	539513	1829827		12	1.11	101.9
46. LN, $Cap^{high}B^{high}H^{low}D^{without}$, $\gamma = 1.0$	3948322	36100	26190	2174	2143380	1737993		2485	0.69	11.9
47. LN, $Cap^{high}B^{low}H^{high}D^{without}$, $\gamma = 1.0$	2429639	32100	30650	917	536126	1829827		19	1.03	10
48. LN, $Cap^{high}B^{high}H^{high}D^{without}$, $\gamma = 1.0$	3940783	31450	27960		2143380	1737993			0.5	31.6

Table 4.6 The numerical results of the experiments with $\gamma = 1.2$ in large network when D^{low} (49 – 56) and $D^{without}$ (57 – 64).

Experiment	Total cost	AC	PC	HC	BC	Transportation Cost			Gap (%)	Running time (hours)
						RTC	DSC	TC		
49. LN, $Cap^{low}B^{low}H^{low}D^{low}$, $\gamma = 1.2$	2307856	34000	30515	476	233284	1681896	327685		0.44	113
50. LN, $Cap^{low}B^{high}H^{low}D^{low}$, $\gamma = 1.2$	2553597	31850	42605	587	30	1665210	813315		0.67	61.9
51. LN, $Cap^{low}B^{low}H^{high}D^{low}$, $\gamma = 1.2$	2211915	31700	28660	1038	281521	1707078	161913	5	1.9	51.1
52. LN, $Cap^{low}B^{high}H^{high}D^{low}$, $\gamma = 1.2$	2559578	30250	43490	4352	30	1664861	815738	858	0.74	55.8
53. LN, $Cap^{high}B^{low}H^{low}D^{low}$, $\gamma = 1.2$	2365198	80850	26320	227	301029	1702739	254033		4.26	18.2
54. LN, $Cap^{high}B^{high}H^{low}D^{low}$, $\gamma = 1.2$	2521020	99350	37650	68	131	1682455	701367		3.75	20.4
55. LN, $Cap^{high}B^{low}H^{high}D^{low}$, $\gamma = 1.2$	2342158	34850	27410	2783	303335	1701702	272056	23	3.31	15.6
56. LN, $Cap^{high}B^{high}H^{high}D^{low}$, $\gamma = 1.2$	2494957	35750	39510	196	34875	1682414	701641	571	2.73	15.2
57. LN, $Cap^{low}B^{low}H^{low}D^{without}$, $\gamma = 1.2$	20595118	42150	25840		18769302	1757826			0.09	60.2
58. LN, $Cap^{low}B^{high}H^{low}D^{without}$, $\gamma = 1.2$	65637052	33100	25820		63813208	1764924			0.01	50.4
59. LN, $Cap^{low}B^{low}H^{high}D^{without}$, $\gamma = 1.2$	20585460	33150	26580		18769302	1756428			0.04	61.4
60. LN, $Cap^{low}B^{high}H^{high}D^{without}$, $\gamma = 1.2$	77181639	45300	27110		75134644	1974583		1	0.39	18.9
61. LN, $Cap^{high}B^{low}H^{low}D^{without}$, $\gamma = 1.2$	2426034	31750	28600	11	535845	1829827			0.83	27.8
62. LN, $Cap^{high}B^{high}H^{low}D^{without}$, $\gamma = 1.2$	4035599	31550	30840	1	2143380	1829827			0.55	8.8
63. LN, $Cap^{high}B^{low}H^{high}D^{without}$, $\gamma = 1.2$	2444819	39950	29320	160	545539	1829827		23	1.62	13.4
64. LN, $Cap^{high}B^{high}H^{high}D^{without}$, $\gamma = 1.2$	4038662	32600	30900	1851	2143484	1829828			0.65	44.1

Table 4.7 The numerical results of the experiments with D^{high} in large network when $\gamma = 1.0$ (65 – 72) and $\gamma = 1.2$ (73 – 80).

Experiment	Total cost	AC	PC	HC	BC	Transportation Cost			Gap (%)	Running time (hours)
						RTC	DSC	TC		
65. LN, Cap^{low}B^{low}H^{low}D^{high}, $\gamma = 1.0$	2771347	33150	27800	23070	307103	1665218	715006		0.82	77.4
66. LN, Cap^{low}B^{high}H^{low}D^{high}, $\gamma = 1.0$	2994207	38100	36380	23476	191000	1657343	1047898	10	1.75	67.4
67. LN, Cap^{low}B^{low}H^{high}D^{high}, $\gamma = 1.0$	2968306	39100	33140	33851	332781	1665422	712509	151503	1.86	107.4
68. LN, Cap^{low}B^{high}H^{high}D^{high}, $\gamma = 1.0$	3166392	34400	42950	31575	196976	1657044	1050660	152787	0.84	51.6
69. LN, Cap^{high}B^{low}H^{low}D^{high}, $\gamma = 1.0$	2335820	32250	27740	362	423403	1725085	126980		1.09	12.7
70. LN, Cap^{high}B^{high}H^{low}D^{high}, $\gamma = 1.0$	2694737	34450	39030	76		1681170	940012		1.13	10.7
71. LN, Cap^{high}B^{low}H^{high}D^{high}, $\gamma = 1.0$	2331647	34250	26340		418992	1725085	126980		0.97	8.5
72. LN, Cap^{high}B^{high}H^{high}D^{high}, $\gamma = 1.0$	2691592	29750	39710	41		1681256	940557	278	1	9.7
73. LN, Cap^{low}B^{low}H^{low}D^{high}, $\gamma = 1.2$	2817027	73650	27770	23236	293174	1664453	734745		2.43	94.3
74. LN, Cap^{low}B^{high}H^{low}D^{high}, $\gamma = 1.2$	3018353	44400	36900	23802	190812	1656361	1066078		1.51	61.5
75. LN, Cap^{low}B^{low}H^{high}D^{high}, $\gamma = 1.2$	2984467	49450	32440	40329	303295	1675619	716633	166700	1.39	82.4
76. LN, Cap^{low}B^{high}H^{high}D^{high}, $\gamma = 1.2$	3187934	34950	41660	44610	189196	1657108	1050094	170315	0.56	42.5
77. LN, Cap^{high}B^{low}H^{low}D^{high}, $\gamma = 1.2$	2398004	33500	25740	773	465334	1724034	148622		3.71	9.1
78. LN, Cap^{high}B^{high}H^{low}D^{high}, $\gamma = 1.2$	2697093	35600	37990	254	2048	1681164	940032	5	1.21	8.6
79. LN, Cap^{high}B^{low}H^{high}D^{high}, $\gamma = 1.2$	2329992	31500	26190	983	419251	1725085	126980	3	0.9	8.6
80. LN, Cap^{high}B^{high}H^{high}D^{high}, $\gamma = 1.2$	2693350	30150	41020	57	4	1681243	940602	275	1.06	8.8

