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SYSTEM OPTIMUM AND COLLABORATIVE PLANNING FOR LINER SHIPPING

A DISSERTATION APPROVED FOR THE
SCHOOL OF INDUSTRIAL & SYSTEMS ENGINEERING

BY

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ABSTRACT

There are multifarious academic research studies available concerning the optimization of a liner shipping company's benefit in terms of its individual behavior. The existing literature on alliance in liner shipping is still scarce, even though more and more carriers are collaborating with other carriers instead of getting improving their businesses by optimizing their own resources and information only. This research presents a unique methodology that a third party logistics firm can utilize to determine best schedules for liner shippers under total collaboration.

A mixed integer linear programming (MIP) optimization model is developed to achieve the system optimum assuming total collaboration among partner shippers on the condition that a win-win solution is guaranteed for all participants. MIP optimization models are presented for a single carrier and for the overall system optimization under total collaboration. The system optimization model incorporates price strategy for equitable cost sharing. The price-strategy policy determines the additional price each liner company should charge other companies for shipping their demand. The methodology is verified for a three-carrier system using FICO^{TM} Xpress Optimization Software to solve the MIP models.

This study presents a practical membership mechanism to allocate resources among partner carriers to facilitate forming alliances most efficiently and equitably. A unique feature of the study is that the MIP models not only consider the shipping cost for the carriers based at a foreign port to US ports but it also includes the cost of shipment from a US port to the final MSA. Hence, the transportation network is

integrated international network including global waterways and inland highways. The methodology can easily be expanded to include other cost elements or variations in the problem formulation.

SECTION 1: INTRODUCTION

1.1 Background, Motivation and Objective

Sea cargo (or sea freight) refers to goods or products transported by ships. In the sea cargo industry, a sea carrier is the party that provides the service via sea; a shipper is the owner or the supplier of the cargo being shipped. Truck-sized intermodal containers are the most commonly preferred method of movement for the long-haul sea cargo industry. In general, the types of cargo ships include general cargo vessels, tankers (which usually carry petroleum products), dry-bulk carriers, and multipurpose vessels. Cargo ships can be divided into two different modes of service: liner and tramp services. In liner shipping, the carriers decide on a set of voyages with a fixed published schedule and fixed tariff rates. In tramp shipping, there is no fixed schedule; more likely, a carrier is contracted to provide the shipper with a service between specific ports within a specific time. Each trip of liner shipping is referred to as *one voyage*. Liner service results in a higher fixed cost due to the number of ships and frequency of voyages being determined by full-load or less-than-full-load shipment options. This fixed cost turns in the significant issue of cost consideration in liner service.

The growing international trade is playing an increasingly important role in the global economy. Today, over 80% of international trade is served by maritime transportation, and the largest part of maritime transportation is containerized, as stated on the Maritime Transportation and Shipping Talk website (Maritime Transportation 2008). Since the last decade, unprecedented growth in containerized imports to the

United States has reconstructed the US economic system (Logistics Today 2006a). The total number of full containers shipped globally is expected to grow to 177.6 million TEUs by 2015 (Transport Division 2005). According to the American Association of Port Authorities (AAPA), the United States, the largest trade nation for both imports and exports, accounts for about 20% of global trade. Hence, more than 2.5 billion tons of freight is handled through US ports and waterways, and the volume is estimated to double by 2020 (AAPA 2006). There have been many changes in the sea cargo industry, one of which is containerized cargo shipping. Dreway (2001) noted that although the percentage of containerized cargo shipments was around 25% in the 1980s, it had increased to 60% by 2001. Also Hingorani et al. (2005) estimated that containerized cargo shipments will be in growth at 8-10% per year in the next several years.

The sea cargo industry is experiencing enormous growth. Liner shippers have been situated at ports to facilitate cargo movement between ports of different countries. Substantial structural modifications have occurred at the ports during past decades in order to accommodate this increasing demand for overseas trade in the form of containerized shipping (Brooks 2000; Notteboom 2004). Similar to the trucking industry, the sea cargo industry started to look at potential benefits that can arise from collaborations among shippers in order to minimize transportation costs and better serve customers in terms of increased efficiency. The researchers in this study investigated the application of optimization models as a tool to improve decision-support systems related to cargo routings, vessel management, and cost-benefit analysis for collaborative shipment strategies.

1.2 Collaborative Trend in Liner Shipping

The primary and distinct impact of the globalization of the liner shipping industry is the enormous growth in containerized shipments. Container shipping is viewed as a revolution in the sea cargo industry. The benefits of container shipping are many: it increases a vessel's capacity due to standardized container dimensions (twenty-foot equivalent unit [TEU]), leading to effective space utilization; it improves the efficiency of port operations; and it eliminates the handling of individual cargos in each container. However, it also creates new challenges, such as the transport of empty containers back to the originating port and empty-vessel return necessitated by the imbalance of global trade. Significant savings can result by addressing the concerns related to empty-container repositioning and better utilization of container fleets.

Voyage management usually focuses on three major areas: (i) price management determines the appropriate price to maintain the marketing share and the company's objectives; (ii) container management refers to problems such as analysis of containers in stock, container traffic and contributions to shipments, and forecasting of container movement; and (iii) capacity management focuses on the best usage of the available cargo capacity (ROI 2002). According to Liu (2007), up to 30% of overall potential cost reductions are related to equipment and reposition costs. The ROI Container Cargo Alliance (ROI Alliance) helps their clients to increase revenue over 14% per year through the solution of effective voyage management.

All liner shippers seek to expand their marketing share and maximize profit by expanding their service. Traditionally, line shippers have optimized their own resources and management to build their competitive advantages. However, to accommodate the increasing demand for overseas trade, recently more and more liner shippers have

switched from independent operations to collaborative operations. Through these collaborations, liner shippers can extend service regions and economies of scales and hence improve asset utilization and provide more frequent and customized service options. The two main types of collaborations are known as *slot sharing* and *total sharing*. Slot sharing, also called partial sharing, and requires vessel capacity to be exchanged at a prefixed proportion. Especially among those shippers who have the same route but different schedules, slot sharing is very popular in serving those time-sensitive orders. Total sharing, which is full collaboration among participants, requires sharing all vessel resources and joint optimization by a trade-off in the sharing the profit.

1.3 Overview of the Research

This research studies total-sharing collaboration among partner shippers and develops methodologies to achieve the system optimum. Thus, the observations include not only the behavior and individual benefits for the participants, but also the system optimum, while achieving a balance of benefits among participants. An optimization model is proposed as a tool for a decision-support system for collaborative planning and network design. We will refer to this research as *the collaborating cargo shipment problem* with the assumption that routes for each carrier are fixed and known in advance. The optimization model will determine the optimal number of vessels to be assigned to each route; the best cargo assignment schedules for each vessel; and the best pricing strategy for each carrier such that each carrier benefits equally from the collaborative assignment. Our model assumes that the shippers are willing to share information and resources with

each other without bias. Under the total-sharing policy, we attempt to determine solutions that benefit each shipper.

In this research, a mixed integer linear programming (MIP) model is developed to solve the cargo shipment problem. The parameters of the problem are determined after examining the operations of the real world of port-to-port shipment and the results from the literature review. The input data, is the MIP model, determines the optimal shipment schedule for each shipper individually to determine the optimal operating cost for each shipper in the absence of collaboration. We then determine how much each shipper should charge other shippers to carry their demand in a way that the optimal solution to the MIP model under the total-sharing policy will lead to equal benefit for each shipper. Hence, the solution produces a win-win solution for all shippers involved. Our model makes assumptions reflecting real-life situations for the container shipping industry: multiple pickup and delivery points during shipping, several routing patterns, and fixed vessel sizes.

This manuscript is organized into five sections. The related literature is discussed in the next section, section 2. In section 3, we propose a mixed integer linear optimization model for each shipper acting independently and also for the collaborative system. We demonstrate how shippers can determine charges for carrying loads for one another that will lead to comparable benefits for all. The models are illustrated by a case study in section 4. We conclude the manuscript by summarizing major contributions of the research, discussing limitations of the research, and providing suggestions for further research in section 5.

SECTION 2: LITERATURE REVIEW

2.1 International Trade

Like traditional business, international trade involves sellers, buyers, and goods or services. The shipper, a concept from transportation, is defined as "the owner of goods being transported by any mode of transport, whether consignors or consignee" (ESC 2013). In the system of international trade, the basic behaviors of parties are fundamentally the same as with domestic trade, but the procedure is more complicated. For example, in importing products to the United States from China, the seller in China prepares the goods, and then the shipper arranges correlative affairs on the delivery of the goods to a US port, which involves the preparation of a huge of number of documents for US customs, all of which must be filed before arrival (CBD 2003). This reflects a change in the role of the shipper in international trade. We can divide shippers into three categories: one commits to a carrier with a long-term contract; one uses a freight forwarder or a logistic provider, who deals with carriers; and one is an independent shipper (Tongzon, 2009). These changes have resulted in bringing two new parties into the system: freight forwarders and carriers. "A freight forwarder, forwarder, or forwarding agent" is defined as "a person or company that organizes shipments for individuals or corporations to get goods from the manufacturer or producer to a market, customer or final point of distribution" (Random House, 1997). A freight forwarder does not transport goods but usually contracts with a various types of carriers to move products by all kinds of transportation modes. In waterborne shipping, which is the

major mode in the international trade system, liner shipping company is the most involved role. Liner shipping specifically refers to the transport of goods by high-capacity ocean ships on a fixed route and schedule, and liner vessels involve mostly containerized transportation and represent around 60% of sea goods transportation in international trade (WSC 2013).

The boom of international trade has stimulated the growth of cargo shipment. Liner service, as the most important mode in cargo shipping, has developed rapidly. For example, liner shipping contributed over 60% of the total waterborne trade for the United States in 2003 (Christiansen et al. 2004). As Barry Rogliano Salles (2006) reported, liner shipping TEU capacity increased from 5,150,000 TEUs to 9,135,000 TEUs, a 77.4% increase, between 2000 and 2006. Currently, more and more all-sized liner companies have started providing long-haul shipping service through all kinds of vessels for the international trade business. The vessels can be classified into five categories based on the type of cargo: oil tankers, bulk carriers, general cargo ships, container ships, and other types of ships (WTR 2012). The sizes of container ship can be grouped into seven major categories, from small feeder (up to 1,000 TEUs) to Very Large Container Ships (10,000 TEUs) (MAN 2009). TEU is the most common expression used to describe container ships. At one time, there were few vessels over 7,000 TEUs in service; 2,000 TEUs was the average vessel size (Gaythwaite, 2004). However, the global economy has increased cargo demand, which has increased vessel size. For example, vessel size has risen to 6,000 TEUs for the Panama Canal (Coracle 2013). In the real world, different companies have their own vessel sizes, and most likely one company provides different vessel sizes for different services.

2.2 Traditional Research in Liner Shipping

The boom in liner shipping has led to increased research, and currently Academic research on these classical cargo ships (e.g., fleet design and routing problems) is vast. Most studies have in common a general focus on optimizations, which include reducing the cost or increasing the profit, for an individual carrier only, which means discussion of the research is limited to the individual carrier's concerns. Liner shipping cost can be summarized into two parts: ship-related costs and port-related costs; ship-related costs are comprised of several major components, such as cargo shipping cost, which is related to the cargo's weight and proportion to the shipping distance, crew cost, fuel cost, and others. Port-related cost is comprised of two principal costs, cargo handling and port entry (Shintani et at., 2007).

Ronen (1983; 1993) and Christiansen et al. (2004) published three outstanding reviews of the large number of academic studies that discuss optimization for individual carriers. Among those, some researchers proceeded from operation cost concerns to focus on how to assign vessels over a set of routes (Jaramillo and Perakis, 1991; Perakis andJaramillo, 1991). Quite a few researchers have discussed the issue of the empty container, and some shipping networks were designed to reposition empty containers (Meng and Wang, 2011; Shintani et. al., 2007). Lam et al. (2007) proposed a novel dynamic approach to solve the empty container problem. Some researchers studied the topic of cargo routing in liner service, such as Agarwal and Ergun (2008), who proposed a space-time network model. There is also a good deal of research focused on the optimization of fleet size over liner routes, taking into consideration frequency, strategic planning and demand forecasting, and so forth (Cho and Perakis, 1996;

Fagerholt, 1999; Lane et al., 1987; ; Sambracos et al., 2004). In addition, many studies highlighted the importance of vessel scheduling problems. Fagerholt (2004) proposed the Turbo Router model to solve vessels' scheduling problems with a heuristic method; Chen et al. (2007) designed a heuristic algorithm for vessel scheduling by considering bidirectional flow. Last but not the least, a number of researchers, such as Rana and Vickson (1988; 1991), investigated the vessel routing problem in order to maximize profit.

In liner shipping, port selection is an important part of the supply chain; however, it has been considered an isolated element by port users and has been ignored by researchers for a long time. The literature on the port-selection topic is limited, which makes the study of port choice important and significant. Among these limited studies, some research is carried out by focusing on a specific group of carriers. Slack (1985) studied the criteria of port choice by surveying those freight forwarders who deal with trans-Atlantic container trade. De Langen (2007) discussed the different criteria of port selection between shipper and freight forwarder in Austria. Also, others, such as Nir et al. (2003), Yeo et al. (2004), and Ugboma et al. (2006), attempted to propose different models from different angles. The study of port choice has three major quantitative determinants: route, cost, and service (D'Este and Meyrick, 1992). Although the cost is the primary concern in port choice, users are more concerned with the low quality of service because of delays, which leads to the loss of marketing and customer satisfaction (Foster, 1978; Tongzon, 1995). Meanwhile, the issue of port location is another main factor, and concerns about location become part of the overall transit cost. For example, Tiwari et al. (2003) have highlighted inland transportation cost as the

major factor in determining the distance from the port to the destination (Tongzon, 2009).

2.3 Collaboration in Liner Shipping

In liner shipping, the increasing pressure of competition forces more and more carriers to attempt collaboration with other carriers instead of improving their business by optimizing their own resources and information only. The shipping industry has cooperated in different kinds of sharing agreements, and putting collaboration and alliances into practice has been widely attempted. In global cargo shipping, more than half of the liner companies are collaborating in order to accomplish the services. For example, the collaboration (sharing vessels) between two liner shipping companies, Sea-Land and Maersk, can be traced back to the 1990s, and today, the collaboration is expanding to a larger scope and deeper degree (Agarwal, 2007). In most collaboration, pattern carriers exchange and allocate parts of ships for other alliance members. This type of collaboration would ideally depend on the willingness of the patterns to share order information and profits, but in reality, liner companies always protect their order information from other patterns and seek their own profit maximum, which often conflicts with other patterns. An industry survey (Logistics Today, 2006b) revealed that such collaboration in practice has not always reached expected goals, and about 40% of alliance companies have started to explore other chances to lower the cost instead of relying on this kind of unprincipled collaboration. Thus, how to improve the effectiveness of collaboration has proven challenging in practice.

More and more research pays attention to this emerging alliance trend in sea cargo ships; however, the published research results on collaboration in liner shipping is still scarce. The following literature discusses collaboration and highlights the potential benefit from collaboration between pattern carriers. Lei et al. (2008) proposed a mathematical model to compare the performances of the container vessel schedule under collaboration and non-collaboration, and the results showed that the advantages of collaboration can be fully attained only when the partner carriers fully share the demand and resources. Agarwal (2007) attempted to create a model and propose a solution for collaboration planning and scheduling problems in liner shipping. Cruijssen (2007) presented results, based on a large-scale survey that showed the potential benefits of horizontal cooperation between Logistics Service Providers (LSP). Panayides (2006) highlighted the priority of integrating liner shipping and collaborative scheduling in the future research.

