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An Analysis of International Transportation Network

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Abstract

This thesis discusses a network design problem based on a case study with a footwear company, which intends to minimize total supply chain costs by establishing a distribution network which bypasses its primary distribution center (DC). Through the new network, called the DC bypass network, the company ships products directly from its Asian factories to a logistics hub at an entry port in the US and then on to customers, a particular group of chosen customers.

We assess the project by comparing costs derived from a baseline and optimization model. A baseline model represents the company's existing logistics network while optimization models capture future supply chains with different scenarios. The models convert a real supply chain network into the relationships between nodes and links. Nodes indicate facilities while links refer to the flow of the product.

In brief, this case study is about how a company evaluates its transportation network. Methods to determine a specific location or multiple locations for the DC bypass operations are discussed. Furthermore, the robustness of an optimal solution will be measured through a sensitivity analysis. Other benefits include the reduction of lead time is discussed in the further research.

Thesis Supervisor: Christopher Caplice

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Finally, I would like to quote an old saying in Taiwan to express my gratitude to my classmates and friends I don't mention here, "There are too many people to thank to. Therefore, I would like to thank God for bringing these people to me."

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1 Introduction

This thesis is mainly related to a network design problem based on a case study with a footwear company, hereafter called the "Shoe Co." The company intends to minimize total supply chain costs[1] by establishing a distribution network which bypasses its primary distribution center in Stoughton, hereafter called the "Stoughton DC." Through the new network, called the distribution center bypass network, Shoe Co. proposes to ship product directly from its Asian factories to a logistics hub at an entry port in the US and then on to selected customers, hereafter called Tier-One Customers.

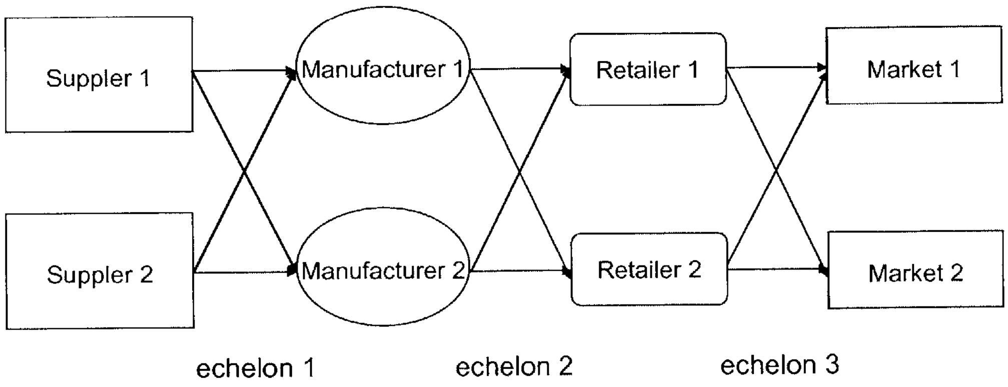
In this chapter, we will define a transportation network, introduce the background of Shoe Co. and its current operation, and identify the scope of the DC bypass project.

1.1 Fundamentals of a Transportation Network

Networks are widely used in our daily lives. They can be communication, electrical, logistics, or others. In this thesis, we focus on Shoe Co.'s transportation network, also called a distribution, logistics, or supply chain network. A transportation network consists of facilities and links. Facilities can be factories, ports, distribution centers, retailer stores, or any place where raw materials, work-in-process products, or finished products are manufactured, stored, or modified by value-added operations. Links are connections between facilities. They represent the shipments or the flow of the products from a facility to another. In general, logistics network provides the structure for supply chain operations such as receiving, putting away, storage, picking, and the transport of products.

Figure 1-1 displays a simple supply chain network for a company. It is a three-echelon network that includes suppliers, manufacturers, retailers, and markets. Suppliers serve manufacturers, which serve retailers, thus meeting the demand of two markets. Each echelon has two parties. Thus, there are 12 links between facilities in total.

Figure 1-1 Example of a Logistics Network



In real life, a supply chain network is more complicated because it involves more parties. A company's logistics network can involve many partners including suppliers, manufacturers, distributors, retailers, carriers, third party service providers, customers, etc. Moreover, a company may also have multiple facilities, such as manufacturing plants, at each echelon. Thus, a network design problem is intrinsically complex and needs a profound assessment.

Network design problems are primarily facility location problems. They determine where to locate facilities and how the product flow affects the supply chain performance in terms of supply chain costs or lead time. When designing a network for a particular product or company,

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[1] Total supply chain cost includes inventory, transportation, facility, handling, and other supply chain related costs.

managers may ask the following questions: does the network design minimize lead time and total supply chain costs? Where should facilities be located? How much capacity should each location have? Which upstream party should serve which downstream party? The upstream-downstream relationships are typically supplier-manufacturer, retailer-market, etc. as shown in Figure 1-1.

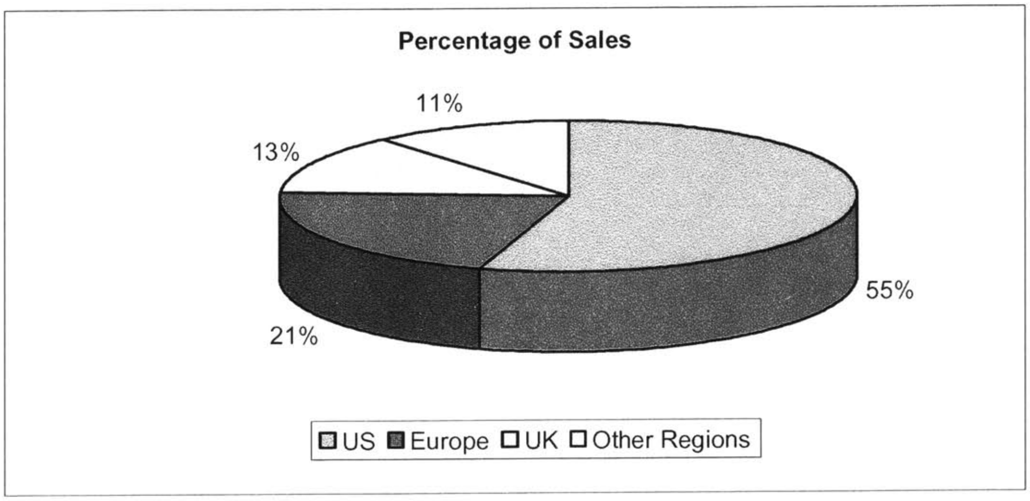
Network design decisions are strategic because the decisions are made for long-term benefits. As we mentioned before, a company needs to consider responses from different parties when it intends to redesign its network. Therefore, it takes time to produce a well-thought analysis about the network. Data collection from different parties is also time-consuming. For example, suppose a company wants to centralize its warehousing system by decreasing the number of the warehouses, it takes time to evaluate which warehouse to close, whether to expand the capacities of remaining warehouses, whether to hire new third party logistics providers or keep the original ones, and whether to keep or lay off current staff. After the evaluation, it also takes efforts to implement the decision and the company also needs to try its best not to worsen its customer service in the transition period. If the new network is better than the original one, the benefits can be large. For example, Billington *at al.* (2001) noted that the redesign of Hewlett-Packard's (HP's) network of Digital Camera and Inkjet Supplies reduced total costs by $130 million while maintaining already-high service levels.

In general, there are three main objectives for a company to assess and redesign its transportation network: to minimize total supply chain costs, to decrease cycle time in the supply chain, or both. In this thesis, we evaluate Shoe Co.'s proposal to implement DC bypass operations for Tier-One Customers to minimize total supply chain costs. We will also discuss the cycle time issue for the further research in Chapter 6.

1.2 Company Background

Shoe Co. manufactures and distributes products including athletic shoes, sportswear, sports accessories, men's casual wear, casual shoes, and apparel. The US is its major market. According to its 2004 annual report, the US market accounts for 55% of sales, Europe for 21%, the UK for 13%, and other regions for 11% (Figure 1-2).

Figure 1-2 Percentage of Sales



Moreover, in 2004, footwear products were the most important business, accounting for 64% of sales while apparel products account for 36%. Footwear products account for around 60% to 70% of the business in North America.

In summary, the footwear products in the US market are the focus according to Shoe Co.'s strategy. Thus, the scope of the DC bypass project focuses on the US market of footwear products.

1.2.1 Current Logistics Operation

In this section, we provide an overview on Shoe Co.'s logistics network.

Shoe Co. currently manufactures all of its footwear products in Asian countries including China, Indonesia, Thailand, and Vietnam. As shown in Figure 1-3, Chinese manufacturers account for the majority of the manufacturing, producing on average 50% of the footwear products annually. Indonesia and Vietnam manufacturers account for 20% of the production each, while Thailand manufacturers account for 10%. After manufacturing, the finished products are loaded in forty foot unit (FEU) containers at the factories, transported via ocean carriers, and shipped to the markets.

Figure 1-3 Location of the Products Produced in Asia

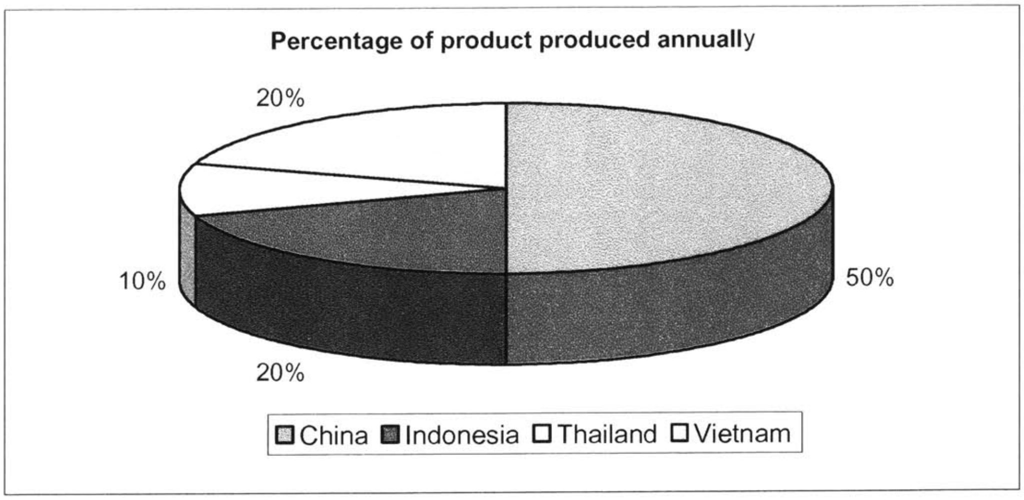


Table 1-1 shows the locations of major plants and export ports Shoe Co. employs in Asia. However, in this project, we do not assume that we export cargo from all of the listed ports. We will explain the reason why we make this assumption in Chapter 3.

Table 1-1 Percentage of the Products Produced in Asia

Country	City	Port
China	Shenzhen	Hong Kong, Shekou, and Yantian
	Fuzhou	Fuzhou and Fuqing
	Zhuhai	Hong Kong
Indonesia	Jakarta	Jakarta
Thailand	Bangkok	Bangkok
Vietnam	Ho Chi Minh City	Ho Chi Mihn City

Shoe Co. classifies customer's orders into two categories: full-container-load (FCL) and less-than-container-load (LCL) orders. Products for FCL orders are shipped directly to customer locations after arriving at the US. These orders are out of the scope of the DC bypass project. Products for LCL orders are processed at the Stoughton DC. In general, 60% of the footwear orders are regarded as FCL orders while the other 40% are LCL orders. The final destinations of LCL-order products are decided either at the Asia factories (50%-60%) or during the ocean transit (40%-50%).

After manufacturing, products for LCL orders are loaded into containers and shipped from the Asian ports via ocean carriers to the US. There are two shipping routes: all-water and mini-land bridge. The all-water route passes through Panama Canal and arrives at the East coast of the US at ports in New Jersey, New York, Baltimore, or Savannah. The mini-land bridge route arrives West Coast ports such as Seattle or Long Beach. After arriving at the US ports, LCL-order containers are shipped to the Stoughton DC. Containers moving via the all-water route are shipped by trucks while those via mini-land are shipped by intermodal[2] or long haul[3]. After cargo arrives at the Stoughton DC, value-added activities, such as price tag labeling, are performed. The largest customers for Stoughton DC are Shoe Co.'s own retailers. When placing orders to

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[2] The use of at least two modes of transportation to complete a shipment such as truck/rail/ or ship/air.