Table 4.8 The numerical results of the experiments integrated opening and closing retailers in large network ($\mathrm{D^{low}}$, $\gamma = 1.0$).

Experiment	Total cost	FC ($\times 10^5$)	AC	PC	HC	BC	Transportation Cost			Gap (%)	Running time (hours)
							RTC	DSC	TC		
81. LN, $\mathrm{Cap^{low}B^{low}H^{low}D^{low}}$, $\gamma = 1.0$	3529537	7	30700	30240	23187	265201	1660414	819794		0.35	87.5
82. LN, $\mathrm{Cap^{low}B^{high}H^{low}D^{low}}$, $\gamma = 1.0$	3741151	6	29400	41890	23224		1636210	1410427		2.24	85.1
83. LN, $\mathrm{Cap^{low}B^{low}H^{high}D^{low}}$, $\gamma = 1.0$	3743054	8	36700	27820	82126	368801	1648666	734853	44089	1.29	124.2
84. LN, $\mathrm{Cap^{low}B^{high}H^{high}D^{low}}$, $\gamma = 1.0$	3919729	7	32600	40920	123307	8156	1626914	1361790	26043	2.25	43.5
85. LN, $\mathrm{Cap^{high}B^{low}H^{low}D^{low}}$, $\gamma = 1.0$	2874810	4	29500	13530		528894	1722086	180800		1.21	10.8
86. LN, $\mathrm{Cap^{high}B^{high}H^{low}D^{low}}$, $\gamma = 1.0$	3235657	4	29850	30060		19232	1678895	1077619		2.7	56.1
87. LN, $\mathrm{Cap^{high}B^{low}H^{high}D^{low}}$, $\gamma = 1.0$	2874380	4	29100	13530		528894	1722086	180800		1.19	10.9
88. LN, $\mathrm{Cap^{high}B^{high}H^{high}D^{low}}$, $\gamma = 1.0$	3236567	4	30050	30770		19232	1678895	1077619		2.71	115.4

4.3 Analysis of findings

4.3.1 The impacts of adopting drop shipping

Figure 2 shows the expected total costs of the cases with considering drop shipping (1 – 9, 17 – 24, and 33 – 40) and without drop shipping (9 – 16, 25 – 32, and 41 – 48) in small, medium, and large network, respectively. The results provide insights on the impact of adopting drop shipping on the expected total cost. Generally, in comparison between couple cases with the same parameters, the expected total costs increase significantly in most of cases without drop shipping. Allocation cost, procurement cost and regular transportation cost are quite similar between these couple cases, whereas backorder cost has remarkably change.

Backorder cost of the cases considering drop shipping is much lower than that of the other cases, especially in the experiments with Cap^{low} and B^{high} such as (2, 10), (4, 12), (18, 26), (20, 28), (34, 42), and (36, 44). It is notable that all odd cases consider low unit backorder cost B^{low}, and vice versa. In comparison between the B^{low} cases, the difference in backorder cost of the experiments with or without drop shipping is not that much. Notably, the Cap^{high} and B^{low} experiments, which are (5, 13), (7, 15), (21, 29), (23, 31), (37, 45), and (39, 47), backorder cost is quite the same. In summary, it is undeniable that a significant improvement was obtained in adopting drop shipping strategy to reduce the backorder cost and the expected total cost as well.

A small but noteworthy thing that the results of each instance in couple instances (5, 13) and (7, 15) are quite equivalent. The reason is even though instance 5 and 7 including drop shipping strategy in model, the detailed results show this strategy is still not adopted. In principle, the results of the couple instances should be the same, but they have a small difference because we set up MIP relative tolerance of 0.05 in CPLEX to make sure the optimal solution can be gained within an acceptable running time.

4.3.2 Sensitivity analysis when changing the unit drop shipping cost

The experiments are organized into 3 groups to analyse how the total costs or the components' costs change when changing unit drop shipping cost. The first group is without drop shipping. Two groups left for D^{low} cases and D^{high} cases have the fixed costs between locations ($C_{sz}^{T}, C_{sr}^{T}, C_{wz}^{T}$) set to (2, 8, 4) and (3, 8, 5), respectively.