There are three common policies in one-way container shipping: the non-collaborative policy, the slot-sharing policy (a partial collaboration policy), and the total-sharing policy (a full collaboration policy). Carriers usually accept and practice the slot-sharing policy, exchanging a prefixed proportion of the vessel capacity, which is an excellent application, especially for those carriers who have the same route but different shipping schedules; the total-sharing policy requires carriers to share all information about operating costs, especially profit, which makes it difficult to implement in practice (Lei 2008). Collaboration can help carriers not only to increase their ability to control the operation cost of the service (Dyer and Singh, 1998), but also to benefit from greater customer value at lower cost (Zineldin and Bredenlow, 2003). Meanwhile,

it provides opportunities for carriers to improve their skills by learning from each other (Kogut, 1988). However, carriers think they cannot afford to share profit with others, and are blind to the fact that alliances can expand their geographic scope and service range and thus increase their potential customers (Bleeke and Ernst, 1995). Consequently, they likely hesitate when facing the opportunity to collaborate, and they carefully select partners because they worry about the market share occupied by partner carriers. All of these concerns shed light on the need for a third party to organize and manage the alliance in order to cut down on the impact of the dark sides of close relationships (Zineldin and Bredenlow, 2003) and the need to build trusting relationships to lower all uncertainty (Tomkins, 2001). Chalos and O'Connor (2004) pointed out that the most difficult part for a manager is increasing partner reliability, finding a way that satisfies everyone. In conclusion, the third part is necessary and required to coordinate the cooperation to be carried on in practice.

Another important responsibility for the third party is determining the gains and allocating the benefits among the partners. A fair allocation of benefits is the bedrock of a successful collaboration. The importance of a fair policy is addressed by Gibson et al. (2002), who stress that expected and unexpected costs must be considered. Revenue sharing (Cachon, 2005) is a policy commonly used in a supply chain. According to Liu and Zhang (2008), both revenue sharing and price-discount strategies are valid ways to coordinate participants in the supply chain. Qin et al. (2007) proposed a linear model for combining pricing and ordering issues through a price-sensitive scenario. He and Warland (2005, 2006) proposed a pricing and revenue-sharing model for internet network providers; they ran a generic pricing model for jointing internet services into a

group provider in the network; their model was run based on serving the Internet network, which has properties similar to our research network. According to their result, a unique solution is reached based on a fair allocation scheme; it is expressed by the ratio of profit-to-cost, which determines the providers' profits in proportion to their costs.

2.4 Review of Relevant Transportation Databases

There are multifarious transportation databases, supported by governments, private agencies, or both, which contain relevant information for US global freight trade. Three main databases are applied in our model: Freight Analysis Framework (FAF^3), Maritime Administration Database (MARAD), and US Army Corps of Engineers' Navigation Data Center (NDC). The FAF^3 database is an open free database that was produced by the Federal Highway Administration (FHWA) for US international freight-flow assignments in 2007, incorporating the forecasts from 2015 to 2040. The MARAD database provides maritime freight-flow information from 1999 to 2011 by "U.S. custom ports" and "trade partner" separately. All imports and exports in MARAD are presented by tonnage or container units. The NDC database supplies a more complete collection of maritime data in the US Waterway Data, which comprises the data on foreign cargos, facilities, and other correlative sources. Yearly maritime freight-flow information is largely offered from 1997 to 2010. Furthermore, the O-D pairs in the NDC database are port-to-port pairs, which include over 200 US ports and over 1,000 foreign ports.

SECTION 3: MODELING OF THE CARGO SHIPMENT PROBLEM

Differing from other researchers, we investigate the liner shipping at the "port-port-final destination" instead of the traditional "port-port" scope. Accordingly the core analysis is expanded by associating logistics concerns with transportation planning issues. And in our research the geographic unit of the final destination is defined at Metropolitan Statistical Areas (MSAs) level in the research.

3.1 Problem Definition

Since US imports are greater than exports, we assume that the liner shipper is home-based at a foreign port. We refer to US imports from a foreign port as "forward shipping" and exports to the same foreign port as "backward shipping". Figure 1 is a schematic representation of the problem being considered in this research. It includes one foreign port, multiple US ports and multiple MSAs. In the real world, all carriers operate with known set of demand with origin (foreign port) and destination (MSA) points specified. Generally speaking, the carrier based on demand patterns selects the ports of entry to the USA. Hence, the only variable in our model will be the port of entry. In view of carriers being home-based at foreign ports, our model focuses on only one foreign port being the origin. It includes multiple US ports and MSAs.

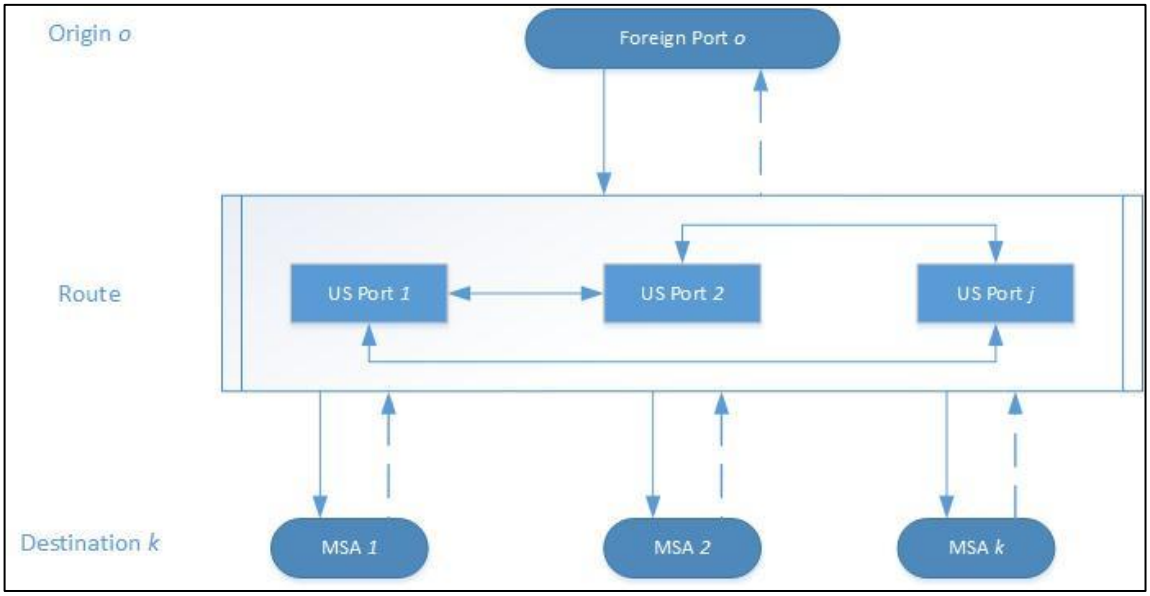

Figure 3.1: Schematic Representation of US Imports and Exports

In Figure 1, imports to the USA originate at node *o* (foreign port) destined to a final node *k* (MSA) through any of the US ports. On the other hand, exported cargoes depart from an MSA via an inland transit mode towards a US port to its final destination, foreign port *o*. Meanwhile, at any US port, cargoes are being loaded or unloaded or waiting on the vessel to be transited to another US port on its way to an MSA.

Two of the main goals of a carrier in liner shipping are to minimize costs (or maximize profits) and improve customer service. So, carriers are always searching ways to shorten the travel time while not increasing the travel cost in order to increase their market share in the business. We present a collaboration model, which leads to better service at lower cost for each carrier while keeping the market share constant. Our model assumes that each carrier has its own set of vessel routes and route frequencies defined. In a way, routes and frequencies can be considered fixed within a time window since they are usually defined three to six months in advance for global cargo transport (long-haul cargo shipping). Our model allows for carrier "a" to carry a portion of carrier

“b”’s shipment on one of its vessels assigned to one of its fixed routes. The level of collaboration among the carriers is decided by a third party logistics firm, which has total visibility of demand and schedules for each carrier. We present an optimization model and pricing strategy for the third part logistics firm to use in a way that the percent cost savings for each carrier will be the same under collaboration.

Hence, in summary, this research presents a decision support system for collaborative liner shipping in the view of the third party, as a planner, a governor or a coordinator. In the collaborative system, the objective is to present a win-win solution for both the system and each carrier. A three-step decision support system is proposed: The first step is to determine the minimum cost demand shipment schedules for each carrier separately using their own demand data, cost, vessel availability and predefined fixed routes. Then, using price strategies we determine how much each carrier should charge each other carrier for carrying its cargo. Using this cost structure and assuming full collaboration from the carriers, a collaborative optimization model is run to determine cargo schedules for each carrier on each route. We then demonstrated that the percent cost savings for each carrier is the same using the proposed cost strategy.

The optimization model has the following assumptions:

- There is only one origin *o* (foreign port) in the network.
- Each carrier is independent and home-based at the foreign port.
- All vessels are initially at the foreign port.
- Every carrier has its own set of predetermined shipping routes between the foreign port and US ports.
- Every port on a given route is visited at least once and at most two times.

- The route from each US port to each destination (MSA) is identified in advance.
- The cargo demand for each carrier is independent.
- Vessel transports cargo back from MSAs to the foreign port.

3.2 Optimization Model for Single Carrier

In this phase we present a mixed integer linear programming optimization model that assigns cargos (demand) to each vessel and each vessel to a fixed route for each carrier in a way to minimize total transportation cost. The total cost is defined as the sum of sea and inland shipping costs. The cost of sea shipping depends on factors such as cargo size, staff, energy consumption, nautical distance, vessels maintenance and loss, port charges and so on. The cost of the inland shipping is a function of the size of the cargo (usually in terms of truck-load), inland distance, driver cost, fuel cost and others. Our research, rather than attempting to define the costs in detail, uses a set of key factors to determine the sea and inland shipping cost. As noted earlier, our main goal is to present an optimization model under carrier collaboration and determine pricing strategies leading to equitable and fair collaboration. Therefore, in order to demonstrate the difference between total transportation costs before and after collaboration, we calculate the sea shipping cost as a function of cargo size, nautical distance, fixed vessel cost and group all other costs under vessel deployment cost. The cost of inland shipping is defined in terms of cargo size, inland distance and all other costs grouped into the parameter of inland shipping cost.

Then, the following terms are defined:

C the total shipping cost of a carrier

K set of MSAs (k)

R set of routes (r)

J set of US ports (j)

L_r set of all links (j, j') or (j, j'') between US ports on the route r, where $j, j', j'' \in J,\ j \neq j'$ and $j \neq j''$

J_r US port of entry j_r, which is the immediate successor of the foreign port o on route r; or US port of exit j_r which is the immediate predecessor of the foreign port o on route r, $J_r \in J$

I_r set of US ports serving as "intermediate" ports on route r, where $\forall\ (j, j') \in L_r$, $(j, j'') \in L_r,\ j' \neq j'',\ I_r \in J$

The decision variables used by the model are as follows:

$x^r_{oj_r}$ imported TEUs shipped from the origin o to the entry j_r on route r, $\forall\ j_r \in J_r$

$y^r_{j_r o}$ exported TEUs shipped from the exit j_r to the origin o on route r, $\forall\ j_r \in J_r$

x^r_{jk} imported TEUs shipped from US port j to MSA k on route r, $\forall\ j \in J, k \in K$

y^r_{kj} exported TEUs shipped from MSA k to US port j on route r, $\forall\ j \in J, k \in K$

$x^r_{jj'}$ imported TEUs shipped from US port j to US port j' on route r, $\forall\ (j, j') \in L_r$

$y^r_{jj'}$ exported TEUs shipped from US port j to US port j' on route r, $\forall\ (j, j') \in L_r$

$v^r_{oj_r}$ number of vessels deployed from the origin o to the entry j_r on route r, $\forall j_r \in J_r$

The parameters used in the model are as follows:

t_{ok} total demand of TEUs shipped from the origin o to MSA k

t_{ko} total demand of TEUs shipped from MSA k to the origin o

V loading capacity (TEUs) for the vessel

ρ sea cost parameter ($/TEU/nautical miles)

σ ground cost parameter ($/TEU/ miles)

τ vessel cost parameter ($)

D_{max} maximum number of available vessels for a carrier

l_{oj_r} nautical distance from the origin *o* to the entry port j_r

l_{j_ro} nautical distance from the exit port j_r to the origin *o*

$l_{jj'}$ nautical distance between US port *j* and j'

l_{jk} ground distance from US port *j* to MSA *k*

l_{kj} ground distance from MSA *k* to US port *j*

The problem for each carrier can be modeled as follows:

The total shipping cost *C* for a carrier is comprised of four components:

$$C = c_1 + c_2 + c_3 + c_4 \tag{3.1}$$

where

c_1 cargo sea shipping cost between the foreign port and US ports

c_2 cargo ground shipping cost between US ports and MSAs

c_3 cargo sea shipping cost between US ports and US ports

c_4 vessel deployment cost

Each component of the cost function can be expressed as:

$$c_1 = \sum_r x^r_{oj_r}.\rho.l_{oj_r} + \sum_r y^r_{j_ro}.\rho.l_{j_ro} \tag{3.2}$$

$$c_2 = \sum_r \sum_j \sum_k x^r_{jk}.\sigma.l_{jk} + \sum_r \sum_k \sum_j y^r_{kj}.\sigma.l_{kj} \tag{3.3}$$

$$c_3 = \sum_r \sum_{(j,j')\in L_r} (x^r_{jj'} + y^r_{jj'}).\rho.l_{jj'} \tag{3.4}$$

$$c_4 = \sum_r v^r_{oj_r}.\tau \tag{3.5}$$

The objective function then is to minimize *C*, the total shipping cost equation (3.1).

The constraints of the model include:

Carrier constraints:

The total number of imported TEUs shipped from the origin *o* to all US ports of entry should be equal to the total demand by all MSAs.

$$\sum_r x^r_{oj_r} = \sum_k t_{ok} \quad \forall\, j_r \in J_r \tag{3.6}$$

The total number of exported TEUs shipped from all of the US ports of exit should be equal to the total TEU demand at the foreign port *o*.

$$\sum_r y^r_{j_r o} = \sum_k t_{ko} \quad \forall\, j_r \in J_r, \tag{3.7}$$

The total number of imported TEUs shipped to MSA *k* over all the routes is equal to the demand at the MSA.

$$\sum_r \sum_j x^r_{jk} = t_{ok} \quad \forall\, k \in K \tag{3.8}$$

The total number of exported TEUs shipped from MSA *k* over all the routes is equal to the demand at the foreign port from the MSA.

$$\sum_r \sum_j y^r_{kj} = t_{ko} \quad \forall\, k \in K \tag{3.9}$$

The constraints related to the in-transit shipments for route r are as follows:

The number of imported TEUs shipped from o to j_r is equal to the total number of imported TEUs received by all the MSAs on the same route *r*.

$$x^r_{oj_r} - \sum_j \sum_k x^r_{jk} = 0 \quad \forall\, j_r \in J_r, r \in R \tag{3.10}$$

The number of exported TEUs shipped from all MSAs is equal to the total number of exported TEUs shipped from j_r to o on the same route *r*.

$$y^r_{j_r o} - \sum_k \sum_j y^r_{kj} = 0 \quad \forall\, j_r \in J_r, r \in R \tag{3.11}$$

The number of imported TEUs in and out of US port of entry j_r should be equal on the same route *r*.

$$x^r_{oj_r} - \sum_k x^r_{j_r k} - x^r_{j_r j'} = 0 \quad \forall\, j_r \in J_r,\ j' \in J,\ j_r \neq j', r \in R \tag{3.12}$$

The number of exported TEUs in and out of US port of exit j_r should be equal on the same route r.

$$y^r_{j_r o} - \sum_k y^r_{k j_r} - y^r_{j' j_r} = 0 \quad \forall\, j_r \in J_r,\ j' \in J,\ j_r \neq j',\ r \in R \tag{3.13}$$

The number of imported TEUs in and out of an intermediate US port *j* should be equal on the same route *r*.

$$x^r_{j' j} - \sum_k x^r_{jk} - x^r_{j\, j''} = 0 \qquad \forall\, j \in I_r,\ r \in R \tag{3.14}$$