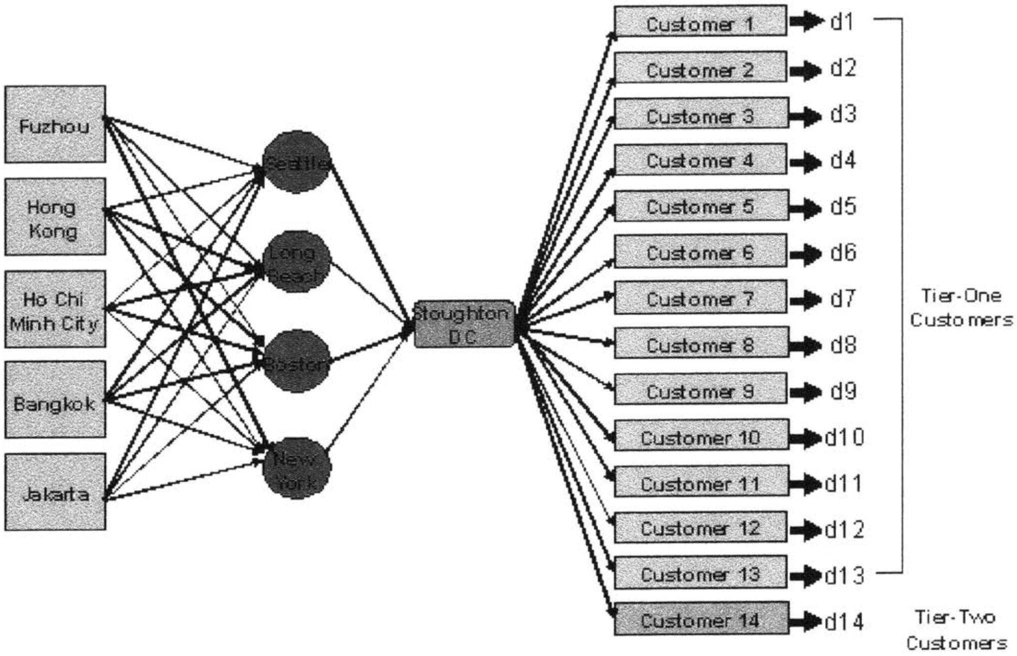
[3] Performed with tractor-trailers, a move that takes place over long distances, generally more than 450 miles.

the Stoughton DC, customers arrange routing from the distribution center to their warehouses and pay for transportation costs.

1.3 Scope of the Distribution Center (DC) Bypass Project

Figure 1-4 displays the existing network, a four-echelon distribution network which includes five departure ports in Asia, four entry ports in the US, a distribution center in Stoughton, hereafter called the Stoughton DC, and customers' locations. Before explaining the figure, we want to stress again that the network displayed in Figure 1-4 is the simplified compared to Shoe Co.'s actual supply chain. We will state the reasons why we simplified it in Chapter 3.

Figure 1-4 Existing Footwear Supply Chain



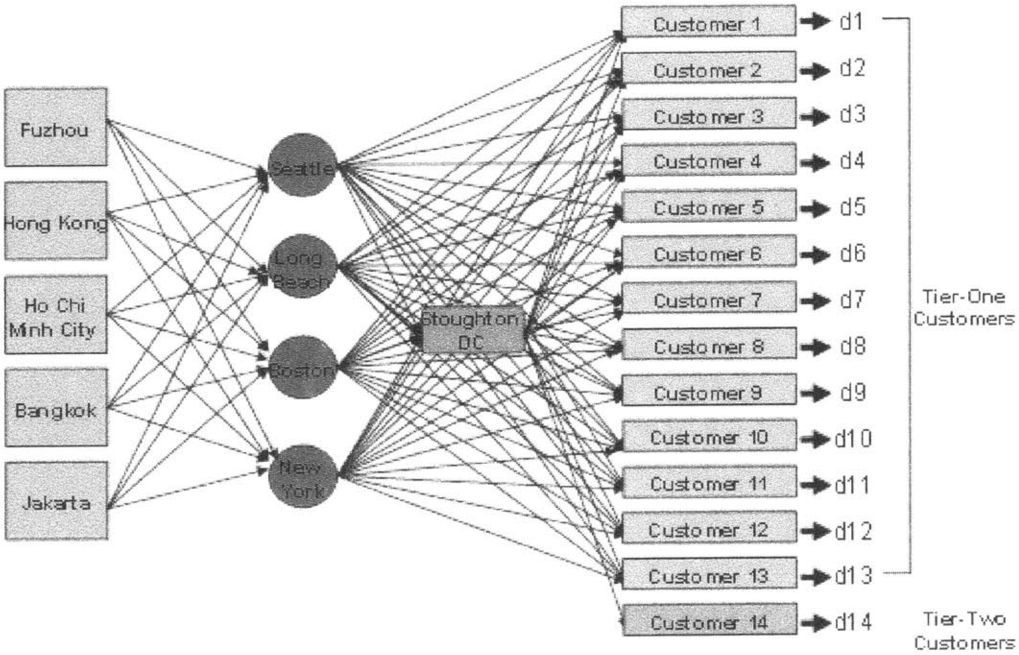
In Figure 1-4, the left nodes represent the location of five departure ports: Fuzhou, Hong Kong, Ho Chi Minh City, Bangkok, and Jakarta. Shoe Co. exports its footwear product via ocean carriers through these five ports to the US market. As we mentioned before, it is a simplified network and thus not all Asian ports are assumed to use in our project. In this case, we use Fuzhou to represent all of the Chinese ports and the reason will be stated in Chapter 3.

There are four potential arrival ports: Seattle, Long Beach, Boston, and New York. These four entry ports are also considered for hosting the DC bypass operation. Thus, these four entry ports will potentially serve as both arrival ports and DC bypass locations.

The Stoughton DC is used in the existing logistics network. It performs traditional warehousing functions including receiving, putting away, storage, picking, and handling. In the DC bypass project, we suggest customers be separated into two tiers. All or some Tier-One Customer orders will be served by shipping products directly to the customers' locations.

The right nodes in Figure 1-5 represent the locations of customers. All customers, which are served by the Stoughton DC, are aggregated into two groups: Tier-One and Tier-Two. Tier-One Customers are represented by specific end locations, usually their distribution centers. Only Tier-One Customers may participate in the DC bypass network. All other customers are classified as Tier-Two Customers and will not participate in the DC bypass network. That is, even if the DC bypass is implemented, Tier-Two Customers will still be served by the Stoughton DC although the exact flow pattern through the network will be determined by the model.

Figure 1-5 Potential Footwear Supply Chain



As shown in Figure 1-5, the DC bypass project converts the three echelon network into a two echelon network for selected items: departure ports to entry ports, then directly on to a customer. After products for Tier-One Customers arrive at an entry port, they are shipped from directly to Tier-One Customers' location or to the Stoughton DC and then onto the customer's location. There are thirteen Tier-One Customers. In Figure 1-5, d denotes annual demand. d1 to d13 represents the Tier-One Customer annual demand which is satisfied by Shoe Co.. All Tier-Two Customers' orders are aggregated into one group, Customer 14, in our model because these orders all destine at the Stoughton DC and the customer pays for the transportation for the Stoughton DC to their distribution centers.

Through the DC bypass project, Shoe Co. expects a reduction in total costs. Possible benefits will be discussed and identified.

Methods to determine a specific location or multiple locations for the DC bypass operations will be discussed. Furthermore, the robustness of the optimal solution will be measured through a sensitivity analysis.

Other benefits from the DC bypass project include the reduction of lead time but we will not cover this topic in this thesis. Intuitively, the lead time from the arrival port directly to the Tier-One Customers' locations will be less than that of the routing through the Stoughton DC because the latter includes the processing time in the Stoughton DC. We will discuss this topic in Chapter 5 for the further research.

In summary, through the DC bypass project, we want to answer the following questions:

1. Should the DC bypass be implemented to minimize the total supply chain costs?
2. If the DC bypass should be implemented, should we implement it for all Tier-One Customers' orders or some of them?
3. What location should be chosen to implement the DC bypass operation?
4. Should we choose one port or multiple facilities for the DC bypass?
5. How many Tier-One Customers' order should go through these entry ports?
6. How does the network solution vary with different costs? For example, if the capital cost to set up a facility for DC bypass operation decrease, will any port become more desirable? How does the optimized result vary if a DC bypass handling cost change?

The remainder of this thesis is organized as follows. Chapter 2 discusses previous methodologies for network design problems and case studies similar to our project. Chapter 3 explains the source of data and summarizes the data and assumptions. Chapter 4 presents the mixed integer linear programming model used in the analysis. Finally, Chapter 5 reviews the analysis and recommends further research.

2 Literature Review - Methodologies and Case Studies

This chapter summarizes commonly used methodologies for the network design problem. Moreover, we refer to previous case studies similar to our project to illustrate these methodologies.

2.1 Minimum Cost Flow Problem

Hillier and Lieberman (2005) note that network analysis is used in many areas including communication, electricity, and transportation. Furthermore, there are many basic prototypes of network problems such as the shortest path problem, the minimum spanning tree problem, and the maximum flow problem. The most commonly applied problem in the network analysis is the minimum cost flow problem. The problem converts a network into the configuration of nodes and links. For example, in a logistics network, nodes are the locations of facilities; links, also called arcs, are transportation movements between facilities. Costs of activities occurring at nodes and arcs are expressed by momentary units such as dollars. For example, when footwear products are shipped by an ocean carrier from Asia to the US, the transportation is expressed by the ocean freight spent on this activity.

Minimum Cost Flow Problems can be formulated and solved by mathematical programming such as linear and mixed integer linear programming. According to Shapiro (2001), mathematical programming models are 'venerable' studies in the field of operations research since the 1950s. They can help managers to make supply chain decisions including network design problems. Linear programming and mixed integer programming can be used in all types of supply chain decisions. They can produce analyses of a system (e.g. a logistics network) with the goal of maximizing or minimizing an objective function subject to constraints, e.g., the maximization of profit given a budget constraint on marketing and production. A study for Citgo Petroleum Corporation (Klingman, Phillips, Steiger, & Young, 1987) is a typical example of applying the minimum cost flow method to improve a company's supply chain. The company developed a linear-programming-based network optimization model that reduced inventory by $116 million. In brief, network design problems can be regarded as minimum cost flow problems, which can be solved by optimization method such as linear programming.

The difference between linear and mixed integer linear programming is that the former assumes all variables are continuous whereas the later suppose some variables are continuous while others are integers. The decision variables of mixed integer linear programming can be both the output of products at and among facilities, and binary variables, which decide whether to open a facility. The objective in a network design problem is typically a minimization of total supply chain costs given five major constraints: capacity constraints, customer services goals (e.g. 99.97% fill rate), logical constraints (e.g. if a facility is built, it must have a product flow), balance constraints (e.g. the number of products moving into a location is equal to the number of products moving out), and demand constraints (all customer demand must be served).

Overall, network design problems are complicated because there are many trade-offs in network design problems. Mathematical programming can help to find the best balance between the trade-offs. For example, an increase in the number of warehouses decreases outbound transportation costs but increases inventory and facility costs. The method can determine how many warehouses to be set to minimize total costs including transportation, inventory, and facility costs. In the mid-1990s, Sery, Perst, and Shobrys (2001) described how BASF North

America, a global chemical company, examined its distribution network. BASF faced conflicting objectives of minimizing transportation costs while improving customer service goals. The costs included fixed costs to run a distribution center, variable handling, inventory costs, and transportation costs. The service was measured by same-day and next-day delivery. Therefore, by using linear programming, Sery *at el.* (2001) helped BASF's management find a balance between the trade-offs. BASF decided to open a new warehouse according to this analysis and increased the volume of goods delivered next day by fifteen percent.

In addition to mathematical programming techniques, Chopra and Meindl (2003) also suggest the use of a gravity model, a mathematical technique used to find the best location of a facility, say, a distribution center, which minimizes distribution costs. The method assumes the locations of facilities are on a Cartesian co-ordinate system in which the origin and the scale in the system is user-defined. It also premises that transportation costs are directly proportional to both distance and volume shipped and that the distance is weighted by the volume of products. The optimal location is that, which minimizes the weighted distance between the facility and the markets.

While the gravity method is easy to solve, it may not lead to a feasible location and tends to oversimplify the problem. For example, supposed a company wants to decide where to locate a warehouse. The result of a gravity model may suggest the best location to minimize the distribution cost is a place at Longitude 41-53'18" N and Latitude 087-36'08" W, which is the location of Lake Michigan! Also, the gravity model assumes that all facilities are open. Thus, optimization method is better than the gravity method for our project because it shall not suggest an infeasible location and consider not just distribution costs but total supply chains costs.

2.2 Baseline, Optimization, and Simulation Models

To derive an optimal solution for a network design, Simchi-Levi, Kaminsky, and Simchi-Levi (2004) suggest a two-step procedure. First, a company should develop a baseline model representing its current logistics network. Then, based on the validated baseline model, the company should build another model to find a feasible solution such as a cheaper or more responsive network by dispatching facilities such as distribution center candidates. They suggest using one of two methodologies: optimization or simulation.

We have already described exact optimization techniques using mixed integer linear programming methods. In addition to exact approaches, there is a whole family of heuristics techniques. Heuristics methods find good but not necessarily optimal solutions. There are two reasons for a company to use heuristics. First, as the size of a network problem increases, it is more difficult to get a feasible solution by exact algorithms. Heuristics can help find a better starting solution for exact methods. Second, heuristics are much faster and are easier to explain.

While optimization is typically used to deal with static information, simulation captures stochastic or random data. Simulation is a process of modeling the random features of a system and then making repeated runs to uncover likely results. It is used to model dynamic systems or systems that are too analytically complex for optimization. For example, suppose that customer demand follows a normal distribution and affects the profits, we can simulate how the profits changes as the demand randomly changes. The requirements of a good transportation network vary with several factors. For example, if demand is concentrated in a certain area, a centralized warehouse tends to be more adequate than multiple warehouses. Simulation can be used to capture the dynamics of a logistics system. However, simulation cannot determine the best network but, rather, can evaluate or score each network configuration. For example, we can develop two logistics network: one has a centralized warehouse while other has multiple warehouses. Then, we can see how supply chain costs vary with the demand under two different logistics network. Then, the managers can choose the better one. In brief, simulation is a tool for the management to select between a set of options, which is not necessarily optimal.