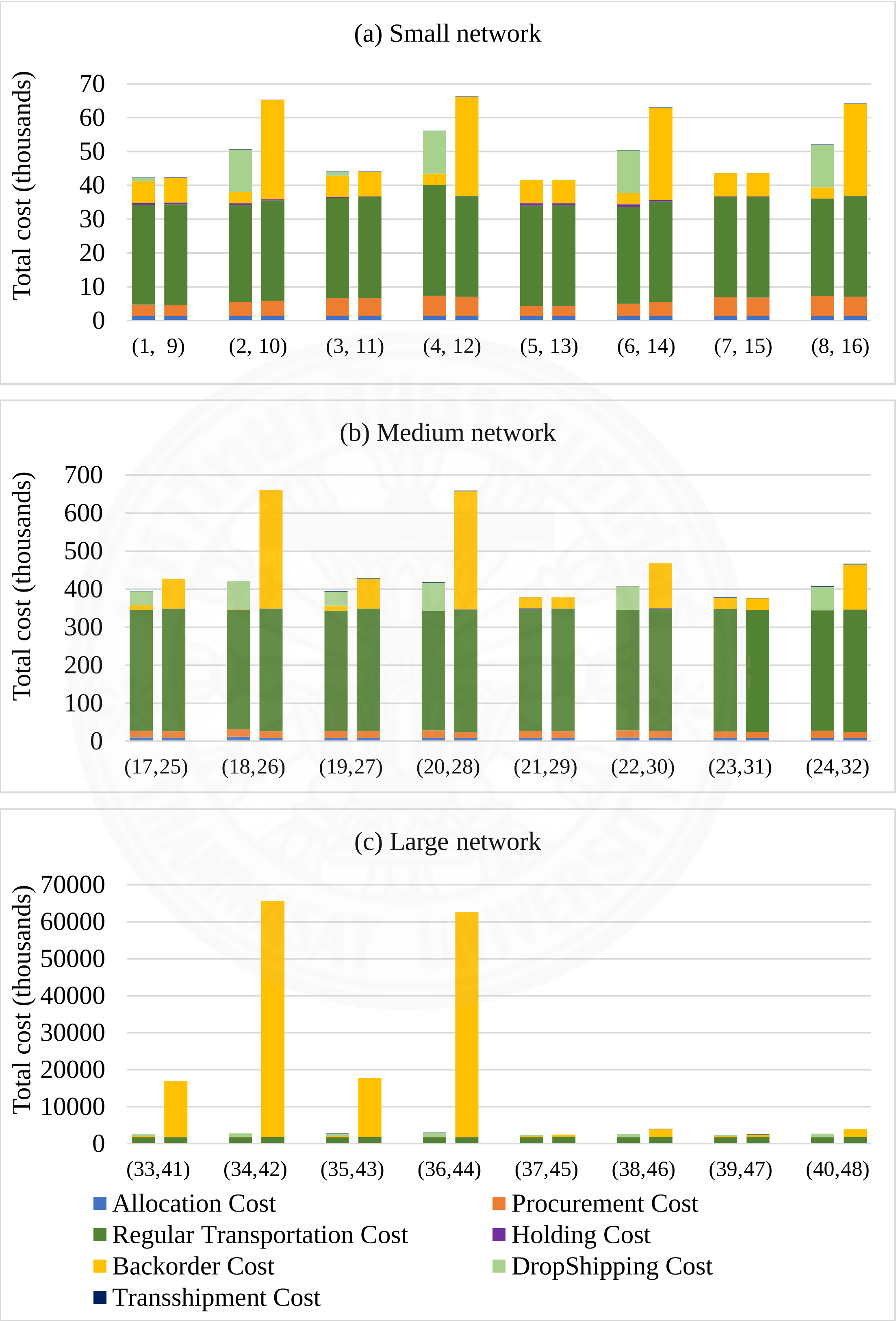

Figure 4.1 The comparison of the expected total costs with or without drop shipping in (a) small network, (b) medium network, (c) large network.

Figure 4.2 and figure 4.3 analyze the sensitivity of the unit drop shipping cost in case of the augmented factor of unit lateral transshipment $\gamma = 1.0$ and $\gamma = 1.2$, respectively. The total costs in all of experiments without drop shipping (41 – 48 and 57 – 64) are higher than those in experiments with the high unit drop shipping cost D^{high} (33 – 40 and 49 – 56) which are higher than those in experiments with the low unit drop shipping cost D^{low} (65 – 72 and 73 – 80). It can be seen clearly that the total cost increase dramatically in experiments (41 – 44 and 57 – 60). The difference between these experiments and the left cases in the same group (45 – 48 and 61 – 64) is at capacity parameters. The first ones consider the low capacity Cap^{low} of retailers and warehouses, whereas the latter ones work with the high capacity of them.

In most of cases, the percentages of total drop shipping costs in the total costs increase when increasing the unit drop shipping cost, excepting for experiments (37, 69), (39, 71) in figure 4.4 and (53, 77), (55, 79) in figure 4.5. In the odd cases with B^{low}, the percentages of total backorder shipping costs in the total costs are much bigger than those of even cases. This is the main reason why the percentages of total drop shipping costs of experiments (37, 69), (39, 71), (53, 77) and (55, 79) decrease although their total costs still increase.

Indeed, the experiments without drop shipping can be considered that their unit drop shipping costs are very high. In conclusion, the application of drop shipping strategy has positive effects on the total costs. When decreasing unit drop shipping cost, the total cost decreases considerably.

4.3.3 Sensitivity analysis when changing the unit lateral transshipment cost

The experiments are organized to analyze how the total costs and the components' costs change when changing unit lateral transshipment cost. The experiments with low unit drop shipping costs D^{low} and high unit drop shipping costs D^{high} have the fixed costs between locations (C_{sz}^{T}, C_{sr}^{T}, C_{wz}^{T}) set to (2, 8, 4) and (3, 8, 5), respectively.