The number of exported TEUs in and out of an intermediate US port *j* should be equal on the same route *r*.

$$\sum_k y^r_{kj} + y^r_{j' j} - y^r_{j j''} = 0 \qquad \forall\, j \in I_r,\ r \in R \tag{3.15}$$

The capacity constraints for route *r*:

The total TEUs from the foreign port to the US should be less than the total capacity of assigned vessels on the same route *r*.

$$x^r_{o j_r} \leq v^r_{o j_r}.V \quad \forall\, j_r \in J_r,\ r \in R \tag{3.16}$$

The total TEUs from US to the foreign port should be less than the total capacity of assigned vessels on the same route *r*.

$$y^r_{j_r o} \leq v^r_{o j_r}.V \qquad \forall\, j_r \in J_r,\ r \in R \tag{3.17}$$

The total TEUs on all the vessels at a US port should be less than the total capacity of assigned vessels on the same route *r*.

$$\sum_k y^r_{kj} - \sum_k x^r_{jk} + x^r_{j' j} + y^r_{j' j} \leq v^r_{o j_r}.V \quad \forall\, j_r \in J_r,\ (j', j) \in L_r,\ r \in R \tag{3.18}$$

The total TEUs shipped out from a US port should be less than the total capacity of assigned vessels on the same route *r*.

$$x^r_{j j'} + y^r_{j j'} \leq v^r_{o j_r}.V \quad \forall\, j_r \in J_r,\ (j', j) \in L_r,\ r \in R \tag{3.19}$$

The total TEUs shipped into a US port should be less than the total capacity of assigned vessels on the same route *r*.

$$x^r_{j'j} + y^r_{j'j} \le v^r_{oj_r}.V \quad \forall\, j_r \in J_r,\ (j', j) \in L_r,\ r \in R \tag{3.20}$$

The total number of vessels can be assigned to route *r* should not exceed the maximum number of all available vessels.

$$\sum_r v^r_{oj_r} \le D_{max} \quad \forall\, j_r \in J_r \tag{3.21}$$

The total TEUs from foreign port to US should be shipped by vessels on the same route *r* as few as possible, which means the number of assigned vessels on the route *r* should be as small as possible.

$$x^r_{oj_r} \ge \left(v^r_{oj_r} - 1\right).V \quad \forall\, j_r \in J_r,\ r \in R \tag{3.22}$$

Non negativity constraints:

$$x^r_{oj_r} \ge 0 \quad \forall\, j_r \in J_r,\ r \in R \tag{3.23}$$

$$y^r_{j_r o} \ge 0 \quad \forall\, j_r \in J_r,\ r \in R \tag{3.24}$$

$$x^r_{jk} \ge 0 \quad \forall\ j \in J, k \in K,\ r \in R \tag{3.25}$$

$$y^r_{kj} \ge 0 \quad \forall\ j \in J, k \in K,\ r \in R \tag{3.26}$$

$$x^r_{jj'} \ge 0 \quad \forall\ (j, j') \in L_r,\ r \in R \tag{3.27}$$

$$y^r_{jj'} \ge 0 \quad \forall\ (j, j') \in L_r,\ r \in R \tag{3.28}$$

$$x^r_{j'j} \ge 0 \quad \forall\ (j', j) \in L_r,\ r \in R \tag{3.29}$$

$$y^r_{j'j} \ge 0 \quad \forall\ (j', j) \in L_r,\ r \in R \tag{3.30}$$

$$x^r_{jj''} \ge 0 \quad \forall\ (j, j'') \in L_r,\ r \in R \tag{3.31}$$

$$y^r_{jj''} \ge 0 \quad \forall\ (j, j'') \in L_r,\ r \in R \tag{3.32}$$

$$v^r_{oj_r} \ge 0 \text{ and integer} \quad \forall\, j_r \in J_r\ ,\ r \in R \tag{3.33}$$

In summary, this optimization model for single carrier solves the problem with the total size of $\sum_r(2|L_r| + 2|L_r + 1||K| + 3)$ variables and $[3 + 2|K| + \sum_r(5|L_r| + 2|L_r + 1||K| + 2|I_r| + 10)]$ constraints.

3.3 System Optimization under Total Collaboration

In this section, we present a mixed integer linear programing model for the carriers under collaboration. Hence, the expanded model involves all carriers, all shipments from the foreign port to all of the MSAs, all carrier routes, all vessels under one large system. The optimal solution to the expanded system while may minimize the total cost, savings for each carrier may not be the same. As a result, a specific carrier may end up saving considerably more than other carriers, a condition which will not be viewed favorable by the other carriers. In order to provide a solution, which results in a fair and equitable savings for all of the carriers, one must determine pricing strategy for each carrier. We discuss the pricing strategy in the next section. In this section, we present the optimization model assuming that carriers charge each other different costs for carrying their cargos (TEUs) and the charges have been determined a priori.

Let μ_{mn} be a parameter indicating the amount carrier *m* will charge extra (that is above the normal shipment cost) to carrier *n,* if carrier *m* carries the cargo for carrier *n*. We will refer to this cost as the penalty cost for carrier *n*. To simplify the discussion, let's assume that we have two carriers, carrier 1 and carrier 2, under the collaborative model. Table 1 shows the breakdown of the costs for each carrier.

Table 3.1: Costs in Collaboration for Carrier *1* and Carrier *2*

	Cargoes belong to carrier *1*	Cargoes belong to carrier *2*
Shipped by carrier *1*	c_{11}	$(1+\mu_{12})\, c_{12}$
Shipped by carrier *2*	$(1+\mu_{21})\, c_{21}$	c_{22}

The costs for each carrier under full collaboration can be determined as follows:

the cost for carrier *1*:

$$C_1 = c_{11} + (1+\mu_{21})c_{21} - \mu_{12}c_{12} + c_{v1} \tag{3.34}$$

the cost for carrier *2*:

$$C_2 = c_{22} + (1+\mu_{12})c_{12} - \mu_{21}c_{21} + c_{v2} \tag{3.35}$$

the total cost for the two-carrier system w/o penalty costs:

$$C = c_{11} + c_{21} + c_{22} + c_{12} + c_{v1} + c_{v2}\ . \tag{3.36}$$

When there are multiple companies in the system, assuming that for each company the total shipping cost before collaboration is known, the model can be generalized as follows:

Let *S* define the set of carriers in question under the collaborative model. For carrier *m* collaborating with carrier *n*, where $m, n \in S, n \neq m$, we define I_r^m, J_r^m, R^m, L_r^m, t_{ok}^m, t_{ko}^m, V^m and D_{max}^m represent I_r, J_r, R, L_r, t_{ok}, t_{ko}, V and D_{max} for carrier m respectively. Then,

the cost for carrier m:

$$C_m = c_{mm} + \sum_n (1+\mu_{nm})c_{nm} - \sum_n \mu_{mn}c_{mn} + c_{vm} \tag{3.37}$$

the cost of system *S* w/o penalty costs:

$$C_S = \sum_m c_{mm} + \sum_m \sum_n c_{mn} + \sum_m c_{vm} \tag{3.38}$$

According the results discussed in section 3.2, each cost portion could be expanded to:

$$c_{mm} = \sum_r x_{oj_r}^{rmm}.\rho.l_{oj_r} + \sum_r y_{j_ro}^{rmm}.\rho.l_{j_ro} + \sum_r \sum_j \sum_k x_{jk}^{rmm}.\sigma.l_{jk} + \sum_r \sum_k \sum_j y_{kj}^{rmm}.\sigma.l_{kj} + \sum_r \sum_{(j,j')\in L_r^m} (x_{jj'}^{rmm} + y_{jj'}^{rmm}).\rho.l_{jj'} \quad (3.39)$$

$$c_{mn(n\neq m)} = \sum_r x_{oj_r}^{rmn}.\rho.l_{oj_r} + \sum_r y_{j_ro}^{rmn}.\rho.l_{j_ro} + \sum_r \sum_j \sum_k x_{jk}^{rmn}.\sigma.l_{jk} + \sum_r \sum_k \sum_j y_{kj}^{rmn}.\sigma.l_{kj} + \sum_r \sum_{(j,j')\in L_r^m} (x_{jj'}^{rmn} + y_{jj'}^{rmn}).\rho.l_{jj'} \quad (3.40)$$

$$c_{nm(m\neq n)} = \sum_r x_{oj_r}^{rnm}.\rho.l_{oj_r} + \sum_r y_{j_ro}^{rnm}.\rho.l_{j_ro} + \sum_r \sum_j \sum_k x_{jk}^{rnm}.\sigma.l_{jk} + \sum_r \sum_k \sum_j y_{kj}^{rnm}.\sigma.l_{kj} + \sum_r \sum_{(j,j')\in L_r^m} (x_{jj'}^{rnm} + y_{jj'}^{rnm}).\rho.l_{jj'} \quad (3.41)$$

$$V_m = \sum_r v_{oj_r}^{rm}.\tau \quad (3.42)$$

Then, the equation 3.37 can be presented as:

$$C_m = \sum_r x_{oj_r}^{rmm}.\rho.l_{oj_r} + \sum_r y_{j_ro}^{rmm}.\rho.l_{j_ro} + \sum_r \sum_j \sum_k x_{jk}^{rmm}.\sigma.l_{jk} + \sum_r \sum_k \sum_j y_{kj}^{rmm}.\sigma.l_{kj} + \sum_r \sum_{(j,j')\in L_r^m} (x_{jj'}^{rmm} + y_{jj'}^{rmm}).\rho.l_{jj'} + \sum_n (1+\mu_{nm})[\sum_r x_{oj_r}^{rnm}.\rho.l_{oj_r} + \sum_r y_{j_ro}^{rnm}.\rho.l_{j_ro} + \sum_r \sum_j \sum_k x_{jk}^{rnm}.\sigma.l_{jk} + \sum_r \sum_k \sum_j y_{kj}^{rnm}.\sigma.l_{kj} + \sum_r \sum_{(j,j')\in L_r^m} (x_{jj'}^{rnm} + y_{jj'}^{rnm}).\rho.l_{jj'}] - \sum_n \mu_{mn}\Big[\sum_r x_{oj_r}^{rmn}.\rho.l_{oj_r} + \sum_r y_{j_ro}^{rmn}.\rho.l_{j_ro} + \sum_r \sum_j \sum_k x_{jk}^{rmn}.\sigma.l_{jk} + \sum_r \sum_k \sum_j y_{kj}^{rmn}.\sigma.l_{kj} + \sum_r \sum_{(j,j')\in L_r^m} (x_{jj'}^{rmn} + y_{jj'}^{rmn})\Big).\rho.l_{jj'}] + \sum_r v_{oj_r}^{rm}.\tau \quad (3.43)$$

The equation 3.38 can be represented as:

$$C_S = \sum_m [\sum_r x_{oj_r}^{rmm}.\rho.l_{oj_r} + \sum_r y_{j_ro}^{rmm}.\rho.l_{j_ro} + \sum_r \sum_j \sum_k x_{jk}^{rmm}.\sigma.l_{jk} + \sum_r \sum_k \sum_j y_{kj}^{rmm}.\sigma.l_{kj} + \sum_r \sum_{(j,j')\in L_r^m} (x_{jj'}^{rmm} + y_{jj'}^{rmm}).\rho.l_{jj'}]^+ \sum_m \sum_n [\sum_r x_{oj_r}^{rmn}.\rho.l_{oj_r} + \sum_r y_{j_ro}^{rmn}.\rho.l_{j_ro} + \sum_r \sum_j \sum_k x_{jk}^{rmn}.\sigma.l_{jk} + \sum_r \sum_k \sum_j y_{kj}^{rmn}.\sigma.l_{kj} + \sum_r \sum_{(j,j')\in L_r^m} (x_{jj'}^{rmn} + y_{jj'}^{rmn}).\rho.l_{jj'}] + \sum_m [\sum_r v_{oj_r}^{rm}.\tau] \quad (3.44)$$

The optimization model for the collaborative system is to minimize the system cost C_S with respect to the set of constraints that:

$$\sum_r x_{oj_r}^{rmm} + \sum_n \sum_r x_{oj_r}^{rnm} = \sum_k t_{ok}^m \qquad \forall\, j_r \in J_r^m, m \in S \tag{3.45}$$

$$\sum_r y_{j_r o}^{rmm} + \sum_n \sum_r y_{j_r o}^{rnm} = \sum_k t_{ko}^m \qquad \forall\, j_r \in J_r^m, m \in S \tag{3.46}$$

$$\sum_r \sum_j x_{jk}^{rmm} + \sum_n \sum_r \sum_j x_{jk}^{rnm} = t_{ok}^m \quad \forall\, k \in K, m \in S \tag{3.47}$$

$$\sum_r \sum_j y_{kj}^{rmm} + \sum_n \sum_r \sum_j\ y_{kj}^{rnm} = t_{ko}^m \quad \forall\, k \in K, m \in S \tag{3.48}$$

$$x_{oj_r}^{rmm} - \sum_j \sum_k x_{jk}^{rmm} = 0 \quad \forall\, j_r \in J_r^m, r \in R^m, m \in S \tag{3.49}$$

$$x_{oj_r}^{rmn} - \sum_j \sum_k x_{jk}^{rmn} = 0 \quad \forall\, j_r \in J_r^m, r \in R^m, m, n \in S \tag{3.50}$$

$$y_{oj_r}^{rmm} - \sum_k \sum_j y_{kj}^{rmm} = 0 \quad \forall\, j_r \in J_r^m, r \in R^m, m \in S \tag{3.51}$$

$$y_{oj_r}^{rmn} - \sum_k \sum_j y_{kj}^{rmn} = 0 \quad \forall\, j_r \in J_r^m, r \in R^m, m, n \in S \tag{3.52}$$

$$x_{oj_r}^{rmm} - \sum_k x_{j_r k}^{rmm} - x_{j_r j'}^{rmm} = 0 \quad \forall\, j_r \in J_r^m,\ j' \in J,\ j_r \neq j', r \in R^m, m \in S \tag{3.53}$$

$$x_{oj_r}^{rmn} - \sum_k x_{j_r k}^{rmn} - x_{j_r j'}^{rmn} = 0 \quad \forall\, j_r \in J_r^m,\ j' \in J,\ j_r \neq j', r \in R^m, m, n \in S \tag{3.54}$$

$$y_{oj_r}^{rmm} - \sum_k y_{kj_r}^{rmm} - y_{j' j_r}^{rmm} = 0 \quad \forall\, j_r \in J_r^m,\ j' \in J,\ j_r \neq j', r \in R^m, m \in S \tag{3.55}$$

$$y_{oj_r}^{rmn} - \sum_k y_{kj_r}^{rmn} - y_{j' j_r}^{rmn} = 0 \quad \forall\, j_r \in J_r^m,\ j' \in J,\ j_r \neq j', r \in R^m, m, n \in S \tag{3.56}$$

$$x_{j'j}^{rmm} - \sum_k x_{jk}^{rmm} - x_{jj''}^{rmm} = 0 \quad \forall\, j \in I_r^m, r \in R^m, m \in S \tag{3.57}$$

$$x_{j'j}^{rmn} - \sum_k x_{jk}^{rmn} - x_{jj''}^{rmn} = 0 \quad \forall\, j \in I_r^m, r \in R^m, m, n \in S \tag{3.58}$$

$$\sum_k y_{kj}^{rmm} + y_{j'j}^{rmm} - y_{jj''}^{rmm} = 0 \quad \forall\, j \in I_r^m, r \in R^m, m \in S \tag{3.59}$$

$$\sum_k y_{kj}^{rmn} + y_{j'j}^{rmn} - y_{jj''}^{rmn} = 0 \quad \forall\, j \in I_r^m, r \in R^m, m, n \in S \tag{3.60}$$