2.3 Conclusion

For many years, these optimization methods have been applied by many companies such as BASF, Citigo, and HP as the above cases showed. Linear-programming-based and mixed-integer-programming-based optimization models are the most commonly used tools in network design problems. Mixed integer programming is a better tool to formulate our project because we need a model to determine the flow of products at the network (continuous variables) and to decide which entry port is used to import the products and open a facility for the DC bypass operations (binary variables). The mixed-integer-based model is used in many case studies. Arntzen, Brown, Harrison, and Trafton (1995) developed a mixed-integer linear program, called the Global Supply Chain Model for Digital Equipment Corporation (DEC). The model represented DEC's distribution, production, and vendor network and helped management redesign DEC's network and saved over $100 million accordingly. We will use mixed integer programming to formulate and solve our problem for this project.

3 Data

As Chapter 2 revealed, we can solve network design problems by using a mixed-integer-linear-programming-based optimization model. This requires a large amount of data, however. In Section 3.1, we will explain the source of the data. In reality, it may not be possible to collect all of the data we need. Therefore, we also need to make assumptions to extract the information we need from the data we actually collect. For example, we need to know port handling charges, but typically door-to-door[4] ocean charges are provided. We have to make assumptions to extract port handling charges from the total costs. In Section 3.2, we will summarize the data we collect and describe the assumptions.

Most of the data are from Shoe Co. However, to protect the privacy of Shoe Co., we have changed or modified data based on particular principles, which will be described later.

3.1 Sources of Data

The model required a large amount of both qualitative and quantitative data. First, we conducted interviews to create a qualitative description of the operation of Shoe Co.'s transportation network. Then, through weekly meetings starting in February, data and the existing network map were validated. Moreover, transactional data was collected from Shoe Co.'s for us to understand

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[4] Door to door refers to the through-transport of goods from a shipper to a consignee. Door-to-Door transportation usually includes multiple modes such as vessels, trucks, or air in one shipment. Many ocean carriers provide door-to- door service to satisfy customers' demand.

the demand pattern. No data is based on future forecasts except the average number of shoes per container in 2005.

All data can be classified into the following groups: customers, commodity, departure and arrival ports, the Stoughton DC, and transportation (Table 3-1). We will illustrate the data we collect and how we make assumptions based on it in Section 3.2.

Table 3-1 Data Collection List

Group	Item	Description
Customer	Zip code	Zip codes are used to identify customers' locations
	Annual demand	Annual demand is in terms of pairs of shoes the customers ordered in past one year. We extracted the data from the transactional file in the Stoughton DC
Commodity	Average product cost	This item represents the value of the item
Departure and Arrival Port	Location	We use the names of the ports and the zip codes to identify their locations
	Maximum capacity	
	Port handling charge	It is derived from the break down of the ocean freight
	Potential handling cost for DC bypass operation	It is estimated by Shoe Co.
The Stoughton DC	Unit handling cost	It Includes order processing, inventory, storage, and labor cost
	Capital	Capital costs are collected to estimate possible costs for the DC bypass facility
	Inventory	Average inventory turn over ratio at the Stoughton DC
Transportation	Ocean Freight	The ocean freight rate is usually measured based on a FEU container
	Inland truckload rate	The rate is based on truckload
	Lead time	It is also called transit time among facilities and measured by 'days'
	Shipment size	The shipment size is based on a particular unit such as a 40' container and a truckload. Thus, we need to know the data at each link to break the freight into rate per pair of shoe
	Transportation mode	Modes can include ocean, truck, rail, and airline. The type of transportation mode affects lead time and the freight.

3.2 Data and Assumptions

In reality, there are over 300 different combinations of routings to ship product from Asia to a customer location. However, we do not build a model based on these combinations but a simplified model. For example, as we mentioned in Chapter 1, we do not assume that we export cargo from all ports Shoe Co. uses now because the DC bypass project is evaluated for selected customers, Tier-One Customers, and thus Shoe Co. chooses major ports to import and export products to aggregate the flow of the products. The aggregation will not hurt the accuracy of the model and we will validate the accuracy in Chapter 4. Moreover, the aggregation by adequately choosing major ports can decrease the complexity of the formulation and consequently reduce the solver time and get a feasible solution more easily. Therefore, we decide to analyze and optimize the network based on a simplified logistics network.

Before optimizing the network, we need to make certain assumptions. The assumptions are as follows:

3.2.1 Commodity

We assume that products are shipped via FEU containers at sea and via a truckload on land. Moreover, to build the optimization model, we need to break the freight into transportation cost per pair of shoes at each link. Therefore, we should know the average numbers of shoes a FEU container and a truckload can hold. According to Shoe Co., the shipment size averages between 6,000 to 6,500 pairs per FEU container. Table 3-2, based on forecasts and historic data, shows the average number of shoes per container for 3 years. In this project, we refer to the average number, 6,171 pairs of shoes, in 2005 to break the door-to-door- ocean rates.

Table 3-2 Average Pairs of Shoes per FEU Container

Year	Units per FEU Container
2003	6,393
2004	6,150
2005	6,171

Moreover, we focus on the annual flow of finished goods, modeled as pairs of shoes. The basic cost unit is cents per pair. According to Shoe Co., each pair of shoes is assumed to weigh 1.5 pound and account for 0.39 cubic feet.

3.2.2 Breakdown of the Ocean Freight

For the modeling, we need to know the following costs in terms of cents per pair of shoe: handling cost at departure and arrival port, port-to-port[5] ocean freight, and inland transportation rate for the shipment from then US entry port to the Stoughton DC. These costs are included into the door-to-door ocean freight. The freight rate per FEU container includes the bunker[6] adjustment factor[7] and security fees[8]. Then, we need to figure out a reasonable assumption to break the door-to-door freight into a cost per unit.

Table 3-3 displays the average ocean freight costs. According to the agreement between Shoe Co. and its ocean carriers, Shoe Co. cannot reveal its rate to other organizations. Therefore,

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[5] Port-to-port denotes the transport of goods via an ocean route from a departure port to an arrival port.

[6] Bunker is a fuel for ships to sail.

[7] Bunker adjustment factor refers to a fee for adjustment applied by shipping carriers to offset the effect of fluctuations in the cost of bunkers.

[8] There two types of security fees: Terminal Security Fee, charged for the shipments via the ports where the threat and the need for increased security are based on a realistic threat; Carrier Security Fee, based on ongoing costs to keep ships and the crew secure.

to avoid breaking the agreement, Shoe Co. provided us the rate quoted by one of the ocean carriers it hires without revealing the carrier's name.

Shoe Co. pays for the door-to-door ocean freight from Asia to the Stoughton DC in the existing network. The basic unit of the door-to-door rate is a FEU container.

In the existing network via all-water routes, the arrival ports are either Boston or New York. Moreover, the door-to-door freight rate, as presented in Table 3-3, is the same regardless of the arrival port.

Table 3-3 Door-to-Door All-Water Ocean Freight

Origin	**Destination**	**All Water Rate**
Fuzhou	Stoughton via New York/Boston	$ 3,630
Hong Kong	Stoughton via New York/Boston	$ 3,330
HCM	Stoughton via New York/Boston	$ 3,830
Bangkok	Stoughton via New York/Boston	$ 3,780
Jakarta	Stoughton via New York/Boston	$ 3,423

To break down the door-to-door ocean rate into cost per unit, we refer to Saanen's research in 2004 (Table 3-4). The door-to-door ocean freight rate consists of different costs for activities such as inland transportation, port handling, and sea shipping. For example, Sannen asserts that 33% of the door-to-door ocean freight costs are due to sea shipping (port to port) costs. Percentages for other activities such as port handling are displayed in Table 3-4.

Table 3-4 Average Share of Ocean Freight

Inland Truck in the Origin Country	Departure Port Handling	Sea Shipping	Arrival Port Handling	Truck/Rail in the Destination Country	Total
16%	8%	33%	9%	34%	100%

Then, as listed in Table3-5, we get the following costs by using Shoe Co.'s freight times a certain percentage derived from Table 3-4. The arrival port is Boston or New York.

Table 3-5 Cost Breakdown

Origin	Destination	All Water Rate	Inland truck from a plant to a departure port	Departure port handling	Shipping	Arrival port handling	Inland trucking from an arrival port to the destination
			16%	8%	33%	9%	34%
Fuzhou	Stoughton	$ 3,630	$ 581	$ 290	$ 1,198	$ 327	$ 1,234
Hong Kong	Stoughton	$ 3,330	$ 533	$ 266	$ 1,099	$ 300	$ 1,132
HCM	Stoughton	$ 3,830	$ 613	$ 306	$ 1,264	$ 345	$ 1,302
Bangkok	Stoughton	$ 3,780	$ 605	$ 302	$ 1,247	$ 340	$ 1,285
Jakarta	Stoughton	$ 3,423	$ 548	$ 274	$ 1,130	$ 308	$ 1,164

Per our assumption, the port handling charge is the same in Boston as in that in New York. Therefore, it is not reasonable for us to have a arrival port handling cost ranging from $300 to $340. Therefore, we decided to unify the handling cost at an arrival port by averaging the arrival port handling costs listed in Table 3-5, that is, $324. Then, we readjust the ocean shipping rate by modifying the number accordingly as shown in Table 3-6.

Table 3-6 Adjusted Cost Breakdown

Origin	Destination	All Water Rate	Inland truck from a plant to a departure port	Departure port handling	Adjusted Shipping	Arrival port handling	Inland trucking from an arrival port to the destination
Fuzhou	Stoughton	$ 3,630	$ 581	$ 290	$ 1,201	$ 324	$ 1,234
Hong Kong	Stoughton	$ 3,330	$ 533	$ 266	$ 1,075	$ 324	$ 1,132
HCM	Stoughton	$ 3,830	$ 613	$ 306	$ 1,285	$ 324	$ 1,302
Bangkok	Stoughton	$ 3,780	$ 605	$ 302	$ 1,264	$ 324	$ 1,285
Jakarta	Stoughton	$ 3,423	$ 548	$ 274	$ 1,114	$ 324	$ 1,164

Likewise, we also get the share of ocean freight for the mini-land route from Asia to Long Beach and Seattle as listed in Table 3-7.

Table 3-7 Adjusted Cost Breakdown According to a Particular Ratio

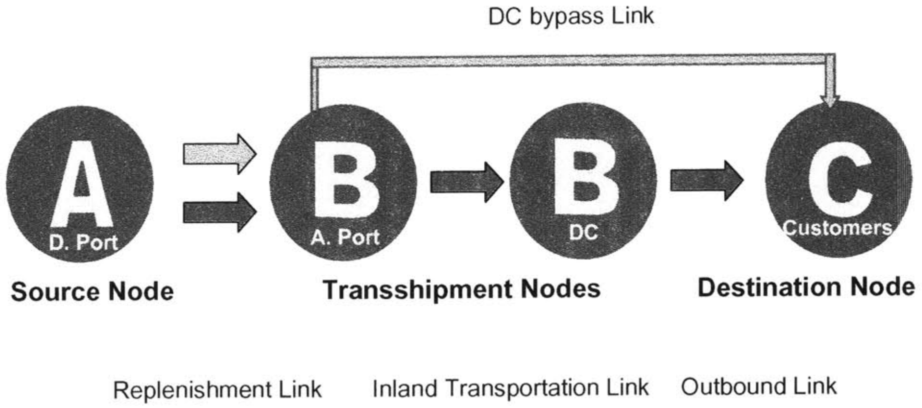
Origin	Destination	All Water Rate	Inland truck from a plant to a departure port	Departure port handling	Adjusted Shipping	Arrival port handling
Fuzhou	Seattle	$ 2,900	$ 581	$ 290	$ 1,770	$ 259
Hong Kong	Seattle	$ 2,700	$ 533	$ 266	$ 1,642	$ 259
HCM	Seattle	$ 2,800	$ 613	$ 306	$ 1,622	$ 259
Bangkok	Seattle	$ 3,000	$ 605	$ 302	$ 1,834	$ 259
Jakarta	Seattle	$ 3,000	$ 548	$ 274	$ 1,919	$ 259
Fuzhou	Long Beach	$ 2,900	$ 581	$ 290	$ 1,770	$ 259
Hong Kong	Long Beach	$ 2,700	$ 533	$ 266	$ 1,642	$ 259
HCM	Long Beach	$ 2,800	$ 613	$ 306	$ 1,622	$ 259
Bangkok	Long Beach	$ 3,000	$ 605	$ 302	$ 1,834	$ 259
Jakarta	Long Beach	$ 3,000	$ 548	$ 274	$ 1,919	$ 259

From Section 3.2.1, we know that average number of shoes in a FEU container is 6,171. Therefore, we can convert the above costs into costs per pair of shoes by dividing the costs by 6,171. Then, we can get unit ocean shipping rate for the replenishment link. Take shipping costs from Fuzhou to Seattle for example, the unit shipping rate is 29 cents per pair of shoes.