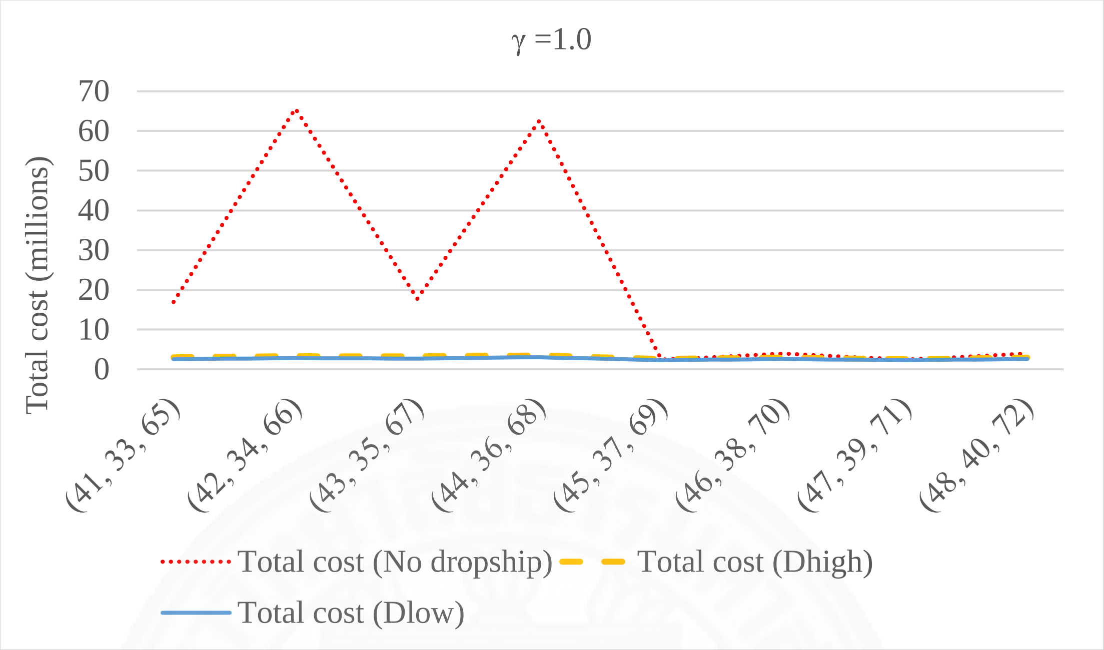

Figure 4.2 Sensitivity analysis of the total cost when changing unit drop shipping cost in case of γ = 1.0.

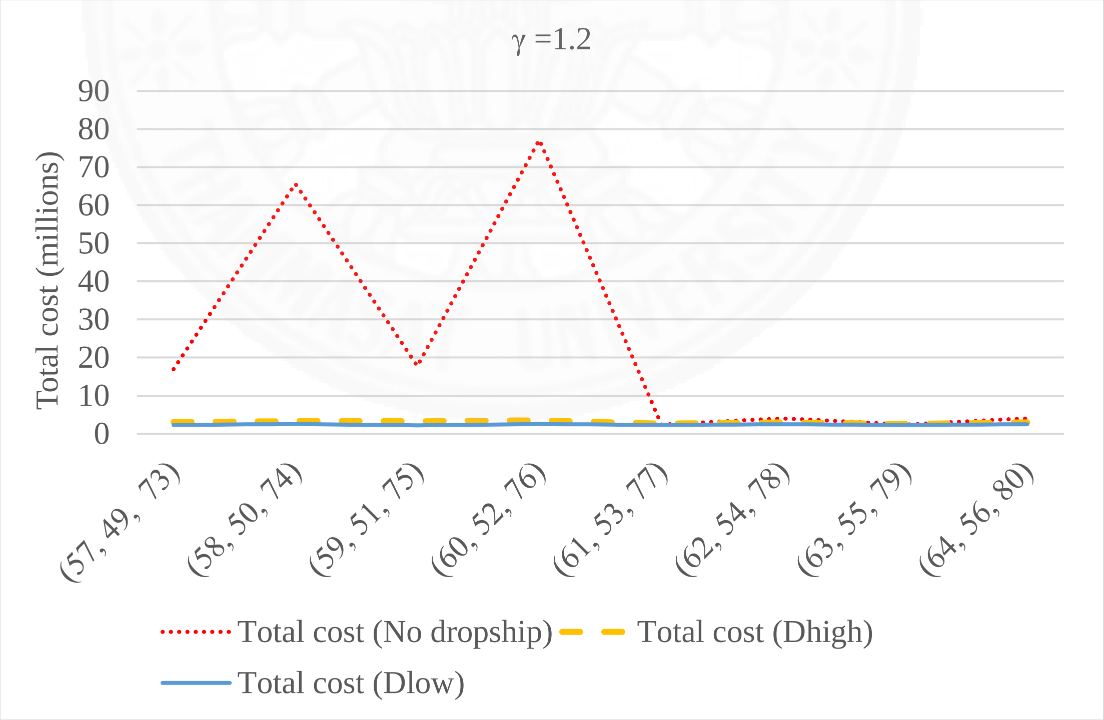

Figure 4.3 Sensitivity analysis of the total cost when changing unit drop shipping cost in case of γ = 1.2.

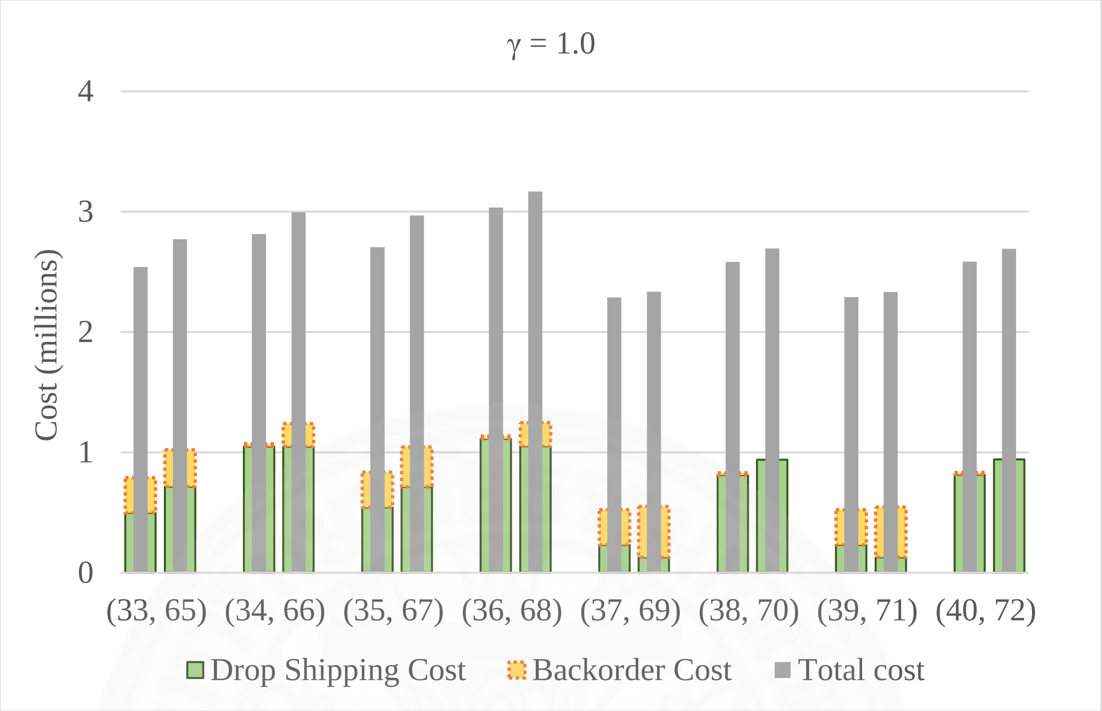

Figure 4.4 Sensitivity analysis of the drop shipping cost and backorder cost when changing unit drop shipping cost in case of γ = 1.0.