$$\sum_n (x_{oj_r}^{rmm} + x_{oj_r}^{rmn}) \leq v_{oj_r}^{rm}.V^m \qquad \forall\, j_r \in J_r^m, r \in R^m, m \in S \tag{3.61}$$

$$\sum_n (y_{j_r o}^{rmm} + y_{j_r o}^{rmn}) \leq v_{oj_r}^{rm}.V^m \qquad \forall\, j_r \in J_r^m, r \in R^m, m \in S \tag{3.62}$$

$$\sum_n[\sum_k(y_{kj}^{rmm}+y_{kj}^{rmn})-\sum_k\left(x_{jk}^{rmm}+x_{jk}^{rmn}\right)+(x_{j'j}^{rmm}+x_{j'j}^{rmn})+(y_{j'j}^{rmm}+$$

$$y_{j'j}^{rmn})]\le v_{oj_r}^{rm}.V \qquad \forall\, j_r\in J_r^m,\ (j',j)\in L_r^m, r\in R^m, m\in S \tag{3.63}$$

$$\sum_n[\,(x_{jj\prime}^{rmm}+x_{jj\prime}^{rmn})+(y_{jj\prime}^{rmm}+y_{jj\prime}^{rmn})]\le v_{oj_r}^{rm}.V^m$$

$$\forall\, j_r\in J_r^m,\ (j',j)\in L_r^m, r\in R^m, m\in S \tag{3.64}$$

$$\sum_n[\,(x_{j\prime j}^{rmm}+x_{j\prime j}^{rmn})+(y_{j\prime j}^{rmm}+y_{j\prime j}^{rmn})]\le v_{oj_r}^{rm}.V^m$$

$$\forall\, j_r\in J_r^m,\ (j',j)\in L_r^m, r\in R^m, m\in S \tag{3.65}$$

$$\sum_n(x_{oj_r}^{rmm}+\ x_{oj_r}^{rmn})\ge\left(v_{oj_r}^{rm}-1\right).V^m \qquad \forall\, j_r\in J_r^m,\ r\in R^m, m\in S \tag{3.66}$$

$$\sum_r v_{oj_r}^{rm}\le D_{max}^m \qquad \forall\, j_r\in J_r^m, m\in S \tag{3.67}$$

$$x_{oj_r}^{rmm}\ge 0 \qquad \forall\, j_r\in J_r^m,\ r\in R^m, m\in S \tag{3.68}$$

$$x_{oj_r}^{rnm}\ge 0 \qquad \forall\, j_r\in J_r^m, r\in R^m, m,n\in S \tag{3.69}$$

$$x_{oj_r}^{rmn}\ge 0 \qquad \forall\, j_r\in J_r^m, r\in R^m, m,n\in S \tag{3.70}$$

$$y_{j_ro}^{rmm}\ge 0 \qquad \forall\, j_r\in J_r^m,\ r\in R^m, m\in S \tag{3.71}$$

$$y_{j_ro}^{rnm}\ge 0 \qquad \forall\, j_r\in J_r^m, r\in R^m, m,n\in S \tag{3.72}$$

$$y_{j_ro}^{rmn}\ge 0 \qquad \forall\, j_r\in J_r^m, r\in R^m, m,n\in S \tag{3.73}$$

$$x_{jk}^{rmm}\ge 0 \qquad \forall\ j\in J, k\in K, r\in R^m, m\in S \tag{3.74}$$

$$x_{jk}^{rnm}\ge 0 \qquad \forall\ j\in J, k\in K, r\in R^m, m,n\in S \tag{3.75}$$

$$x_{jk}^{rmn}\ge 0 \qquad \forall\ j\in J, k\in K, r\in R^m, m,n\in S \tag{3.76}$$

$$y_{kj}^{rmm}\ge 0 \qquad \forall\ j\in J, k\in K,\ r\in R^m, m\in S \tag{3.77}$$

$$y_{kj}^{rnm}\ge 0 \qquad \forall\ j\in J, k\in K, r\in R^m, m,n\in S \tag{3.78}$$

$$y_{kj}^{rmn}\ge 0 \qquad \forall\ j\in J, k\in K, r\in R^m, m,n\in S \tag{3.79}$$

$$x_{jj'}^{rmm}\ge 0 \qquad \forall\ (j,j')\in L_r^m,\ r\in R^m, m\in S \tag{3.80}$$

$$x_{jj\prime}^{rmn}\ge 0 \qquad \forall\ (j,j')\in L_r^m, r\in R^m, m,n\in S \tag{3.81}$$

$$y_{jj\prime}^{rmm} \geq 0 \qquad \forall\ (j,j') \in L_r^m,\ r \in R^m, m \in S \tag{3.82}$$

$$y_{jj\prime}^{rmn} \geq 0 \qquad \forall\ (j,j') \in L_r^m, r \in R^m, m,n \in S \tag{3.83}$$

$$x_{j\prime j}^{rmm} \geq 0 \qquad \forall\ (j,j') \in L_r^m,\ r \in R^m, m \in S \tag{3.84}$$

$$x_{j\prime j}^{rmn} \geq 0 \qquad \forall\ (j,j') \in L_r^m, r \in R^m, m,n \in S \tag{3.85}$$

$$y_{j\prime j}^{rmm} \geq 0 \qquad \forall\ (j,j') \in L_r^m,\ r \in R^m, m \in S \tag{3.86}$$

$$y_{j\prime j}^{rmn} \geq 0 \qquad \forall\ (j,j') \in L_r^m, r \in R^m, m,n \in S \tag{3.87}$$

$$x_{jj\prime\prime}^{rmm} \geq 0 \qquad \forall\ (j,j') \in L_r^m,\ r \in R^m, m \in S \tag{3.88}$$

$$x_{jj\prime\prime}^{rmn} \geq 0 \qquad \forall\ (j,j') \in L_r^m, r \in R^m, m,n \in S \tag{3.89}$$

$$y_{jj\prime\prime}^{rmm} \geq 0 \qquad \forall\ (j,j') \in L_r^m,\ r \in R^m, m \in S \tag{3.90}$$

$$y_{jj\prime\prime}^{rmn} \geq 0 \qquad \forall\ (j,j') \in L_r^m, r \in R^m, m,n \in S \tag{3.91}$$

$$v_{oj_r}^{rm} \geq 0 \text{ and integer} \qquad \forall\ j_r \in J_r^m,\ r \in R^m, m \in S \tag{3.92}$$

$$C_m - \widetilde{C_{\mathrm{m}}} \leq 0 \quad \text{where } \widetilde{C_{\mathrm{m}}} \text{ is the total cost before collaboration for } m \tag{3.93}$$

In summary, this optimization model for h-carrier system solves the problem with the total size of $\sum_m \sum_r (2h|L_r^m| + 2h|L_r^m + 1|\,|K| + 2h + 1)$ variables and $[\ \sum_m \sum_r\ (\ 2h|L_r^m| + 2h|L_r^m + 1|\,|K| + 2h|I_r^m| + 3|L_r^m| + 6h + 4\ )\ +\ 2h\ (|K| + 2)\ ]$ constraints.

3.4 Price Strategy for Equitable Cost Sharing

We next present a methodology to determine the penalty costs for each company in order for the optimization model to result in fair and equitable cost savings for each carrier. Our research will adopt the following revenue sharing strategy described by He and Walrand (2006). Under the revenue-sharing strategy, the profit of each provider

should be the same proportion to its cost. Assume there are h providers in the system. The revenue-sharing strategy can be represented as

$$\frac{p_1-q_1}{q_1} = \frac{p_2-q_2}{q_2} = \cdots = \frac{p_h-q_h}{q_h} \tag{3.94}$$

where p_1, p_2,..., p_h, are respective prices for provider *1,2,…, h*; and q_1, q_2,..., q_h, are respective costs for provider *1,2,…, h*.

For our multi-carrier collaboration model, we transform the revenue sharing strategy into the cost saving sharing strategy. Hence, for our model the proportion of the cost savings to the original cost should be the same for each carrier, that is:

$$\frac{\widetilde{C_1}-C_1}{\widetilde{C_1}} = \frac{\widetilde{C_2}-C_2}{\widetilde{C_2}} = \cdots = \frac{\widetilde{C_h}-C_h}{\widetilde{C_h}} \tag{3.95}$$

where $\widetilde{C_1}$, $\widetilde{C_2}$,…, $\widetilde{C_h}$ are initial costs for carrier *1,2,…, h*; and C_1, C_2,..., C_h, are current costs for carrier *1,2,…, h* in collaboration.

Let ΔC is the total cost savings for the system; θ_1, θ_2,…, θ_h are the cost saving coefficient for carrier *1,2,…, h*, respectively, where $\theta_1, \theta_2, \ldots, \theta_h \in (0,1)$, then:

$$\begin{aligned} \widetilde{C_1} - C_1 &= \theta_1 \Delta C \\ \widetilde{C_2} - C_2 &= \theta_2 \Delta C \\ &\vdots \\ \widetilde{C_h} - C_h &= \theta_h \Delta C \end{aligned} \tag{3.96}$$

Thus,

$$\begin{aligned} C_1 &= \widetilde{C_1} - \theta_1 \Delta C \\ C_2 &= \widetilde{C_2} - \theta_2 \Delta C \\ &\vdots \\ C_h &= \widetilde{C_h} - \theta_h \Delta C \end{aligned} \tag{3.97}$$

Then, using the above cost savings sharing formula, equation 3.95 can be rewritten as:

$$\frac{\widetilde{C_1}-(\widetilde{C_1}-\theta_1\Delta C)}{\widetilde{C_1}} = \frac{\widetilde{C_2}-(\widetilde{C_2}-\theta_2\Delta C)}{\widetilde{C_2}} = \cdots = \frac{\widetilde{C_h}-(\widetilde{C_h}-\theta_h\Delta C)}{\widetilde{C_h}} \tag{3.98}$$

Also it can be further simplified as:

$$\frac{\theta_1}{\widetilde{C_1}} = \frac{\theta_2}{\widetilde{C_2}} = \cdots = \frac{\theta_h}{\widetilde{C_h}} \tag{3.99}$$

Hence,

$$\begin{aligned} \theta_2 &= \theta_1 \frac{\widetilde{C_2}}{\widetilde{C_1}} \\ &\vdots \\ \theta_h &= \theta_1 \frac{\widetilde{C_h}}{\widetilde{C_1}} \end{aligned} \tag{3.100}$$

Since

$$\theta_1 + \theta_2 + \cdots + \theta_h = 1 \tag{3.101}$$

Then,

$$\theta_1 + \theta_1 \frac{\widetilde{C_2}}{\widetilde{C_1}} + \cdots + \theta_1 \frac{\widetilde{C_h}}{\widetilde{C_1}} = 1 \tag{3.102}$$

Hence, one can calculate θ_i as:

$$\begin{aligned} \theta_1 &= \frac{\widetilde{C_1}}{\widetilde{C_1}+\widetilde{C_2}+\cdots+\widetilde{C_h}} \\ \theta_2 &= \frac{\widetilde{C_2}}{\widetilde{C_1}+\widetilde{C_2}+\cdots+\widetilde{C_h}} \\ &\vdots \\ \theta_h &= \frac{\widetilde{C_h}}{\widetilde{C_1}+\widetilde{C_2}+\cdots+\widetilde{C_h}} \end{aligned} \tag{3.103}$$

These values represent the ratios describing the fair allocation of the saving cost among the carriers involved in the collaboration.

After one determines the values for θ_1, θ_2,…, θ_h, the penalty cost can be calculated in the next step. The result of optimization model (w/o price strategy) demonstrates all detailed shipments for each carrier operating on every route. Thus the equation 3.37 could be represented as

The cost for carrier m:

$$C_m = f_m\left(\mu_{\mathrm{m1}}, \dots, \mu_{mn}, \dots, \mu_{mh}, \mu_{\mathrm{1m}}, \dots, \mu_{nm}, \dots, \mu_{hm}\right) \quad \forall\ m, n \in S, n \neq m \qquad (3.104)$$

Let's assume one carrier will charge the same extra fee for shipping cargos for all other carriers, Then the equation 3.97 can be written by

$$\begin{aligned} f_1\left(\mu_1, \mu_2, \dots, \mu_h\right) &= \widetilde{C_1} - \theta_1 \Delta C \\ f_2\left(\mu_1, \mu_2, \dots, \mu_h\right) &= \widetilde{C_2} - \theta_2 \Delta C \\ &\vdots \\ f_h\left(\mu_1, \mu_2, \dots, \mu_h\right) &= \widetilde{C_h} - \theta_h \Delta C \end{aligned} \qquad (3.105)$$

Although we cannot determine the value for each penalty cost, we can determine the relationship between penalty costs since there are h variables in (h-1) independent equations or find the best result by applying the least square method.

SECTION 4: CASE STUDY: THREE-CARRIER SYSTEM

In this section, a case study is presented to demonstrate the implementation of the model described in section 3. The case study involves thee companies. The input data for this case is extracted from the public transportation databases (FAF^3, 2012; MARAD, 2012; NDC, 2012) and the official websites for carriers (COSCO, 2012; OOCL, 2012; Maersk, 2012). In order to interpret the practical operation we use the real data in the model as far as possible.

4.1 Network Design and Input Data

In this case study, there are one foreign port, three US ports, and three MSAs in the network. Network data needed for the ports and MSAs are extracted from the Navigation Data Center (NDC) and Freight Analysis Framework (FAF^3).

Foreign port o:

The foreign port of Shanghai in China (SH).

US ports:

Long Beach (LGB);

Seattle (SEA);

Oakland (OAK).

Final destinations (MSAs):

Oklahoma City-Shawnee, OK (OK Oklah);

Los Angeles-Long Beach-Riverside, CA (CA Los);

Seattle-Tacoma-Olympia, WA CSA (WA Seatt).

The nautical distance information between sea ports is taken from the website: sea-rates (http://www.searates.com/) and sea distances-voyage calculator from the web site (http://sea-distances.com/). We also utilized information from the report of *Distance between US Ports* from National Oceanic and Atmospheric Administration (NOAA, 2012).

Table 4.1: Nautical Distance between the Foreign Port and US Ports: l_{oj_r} (l_{j_ro})

FPORT	US PORT	NAUTICAL MILES
SH	LGB	5728
SH	SEA	5071
SH	OAK	5412

Table 4.2: Nautical Distance between US Ports: $l_{jj'}$

US PORT	PORT	NAUTICAL MILES
LGB	OAK	364
OAK	SEA	923

The information on the ground distance between US ports and MSAs is taken from the Google map as given in Table 4.3.

Table 4.3: Ground Distance between US ports and MSAs: l_{jk}(l_{kj})

PORT	MSA	MILES
LGB	OKC	1339
LGB	WA	1153
LGB	LA	20
SEA	OKC	2052
SEA	WA	20
SEA	LA	1146
OAK	OKC	2059
OAK	WA	796
OAK	LA	375

The demand data for cargo shipping is generated by integrating three publicly available transportation databases: Navigation Data Center (NDC), Freight Analysis Framework (FAF3) and Maritime Administration (MARAD). Figure 4.1 shows the diagram of the integration. The details refer to Wang et al. (2008) who proposed a data mining mechanism for the development a global freight movement database.