3.2.3 Link- Replenishment, Inland Transportation, the DC bypass, and Outbound

As shown in Figure 3-1, There are four types of links in our analysis: replenishment, inland transportation, the DC bypass, and outbound. Replenishment links represent shipments between Asian departure ports and the US arrival ports. Inland transportation links identify the distribution between arrival ports and the Stoughton. Outbound links capture the transportation, paid by the customers, from the Stoughton DC to Tier-One Customers' locations. DC bypass link is similar to the outbound link. It represents the shipments from the arrival ports to the Tier-One Customers' locations but the transportation costs are paid by Shoe Co..

Figure 3-1 Links in Shoe Co.'s Supply Chain



In summary, there are two flows in Figure 3-1. One is the flow of products in the existing supply chain network. They depict the flow of finished products in the existing three-echelon network including departure ports, arrival ports, Stoughton DC, and customers. The other is the flow of products in the DC bypass network, a two-echelon logistics network including departure ports, arrival ports, and customers.

Replenishment Link

In general, ocean contract rates are confidential and can only be issued with the carrier's permission to the third party. Therefore, as we mentioned in the beginning of the chapter, all rates are real without knowing the carrier's name.

The majority of Shoe Co.'s product is shipped via full containers from the factory. Very few of them are transloaded at the port. Transloading is the process of transferring a shipment from one mode of transportation to another. It usually refers to an operation to discharge cargo from a container on a rail car to a truck, and then eventually delivered to the customers' door by a truck. The reason why transloading is performed is for the benefit of economies of scale because the size of a truckload in the US is bigger than that of a standard intermodal container.

Table 3-8 shows the lead time (days) from Asian ports to the US ports. Though the purpose of this project is to seek the least cost solution, the data can be used in the further research, which includes a consideration of the lead time.

Table 3-8 Lead Time (day) at Replenishment Link

		Arrival Port			
		Seattle	Long Beach	Boston	New York
Departure Port	Fuzhou	22	23	36	36
	Hong Kong	16	14	32	32
	Ho Chi Mihm City	22	19	40	40
	Bangkok	21	21	39	39
	Jakarta	23	29	38	38

Inland Transportation Link, DC bypass Link, and Outbound Link

Truckload transportation rates were based on $2 billion of total truckload movements. A regression of this freight resulted in an estimated cost function. The resulting equation is $262 + $1.05*Distance (mile). By this equation, we derive unit rate (cent) for inland transportation and the DC bypass link (Table 3-9 and Table 3-10). Distribution at inland transportation link is paid by Shoe. Co while the outbound transportation rate from the Stoughton DC to a customer is paid by the customer. Therefore, in the model, we assume that the unit rate from the Stoughton DC to customers' location is zero (Table 3-10).

Table 3-9 Unit Transportation Rate at Inland Transportation Link

		The Stoughton DC
Arrival Port	Seattle	36.30
	Long Beach	37.67
	Boston	3.51
	New York	5.63

Table 3-10 Unit Transportation Rate at Inland Transportation and Outbound Link

	Tier-One Customer												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Seattle	38.6	27.4	20.1	31.4	35.1	27.4	31.6	44.1	43.9	40.6	39.0	20.2	20.2
Long Beach	33.9	24.6	4.3	24.0	26.3	24.6	24.1	42.9	44.8	36.4	36.1	4.3	4.3
Boston	21.5	26.7	46.8	30.1	31.0	26.7	30.2	11.8	7.1	19.7	17.6	47.1	47.0
New York	18.4	24.2	44.3	27.2	28.0	24.2	27.3	8.9	4.3	16.6	14.5	44.7	44.6
Stoughton	-	-	-	-	-	-	-	-	-	-	-		-

Likewise, though we do not use the data about the lead time, we still collect the data for the further research in Chapter 6 (Table 3-11 and Table 3-12).

Table 3-11 Lead Time (day) at the DC Transfer Link

DC Transfer		The Stoughton DC
Arrival Port	Seattle	5
	Long Beach	4
	Boston	1
	New York	1

Table 3-12 Lead Time (day) at DC Transfer and Outbound Link

	Tier-One Customer												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Seattle	5	4	3	4	5	4	4	5	5	5	5	3	3
Long Beach	4	4	1	3	3	4	3	5	4	4	4	1	1
Boston	3	4	4	4	4	4	4	2	1	3	3	4	4
New York	3	3	4	4	4	3	4	2	1	3	3	4	4
Stoughton	3	4	4	4	4	4	4	2	1	3	3	4	4

3.2.4 Ports- Departure and Arrival

In this section, we discuss the data about the port data and the underlying assumptions.

Departure Ports

Shoe Co. manufactures all shoes in Asia at factories near one of the departure ports, which are Fuzhou, Hong Kong, Ho Chi Minh City, Bangkok, and Jakarta. We assume that Shoe Co. exports its footwear product through these ports to the US market. According to Shoe Co.'s historic data for the last year, each port accounts for 20% of the total export volume as shown in Table 3-13. In our model, the percentage at the departure ports is fixed at this historic level. That is, in this project, the choice of the departure ports is not the decision we would like to make because we assume products are exported from Asia based on the percentage presented in Table 3-13. Moreover, the number of units also represents the maximum throughput at each port.

Table 3-13 Historic Export Volume at a Departure Port

Departure Port	Unit	Percentage
Fuzhou	4,350,990	20%
Hong Kong	4,350,990	20%
Ho Chi Mihm City	4,350,990	20%
Bangkok	4,350,990	20%
Jakarta	4,350,990	20%
Total	21,754,950	100%

Moreover, we do not assume other costs except port handling costs at departure ports as shown in Table 3-14, which are derived from door-to-door ocean rate as we illustrated earlier in this chapter.

Table 3-14 Handling Cost at a Departure Port

	Cent/Unit
Fuzhou	4.70
Hong Kong	4.31
Ho Chi Mihm City	4.96
Bangkok	4.89
Jakarta	4.44

Arrival Ports and Candidates for the DC bypass Operation

In practice, Shoe Co. imports cargo via the US entry ports including Seattle, Tacoma, Long Beach, Houston, Miami, Charleston, Savannah, Norfolk, New York, Boston, and Halifax. Shipments arriving at Halifax are shipped on a feeder ship to Boston.

However, in our project, we assume that we import cargo via Long Beach, Seattle, Boston, or New York because we focus on Tier-One Customer orders and above ports are major entry ports for these customers. Moreover, all shipments to customers are via truck.

According to Shoe Co.'s historic data, each arrival port processes a certain percentage of the import volume (Table 3-15). The number of units also represents the maximum throughput at each port in our modeling. This maximum throughput, worked as the higher bound in the mixed integer linear programming, is used as a capacity constraint.

Table 3-15 Historic Import Volume at an Arrival Port

Arrival Port	Unit	Percentage
Seattle	1,087,748	5%
Long Beach	5,438,738	25%
Boston	870,198	4%
New York	14,358,267	66%
Total	21,754,950	100%

A capacity constraint is applied because of a risk issue. Few companies import products through one port because of the concept of portfolio. For example, suppose Shoe Co. imports all products via Long Beach in the peak season. If there is a congestion or strike in Long Beach, the transit time will increase and hurts Shoe Co.'s business because it cannot meet the demand of the peak season.

However, we may assume there is no capacity constraint under some scenarios to examine whether releasing the capacity constraint can cause savings in total supply chain costs and how the reallocation of the import volume affects the solutions.

Table 3-16 reveal possible unit handling cost for the DC bypass operation. The cost is estimated by Shoe Co. for the DC bypass network. Therefore, we need to conduct a sensitivity analysis to reveal how the change in this cost will affect the optimal results.

Table 3-16 Handling Cost for the DC Bypass Operation

Handling for the DC bypass operation	Cent/Unit
Seattle	5
Long Beach	5
Boston	5
New York	5

3.2.5 Stoughton Distribution Center

Shoe Co. actually has two DCs. A bigger one is at Stoughton while a smaller one is at Norwood. However, Shoe Co. employs one warehouse management system to operate both warehouses. The system regards two DCs as one DC in its database, Therefore, the transactional files we collected assume there is only one DC which serves Shoes Co.'s customers. Therefore, we premise that there is only one DC, the Stoughton DC, in the existing logistics network.

The new network will bypass the Stoughton DC. Now all footwear products of LCL orders are shipped to Stoughton DC directly after arriving at the entry ports in the US. In the DC bypass network, all or some Tier-One Customer orders will bypass the Stoughton DC. That is, if the DC bypass is implemented, related costs accruing in the Stoughton SC will be eliminated while other DC bypass costs will incur.

Inventory

Average inventory at the Stoughton DC is 4.1 million with an average inventory turnover ratio of four. That is, inventory stays in the Stoughton DC for 3 month on average. However, because our focus is on the minimization of total supply chain cost, not the lead time issue, we will not include this data in our analysis.

Handling Cost

Average handling cost in the Stoughton DC is $0.92 per pair. This cost includes inventory, order processing, and labor costs.

Facility Cost

Capital cost of the Stoughton DC is $2.5 million while Norwood is $1.6 million. We need this information to estimate facility cost for DC bypass project. The higher the facility cost, the lower the chance the optimization model would suggest multiple locations for a DC bypass. In some initial models, we assume that it costs $2 million (the rough average of $2.5 and $1.6 million) if we build a new facility for the DC bypass project. However, this estimation may be too high because of two reasons: 1) the volume of products is less than the throughput at Stoughton DC because only some of the customers will participate this project; 2) Shoe Co. may hire a third party logistics firm to handle the DC bypass operation and thus may not have fixed costs. Due to the above reasons, we will conduct sensitivity analysis on facility costs to see how they impact the solution. The related analysis will be discussed in Chapter 5.

3.2.6 Customers

From the transactional file Shoe Co. provided, we can rank the top 13 customers according to order quantity in the past year as shown in the Table 3-17.

Table 3-17 Top 13 Customers

Rank	Shipment Quantity	%
1	4,497,813	21%
2	857,774	4%
3	744,678	3%
4	744,565	3%
5	652,326	3%
6	502,499	2%
7	485,674	2%
8	420,561	2%
9	400,905	2%
10	360,926	2%
11	353,941	2%
12	340,391	2%
13	325,398	1%
Total	21754950	100%

However, not all of these customers are candidates for the DC bypass project. Customers are classified into two tiers. Customers, which are served by Stoughton DC, are aggregated into two groups: Tier-One Customers and Tier-Two Customers. Tier-One Customers are represented by specific end locations, usually their distribution centers. Only Tier-One Customers may participate in the DC bypass network. Shoe Co. chose DC bypass partner based the following criteria: 1) potential order quantity in the future; 2) general order pattern; 3) ease and willingness to join the DC bypass project; and 4) the location of customers. Table 3-18 summarizes the order quantity of 13 potential customers for this DC bypass customers. These customers, Tier-One Customers, account for 26% of order quantity shipping from Stoughton DC.

Table 3-18 Tier-One Customers in the DC Bypass project

Customer	Customer Location	Demand (Units)	Demand Weight (Pounds)	Demand (CWT[9])	Demand (CFT[10])	% of Total Volume
1	Birmingham, AL	353,946	530,919	5,309	137,082	2%
2	Junction City, KS	400,905	530,919	6,014	155,269	2%
3	West Puente Valle, CA	360,926	601,358	5,414	139,785	2%
4	Haslet, TX	652,326	541,389	9,785	252,643	3%
5	Katy, TX	485,674	978,489	7,285	188,099	2%
6	Junction City, KS	260,996	728,511	3,915	101,083	1%
7	Fort Worth, TX	744,678	24,280,812	11,170	288,410	3%
8	Newport News, VA	325,398	1,117,017	4,881	126,025	1%
9	Bronx, NY	502,499	488,097	7,537	194,616	2%
10	McDonough, GA	744,565	753,749	11,168	288,367	3%
11	Whites Village, TN	156,565	1,116,848	2,348	60,637	1%
12	Watts, CA	238,873	234,848	3,583	92,514	1%
13	Downey, CA	340,391	358,310	5,106	131,832	2%

We find that these locations of Tier-One Customers correspond to Top 10 Cities, where the major destinations of orders served by the Stoughton DC in the past one year (Table 3-19). These orders include the demand from both Tier-One and Tier-Two Customers.

Table 3-19 Top 10 Cities

Top 10 Cities with the Largest Annual Volume			
City	Zip	Shipment Quantity	% of Total Volume
Junction City, KS	66441	1,175,556	5.10%
Bronx, NY	10461	504,248	2.19%
Katy, TX	77449	485,674	2.11%
Haslet, TX	76052	447,380	1.94%
Carlisle, PA	17013	417,613	1.81%
Birmingham, AL	35211	351,309	1.52%
Evansville, IN	47725	293,437	1.27%
Fontana, CA	92336	269,790	1.17%
Los Angeles, CA	90061	241,728	1.05%
Irving, TX	75061	220,136	0.96%

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[9] An abbreviation for a hundred weight, or weight in hundreds of pounds.

[10] An abbreviation for hundred foot.