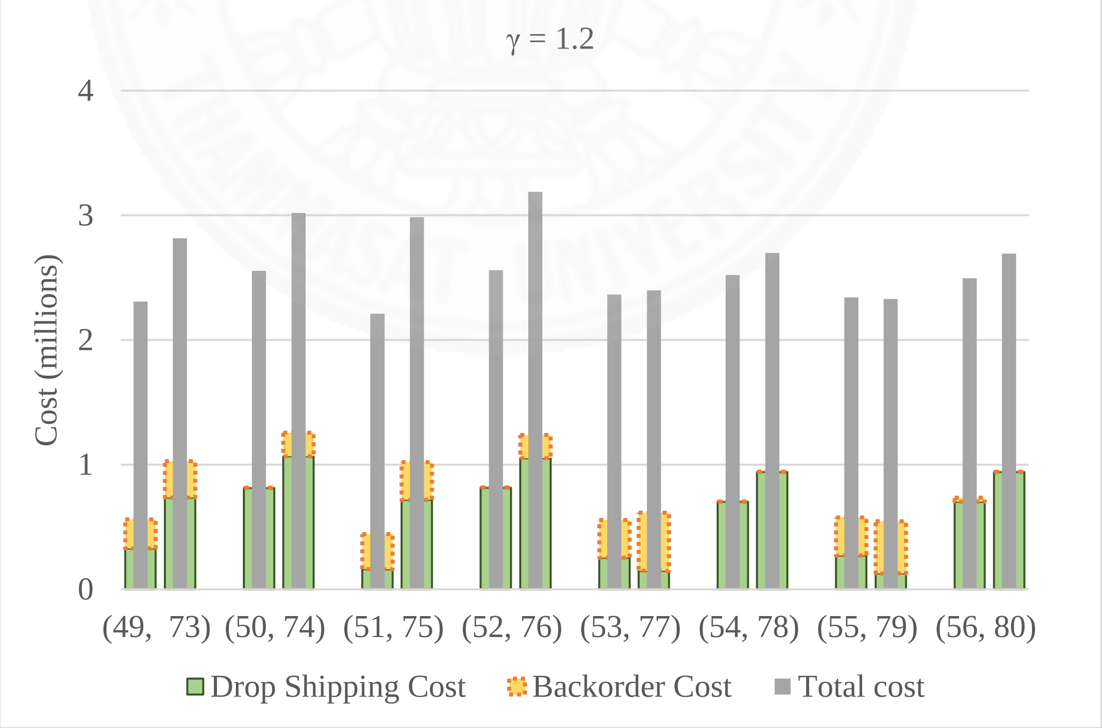

Figure 4.5 Sensitivity analysis of the drop shipping cost and backorder cost when changing unit drop shipping cost in case of γ = 1.2.

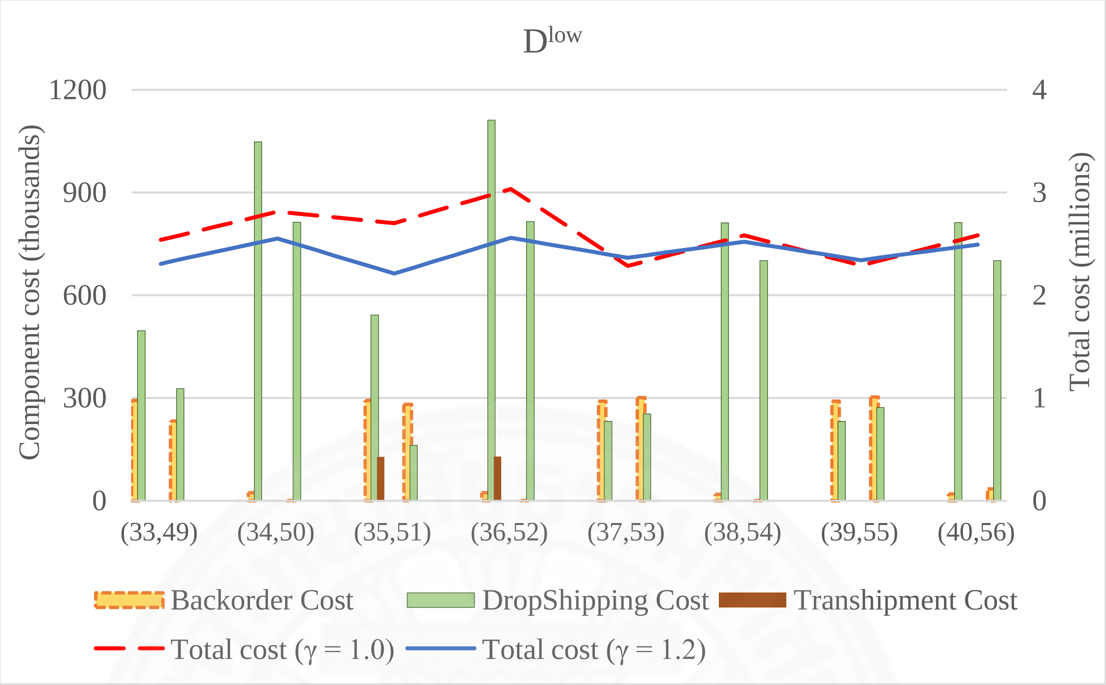

Figure 4.6 Sensitivity analysis of the total cost when changing unit lateral transshipment cost in case of D^{low}.