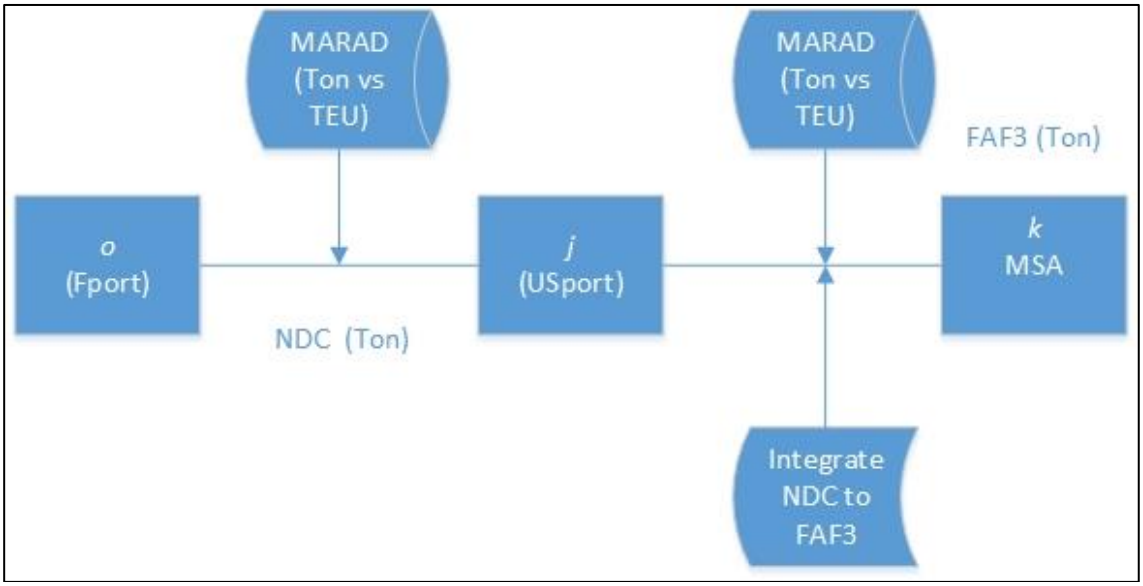

Figure 4.1: Integration Mechanism

Based on the result of the integration, the cargo shipping information (US major imports and exports in 2010) are shown in Tables 4.4 and 4.5. Detailed shipment demand information of a company is generally kept confidential and hence, cannot be found using open sources. Without any loss of generality, we can assume each company has the same shipping demand patterns as shown in that Tables 4.4 and 4.5.

Table 4.4: US Imported Cargo Shipping: t_{ok}

o	*k*	TEUs
SH 57035	OK	4743.724
SH 57035	WA	3984.151
SH 57035	LA	49185.4

Table 4.5: US Exported Cargo Shipping: t_{ko}

k	o	TEUs
OK	SH 57035	4402.057
WA	SH 57035	6434.995
LA	SH 57035	13892.08

We define the parameters in this case as follows:

- The vessel size V_s =2000 TEU, which is based on the research by Gaythwaite (2004) that 2,000 TEUs was the average vessel size.
- We determine the parameter of cargo ocean shipping cost ρ = 0.2 and the parameter cargo ground shipping cost σ =1, which is based on several research facts: UNECE (2012) studied on the topic of "Euro Asian Transport links inland vs. Maritime Transport", determined the ratios of total road cost over total maritime cost were different between origins and destinations to be from 2.2 to 6 or even more. According the US industry report by HB (2013), the ratio of energy efficiency by waterway transportation is more than twice than rail transportation and about eight time of truck transportation.
- We also set the fixed cost of one vessel with the size of 2000 TEUs, τ =10,000($US). In this case study the fixed cost mainly refers to the port entry cost. According to the study by Shintani et al. (2007), that cost per entry at a port equals to 1.95 times the capacity plus 5200, so for 2000 TEUS vessel, the result is close to $10,000.

4.2 Information on the Carrier A, B and C

Three large liner-shipping companies in the world are selected as the participants for this case study. Carrier A is based on the prototype of company: COSCO; Carrier B is

based on company: OOCL; and Carrier C is based on company: Maersk Line (Maersk). We design the shipping routes for each company based on the information of publicized service routes on their websites.

The following figures, Figure 4.2-4.5, present the shipping routes (network) of COSCO.

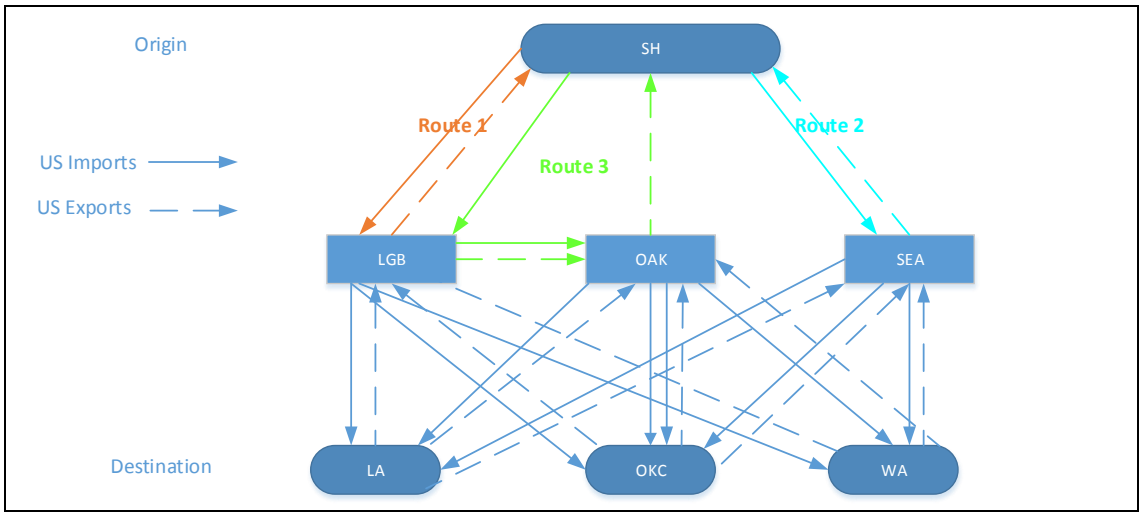

Figure 4.2: The Network of Carrier A: COSCO

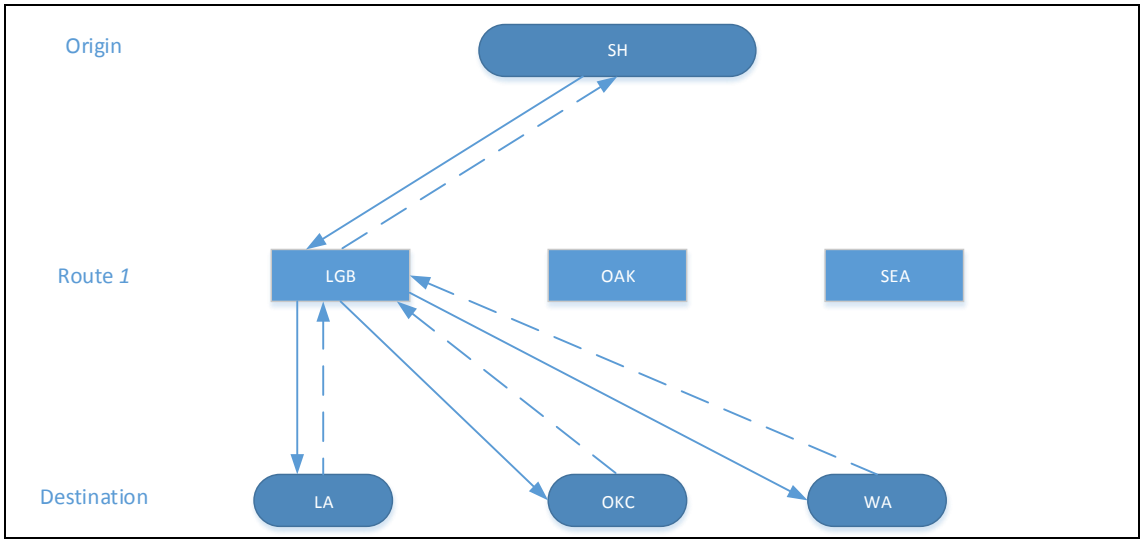

Figure 4.3: Route 1 of COSCO's Network

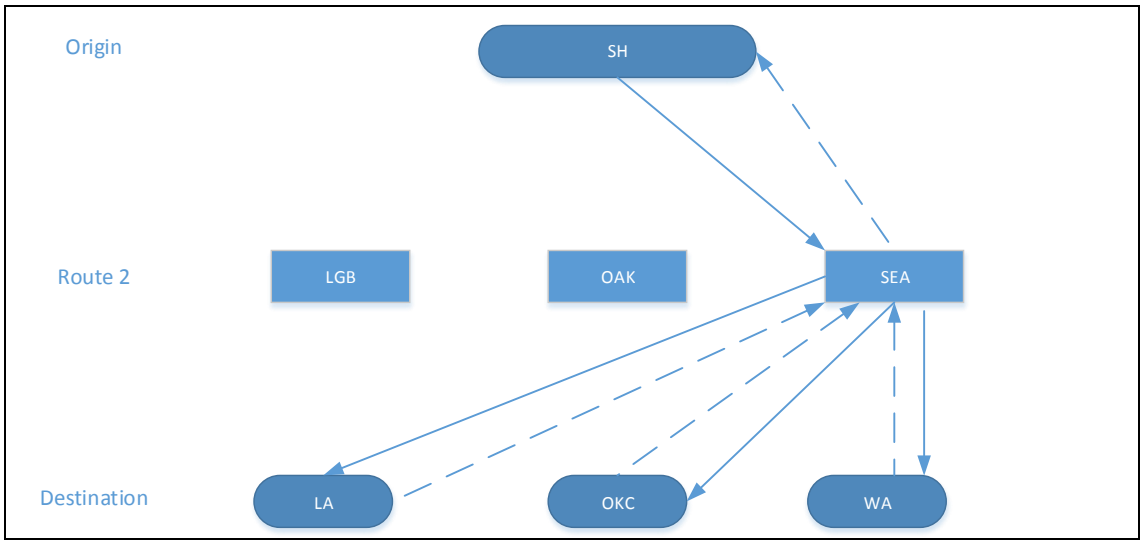

Figure 4.4: Route 2 of COSCO's Network

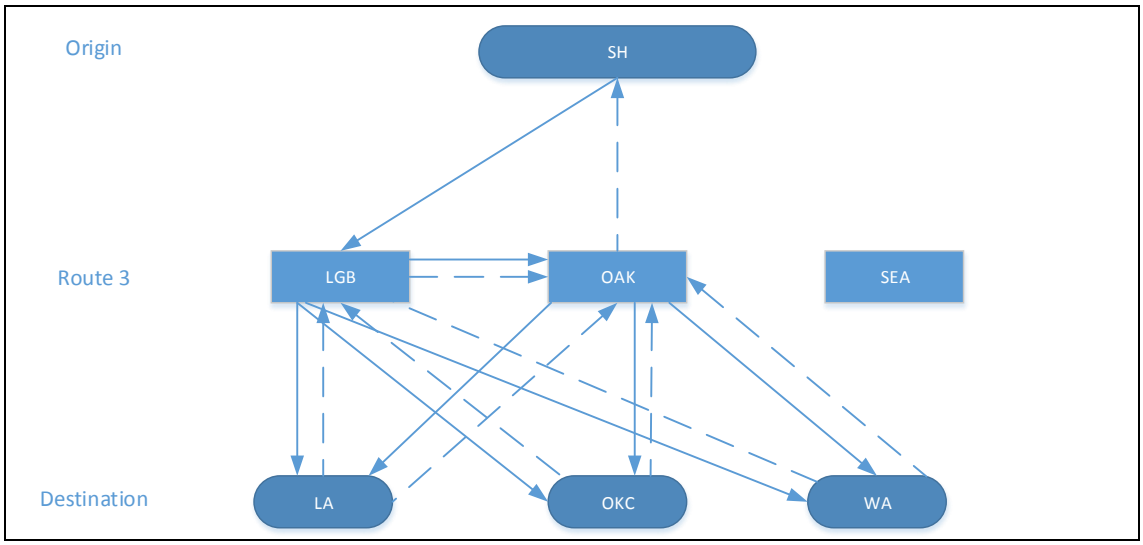

Figure 4.5: Route 3 of COSCO's Network

The following figures, Figure 4.6-4.8 present the shipping routes (network) of OOCL.

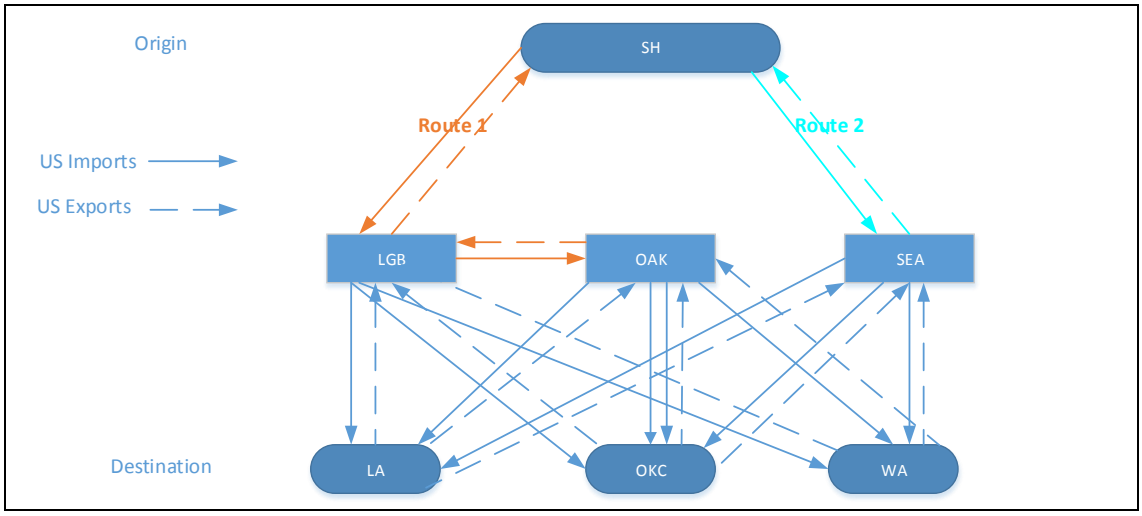

Figure 4.6: The Network of Carrier B: OOCL

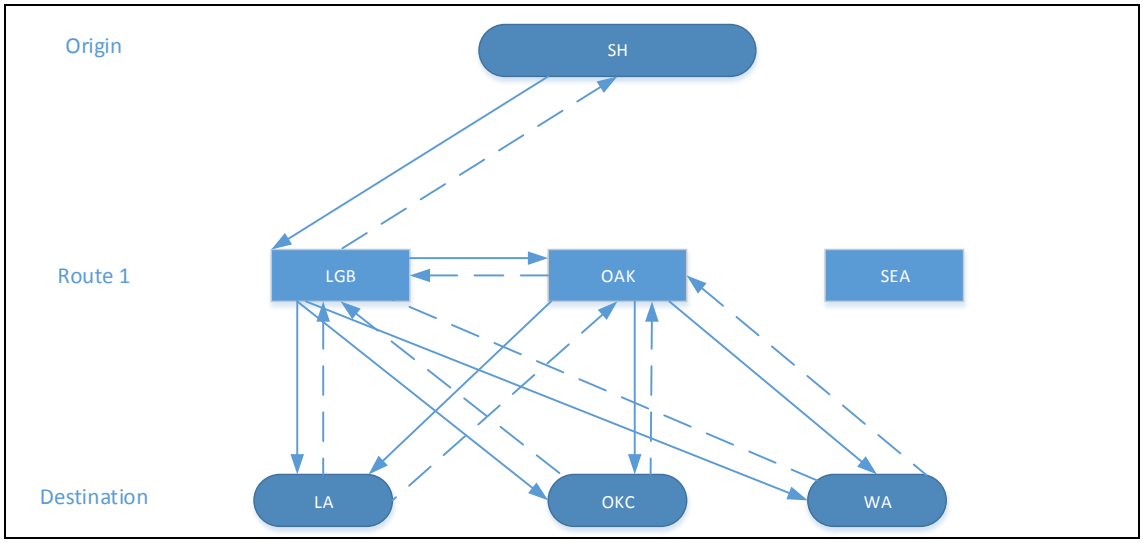

Figure 4.7: Route 1 of OOCL's Network

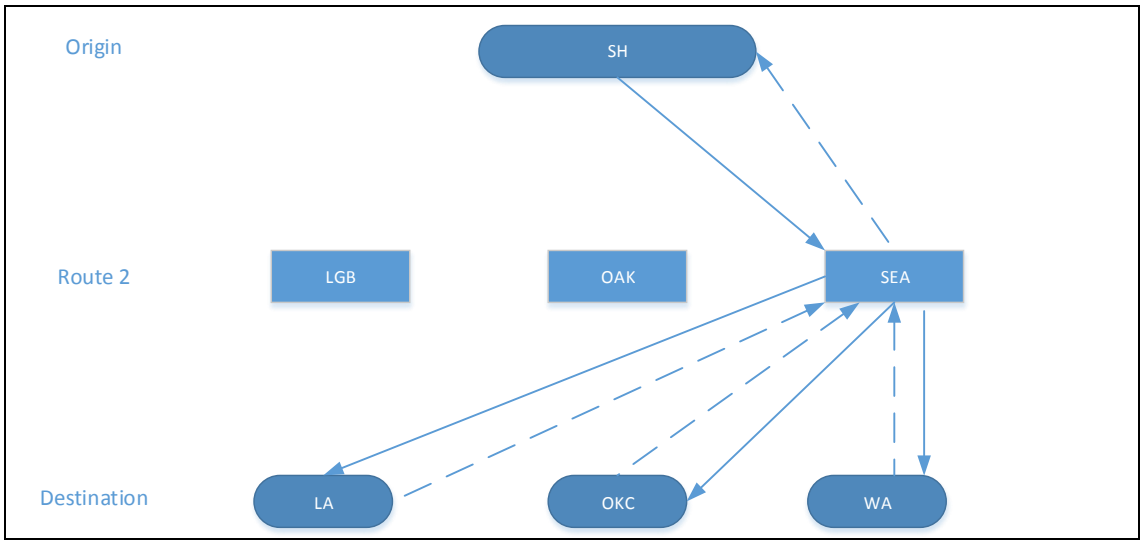

Figure 4.8: Route 2 of OOCL's Network

The following figures, Figure 4.9-4.11 present the shipping routes (network) of Maersk.