4 Model

Section 4.1 illustrates the methodology we use to assess Shoe Co.'s transportation network. The methodology consists of two procedures. First, we create a baseline model to represent the existing network. Second, we develop models with different scenarios to optimize the logistics network. Section 4.2 explains the formulations used in the optimization model. The optimization model is based on assumptions described in Chapter 3

4.1 Methodology

The baseline model represents Shoe Co.'s existing logistics network. This allows us to assess the correctness and accuracy of our model. We can derive total supply chain costs from the baseline model and then compare the cost with actual costs Shoe Co. spends. If the cost from the baseline model is similar to the cost in the real world, the baseline model is built correctly. After validating the baseline model, we build the optimization models under different scenarios.

The method we use to optimize the logistics network is called mixed integer linear programming, which is used to solve the minimum cost flow problem. Behind the optimization models, two points are emphasized: trade-offs and scenarios. We can understand the possible impacts from the new network through the trade-offs among different costs. For example, increases in products flowing through the DC bypass network raise the inland transportation costs between arrival ports to customers' locations but lowers handling costs at the Stoughton DC. Through mixed integer linear programming, we can find the optimal flow of products through the network to minimize total costs. As to scenarios, because changes in assumptions may change the results, several scenarios are described and the resulting solutions under different scenarios will be discussed in Chapter 5.

4.1.1 Baseline Model

In this project, a baseline model assumes all products are shipped through the Stoughton DC. A good baseline model must illustrate the existing logistics network. The total costs and lead times accrued by the baseline should be similar to the costs the real network has. Table 4-1 shows annual costs from the baseline model.

Table 4-1 Cost in Baseline Model

	Tier-One Customer	**Tier-Two Customer**	**Subtotal**
Facility			
DC Bypass Facility	$ -	$ -	$ -
Port Facility	$ -	$ -	$ -
Transportation			
Replenishment Costs	$ 1,978,074	$ 5,752,706	$ 7,730,781
Inland Costs	$ 2,095,499	$ 1,187,445	$ 3,282,943
Outbound Costs	$ -	$ -	$ -
Handling			
Asia Port	$ 249,805	$ 760,843	$ 1,010,648
US Port	$ 281,802	$ 791,668	$ 1,073,470
DC Bypass	$ -	$ -	$ -
Stoughton DC	$ 5,122,323	$ 14,892,231	$ 20,014,554

	Facility	**$ -**
	Transportation	**$ 11,013,724**
	Handling	**$ 22,098,672**
	Total Cost	**$ 33,112,396**
	Unit Cost	$ 1.52

The real unit supply chain costs are not available in this case. The similar data we have is that Shoe Co. pays door-to-door freight rate about 63 cents per pair of shoes. Thus, we derive unit door-to-door distribution costs from Table 4-1 to validate the baseline model. The door-to-door costs include transportation and port handling charges. The average unit cost in the baseline model is 60 cents, which only has 4% difference compared to real unit costs. Therefore, we can prove the accuracy of the baseline model. Then, we can derive costs in optimization models to see whether a optimized network save costs. In the Chapter 5, we will use unit supply chain cost ($/pair) to compare the costs in each scenario with those in the baseline model.

4.1.2 Optimization Model

The optimization model represents the future footwear supply chain Shoe Co. may implement. It consists of the existing and the DC bypass network. In this model, all Tier-Two Customers' demand is served by the existing network while Tier-One Customers' demand can be served either by the existing logistics network or the DC bypass network or both.

4.1.2.1 Trade-offs

We intend to find the least total supply chain cost. Before building optimization models, we should understand possible trade-offs about different cost such as transportation and handling costs. There are three main trade-offs in this project:

Transportation Cost

As we mentioned before, customers arrange and pay for outbound transportation in the existing network. If the DC bypass operation is implemented, Shoe Co. needs to pay for the distribution from the logistics hub to customer locations. Therefore, from the distribution point of view, Shoe Co. pays for the transportation from the entry ports to Stoughton DC in the existing operation. If the DC bypass operation is implemented, Shoe Co. will pay for the transportation from a chosen entry port to a customer location directly. Therefore, the trade-offs about costs between these two routes should be noticed.

Capacity Constraint

In the existing network, Shoe Co. imports shoes according to a fixed percentage as we described in Section 3.2.4. We call the scenario with this assumption as a model with a capacity constraint. In our optimization model, we will relax the capacity constraint to see how the optimal results are different with those with a capacity constraint.

Handling Cost

There are three kinds of handling costs in this model: port, the bypass DC, and the Stoughton DC. The trade-off in handling costs is between the Stoughton DC and the bypass DC. If the customer's demand is served by the existing network, products are processed in the Stoughton DC and shipped to customers' locations. On the other hand, if the customers' demand is served by the DC bypass network, the products are processed at the entry port and then shipped to the customers' locations. Therefore, the scale of these handling costs will determine which network is more desirable.

Facility Cost

If the DC bypass network is built, there must be a facility set up in the entry port to perform the logistics operations. Therefore, the scale of the facility cost affects whether the DC bypass network is attractive for Shoe Co.

In summary, mixed-integer-linear-programming models are useful to find a best solution among above trade-offs, in which the breakeven points will be discussed further in Chapter 5.

4.1.2.2 Scenarios

There are five groups of scenarios. Each group has its purpose as summarized in Table 4-2. Each group has particular assumptions and can also be divided into two subgroups: scenarios with a capacity constraint and without a capacity constraint. Each run, except forced runs, assume that the maximum number of entry ports and candidates for the DC bypass operation is four: Seattle, Long Beach, New York, and Boston.

Table 4-2 Group of Scenarios

Number	Group	Description
1	Initial Runs	Scenarios with simplest assumptions. They assume 1) All ports are open; 2) there is no facility cost if the DC bypass facility is open.
2	Forced Runs	Only a particular US entry port is chosen in an optimization model
3	Facility Runs	Runs to find Breakeven Points of Facility Costs. Through these runs, we identify the range of facility costs, which recommends a particular number of facilities for the DC bypass operation in the optimized results
4	DC Handling Runs	Runs to find Breakeven Points of Handling Costs at the Stoughton DC. Through these runs, we identify the range of minimum handling costs at the Stoughton DC, which supports the DC bypass network.
5	DC bypass Handling Runs	Runs to find Breakeven Points of Handling Costs at the US Entry Port. Through these runs, we identify the range of minimum handling costs at the US entry port, which supports the DC bypass network.

Furthermore, we created a table, Table 4-3, which summarizes different assumptions made in each model run.

Table 4-3 Notation of the Network Model

Description	Notation
A port is allowed without a restricted capacity	O
A port is restricted	Φ
A port is allowed with a set capacity	●

For example, Table 4-4 represents initial runs. Model 3 captures the initial run without a capacity constraint while Model 4 with a capacity constraint.

Table 4-4 Assumptions of Initial Runs

No. of Model	**SEA**	**LGB**	**NYC**	**BOS**	**Max No. of Port**	**Max. No of DCB**	**Capital Cost**
3	O	O	O	O	4	4	$ -
4	●	●	●	●	4	4	$ -

As shown in Table 4-5, Models 5 to 12 represent runs when a port is forced to open for the DC bypass operation. Models 5 to 8 are runs without a capacity constraint while Models 9 to 12 places a capacity constraint on the entry ports.

Table 4-5 Assumptions of Forced Runs

No. of Model	**SEA**	**LGB**	**NYC**	**BOS**	**Max No. of Port**	**Max. No of DCB**	**Capital Cost**
5	O	Φ	Φ	Φ	4	1	$ -
6	Φ	O	Φ	Φ	4	1	$ -
7	Φ	Φ	O	Φ	4	1	$ -
8	Φ	Φ	Φ	O	4	1	$ -
9	●	Φ	Φ	Φ	4	1	$ -
10	Φ	●	Φ	Φ	4	1	$ -
11	Φ	Φ	●	Φ	4	1	$ -
12	Φ	Φ	Φ	●	4	1	$ -

Like runs to find breakeven points of facility costs, runs to find breakeven points of handling Costs at the Stoughton DC and at the US entry ports are for the purpose of sensitivity analyses to seek the range of costs which creates the similar optimization results. Similarly, the range of handling costs will also be identified and discussed in Chapter 5.

4.2 Formulation

Table 4-6 shows that notations used in our formulation. There are four groups of notations: a logistics network, decision variables, cost parameters, and other parameters.

Table 4-6 Notation of the Formulation

Group	Notation	Description
Set	A	Set of departure ports, $\forall A \in \{1,\ldots,5\}$
	U	Set of arrival ports and facilities for the DC bypass operations, $\forall U \in \{1,..,4\}$
	S	A distribution center
	K	Set of Tier-One Customers; $\forall K \in \{1,..,13\}$
	C	Customer class C, $\forall C \in \{1,2\}$
Decision Variable	x_{ij}^{c}	Network flow of the customer class C from node i to node j; unit: pairs of shoes
	y_j	Binary variable to decide whether or not to import products through an entry port j. y_j =1, if product flows through port j; otherwise y_j =0.
	z_i	Binary variable to decide whether or not to open a facility for the distribution center bypass at an entry port i. z_i = 1, if product flows through port j; otherwise z_i = 0.
Cost Parameter	F_i	Fixed cost (¢/facility) to set up a facility for the distribution center bypass
	f_i	Fixed cost (¢/port) to set up a port for the import
	M_i	Large number
	h_j^d	Unit handling cost (¢/pair) at a departure port j
	h_j^a	Unit handling cost (¢/pair) at an arrival port j
	h_j^s	Unit handling cost (¢/pair) at the Stoughton DC
	t_{ij}	Unit transportation cost (¢/pair) from node i to node j
Other Parameter	T_i	Maximum throughput at a port i
	d_j^c	Annual demand at node j for Customer class C, $\forall C \in \{1,2\}$; unit: pairs of shoes
	a	Maximum number of arrival ports
	b	Maximum number of Bypass distribution centers

The objective function for the mixed integer linear programming formulation of this problem is:

$$Min \sum_{c\in C} \sum_{i\in A} \sum_{j\in U} t_{ij} x_{ij}^{c} + \sum_{c\in C} \sum_{i\in U} \sum_{j\in S} t_{ij} x_{ij}^{c} + \sum_{i\in U} \sum_{j\in K} t_{ij} x_{ij}^{1}$$

$$+ \sum_{c\in C} \sum_{i\in U} \sum_{j\in S} h_j^s x_{ij}^c + \sum_{c\in C} \sum_{j\in A} h_j^d (\sum_{i\in U} x_{ji}^c) + \sum_{c\in C} \sum_{j\in U} h_j^a (\sum_{i\in A} x_{ij}^c) + \sum_{i\in U} F_i z_i + \sum_{i\in U} f_i y_i \qquad (1)$$

The objective (1) is to minimize the total supply chain cost of sending the finished footwear product through the network to satisfy the given demand. Total supply chain cost includes transportation, handling, and facility costs

The first term, $\sum_{c\in C}\sum_{i\in A}\sum_{j\in U} t_{ij}x_{ij}^{c}$, captures the transportation cost from Asian ports to the US ports. The second term, $\sum_{c\in C}\sum_{i\in U}\sum_{j\in S} t_{ij}x_{ij}^{c}$, represents the inland transportation cost from the US ports to the Stoughton DC. Then, the third term, $\sum_{i\in U}\sum_{j\in K} t_{ij}x_{ij}^{1}$, indicates the outbound cost paid by Shoe Co. to transport footwear product from the Stoughton DC to Tier-One Customers' locations in the DC bypass network. The fourth term, $\sum_{c\in C}\sum_{i\in U}\sum_{j\in S} h_j^{s}x_{ij}^{c}$, identifies the handling costs at the Stoughton DC. The fifth term, $\sum_{c\in C}\sum_{j\in A} h_j^{d}(\sum_{i\in U} x_{ji}^{c})$, generates handling costs at Asian ports. The sixth term, $\sum_{c\in C}\sum_{j\in U} h_j^{a}(\sum_{i\in A} x_{ij}^{c})$, captures the port handling costs at arrival ports in the US. The seventh term, $\sum_{i\in U} F_i z_i$, represents the fixed cost for building DC bypass facility. The final term, $\sum_{i\in U} f_i y_i$, identifies the fixed cost Shoe Co. pays to use arrival ports.