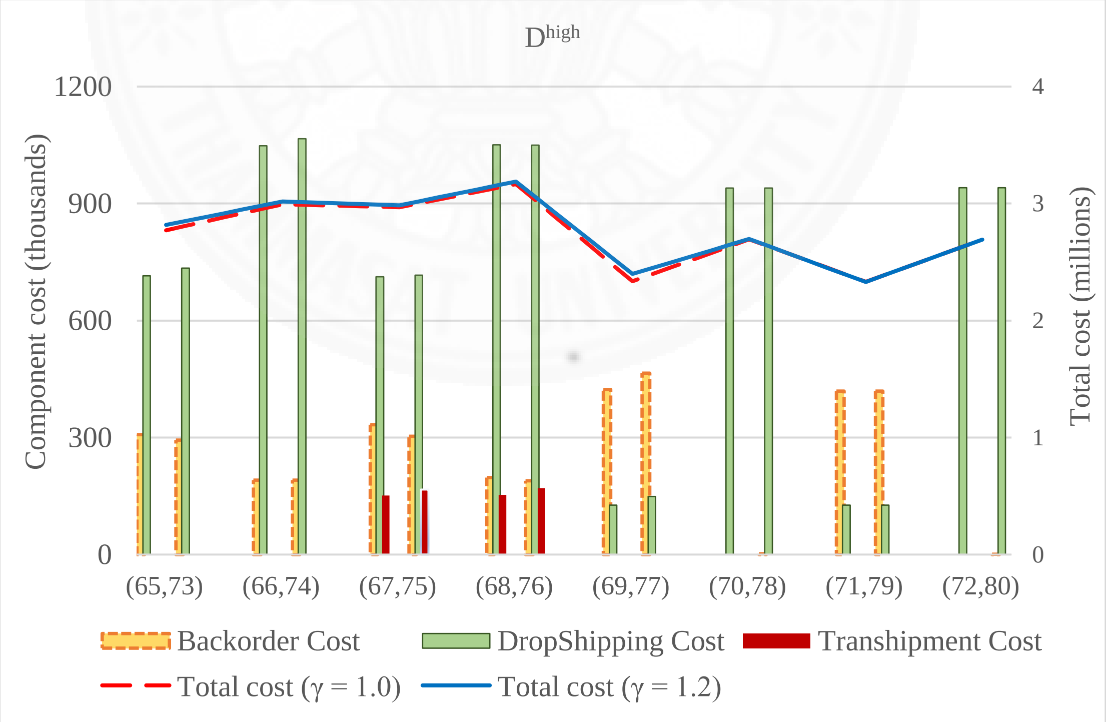

Figure 4.7 Sensitivity analysis of the total cost when changing unit lateral transshipment cost in case of D^{high}.

Figure 4.6 and 4.7 show the total costs decrease when the augmented factor for unit lateral transshipment cost γ decreases in cases of D^{high}. However, this is reversed in cases of D^{low}, especially in D^{low} CAP^{low} cases (33 – 36, 49 – 52). This can be that solutions tend to adopt drop shipping when both the unit drop shipping and the facilities' capacity are low.

4.3.4 Decision of opening or closing a facility

It is apparent from figure 4.8 that the number of facilities decreases when the capacity of facilities increases. In the Cap^{low} cases (81 – 84), there are from 6 to 8 opening facilities, whereas this number goes down to 4 in the Cap^{high} cases. In similarity to previous analysis, the drop shipping costs outperform in the even cases with B^{high} and the backorder costs are dominant in the others.

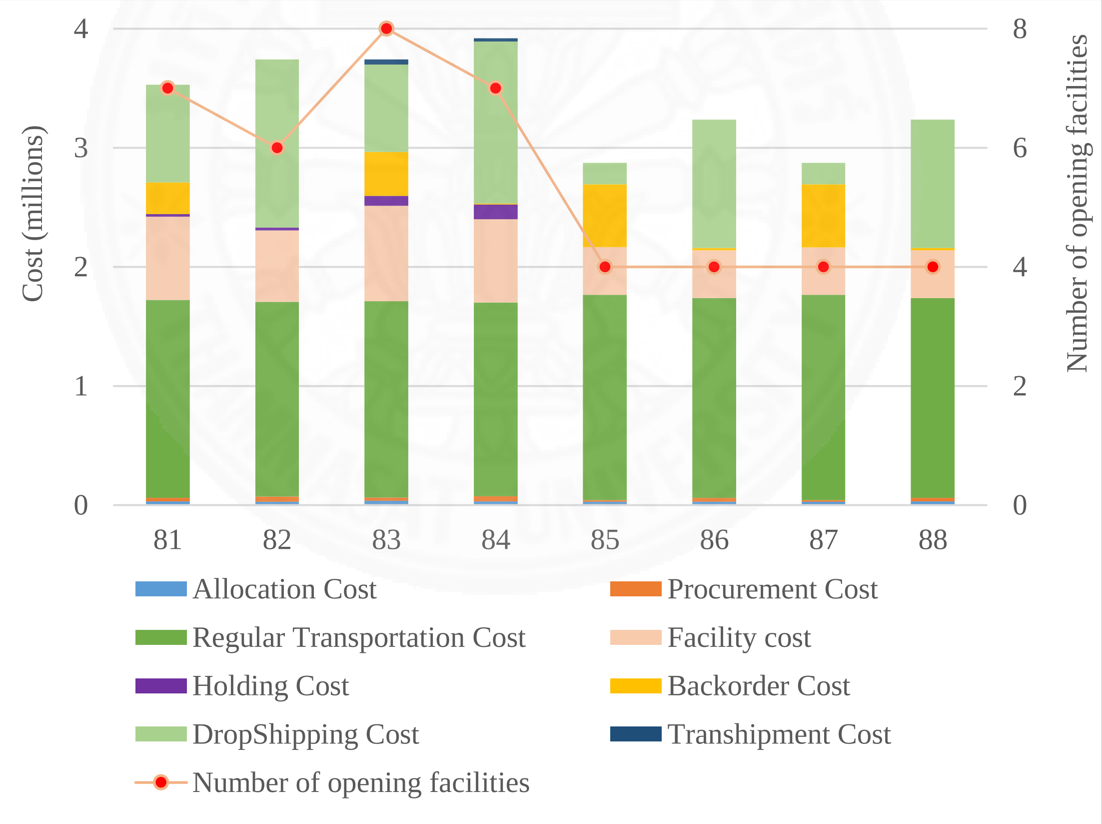

Figure 4.8 The results of experiments in the joint location-distribution-inventory model.