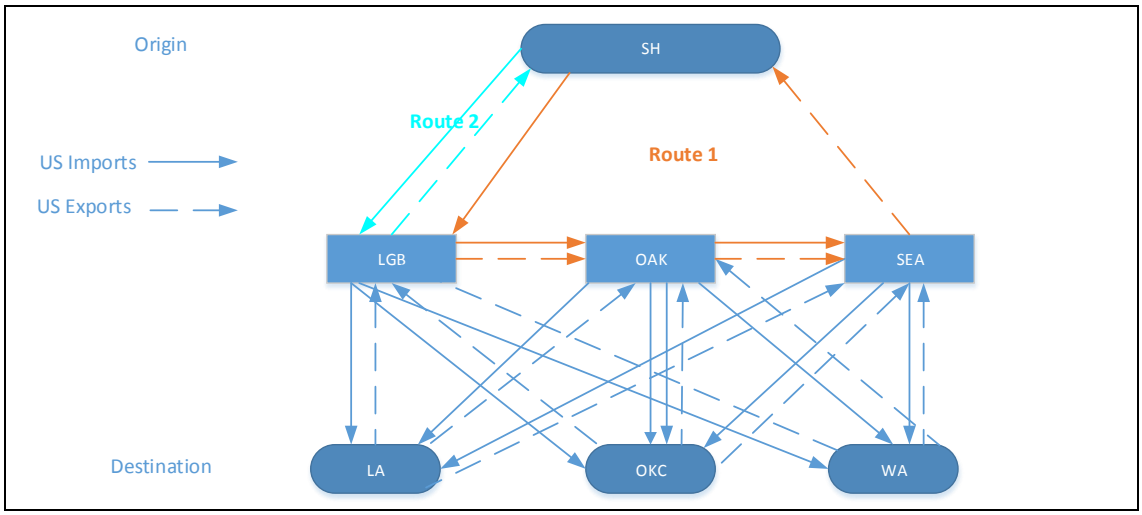

Figure 4.9: The Network of Carrier C: Maersk

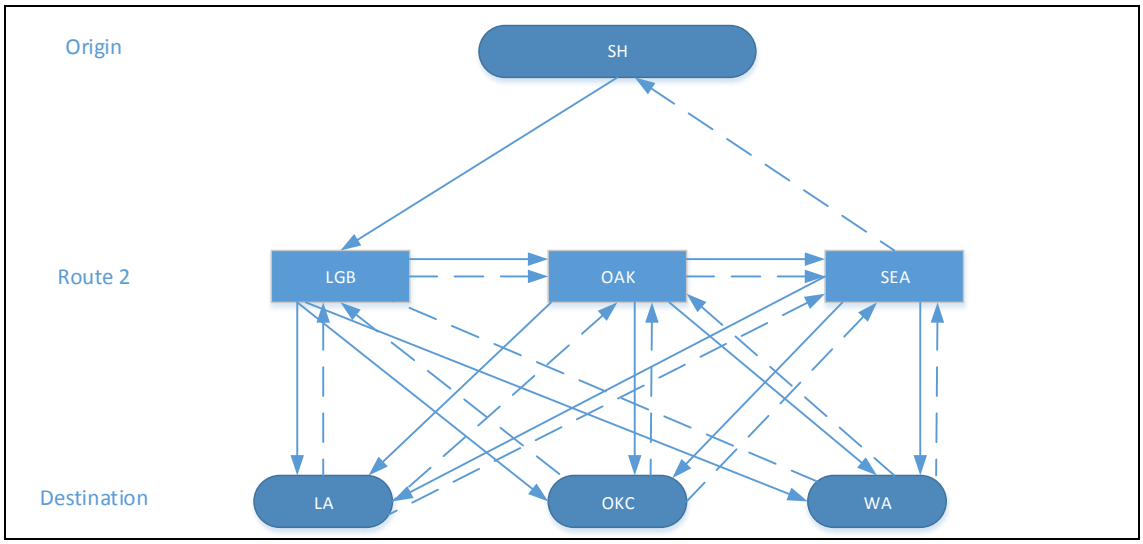

Figure 4.10: Route 1 of Maersk's Network

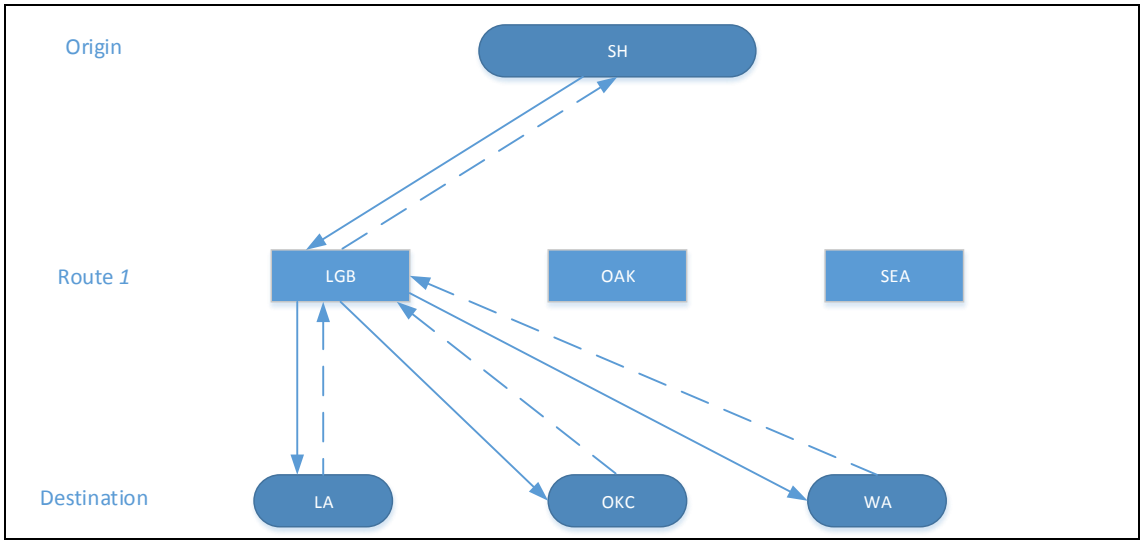

Figure 4.11: Route 2 of Maersk's Network

4.3 Optimization Model Results for the Case Study

The optimization model corresponding to this case study is solved by Xpress (simplex optimizer applying dual methods).

We first solve the optimization model for each company separately. The optimal solution for each carrier results in the following minimum cost total cost for each company: $\widetilde{C_A}$ = 107698634, $\widetilde{C_B}$=107757793 and $\widetilde{C_C}$= 108871231. The number of vessels used = 30 for each company.

Next, we assume that partners fully collaborate and treat the partners' cargo the same as their own, which means they do not charge extra fee for shipping partners' cargos. After collaboration, the cost of company C_A = 107698634 (which results in no savings), company C_B = 107737793 (saves 10000 from the individual result) and company C_C = 106490653 (saves 2381073 from the individual result). More details are shown in Table 4.6.

Table 4.6: Summary of Results for Collaboration

Company A				
Total $\widetilde{C_A}$	cost:	107698634		
Route1	SH_LGB_SH	Vessel	No	26
Route2	SH_LGB_OAK_SH	Vessel	No	3
Route3	SH_SEA_SH	Vessel	No	1
Company B				
Total $\widetilde{C_B}$	cost:	107757793		
Route1	SH_LGB_OAK_LBG_SH	Vessel	No	27
Route2	SH_SEA_SH	Vessel	No	3
Company C				
Total $\widetilde{C_C}$	cost:	108871231		
Route1	SH_LGB_SH	Vessel	No	4
Route2	SH_LGB_OAK_SEA	Vessel	No	26
System C_S				
Total cost	321936580			
C_A cost	107698634	Saving	0	0%
C_B cost	107737793	Saving	10000	0.9%
C_C cost	106490153	Saving	2381078	2.18%
Route11	SH_LGB_SH	Vessel	No	26

Route12	SH_LGB_OAK_SH	Vessel	No	4
Route13	SH_SEA_SH	Vessel	No	0
Route21	SH_LGB_OAK_LGB_SH	Vessel	No	25
Route22	SH_SEA_SH	Vessel	Vessel	2
Route31	SH_LGB_SH	Vessel	Vessel	28
Route32	SH_LGB_OAK_SEA_SH	Vessel	Vessel	2

4.4 The Analysis of the Results

The above results show that the companies can experience cost savings under the collaborative policy. However, without any pricing strategy under collaboration, it is very likely for one company to take all the cost savings, just as in this example, company C almost experiences all the cost savings. By comparison, company A failed to get any benefit from the collaboration. Under this situation, the collaboration is rarely to be implemented in the real world. In order to guarantee fairness under collaboration, we proposed the price strategy model, where an extra charge occurs when a carrier carries a partner's cargo.

4.5 Implementation of the Price Strategy

Applying revenue sharing policy in this case, we can get the following equations (4.1-4.3) from the equation 3.103, where

$$\theta_A = \frac{\widetilde{C_A}}{\widetilde{C_A}+\widetilde{C_B}+\widetilde{C_C}} \tag{4.1}$$

$$\theta_B = \frac{\widetilde{C_B}}{\widetilde{C_A}+\widetilde{C_B}+\widetilde{C_C}} \tag{4.2}$$

$$\theta_C = \frac{\widetilde{C_C}}{\widetilde{C_A}+\widetilde{C_B}+\widetilde{C_C}} \tag{4.3}$$

Using the appropriate costs, the θ values can be calculated as:

$$\theta_A = \frac{107698634}{324327658} = 0.332067$$

$$\theta_B = \frac{107757793}{324327658} = 0.332250$$

$$\theta_C = \frac{108871231}{324327658} = 0.335683$$

Hence cost savings will be distributed to each company as follows: company A will save $793,998; company B will save $794,435; and company C will save $802,644.

We next demonstrated that if the carriers charge each other extra fee for carrying each other's cargo using the pricing strategy, then under the full collaborative model, they indeed realize fair and equitable cost savings. We assume one carrier charges the same extra fee for shipping cargoes for all other carriers.

In this case, the equation 3.105 can be represented by:

$$f_A(\mu_A, \mu_B, \mu_C) = \widetilde{C_A} - \theta_A \Delta C \quad (4.4)$$

$$f_B(\mu_A, \mu_B, \mu_C) = \widetilde{C_B} - \theta_B \Delta C \quad (4.5)$$

$$f_C(\mu_A, \mu_B, \mu_C) = \widetilde{C_C} - \theta_C \Delta C \quad (4.6)$$

Then we get:

$$159828666\mu_A - 80371\mu_B - 70853940\mu_C = 3969994 \quad (4.7)$$

$$-139625037\mu_A + 132041210\mu_B - 44639360\mu_C = 3922175 \quad (4.8)$$

Applying the least square method, we can get $\mu_A = 0.025$, $\mu_B = 0.056$ and $\mu_C = 0$. Substituting the values of $\mu_A, \mu_B, \mu_C, \theta_A, \theta_B, \theta_C$ into system optimization model, the returned results of the optimization model can be summarized as follows:

The minimal total cost for company A = 106904635 (793998 or 0.73% savings from the individual result), company B = 106963358 (794435 or 0.73% savings from the

individual result) and company C = 108068587 (802644 or 0.73% savings from the individual result). More details are shown in Table 4.7.

Table 4.7: Summary of Results for Collaboration (with price strategy)

Company A				
Total $\widetilde{C_A}$	cost:	107698634		
Route1	SH_LGB_SH	Vessel	No	26
Route2	SH_LGB_OAK_SH	Vessel	No	3
Route3	SH_SEA_SH	Vessel	No	1
Company B				
Total $\widetilde{C_B}$	cost:	107757793		
Route1	SH_LGB_OAK_LBG_SH	Vessel	No	27
Route2	SH_SEA_SH	Vessel	No	3
Company C				
Total $\widetilde{C_C}$	cost:	108871231		
Route1	SH_LGB_SH	Vessel	No	4
Route2	SH_LGB_OAK_SEA	Vessel	No	26
System C_S				
Total cost	321936580			
C_A cost	106904635	Saving	793998.88	0.73%
C_B cost	106963358	Saving	794435	0.73%
C_C cost	108068587	Saving	802643.75	0.73%
Route11	SH_LGB_SH	Vessel	No	30
Route12	SH_LGB_OAK_SH	Vessel	No	0
Route13	SH_SEA_SH	Vessel	No	0
Route21	SH_LGB_OAK_LGB_SH	Vessel	No	21
Route22	SH_SEA_SH	Vessel	Vessel	6
Route31	SH_LGB_SH	Vessel	Vessel	30
Route32	SH_LGB_OAK_SEA_SH	Vessel	Vessel	0

SECTION 5: CONCLUSIONS AND FUTURE RESEARCH

5.1 Conclusions

This research was initiated by an idea generated during the last phase of the Containerized Freight Movement Model (CFMM) project (OTC, 2011), which inspired us to divert our interests from the view of transportation planners to the view of parties of the supply chain. We wanted to research the behavior of container companies in the global freight network. Also, we wanted to continue the research on a novel expanded global freight network, which extends the network from US ports to MSAs to include from port to US port connections.

In this study, we have proposed a mixed integer programming (MIP) optimization model to study a currently promising research topic in liner shipping: system optimum vs. individual carrier behaviors. And we present a membership mechanism to allocate resources among partner carriers for forming alliances most efficiently and equitably sharing benefits. The developed MIP model includes individual optimization, system optimization, and price strategy. The individual optimization model determines the minimum cost for a liner to accomplish the required cargo shipments through a high-condensed cost function. We then introduce a system optimization model to gain the highest possible cost saving for the system with the precondition of no increase in any participant's obtained cost in their individual optimization system. Hence, a win-win solution is guaranteed for all participants. It has been observed that one result of system optimization has also been that the total cost saving from the alliance can be unfairly

taken by one or more participants instead the savings being distributed equally among all participants. A revenue-sharing policy, which is interpreted by our price-strategy policy, has been introduced in the next section to solve this problem. The price-strategy policy helps to determine the penalty cost each liner company should charge other companies for shipping their demand. The designed MIP model is also verified in a three-carrier system from analog to real-life circumstances.