The objective function (1) is subject to the following constraints:

$$\sum_{c\in C}\sum_{j\in U} x_{ij}^{c} \le T_i,\ \forall i\in A \qquad (2)$$

The above capacity constraint (2) represents that the aggregation of the flow at each departure port is less than or equal to a given maximum throughput. The given maximum throughput, T_i, is given by Shoe Co. based on the historic import data. Likewise, the aggregation of the flow at each arrival port is less than or equal to a given throughput and the capacity constraint (3) is show as follows:

$$\sum_{c \in C} \sum_{j \in A} x_{ji}^c \leq T_i, \forall i \in U \tag{3}$$

Besides capacity constraints, flow constraints are used to ensure the balance between supply and demand at each node. The first flow constraint (4) represents that the aggregation of the flow to an arrival port is equal to the flow from the arrival port to the Stoughton DC and Tier-One Customers' locations.

$$\sum_{i \in A} x_{ij}^c = \sum_{i \in S} x_{ji}^c + \sum_{i \in K} x_{ji}^c, \forall j \in U, \ \forall c \in C \tag{4}$$

The Tier-One Customers' orders may be processed by Stoughton DC if they are not processed through the distribution center bypass route. Thus, the second flow constraint (5) indicates that the summation of the flow to satisfy the Tier-One Customers' demand from arrival ports to the Stoughton DC must be equal to the summation of the flow from Stoughton DC to the Tier-One Customers' locations.

$$\sum_{i \in U} \sum_{j \in S} x_{ij}^c = \sum_{i \in S} \sum_{j \in K} x_{ij}^c, \text{ for c = 1} \tag{5}$$

The third flow constraint (6) is set up to ensure that all Tier-One Customers' demand is satisfied. The aggregation of the flow for a particular Tier-One Customer from arrival ports and Stoughton DC should be equal to the given customer's annual demand, d_j^c.

$$\sum_{i \in S} \sum_{j \in K} x_{ij}^c + \sum_{i \in U} \sum_{j \in K} x_{ij}^c = d_j^c, \forall j \in K, \text{ for c = 2} \tag{6}$$

The fourth flow constraint (7) ensures that total flow for the Tier-One Customers from a departure port i to an arrival port j is equal to the total annual demand of the customers.

$$\sum_{i \in A} \sum_{j \in U} x_{ij}^{c} = \sum_{j \in K} d_{j}^{c}, \ \forall c \in C \tag{7}$$

The fifth flow constraint (8) shows that total flow from an arrival port i to Stoughton DC and to Tier-One Customers' location is equal to the total annual demand of the Tier-One Customers.

$$\sum_{i \in U} \sum_{j \in S} x_{ij}^{c} + \sum_{i \in U} \sum_{j \in K} x_{ij}^{c} = \sum_{j \in K} d_{j}^{c}, \text{ for c = 1} \tag{8}$$

The final flow constraint (9) represents that total flow for the Tier-Two Customer from a departure port i to an arrival port j must be equal to the total flow for the Tier-Two Customer from an arrival port to the Stoughton DC.

$$\sum_{i \in A} \sum_{j \in U} x_{ij}^{c} = \sum_{i \in U} \sum_{j \in S} x_{ij}^{c}, \text{ for c = 2} \tag{9}$$

Moreover, three logic constraints are needed to ensure that the facility must be open if there is a flow going through. The logic constraint (10) represents that if there is a flow from an arrival port i, a facility at an arrival port i to implement the distribution center bypass operation must be open.

$$\sum_{j \in K} x_{ij}^{1} \leq z_i M_i, \forall i \in U \tag{10}$$

Likewise, the logic constraint (11) represents that if there is a flow from a departure port j to an arrival port i, an arrival port i to process the import must be open.

$$\sum_{j \in A} x_{ji}^{c} \leq y_i M_i, \forall i \in U \tag{11}$$

The final logic constraint (12) ensures that if the distribution center bypass operation is open, that port must be open.

$$z_i \le y_i, \forall i \in U \qquad (12)$$

Then, constraint (13) limits the maximum number of the ports while the constraint (14) limits the maximum number of the distribution center bypasses.

$$\sum_{i \in U} y_i \le a \qquad (13)$$

$$\sum_{i \in U} z_i \le b \qquad (14)$$

Finally, (15) represents that all decision variables x_{ij}^c, y_j, and z_i are positive real numbers, and y_j and z_i are binary variables.

$$x_{ij}^c, y_i, z_i \in Z^+, \forall i;\ y_i, z_i \in \{0,1\}, \forall j \in U \qquad (15)$$

In brief, the formulation focuses on the minimization of total supply chain costs spent by Shoe Co. to serve customers' demand. Total supply chain cost consist of transportation, handling, and facility costs. The term, $\sum_{c \in C} \sum_{i \in A} \sum_{j \in U} t_{ij} x_{ij}^c + \sum_{c \in C} \sum_{i \in U} \sum_{j \in S} t_{ij} x_{ij}^c + \sum_{i \in U} \sum_{j \in K} t_{ij} x_{ij}^1$, captures total transportation cost in this logistics network. The term, $\sum_{c \in C} \sum_{i \in U} \sum_{j \in S} h_j^s x_{ij}^c + \sum_{c \in C} \sum_{j \in A} h_j^d (\sum_{i \in U} x_{ji}^c) + \sum_{c \in C} \sum_{j \in U} h_j^a (\sum_{i \in A} x_{ji}^c)$, identifies total handling cost in the whole network. The term, $\sum_{i \in U} F_i z_i + \sum_{i \in U} f_i y_i$, represents total facility cost in the supply chain.

5 Conclusions

The objective of the DC bypass project is the minimization of total supply chain costs. Consequently, the DC bypass should be implemented because it decreases costs. Unit supply chain cost ranges from \$ 1.24 to \$1.47 per pair of shoe under different scenarios in the optimization models while \$ 1.52 per pair of shoe is spent in the baseline model. For example, \$1.24 represents a scenario with the following assumptions: 1) no annual facility cost is assumed; 2) no capacity constraint is set on each arrival port. Under this scenario, the optimization result suggests that all Tier-One Customers' orders are served by the DC bypass network via Long Beach while all Tier-Two Customers' orders are served by the existing logistics network via Boston. Moreover, we should notice that only one location, Long Beach, is chosen to implement the DC bypass operation. \$ 1.47 represents the worst case in the optimization model, Model 9, including the following assumptions: 1) Tier-One Customers' orders are forced to be served by Seattle if they participated in the DC bypass network; 2) no annual facility cost is assumed; 2) Capacity constraints are set on each arrival port.

The reason why the DC bypass network causes lower costs than those in the existing network is that total saving from transportation and handling costs are higher than the annualized facility costs. 6 models are selected to explain why total costs in the DC bypass network are lower. The assumptions of selected models are summarized in Table 5-1. In general, models with odd numbers are scenarios without capacity constraints while those with even numbers represent models with capacity constraint. Other assumptions were stated in Chapter 4. We select initial runs because it includes fewer constraints so that we can clearly observe how optimization models change results. Then, we add facility costs in facility runs to see how changes in facility costs affect the optimized results.

Table 5-1 Assumptions of Selected Models

Group	No. of Model	**Seattle**	**Long Beach**	**New York**	**Boston**	**Facility Cost**
Baseline		●	●	●	●	$ -
Initial Runs	3	O	O	O	O	$ -
	4	●	●	●	●	$ -
Facility Runs	13	O	O	O	O	$ 2,000,000
	14	●	●	●	●	$ 2,000,000
	15	O	O	O	O	$ 100,000
	16	●	●	●	●	$ 100,000
	17	O	O	O	O	$ 5,000
	18	●	●	●	●	$ 5,000

Table 5-2 represents results of selected models. Comparing the costs in baseline model with those in initial runs, we can find that both transportation and handling costs decrease after optimized. If we assume there are annual costs of keeping a DC bypass facility open as stated in facility runs, the models still support at least one facility is open because the saving in transportation and handling costs are higher than facility costs.

Table 5-2 Costs of Selected Models

		Cost				
Group	No. of Model	$/pair	Total	Facility	Transportation	Handling
Baseline	-	$1.52	$33,112,396	$0	$ 11,013,724	$22,098,672
Initial Runs	3	$1.24	$26,867,876	$0	$ 9,581,101	$17,286,775
	4	$1.27	$27,601,411	$0	$ 10,346,674	$17,254,736
Facility Runs	13	$1.34	$29,196,182	$2,000,000	$ 9,931,347	$17,264,835
	14	$1.37	$29,753,419	$2,000,000	$ 10,386,448	$17,366,970
	15	$1.24	$27,082,078	$200,000	$ 9,595,303	$17,286,775
	16	$1.28	$27,801,411	$200,000	$ 10,346,674	$17,254,736
	17	$1.24	$26,882,876	$15,000	$ 9,581,101	$17,286,775
	18	$1.27	$27,611,411	$10,000	$ 10,346,674	$17,254,736

Then, we want to ask a question: why do transportation and handling costs decrease after optimized? We will answer it in Sections 5.1 and 5.2.

5.1 Transportation Costs

Table 5-3 shows two phenomena in the optimization models. First, total transportation costs in the new network are lower than those in the existing network. Second, when there is no capacity constraint, replenishment costs tend to be higher than that in the baseline model. However, the sum of inland transportation and outbound costs are much lower inland transportation in the baseline model.

Table 5-3 Transportation Costs of Selected Models

Group	No. of Model	Replenishment	Inland Transportation	Outbound	Subtotal
Baseline	-	$7,730,781	$3,282,943	$ -	$11,013,724
Initial Runs	3	$8,064,399	$568,965	$947,737	$9,581,101
	4	$7,730,781	$1,450,903	$1,164,990	$10,346,674
Facility Runs	13	$7,883,218	$568,965	$1,479,163	$9,931,347
	14	$7,730,781	$1,234,279	$1,421,388	$10,386,448
	15	$8,097,220	$568,965	$929,118	$9,595,303
	16	$7,730,781	$1,450,903	$1,164,990	$10,346,674
	17	$8,064,399	$568,965	$947,737	$9,581,101
	18	$7,730,781	$1,450,903	$1,164,990	$10,346,674

Inland transportation costs play a major role in cost saving. In the baseline model, Seattle and Long Beach are forced to play as the entry ports based on fixed percentage of import and the inland transportation cost from there to Stoughton DC is high. However, in optimization models, the DC bypass network can eliminate the routing from the West Cost to the Stoughton DC and thus save costs.

Optimization models suggest different routing to import the products no matter whether is a capacity constraint. The notations in Table 5-4 are used to summarize different choices of US entry ports and the locations for the DC bypass operations under different scenarios.

Table 5-4 Notation of the Optimized Network Model

Description	Notation
A port is chosen as an entry port	x
A port is chosen for distribution bypass (DC) operation	Δ
An port is chosen as an entry port for Tier-One Customer	◙
An port is chosen as an entry port for Tier-Two Customers	Θ

From Table 5-5, we can see that the models suggest all Tier-One Customers' demand is served by the DC bypass network. The only exception is in Model 14, which includes a capacity constraint and a very high facility costs ($ 2,000,000). In this model, a Tier-One customer's demand goes through the Stoughton DC because its location is in the Bronx, New York because the facility costs in this scenario are too high and thus cannot justify the inland transportation cost from Long Beach to New York.

Table 5-5 Tier-One Customers' Network

		No. of the Distribution Center Bypass				Demand Tier-One Cust	
Group	No. of Model	Seattle	Long Beach	Boston	New York	Through DC Bypass	Through Stoughton DC
Baseline	Baseline					-	5,567,742
Initial Runs	3	Δ	Δ		Δ	5,567,742	-
	4		Δ		Δ	5,567,742	-
Facility Runs	13		Δ			5,567,742	-
	14		Δ			5,438,738	129,005
	15		Δ		Δ	5,567,742	-
	16		Δ		Δ	5,567,742	-
	17	Δ	Δ		Δ	5,567,742	-
	18		Δ			5,567,742	-

As shown in Table 5-5, Long Beach is the best location and then New York is the second best location for the DC bypass operation if the models allow two facilities are open. Why are they chosen? What is the underlying intuition behind this result?

The reason why the DC bypass network is attractive is that the existing inland transportation cost are high because the geographical location of Stoughton DC is at the north-east of the US, which is far from the customers at the West and the Middle. Therefore, it is not economically justified to pay for the DC transfer distribution freight from the West port like Seattle and Long Beach to Stoughton compared to the DC bypass route, which satisfy these customer from Long Beach to the CA and the Middle directly.

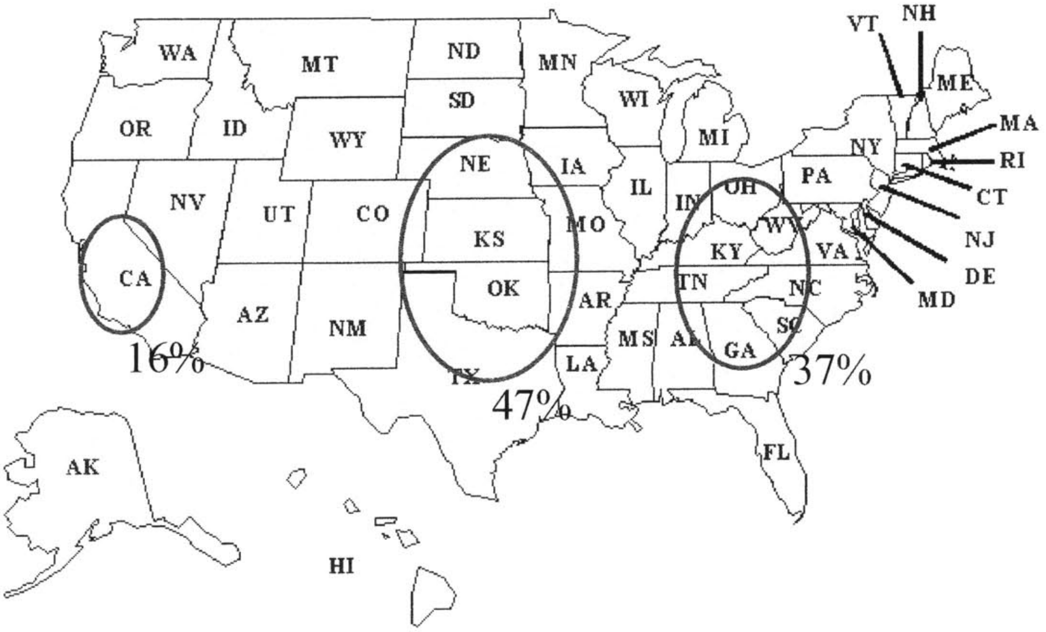
Intuitively, the choice of the location for the DC bypass is mainly caused by Tier-One Customers' location and their annual volume. As we can see in Table 5-6, Tier One Customers are distributed in the following states: Alabama (AL), California (CA), Georgia (GA), Kansas (KS), New York (NY), Tennessee (TN), Texas (TX), Virginia (VA).