CHAPTER 5
CONCLUSIONS AND FUTURE DIRECTIONS

5.1 Conclusion

This research proposes a multi-echelon pull supply chain incorporating network design into distribution planning and inventory optimization problem under demand uncertainty by adopting DRP approach. It is intended that the findings enable companies’ executives to react to the ever-changing demand through using the flexible distribution strategies in addition to the regular distribution strategy. These strategies are using simultaneously, including multi-sourcing, drop shipping, and lateral transshipments between retailers in supply chain of the same company. The study is suggested to apply for enterprises which sell products through both their physical stores and online stores on e-commerce platforms or the company's private website. Besides providing solutions of distribution and inventory, the proposal model supports decisions of opening or closing facilities from a set of predefined facilities to minimize the expected total cost of supply chain. The model support companies’ executives in decision making of long-term and medium-term supply chain planning through conducting various scenarios corresponding to practical supply chain contexts. It simulates investment alternatives such as opening, relocating or closing a facility, enlarging or shrinking the capacity of stocking point. The numerical results provide insights on the impact of adopting drop shipping on the expected total cost and the other cost components as well. Generally, without drop shipping, the expected total costs increase significantly, which proves the deniable benefits of this strategy.

5.2 Future directions

Besides aforementioned contributions, the study has some restrictions. Despite avoiding sub-optimality solutions with the joint location-distribution-inventory model, this integration is worth thinking about its practicality. As mentioned, the model generates a time-based inventory replenishment plan, which is normally in date, while network design is a strategic decision. Application of the model in long-term planning seems infeasible, however, it can be applied when the executives need to adjust strategic decisions of location and capacity according to actual situation. Additionally, the long running time may be a motive to improve the model 's performance, such as building up a heuristic approach instead of an optimization model. Also, future work should conduct a real case study to demonstrate the practical significance of the proposed model.

REFERENCES

Ahmadi-Javid, A., & Seddighi, A. H. (2012). A location-routing-inventory model for designing multisource distribution networks. *Engineering Optimization, 44*(6), 637-656.

Alawneh, F., & Zhang, G. (2018). Dual-channel warehouse and inventory management with stochastic demand. *Transportation Research Part E: Logistics and Transportation Review, 112*, 84-106.

Amiri-Aref, M., Klibi, W., & Babai, M. Z. (2018). The multi-sourcing location inventory problem with stochastic demand. *European Journal of Operational Research, 266*(1), 72-87.

Axsäter, S. (1990). Modelling emergency lateral transshipments in inventory systems. *Management Science, 36*(11), 1329-1338.

Axsäter, S. (2003). A new decision rule for lateral transshipments in inventory systems. *Management Science, 49*(9), 1168-1179.

Axsäter, S. (2015). *Inventory control* (Vol. 225): Springer.

Axsäter, S., Howard, C., & Marklund, J. (2013). A distribution inventory model with transshipments from a support warehouse. *IIE Transactions, 45*(3), 309-322.

Ayanso, A., Diaby, M., & Nair, S. K. (2006). Inventory rationing via drop-shipping in Internet retailing: A sensitivity analysis. *European Journal of Operational Research, 171*(1), 135-152.

Bailey, J. P., & Rabinovich, E. (2005). Internet book retailing and supply chain management: an analytical study of inventory location speculation and postponement. *Transportation Research Part E: Logistics and Transportation Review, 41*(3), 159-177.

Benyoucef, L., Xie, X., & Tanonkou, G. A. (2013). Supply chain network design with unreliable suppliers: a Lagrangian relaxation-based approach. *International Journal of Production Research, 51*(21), 6435-6454.

Cardona-Valdés, Y., Álvarez, A., & Ozdemir, D. (2011). A bi-objective supply chain design problem with uncertainty. *Transportation Research Part C: Emerging Technologies, 19*(5), 821-832.

Chen, J., Chen, Y., Parlar, M., & Xiao, Y. (2011). Optimal inventory and admission policies for drop-shipping retailers serving in-store and online customers. *IIE Transactions, 43*(5), 332-347.

Dennis, Z. Y., Cheong, T., & Sun, D. (2017). Impact of supply chain power and drop-shipping on a manufacturer’s optimal distribution channel strategy. *European Journal of Operational Research, 259*(2), 554-563.

Dong, L., & Rudi, N. (2004). Who benefits from transshipment? Exogenous vs. endogenous wholesale prices. *Management Science, 50*(5), 645-657.

Dumrongsiri, A., Fan, M., Jain, A., & Moinzadeh, K. (2008). A supply chain model with direct and retail channels. *European Journal of Operational Research, 187*(3), 691-718.

Firoozi, M. (2018). *Multi-echelon Inventory optimization under supply and demand uncertainty*. (Doctoral dissertation), University of Bordeaux, the HAL Open Archives System. Retrieved from https://tel.archives-ouvertes.fr/tel-02129713

Firoozi, M., Babai, M. Z., Klibi, W., & Ducq, Y. (2020). Distribution planning for multi-echelon networks considering multiple sourcing and lateral transshipments. *International Journal of Production Research, 58*(7), 1968-1986.

Glock, C. H., & Ries, J. M. (2013). Reducing lead time risk through multiple sourcing: the case of stochastic demand and variable lead time. *International Journal of Production Research, 51*(1), 43-56.

Grahovac, J., & Chakravarty, A. (2001). Sharing and lateral transshipment of inventory in a supply chain with expensive low-demand items. *Management Science, 47*(4), 579-594.

Gupta, A., & Maranas, C. D. (2003). Managing demand uncertainty in supply chain planning. *Computers & chemical engineering, 27*(8-9), 1219-1227.