The following are some efficient and useful operations and techniques developed and established in the MIP model.

We create a network with new angles. The network defined in the model extends routes from waterways only to routes combining an international waterway and an inland highway network, which is more like how a transportation planner would view it. It is helpful to develop the evaluation on the service's efficiency overall, on the supply chain from the origin to final destination. Although the mode of the inland freight movement network is the truck, this simplification of the inland part does no harm to our research results. For the grand international freight movement network, the key change is to link the global waterway to the inland network, and the key observations come from the extension of the connection, not the complexity of the inland network.

Although in the real world there are multiple origins and multiple destinations for the demand of liner shipping services in international trade, we determine only one foreign port (o) as the origin in the network by the fact that the origin is an independent factor in shipping demand that is known before a company schedules shipping service. Thus, including one origin (o) in the model is a reasonable operational procedure. Also,

we specify that all vessels are home based and required to go back the starting point; thus, we combine US imports and exports in the model.

Assumptions of our model, such as multiple pickup and delivery points during shipping, several routing patterns, and fixed vessel sizes and schedules, reflect real-life situations for the container shipping industry. Furthermore, the correlative parameters are based on research done by other scholars. In the case study, we select three of the currently largest and most active liner shipping companies in cargo shipping between Asia and the United States. All the input data come from the public transportation database and these companies' open resources. These efforts try to simulate the model in an analogic real world.

The target of the optimization in our MIP model is cost. The cost function in the paper is expressed by a highly summarized formula. According to the literature review, we group the cost into three parts: ocean shipping cost, vessel cost, and inland shipping cost. Both ocean shipping cost and inland shipping cost are functions related to cargo and distance. Since cargo is the variable in our MIP model, shipping costs can be considered as variable costs. Vessel cost is the one not related to the cargo; instead, it is determined by the departed vessel's fixed cost. The cost function is deficient in some details; however, it covers highly grouped fixed cost and variable cost from a general business definition. More importantly, the objective of the MIP model is to determine the benefit from the alliance by comparing the participant's cost before and after collaboration. Thus, once we set up the cost function in consistency, the result is still accurate without prejudice. Besides, it helps to concentrate on our objective without interference from by other issues during the model's initial exploration phase.

Some useful software is applied during the research. Xpress is the most important optimization mechanism selected to implement the model because it considers capability and availability compositely. The current MIP model is discussed and applied to a small number of data; when implemented for a large number of data sets, our model can be easily generalized to solve large-scale problems in Xpress.

The MIP model sheds light on the need for continued study of possible collaboration methods in liner shipping. Although our MIP model is designed to increase cost savings by fully sharing resources and exchanging shipments, it can be flexibly revised and widely applied to solve other problems in collaboration in the liner shipping industry.

In conclusion, this study presents a practical membership mechanism to allocate resources among partner carriers to facilitate forming alliances most efficiently and equitably. An MIP model is developed and coupled with a pricing strategy to deliver best shipping schedules for each carrier. A unique feature of the study is that the MIP models not only consider the shipping cost for the carriers based at a foreign port to US ports but it also includes the cost of shipment from a US port to the final MSA. Hence, the transportation network is integrated international network including global waterways and inland highways.

5.2 Recommendations for Future Research

From the long-term view, there are still some parts of the MIP model that could be possibly improved for future research.

One obvious improvement on the model is to complicate the current network so that it more accurately represents the real world. First, the foreign port in the network can be expanded from one to multiple ports. As we analyzed in the previous section, considering only one foreign port in the model does no harm to the results; however, if we introduce more origins (foreign ports) into the network, it will affect a carrier's overall decision on the allocating the vessels on one foreign ports under limited vessel resources. Second, the inland network currently considers only the US highway network; the railway, another important freight movement mode, could be added to it. And if we add railway to the inland part, more interesting observations can be made, such as the how the container shipping companies choose the shipping mode for the final destinations. Also, the final destination is currently defined at the MSA level, which can be narrowed to lower geographic levels, such as cities, or even zip codes.

The cost function can be improved in future research, especially for the ocean part. According to Shintani et al. (2007), the shipping cost could be more complicated if the impact from crew cost, fuel cost, insurance cost, repair and maintenance cost, interest, and so forth are considered. The cost function has an influence on the optimal route configuration for the repositioning of cargo.

In our MIP model, we attempted to include a revenue-sharing policy to allocate benefits among participants. Other policies, such as a price-discount strategy (Liu et al. 2008), have been discussed by other scholars and can be applied in our model in future research. The aim of the price-strategy policy in the model is aim to find the penalty cost (μ^*) of a company. The criterion for the determinant on the value of μ^* is based on the optimal cost for each company during its individual shipping schedule. In future

research, we will attempt more varied methods for the price-strategy model, not limited only by the concept of penalty cost; penalty cost could be determined by more criteria, such as companies' market sharing, fixed ratio, or others.

The benefit for a carrier discussed in this study is the cost saving. More potential benefits from the alliance can be discussed in the future. All of these potential benefits address carriers' chief concerns in liner shipping. In particular, an alliance offers more choices to a company in terms of the time schedule issue, which improves carriers' ability to offer more diverse services and increases competition in the market. Our MIP model could be improved by introducing a time window factor to achieve this.

The case study of three-carrier system demonstrates the possible benefits under total collaboration for each carrier; however, the result implies each carrier's improvement is at a low percentage. We believe every participant is expected to achieve more cost savings in a larger collaboration system. Thus, additional research is required to study the impact of variables such as the number of the carriers, ports, routes, MSAs and vessel's capacity on the magnitude of cost savings for each carrier. In order for a third – party logistics provider to operate profitably significant cost savings need to be realized for the carrier to collaborate with other carriers. The MIP model uses Xpress optimization software to determine the system optimum. The tuner tools of the Xpress-Optimizer provide user customer-defined parameters to find the values of the models. In the future, computational efficiency of the MIP model can be studied by changing the parameter sizes for the problem.

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Appendix 1: Results of Individual Optimization Model for Carrier A

Problem status	optimal solution found
Total cost	107698633.67
C1_R1_I_SH_LGB	52000.00
C1_R2_I_SH_SEA	4000.00
C1_R3_I_SH_LGB	1913.28
C1_R1_E_LGB_SH	18294.13
C1_R2_E_SEA_SH	6000.00
C1_R3_E_OAK_SH	434.99
C1_R1_I_LGB_OKC	2814.60
C1_R1_I_LGB_WA	0.00
C1_R1_I_LGB_LA	49185.40
C1_R2_I_SEA_OKC	15.85
C1_R2_I_SEA_WA	3984.15
C1_R2_I_SEA_LA	0.00
C1_R3_I_LGB_OKC	1913.28
C1_R3_I_LGB_WA	0.00
C1_R3_I_LGB_LA	0.00
C1_R3_I_OAK_OKC	0.00
C1_R3_I_OAK_WA	0.00
C1_R3_I_OAK_LA	0.00
C1_R1_E_OKC_LGB	4402.06
C1_R1_E_WA_LGB	0.00
C1_R1_E_LA_LGB	13892.08
C1_R2_E_OKC_SEA	0.00
C1_R2_E_WA_SEA	6000.00
C1_R2_E_LA_SEA	0.00
C1_R3_E_OKC_LGB	0.00
C1_R3_E_WA_LGB	0.00
C1_R3_E_LA_LGB	0.00
C1_R3_E_OKC_OAK	0.00
C1_R3_E_WA_OAK	434.99
C1_R3_E_LA_OAK	0.00
C1_R3_I_LGB_OAK	0.00
C1_R3_E_LGB_OAK	0.00
vessel_1	26.00
vessel_2	3.00
vessel_3	1.00

Appendix 2: Results of Individual Optimization Model for Carrier B

Problem status	optimal solution found
Total cost	107757792.92
C2_R1_I_SH_LGB	53913.28
C2_R2_I_SH_SEA	4000.00
C2_R1_E_LGB_SH	18729.13
C2_R2_E_SEA_SH	6000.00
C2_R1_I_LGB_OKC	4727.87
C2_R1_I_LGB_WA	0.00
C2_R1_I_LGB_LA	49185.40
C2_R1_I_OAK_OKC	0.00
C2_R1_I_OAK_WA	0.00
C2_R1_I_OAK_LA	0.00
C2_R2_I_SEA_OKC	15.85
C2_R2_I_SEA_WA	3984.15
C2_R2_I_SEA_LA	0.00
C2_R1_E_OKC_LGB	4402.06
C2_R1_E_WA_LGB	0.00
C2_R1_E_LA_LGB	13892.08
C2_R1_E_OKC_OAK	0.00
C2_R1_E_WA_OAK	434.99
C2_R1_E_LA_OAK	0.00
C2_R2_E_OKC_SEA	0.00
C2_R2_E_WA_SEA	6000.00
C2_R2_E_LA_SEA	0.00
C2_R1_I_LGB_OAK	0.00
C2_R1_E_OAK_LGB	434.99
vessel_1	27.00
vessel_2	3.00

Appendix 3: Results of Individual Optimization Model for Carrier C

Problem status	optimal solution found
Total cost	108871231.10
C3_R1_I_SH_LGB	6000.00
C3_R2_I_SH_LGB	51913.28
C3_R1_E_SEA_SH	6434.99
C3_R2_E_LGB_SH	18294.13
C3_R1_I_LGB_OKC	0.00
C3_R1_I_LGB_WA	0.00
C3_R1_I_LGB_LA	2015.85
C3_R1_I_OAK_OKC	0.00
C3_R1_I_OAK_WA	0.00
C3_R1_I_OAK_LA	0.00
C3_R1_I_SEA_OKC	0.00
C3_R1_I_SEA_WA	3984.15
C3_R1_I_SEA_LA	0.00
C3_R2_I_LGB_OKC	4743.72
C3_R2_I_LGB_WA	0.00
C3_R2_I_LGB_LA	47169.55
C3_R1_E_OKC_LGB	0.00
C3_R1_E_WA_LGB	0.00
C3_R1_E_LA_LGB	0.00
C3_R1_E_OKC_OAK	0.00
C3_R1_E_WA_OAK	0.00
C3_R1_E_LA_OAK	0.00
C3_R1_E_OKC_SEA	0.00
C3_R1_E_WA_SEA	6434.99
C3_R1_E_LA_SEA	0.00
C3_R2_E_OKC_LGB	4402.06
C3_R2_E_WA_LGB	0.00
C3_R2_E_LA_LGB	13892.08
C3_R1_I_LGB_OAK	3984.15
C3_R1_I_OAK_SEA	3984.15
C3_R1_E_LGB_OAK	0.00
C3_R1_E_OAK_SEA	0.00
vessel_1	4.00
vessel_2	26.00

Appendix 4: Results of Collaboration System

Problem status	optimal solution found		
Total cost:	321936580.04		
C1_Total cost:	107698633.67	Original Cost	107698633.67
C2_Total cost:	107747792.92	Original Cost	107757792.92
C3_Total cost:	106490153.46	Original Cost	108871231.10
11_C1_R1_I_SH_LGB	47256.28		
11_C1_R2_I_SH_SEA	3968.30		
11_C1_R3_I_SH_LGB	0.00		
11_C1_R1_E_LGB_SH	18294.13		
11_C1_R2_E_SEA_SH	0.00		
11_C1_R3_E_OAK_SH	0.00		
11_C1_R1_I_LGB_OKC	0.00		
11_C1_R1_I_LGB_WA	0.00		
11_C1_R1_I_LGB_LA	47256.28		
11_C1_R2_I_SEA_OKC	0.00		
11_C1_R2_I_SEA_WA	3968.30		
11_C1_R2_I_SEA_LA	0.00		
11_C1_R3_I_LGB_OKC	0.00		
11_C1_R3_I_LGB_WA	0.00		
11_C1_R3_I_LGB_LA	0.00		
11_C1_R3_I_OAK_OKC	0.00		
11_C1_R3_I_OAK_WA	0.00		
11_C1_R3_I_OAK_LA	0.00		
11_C1_R1_E_OKC_LGB	4402.06		
11_C1_R1_E_WA_LGB	0.00		
11_C1_R1_E_LA_LGB	13892.08		
11_C1_R2_E_OKC_SEA	0.00		
11_C1_R2_E_WA_SEA	0.00		
11_C1_R2_E_LA_SEA	0.00		
11_C1_R3_E_OKC_LGB	0.00		
11_C1_R3_E_WA_LGB	0.00		
11_C1_R3_E_LA_LGB	0.00		
11_C1_R3_E_OKC_OAK	0.00		
11_C1_R3_E_WA_OAK	0.00		
11_C1_R3_E_LA_OAK	0.00		
11_C1_R3_I_LGB_OAK	0.00		
11_C1_R3_E_LGB_OAK	0.00		
12_C1_R1_I_SH_LGB	4743.72		
12_C1_R2_I_SH_SEA	0.00		
12_C1_R3_I_SH_LGB	0.00		

12_C1_R1_E_LGB_SH	13935.25
12_C1_R2_E_SEA_SH	6434.99
12_C1_R3_E_OAK_SH	0.00
12_C1_R1_I_LGB_OKC	4743.72
12_C1_R1_I_LGB_WA	0.00
12_C1_R1_I_LGB_LA	0.00
12_C1_R2_I_SEA_OKC	0.00
12_C1_R2_I_SEA_WA	0.00
12_C1_R2_I_SEA_LA	0.00
12_C1_R3_I_LGB_OKC	0.00
12_C1_R3_I_LGB_WA	0.00
12_C1_R3_I_LGB_LA	0.00
12_C1_R3_I_OAK_OKC	0.00
12_C1_R3_I_OAK_WA	0.00
12_C1_R3_I_OAK_LA	0.00
12_C1_R1_E_OKC_LGB	43.18
12_C1_R1_E_WA_LGB	0.00
12_C1_R1_E_LA_LGB	13892.08
12_C1_R2_E_OKC_SEA	0.00
12_C1_R2_E_WA_SEA	6434.99
12_C1_R2_E_LA_SEA	0.00
12_C1_R3_E_OKC_LGB	0.00
12_C1_R3_E_WA_LGB	0.00
12_C1_R3_E_LA_LGB	0.00
12_C1_R3_E_OKC_OAK	0.00
12_C1_R3_E_WA_OAK	0.00
12_C1_R3_E_LA_OAK	0.00
12_C1_R3_I_LGB_OAK	0.00
12_C1_R3_E_LGB_OAK	0.00
13_C1_R1_I_SH_LGB	0.00
13_C1_R2_I_SH_SEA	3984.15
13_C1_R3_I_SH_LGB	0.00
13_C1_R1_E_LGB_SH	0.00
13_C1_R2_E_SEA_SH	0.00
13_C1_R3_E_OAK_SH	0.00
13_C1_R1_I_LGB_OKC	0.00
13_C1_R1_I_LGB_WA	0.00
13_C1_R1_I_LGB_LA	0.00
13_C1_R2_I_SEA_OKC	0.00
13_C1_R2_I_SEA_WA	3984.15
13_C1_R2_I_SEA_LA	0.00
13_C1_R3_I_LGB_OKC	0.00
13_C1_R3_I_LGB_WA	0.00