Table 5-6 Demand of Tier-One Customers

Customer	Customer Location	Demand (Quantity)	%
1	Birmingham, AL	353,946	6%
2	Junction City, KS	400,905	7%
3	West Puente Valle, CA	360,926	6%
4	Haslet, TX	652,326	12%
5	Katy, TX	485,674	9%
6	Junction City, KS	260,996	5%
7	Fort Worth, TX	744,678	14%
8	Newport News, VA	325,398	6%
9	Bronx, NY	502,499	9%
10	McDonough, GA	744,565	13%
11	Whites Village, TN	156,565	3%
12	Watts, CA	238,873	4%
13	Downey, CA	340,391	6%
		5,567,742	100%

Suppose we aggregate these Tier-One Customers' orders according to their geographical locations from the West to the East. We can circle their locations into three major areas: the West, the Middle, and the East. From cost point of view, Long Beach is always the first choice to implement the DC bypass network because the facility in Long Beach can serve customers in CA, KS, and TX at a lower cost and these customer accounts for 63% of Tier One demand.

Figure 5-1 Aggregation of the Tier-One Customer Demand



In brief, Tier-One Customers' locations are good to served by the DC Bypass network. Outbound plus inland transportation cost in the DC bypass network is lower than inland transportation cost in the existing network. Therefore, we would like to know: cost compared to DC transfer cost is too high compared.

5.2 Handling Costs

Another reason why the DC bypass network decreases the total cost is that handling cost at Stoughton is too high compared to the handling cost at an arrival port. Thus, DC bypass can eliminate the total handling cost. Table 5-7 shows that port handling costs do not change a lot. However, the sum of handling costs for the DC bypass and at the Stoughton DC handling are much less than the DC handling costs in the baseline model by at least 24% .

Table 5-7 Handling Costs of Selected Models

Group	No. of Model	Asia Port	US Port	DC Bypass	Stoughton DC
Baseline	-	$ 1,010,648	$ 1,073,470	$ -	$ 20,014,554
Initial Runs	3	$ 1,010,648	$ 1,105,509	$ 278,387	$ 14,892,231
	4	$ 1,010,648	$ 1,073,470	$ 278,387	$ 14,892,231
Facility Runs	13	$ 1,010,648	$ 1,083,568	$ 278,387	$ 14,892,231
	14	$ 1,010,648	$ 1,073,470	$ 271,937	$ 15,010,916
	15	$ 1,010,648	$ 1,105,509	$ 278,387	$ 14,892,231
	16	$ 1,010,648	$ 1,073,470	$ 278,387	$ 14,892,231
	17	$ 1,010,648	$ 1,105,509	$ 278,387	$ 14,892,231
	18	$ 1,010,648	$ 1,073,470	$ 278,387	$ 14,892,231

Then, two questions arise. First, what if DC Bypass handling cost increase to make the DC bypass network become less desirable? How much increase in the DC bypass handling cost will cause the DC bypass solution is not attractive? Second, what if handling cost at the Stoughton DC can decrease to make the DC bypass operation no sense? How much decrease in handling cost at the Stoughton DC can make DC bypass network less desirable?

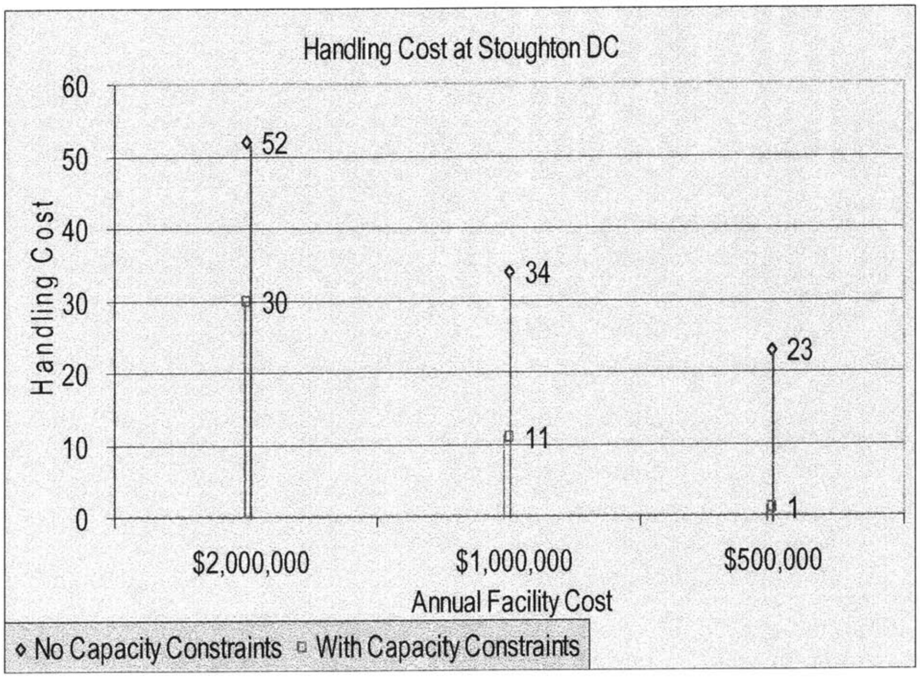
Section 5.2.1 and 5.2.2 answer these two question as follows:

5.2.1 Handling Cost at the Stoughton DC

Figure 5-2 summarizes the range of handling costs at the Stoughton DC, which makes the DC bypass network no sense. With different assumptions of facility costs and a capacity constraint, the maximum cost, which makes the DC bypass undesirable, is different. Suppose that there is no capacity constraint. The maximum handling costs at the Stoughton DC is 52 cents per pair of shoes when the annual cost to run a DC bypass facility is $2,000,000, 34 cents when the annual cost to run a DC bypass facility is $1,000,000, and 23 cents when the annual cost to run a DC bypass facility is $500,000. On the other hand, if there is a capacity constraint at the

Stoughton DC, the maximum handling costs is 30 cents per pair of shoes when the annual cost to run a DC bypass facility is $2,000,000, 11 cents when the annual cost to run a DC bypass facility is $1,000,000, and 1 cent when the annual cost to run a DC bypass facility is $500,000.

Figure 5-2 DC Handling costs which makes the DC bypass network undesirable

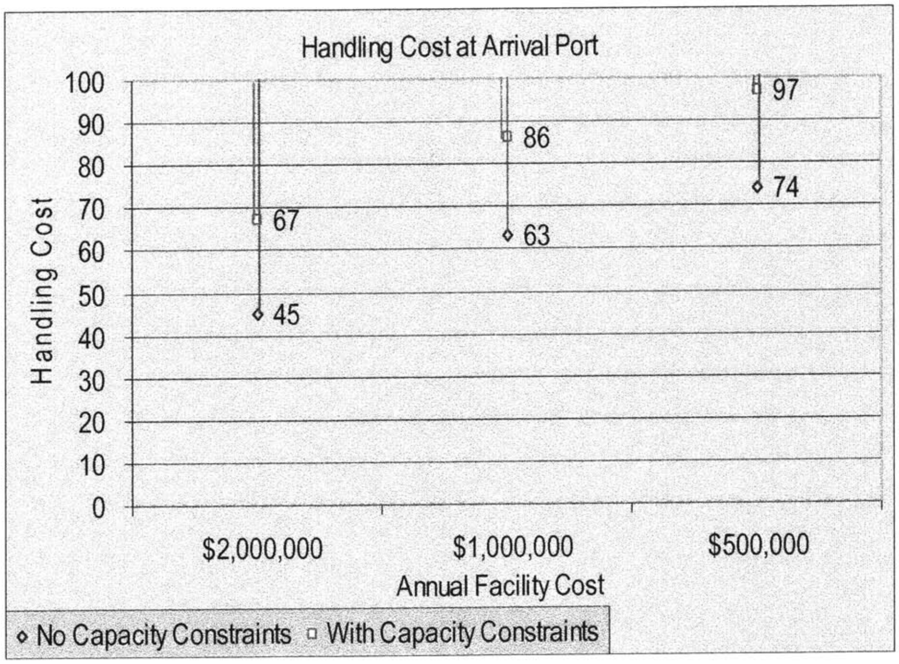


Beside the exact breakeven points we derive, we can observe a phenomenon: the higher the facility cost, the less desirable the DC bypass network, the higher minimum handling costs at the Stoughton DC the model will require to make the DC bypass network unattractive.

5.2.2 Handling Cost at the US entry Port

Figure 5-3 shows the range of handling cost at the US entry ports which makes the DC bypass network no sense. With different assumptions of facility costs and a capacity constraint, the minimum cost which makes the DC bypass undesirable is different. Given that there is no capacity constraint, the minimum handling costs at the US entry ports is 45 cents per pair of shoes when the annual cost to run a DC bypass facility is $2,000,000. If increases to 63 cents when the annual cost to run a DC bypass facility is $1,000,000, and to 74 cents when the annual cost to run a DC bypass facility is $500,000. On the other hand, if there is a capacity constraint at the US entry port, the minimum handling costs at the US entry ports is 67 cents per pair of shoes when the annual cost to run a DC bypass facility is $2,000,000, 86 cent when the annual cost to run a DC bypass facility is $1,000,000, and 97 cents when the annual cost to run a DC bypass facility is $500,000.

Figure 5-3 Bypass DC handling costs which makes the DC bypass network undesirable

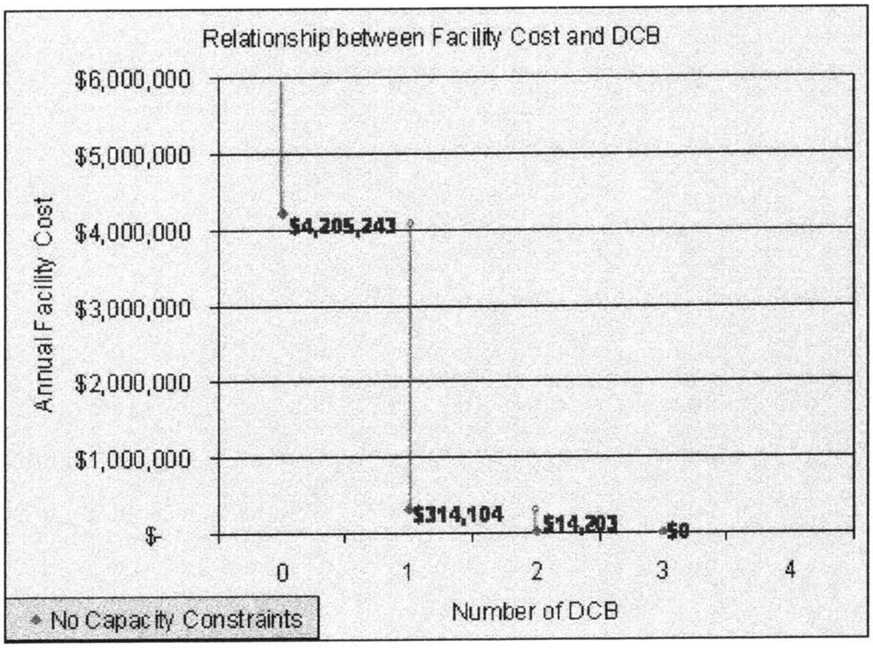


Like what we observed in Section 5.1.2.2, we can see a similar phenomenon: the higher the facility cost, the less desirable the DC bypass network, the lower minimum handling costs at the US entry ports the model will require to make the DC bypass network unattractive.

5.3 Facility Costs

Figure 5-4 summarizes the range of facility cost with a particular number of the facilities for the DC bypass operation given that there is no capacity constraint at the US entry ports. In general, the lower the facility cost, the more number of facilities for the DC bypass operation is suggested. If the facility cost is more than $314,104. 1 facility for the DC bypass operations is suggested; if from $14203 to $314103, 2 facilities for the DC bypass operations are recommended; from $1 to $14202; 3 facilities are the best. If there is no facility cost, all of 4 facilities should be open.

Figure 5-4 Relationship between Facility Cost and No. of Facility for the DC Bypass Operation



Unlike Figure 5-4, Figure 5-5 shows the scenario which takes capacity constraint into account. If the facility cost is more than $152,008. the optimal result suggests 1 facility open in Long Beach; if from $1 to $152,007, 2 facilities in Long Beach and New York is recommended; 3 facilities is never suggested no matter how we change the figure of the facility cost. If we do not consider facility cost, all of 4 facilities should be open.