Ho, C. j. (1990). Distribution Requirements Planning: A Generalised System for Delivery Scheduling in a Multi-Sourcing Logistics System. *International Journal of Physical Distribution & Logistics Management*.

Jin-Hong, Z., Rui-Xuan, J., & Gui, Z. (2015). Multi-item distribution policies with supply hub and lateral transshipment. *Mathematical Problems in Engineering, 2015*.

Khouja, M., & Stylianou, A. C. (2009). A (Q, R) inventory model with a drop-shipping option for e-business. *Omega, 37*(4), 896-908.

Klibi, W., Lasalle, F., Martel, A., & Ichoua, S. (2010). The stochastic multiperiod location transportation problem. *Transportation Science, 44*(2), 221-237.

Kumar, R. S., Choudhary, A., Babu, S. A. I., Kumar, S. K., Goswami, A., & Tiwari, M. K. (2017). Designing multi-period supply chain network considering risk and emission: A multi-objective approach. *Annals of Operations Research, 250*(2), 427-461.

Lee, Y. H., Jung, J. W., & Jeon, Y. S. (2007). An effective lateral transshipment policy to improve service level in the supply chain. *International Journal of Production Economics, 106*(1), 115-126.

Ly, D. T. T., & Rujira, C. (2019). *Inventory Management of Dual-Channel Distribution for Online Retailers* Paper presented at the International Conference on Knowledge, Information and Creativity Support Systems, Vietnam.

Martel, A. (2003). Policies for multi-echelon supply: DRP systems with probabilistic time-varying demands. *INFOR: Information Systems and Operational Research, 41*(1), 71-91.

McDonald, C. M., & Karimi, I. A. (1997). Planning and scheduling of parallel semicontinuous processes. 1. Production planning. *Industrial & Engineering Chemistry Research, 36*(7), 2691-2700.

Min, C. (2008). *Lateral transshipments in inventory models.* (Master), University of Amsterdam, The Netherlands. Retrieved from https://beta.vu.nl/nl/Images/werkstuk-chen_tcm235-91335.pdf

Miranda, P. A., & Garrido, R. A. (2008). Valid inequalities for Lagrangian relaxation in an inventory location problem with stochastic capacity. *Transportation Research Part E: Logistics and Transportation Review, 44*(1), 47-65.

Nakandala, D., Lau, H., & Shum, P. K. (2017). A lateral transshipment model for perishable inventory management. *International Journal of Production Research, 55*(18), 5341-5354.

Olsson, F. (2009). Optimal policies for inventory systems with lateral transshipments. *International Journal of Production Economics, 118*(1), 175-184.

Özdemir, D., Yücesan, E., & Herer, Y. T. (2013). Multi-location transshipment problem with capacitated production. *European Journal of Operational Research, 226*(3), 425-435.

Paterson, C., Kiesmüller, G., Teunter, R., & Glazebrook, K. (2011). Inventory models with lateral transshipments: A review. *European Journal of Operational Research, 210*(2), 125-136.

Paterson, C., Teunter, R., & Glazebrook, K. (2012). Enhanced lateral transshipments in a multi-location inventory system. *European Journal of Operational Research, 221*(2), 317-327.

Petkov, S. B., & Maranas, C. D. (1997). Multiperiod planning and scheduling of multiproduct batch plants under demand uncertainty. *Industrial & Engineering Chemistry Research, 36*(11), 4864-4881.

Prakash, S., Kumar, S., Soni, G., Jain, V., & Rathore, A. P. S. (2020). Closed-loop supply chain network design and modelling under risks and demand uncertainty: an integrated robust optimization approach. *Annals of Operations Research, 290*(1), 837-864.

Prakash, S., Soni, G., & Rathore, A. P. S. (2017). Embedding risk in closed-loop supply chain network design. *Journal of Modelling in Management*.

Ramezani, M., Kimiagari, A. M., Karimi, B., & Hejazi, T. H. (2014). Closed-loop supply chain network design under a fuzzy environment. *Knowledge-Based Systems, 59*, 108-120.

Ross, D. F. (2015). *Distribution Planning and control: managing in the era of supply chain management*: springer.

Schneeweiss, C. (2012). *Distributed decision making*: Springer Science & Business Media.

Shapiro, A. (2008). Stochastic programming approach to optimization under uncertainty. *Mathematical Programming, 112*(1), 183-220.

Silbermayr, L., & Minner, S. (2014). A multiple sourcing inventory model under disruption risk. *International Journal of Production Economics, 149*, 37-46.

Silbermayr, L., & Minner, S. (2016). Dual sourcing under disruption risk and cost improvement through learning. *European Journal of Operational Research, 250*(1), 226-238.

Subulan, K., Baykasoğlu, A., Özsoydan, F. B., Taşan, A. S., & Selim, H. (2015). A case-oriented approach to a lead/acid battery closed-loop supply chain network design under risk and uncertainty. *Journal of Manufacturing Systems, 37,* 340-361.

Wang, G., Jiang, Z., Li, Z., & Liu, W. (2008). Supplier selection and order splitting in multiple-sourcing inventory systems. *Frontiers of Mechanical Engineering in china, 3*(1), 23-27.

Wee, K. E., & Dada, M. (2005). Optimal policies for transshipping inventory in a retail network. *Management Science, 51*(10), 1519-1533.

Yang, Y., Pan, S., & Ballot, E. (2017). Innovative vendor-managed inventory strategy exploiting interconnected logistics services in the Physical Internet. *International Journal of Production Research, 55*(9), 2685-2702.

Yoo, Y. J., Kim, W. S., & Rhee, J. T. (1997). Efficient inventory management in multi-echelon distribution systems. *Computers & industrial engineering, 33*(3-4), 729-732.

Zhao, F., Wu, D., Liang, L., & Dolgui, A. (2016). Lateral inventory transshipment problem in online-to-offline supply chain. *International Journal of Production Research, 54*(7), 1951-1963.

Zhao, J., Duan, Y., Wang, S., & Huo, J. (2012). Coordinated drop shipping commitment contract in dual-distribution channel supply chain. *Journal of Electronic Commerce in Organizations (JECO), 10*(4), 19-30.

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