Figure 5-5 Relationship between Facility Cost and No. of Facility for the DC Bypass Operation

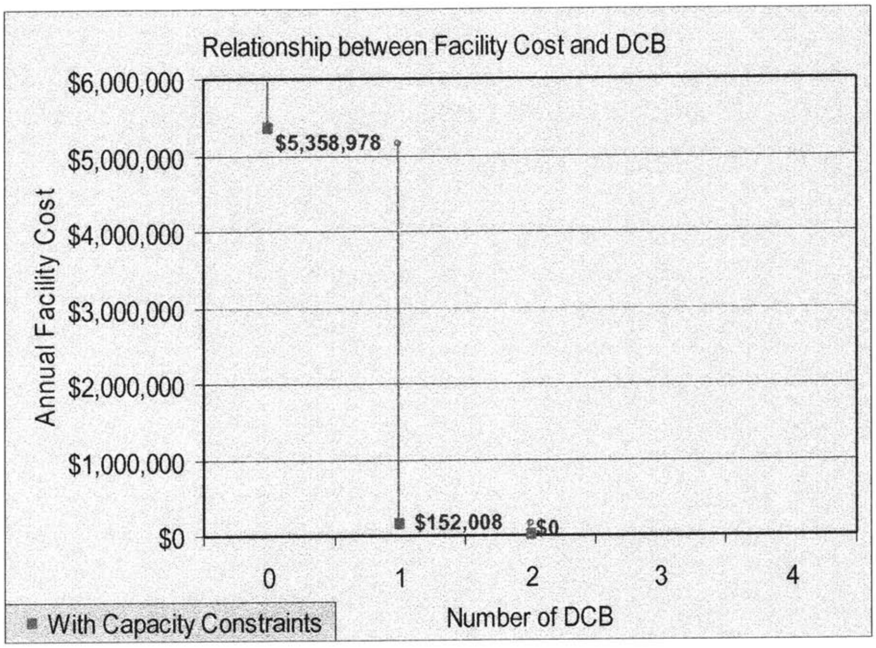


Figure 5-4 and Figure 5-5 have one thing in common: the choice of locations. If the optimal number of the DC bypass facilities is one, the best location will be Long Beach. If the number is two, the best locations are Long Beach and New York. If the number is three, the locations will be Long Beach, New York, and Seattle. The factor is Tier-One Customers' locations as stated in Section 5.1.

Comparing Figure 5-4 and Figure 5-5, we intuitively think the range of cost is unreasonable. For example, the minimum cost to make the DC bypass network non-optimal is $5,358,978 under the scenario with a capacity constraint while that is $4,205,243 under the scenario without a capacity constraint. This is counter-intuitive because fewer constraints should lead to a lower threshold. However, after we studied results, we found that the figures represent breakeven points to decide whether the DC bypass network is desirable. When there is a capacity constraint, it is less possible to decrease inland transportation cost through the reallocation of the flow of imported products, which plays one of the factor to make the DC bypass network more desirable. Then, the breakeven point under this scenario will increase.

Summary of the Result

In Chapter 1, we asked six questions for this project. Through the above analysis, we can summarize the answer as follows:

1. Should the DC bypass be implemented to minimize the total supply chain costs?

Yes, the DC Bypass should be implemented because it decreases total supply chain costs. In summary, we find two reasons for the cost savings. First, transportation costs are too high in the baseline model because Long Beach and Seattle are forced to serve as entry ports and the inland transportation costs from there to the Stoughton DC are higher than the distribution costs from these two ports directly to Tier-One Customer locations. Second, the handling cost in the Stoughton DC is much higher than the handling costs in the DC bypass facility.

2. If the DC bypass should be implemented, should we implement it for all Tier-One Customers' orders or some of them?

It depends upon whether there is a capacity constraint at the US entry port. If the DC bypass operation can be implemented without any capacity constraint, the optimized result will support all orders of Tier One Customer should go through the DC bypass network. On the other hand, if there is a capacity constraint, the models recommend that demand in the East be satisfied by the Stoughton DC.

3. What location should be chosen to implement the DC bypass operation?

If we only choose one location, Long Beach is the best location. If two are required, Long Beach and New York are the best locations. The underling factor is that 63% of Tier-One Customers' demand is at the West and the Middle so that inland transportation costs in the existing network are much higher than the sum of inland transportation and outbound in the DC bypass network.

4. Should we choose one port or multiple facilities for the DC bypass?

Facility costs determine the number of facilities for the DC bypass network. The higher the facility cost, the less number of facilities for the DC bypass operation will be suggested by the optimization model. The range of facility costs is illustrated in Section 5.3.

5. *How many Tier-One Customers' order should go through these entry ports?*

If there is no capacity constraint at the US entry port, the models suggest that all Tier-One Customer demand is served by the DC bypass network. If there is a capacity constraint, the optimized results suggest that some of Tier-One Customers' demand such as orders at Bronx, New York is served by the Stoughton DC.

6. *How does the network solution vary with different costs? For example, if the capital cost to set up a facility for DC bypass operation decrease, will any port become more desirable? How does the optimized result vary if a DC bypass handling cost change?*

In general, changes in facility costs, DC handling costs, and DC bypass handling costs may make the DC bypass undesirable. For example, two situations will make the DC bypass network less attractive: 1) the handling cost at the Stoughton DC drops; 2) the handling cost for the DC bypass operation in the US entry port is higher than what we estimate now. Thus, we are interested in sensitivity analysis to know what range of costs will lead to the change in the optimized results. The range of costs for above cost items is illustrated from Section 5.3, 5.2.1, and 5.1.2 separately.

5.4 Further Research – Cooperating lead time issue into the project

In this project, we do not consider the lead time issue. Our main focus is the minimization of total supply chain costs. However, in a real supply chain, the lead time is also one of crucial measurements for a supply chain performance. For example, if a network can response Shoe Co.'s customers more efficiently, i.e. the reduction of total lead time, the satisfaction of customer will increase and Shoe Co.'s competitiveness will also increase. Thus, in future research, we suggest that the project can take the lead time issue into consideration. That is, the purpose of extended project is the minimization of total supply chain cost and lead time to market.

To add the consideration of the lead time into our new formulation, we express the value of lead time by converting it into two kinds of cost: in-transit inventory cost and on-site inventory cost. In-transit inventory cost is calculated by lead time (day) times unit inventory cost (¢/day/pair) at each link times the flow of the footwear product (pair). On-site inventory cost is calculated by lead time (day) times unit inventory cost ($/day/pair) at each location times the flow of the footwear product (pair). Table 5-8 shows the notation for the advanced formulation.

Table 5-8 Notation of the New Formulation

Group	Notation	Description
Set	A	Set of departure ports, $\forall A \in \{1,\ldots,5\}$
	U	Set of arrival ports and facilities for the DC bypass operations, $\forall U \in \{1,..,4\}$
	S	A distribution center
	K	Set of Tier-One Customers; $\forall K \in \{1,..,13\}$
	C	Customer class C, $\forall C \in \{1,2\}$
Decision Variable	x^c_{ij}	Network flow of the customer class C from node i to node j; unit: pairs of shoes
	y_j	Binary variable to decide whether or not to import products through an entry port j. y_j =1, if product flows through port j; otherwise y_j =0.
	z_i	Binary variable to decide whether or not to open a facility for the distribution center bypass at an entry port i. z_i = 1, if product flows through port j; otherwise z_i = 0.
Cost Parameter	F_i	Fixed cost (¢/facility) to set up a facility for the distribution center bypass
	f_i	Fixed cost (¢/port) to set up a port for the import
	M_i	Large number
	h^d_j	Unit handling cost (¢/pair) at a departure port j
	h^a_j	Unit handling cost (¢/pair) at an arrival port j
	h^s_j	Unit handling cost (¢/pair) at the Stoughton DC
	t_{ij}	Unit transportation cost (¢/pair) from node i to node j
	v_{ij}	Unit inventory cost (¢/day/pair) from node i to node j
Other Parameter	T_i	Maximum throughput at a port i
	k^c_j	Lead time (day) at a node j for Customer class C, $\forall C \in \{1,2\}$
	l^c_{ij}	Lead time (day) from node i to node j for Customer class C, $\forall C \in \{1,2\}$
	d^c_j	Annual demand at node j for Customer class C, $\forall C \in \{1,2\}$; unit: pairs of shoes
	a	Maximum number of arrival ports
	b	Maximum number of Bypass distribution centers

The objective function for the formulation of this problem is:

$$Min \sum_{c\in C} \sum_{i\in A} \sum_{j\in U} t_{ij} x^c_{ij} + \sum_{c\in C} \sum_{i\in U} \sum_{j\in S} t_{ij} x^c_{ij} + \sum_{i\in U} \sum_{j\in K} t_{ij} x^1_{ij}$$

$$+ \sum_{c\in C} \sum_{i\in U} \sum_{j\in S} h^s_j x^c_{ij} + \sum_{c\in C} \sum_{j\in A} h^d_j \left(\sum_{i\in U} x^c_{ji}\right) + \sum_{c\in C} \sum_{j\in U} h^a_j \left(\sum_{i\in A} x^c_{ij}\right) + \sum_{i\in U} F_i z_i + \sum_{i\in U} f_i y_i$$

$$+\sum_{c\in C}\sum_{i\in A}\sum_{j\in U} l_{ij}^{c} v_{ij} x_{ij}^{c} + \sum_{c\in C}\sum_{i\in U}\sum_{j\in S} l_{ij}^{c} v_{ij} x_{ij}^{c} + \sum_{i\in U}\sum_{j\in K} l_{ij}^{c} v_{ij} x_{ij}^{1} + \sum_{i\in S}\sum_{j\in K} l_{ij}^{c} v_{ij} x_{ij}^{c}$$

$$+\sum_{c\in C}\sum_{i\in U}\sum_{j\in S} k_{j}^{c} v_{ij} x_{ij}^{c} + \sum_{c\in C}\sum_{j\in A} k_{j}^{c} v_{ij}\Big(\sum_{i\in U} x_{ji}^{c}\Big) + \sum_{c\in C}\sum_{j\in U} k_{j}^{c} v_{ij}\Big(\sum_{i\in A} x_{ji}^{c}\Big) \qquad (16)$$

The objective (16) is similar to the equation (1). The purpose of the new formulation is to minimize the total supply chain cost of sending the finished footwear product through the network to satisfy the given demand. The difference is that the equation (16) takes lead time issue , expressed by in-transit and on-site inventory cost, into consideration. Thus, total supply chain cost here includes transportation, handling, facility, and cycle inventory costs.

In this new objective function, we add seven terms to capture total inventory costs in the logistics network. The first term, $\sum_{c\in C}\sum_{i\in A}\sum_{j\in U} l_{ij}^{c} v_{ij} x_{ij}^{c}$, represents the in-transit time cost for the ocean shipments from Asian ports to the US ports. The second term, $\sum_{c\in C}\sum_{i\in U}\sum_{j\in S} l_{ij}^{c} v_{ij} x_{ij}^{c}$, means the in-transit inventory cost spent for the inland distribution from the US ports to the Stoughton DC. Then, the third term, $\sum_{i\in U}\sum_{j\in K} l_{ij}^{c} v_{ij} x_{ij}^{1}$, indicates the in-transit inventory costs paid for the outbound shipments from an arrival port to Tier-One Customers' locations in the DC bypass network. The fourth term, $\sum_{i\in S}\sum_{j\in K} l_{ij}^{c} v_{ij} x_{ij}^{c}$, captures the in-transit inventory cost for the outbound shipment from the Stoughton DC to the customers' location in the existing logistics network. The fifth term, $\sum_{c\in C}\sum_{i\in U}\sum_{j\in S} k_{j}^{c} v_{ij} x_{ij}^{c}$, identifies the on-site inventory costs at the Stoughton DC. The sixth term, $\sum_{c\in C}\sum_{j\in A}k_j^c v_{ij}(\sum_{i\in U}x_{ji}^c)$, generates on-site inventory costs at Asian ports. The seventh term, $\sum_{c\in C}\sum_{j\in U}k_j^c v_{ij}(\sum_{i\in A}x_{ji}^c)$, captures the on-site inventory costs at arrival ports in the US.

Through we add more terms in our new objective function, the constraints in the new formulation are the same as we listed in section 4.2.

In brief, the advanced formulation focuses on the minimization of total supply chain costs spent by Shoe Co. to serve customers' demand. Total supply chain costs consist of transportation, handling, facility, and inventory costs. As we discussed before, the inventory cost is set to be a part of total supply chain cost so that we can take the lead time issue into account. In this advanced formulation, we add two terms in the objective function. The first term, $\sum_{c\in C}\sum_{i\in A}\sum_{j\in U}l_{ij}^c v_{ij}x_{ij}^c+\sum_{c\in C}\sum_{i\in U}\sum_{j\in S}l_{ij}^c v_{ij}x_{ij}^c+\sum_{i\in U}\sum_{j\in K}l_{ij}^c v_{ij}x_{ij}^1+\sum_{i\in S}\sum_{j\in K}l_{ij}^c v_{ij}x_{ij}^c$, captures total in-transit inventory costs spent for the shipments from node i to node j. The second term, $\sum_{c\in C}\sum_{i\in U}\sum_{j\in S}k_j^c v_{ij}x_{ij}^c+\sum_{c\in C}\sum_{j\in A}k_j^c v_{ij}(\sum_{i\in U}x_{ji}^c)+\sum_{c\in C}\sum_{j\in U}k_j^c v_{ij}(\sum_{i\in A}x_{ji}^c)$, identifies total on-site inventory costs at node j.

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