13_C1_R3_I_LGB_LA	0.00
13_C1_R3_I_OAK_OKC	0.00
13_C1_R3_I_OAK_WA	0.00
13_C1_R3_I_OAK_LA	0.00
13_C1_R1_E_OKC_LGB	0.00
13_C1_R1_E_WA_LGB	0.00
13_C1_R1_E_LA_LGB	0.00
13_C1_R2_E_OKC_SEA	0.00
13_C1_R2_E_WA_SEA	0.00
13_C1_R2_E_LA_SEA	0.00
13_C1_R3_E_OKC_LGB	0.00
13_C1_R3_E_WA_LGB	0.00
13_C1_R3_E_LA_LGB	0.00
13_C1_R3_E_OKC_OAK	0.00
13_C1_R3_E_WA_OAK	0.00
13_C1_R3_E_LA_OAK	0.00
13_C1_R3_I_LGB_OAK	0.00
13_C1_R3_E_LGB_OAK	0.00
21_C2_R1_I_SH_LGB	0.00
21_C2_R2_I_SH_SEA	15.85
21_C2_R1_E_LGB_SH	0.00
21_C2_R2_E_SEA_SH	0.00
21_C2_R1_I_LGB_OKC	0.00
21_C2_R1_I_LGB_WA	0.00
21_C2_R1_I_LGB_LA	0.00
21_C2_R1_I_OAK_OKC	0.00
21_C2_R1_I_OAK_WA	0.00
21_C2_R1_I_OAK_LA	0.00
21_C2_R2_I_SEA_OKC	0.00
21_C2_R2_I_SEA_WA	15.85
21_C2_R2_I_SEA_LA	0.00
21_C2_R1_E_OKC_LGB	0.00
21_C2_R1_E_WA_LGB	0.00
21_C2_R1_E_LA_LGB	0.00
21_C2_R1_E_OKC_OAK	0.00
21_C2_R1_E_WA_OAK	0.00
21_C2_R1_E_LA_OAK	0.00
21_C2_R2_E_OKC_SEA	0.00
21_C2_R2_E_WA_SEA	0.00
21_C2_R2_E_LA_SEA	0.00
21_C2_R1_I_LGB_OAK	0.00
21_C2_R1_E_OAK_LGB	0.00
22_C2_R1_I_SH_LGB	45256.28

22_C2_R2_I_SH_SEA	3984.15
22_C2_R1_E_LGB_SH	494.82
22_C2_R2_E_SEA_SH	0.00
22_C2_R1_I_LGB_OKC	0.00
22_C2_R1_I_LGB_WA	0.00
22_C2_R1_I_LGB_LA	45256.28
22_C2_R1_I_OAK_OKC	0.00
22_C2_R1_I_OAK_WA	0.00
22_C2_R1_I_OAK_LA	0.00
22_C2_R2_I_SEA_OKC	0.00
22_C2_R2_I_SEA_WA	3984.15
22_C2_R2_I_SEA_LA	0.00
22_C2_R1_E_OKC_LGB	494.82
22_C2_R1_E_WA_LGB	0.00
22_C2_R1_E_LA_LGB	0.00
22_C2_R1_E_OKC_OAK	0.00
22_C2_R1_E_WA_OAK	0.00
22_C2_R1_E_LA_OAK	0.00
22_C2_R2_E_OKC_SEA	0.00
22_C2_R2_E_WA_SEA	0.00
22_C2_R2_E_LA_SEA	0.00
22_C2_R1_I_LGB_OAK	0.00
22_C2_R1_E_OAK_LGB	0.00
23_C2_R1_I_SH_LGB	4743.72
23_C2_R2_I_SH_SEA	0.00
23_C2_R1_E_LGB_SH	18294.13
23_C2_R2_E_SEA_SH	0.00
23_C2_R1_I_LGB_OKC	4743.72
23_C2_R1_I_LGB_WA	0.00
23_C2_R1_I_LGB_LA	0.00
23_C2_R1_I_OAK_OKC	0.00
23_C2_R1_I_OAK_WA	0.00
23_C2_R1_I_OAK_LA	0.00
23_C2_R2_I_SEA_OKC	0.00
23_C2_R2_I_SEA_WA	0.00
23_C2_R2_I_SEA_LA	0.00
23_C2_R1_E_OKC_LGB	4402.06
23_C2_R1_E_WA_LGB	0.00
23_C2_R1_E_LA_LGB	13892.08
23_C2_R1_E_OKC_OAK	0.00
23_C2_R1_E_WA_OAK	0.00
23_C2_R1_E_LA_OAK	0.00
23_C2_R2_E_OKC_SEA	0.00

23_C2_R2_E_WA_SEA	0.00
23_C2_R2_E_LA_SEA	0.00
23_C2_R1_I_LGB_OAK	0.00
23_C2_R1_E_OAK_LGB	0.00
31_C3_R1_I_SH_LGB	2672.85
31_C3_R2_I_SH_LGB	4000.00
31_C3_R1_E_SEA_SH	6434.99
31_C3_R2_E_LGB_SH	0.00
31_C3_R1_I_LGB_OKC	743.72
31_C3_R1_I_LGB_WA	0.00
31_C3_R1_I_LGB_LA	1929.13
31_C3_R1_I_OAK_OKC	0.00
31_C3_R1_I_OAK_WA	0.00
31_C3_R1_I_OAK_LA	0.00
31_C3_R1_I_SEA_OKC	0.00
31_C3_R1_I_SEA_WA	0.00
31_C3_R1_I_SEA_LA	0.00
31_C3_R2_I_LGB_OKC	4000.00
31_C3_R2_I_LGB_WA	0.00
31_C3_R2_I_LGB_LA	0.00
31_C3_R1_E_OKC_LGB	0.00
31_C3_R1_E_WA_LGB	0.00
31_C3_R1_E_LA_LGB	0.00
31_C3_R1_E_OKC_OAK	0.00
31_C3_R1_E_WA_OAK	0.00
31_C3_R1_E_LA_OAK	0.00
31_C3_R1_E_OKC_SEA	0.00
31_C3_R1_E_WA_SEA	6434.99
31_C3_R1_E_LA_SEA	0.00
31_C3_R2_E_OKC_LGB	0.00
31_C3_R2_E_WA_LGB	0.00
31_C3_R2_E_LA_LGB	0.00
31_C3_R1_I_LGB_OAK	0.00
31_C3_R1_I_OAK_SEA	0.00
31_C3_R1_E_LGB_OAK	0.00
31_C3_R1_E_OAK_SEA	0.00
32_C3_R1_I_SH_LGB	3929.13
32_C3_R2_I_SH_LGB	0.00
32_C3_R1_E_SEA_SH	0.00
32_C3_R2_E_LGB_SH	3864.06
32_C3_R1_I_LGB_OKC	0.00
32_C3_R1_I_LGB_WA	0.00
32_C3_R1_I_LGB_LA	3929.13

32_C3_R1_I_OAK_OKC	0.00
32_C3_R1_I_OAK_WA	0.00
32_C3_R1_I_OAK_LA	0.00
32_C3_R1_I_SEA_OKC	0.00
32_C3_R1_I_SEA_WA	0.00
32_C3_R1_I_SEA_LA	0.00
32_C3_R2_I_LGB_OKC	0.00
32_C3_R2_I_LGB_WA	0.00
32_C3_R2_I_LGB_LA	0.00
32_C3_R1_E_OKC_LGB	0.00
32_C3_R1_E_WA_LGB	0.00
32_C3_R1_E_LA_LGB	0.00
32_C3_R1_E_OKC_OAK	0.00
32_C3_R1_E_WA_OAK	0.00
32_C3_R1_E_LA_OAK	0.00
32_C3_R1_E_OKC_SEA	0.00
32_C3_R1_E_WA_SEA	0.00
32_C3_R1_E_LA_SEA	0.00
32_C3_R2_E_OKC_LGB	3864.06
32_C3_R2_E_WA_LGB	0.00
32_C3_R2_E_LA_LGB	0.00
32_C3_R1_I_LGB_OAK	0.00
32_C3_R1_I_OAK_SEA	0.00
32_C3_R1_E_LGB_OAK	0.00
32_C3_R1_E_OAK_SEA	0.00
33_C3_R1_I_SH_LGB	49185.40
33_C3_R2_I_SH_LGB	0.00
33_C3_R1_E_SEA_SH	6434.99
33_C3_R2_E_LGB_SH	0.00
33_C3_R1_I_LGB_OKC	0.00
33_C3_R1_I_LGB_WA	0.00
33_C3_R1_I_LGB_LA	49185.40
33_C3_R1_I_OAK_OKC	0.00
33_C3_R1_I_OAK_WA	0.00
33_C3_R1_I_OAK_LA	0.00
33_C3_R1_I_SEA_OKC	0.00
33_C3_R1_I_SEA_WA	0.00
33_C3_R1_I_SEA_LA	0.00
33_C3_R2_I_LGB_OKC	0.00
33_C3_R2_I_LGB_WA	0.00
33_C3_R2_I_LGB_LA	0.00
33_C3_R1_E_OKC_LGB	0.00
33_C3_R1_E_WA_LGB	0.00

33_C3_R1_E_LA_LGB	0.00
33_C3_R1_E_OKC_OAK	0.00
33_C3_R1_E_WA_OAK	0.00
33_C3_R1_E_LA_OAK	0.00
33_C3_R1_E_OKC_SEA	0.00
33_C3_R1_E_WA_SEA	6434.99
33_C3_R1_E_LA_SEA	0.00
33_C3_R2_E_OKC_LGB	0.00
33_C3_R2_E_WA_LGB	0.00
33_C3_R2_E_LA_LGB	0.00
33_C3_R1_I_LGB_OAK	0.00
33_C3_R1_I_OAK_SEA	0.00
33_C3_R1_E_LGB_OAK	0.00
33_C3_R1_E_OAK_SEA	0.00
C1_vessel_1	26.00
C1_vessel_2	4.00
C1_vessel_3	0.00
C2_vessel_1	25.00
C2_vessel_2	2.00
C3_vessel_1	28.00
C3_vessel_2	2.00

Appendix 5: Results of Collaboration System (with Price Strategy)

Problem status	optimal solution found		
Total cost:	321936580.06		
C1_Total cost:	106904634.79	Original Cost	107698633.67
C2_Total cost:	106963357.92	Original Cost	107757792.92
C3_Total cost:	108068587.35	Original Cost	108871231.10
11_C1_R1_I_SH_LGB	53929.13		
11_C1_R2_I_SH_SEA	0.00		
11_C1_R3_I_SH_LGB	0.00		
11_C1_R1_E_LGB_SH	18294.13		
11_C1_R2_E_SEA_SH	0.00		
11_C1_R3_E_OAK_SH	0.00		
11_C1_R1_I_LGB_OKC	4743.72		
11_C1_R1_I_LGB_WA	0.00		
11_C1_R1_I_LGB_LA	49185.40		
11_C1_R2_I_SEA_OKC	0.00		
11_C1_R2_I_SEA_WA	0.00		
11_C1_R2_I_SEA_LA	0.00		
11_C1_R3_I_LGB_OKC	0.00		
11_C1_R3_I_LGB_WA	0.00		
11_C1_R3_I_LGB_LA	0.00		
11_C1_R3_I_OAK_OKC	0.00		
11_C1_R3_I_OAK_WA	0.00		
11_C1_R3_I_OAK_LA	0.00		
11_C1_R1_E_OKC_LGB	4402.06		
11_C1_R1_E_WA_LGB	0.00		
11_C1_R1_E_LA_LGB	13892.08		
11_C1_R2_E_OKC_SEA	0.00		
11_C1_R2_E_WA_SEA	0.00		
11_C1_R2_E_LA_SEA	0.00		
11_C1_R3_E_OKC_LGB	0.00		
11_C1_R3_E_WA_LGB	0.00		
11_C1_R3_E_LA_LGB	0.00		
11_C1_R3_E_OKC_OAK	0.00		
11_C1_R3_E_WA_OAK	0.00		
11_C1_R3_E_LA_OAK	0.00		
11_C1_R3_I_LGB_OAK	0.00		
11_C1_R3_E_LGB_OAK	0.00		
12_C1_R1_I_SH_LGB	1135.87		
12_C1_R2_I_SH_SEA	0.00		
12_C1_R3_I_SH_LGB	0.00		

12_C1_R1_E_LGB_SH	14828.10
12_C1_R2_E_SEA_SH	0.00
12_C1_R3_E_OAK_SH	0.00
12_C1_R1_I_LGB_OKC	1135.87
12_C1_R1_I_LGB_WA	0.00
12_C1_R1_I_LGB_LA	0.00
12_C1_R2_I_SEA_OKC	0.00
12_C1_R2_I_SEA_WA	0.00
12_C1_R2_I_SEA_LA	0.00
12_C1_R3_I_LGB_OKC	0.00
12_C1_R3_I_LGB_WA	0.00
12_C1_R3_I_LGB_LA	0.00
12_C1_R3_I_OAK_OKC	0.00
12_C1_R3_I_OAK_WA	0.00
12_C1_R3_I_OAK_LA	0.00
12_C1_R1_E_OKC_LGB	936.02
12_C1_R1_E_WA_LGB	0.00
12_C1_R1_E_LA_LGB	13892.08
12_C1_R2_E_OKC_SEA	0.00
12_C1_R2_E_WA_SEA	0.00
12_C1_R2_E_LA_SEA	0.00
12_C1_R3_E_OKC_LGB	0.00
12_C1_R3_E_WA_LGB	0.00
12_C1_R3_E_LA_LGB	0.00
12_C1_R3_E_OKC_OAK	0.00
12_C1_R3_E_WA_OAK	0.00
12_C1_R3_E_LA_OAK	0.00
12_C1_R3_I_LGB_OAK	0.00
12_C1_R3_E_LGB_OAK	0.00
13_C1_R1_I_SH_LGB	4935.00
13_C1_R2_I_SH_SEA	0.00
13_C1_R3_I_SH_LGB	0.00
13_C1_R1_E_LGB_SH	13892.08
13_C1_R2_E_SEA_SH	0.00
13_C1_R3_E_OAK_SH	0.00
13_C1_R1_I_LGB_OKC	0.00
13_C1_R1_I_LGB_WA	0.00
13_C1_R1_I_LGB_LA	4935.00
13_C1_R2_I_SEA_OKC	0.00
13_C1_R2_I_SEA_WA	0.00
13_C1_R2_I_SEA_LA	0.00
13_C1_R3_I_LGB_OKC	0.00
13_C1_R3_I_LGB_WA	0.00

13_C1_R3_I_LGB_LA	0.00
13_C1_R3_I_OAK_OKC	0.00
13_C1_R3_I_OAK_WA	0.00
13_C1_R3_I_OAK_LA	0.00
13_C1_R1_E_OKC_LGB	0.00
13_C1_R1_E_WA_LGB	0.00
13_C1_R1_E_LA_LGB	13892.08
13_C1_R2_E_OKC_SEA	0.00
13_C1_R2_E_WA_SEA	0.00
13_C1_R2_E_LA_SEA	0.00
13_C1_R3_E_OKC_LGB	0.00
13_C1_R3_E_WA_LGB	0.00
13_C1_R3_E_LA_LGB	0.00
13_C1_R3_E_OKC_OAK	0.00
13_C1_R3_E_WA_OAK	0.00
13_C1_R3_E_LA_OAK	0.00
13_C1_R3_I_LGB_OAK	0.00
13_C1_R3_E_LGB_OAK	0.00
21_C2_R1_I_SH_LGB	0.00
21_C2_R2_I_SH_SEA	3984.15
21_C2_R1_E_LGB_SH	0.00
21_C2_R2_E_SEA_SH	0.00
21_C2_R1_I_LGB_OKC	0.00
21_C2_R1_I_LGB_WA	0.00
21_C2_R1_I_LGB_LA	0.00
21_C2_R1_I_OAK_OKC	0.00
21_C2_R1_I_OAK_WA	0.00
21_C2_R1_I_OAK_LA	0.00
21_C2_R2_I_SEA_OKC	0.00
21_C2_R2_I_SEA_WA	3984.15
21_C2_R2_I_SEA_LA	0.00
21_C2_R1_E_OKC_LGB	0.00
21_C2_R1_E_WA_LGB	0.00
21_C2_R1_E_LA_LGB	0.00
21_C2_R1_E_OKC_OAK	0.00
21_C2_R1_E_WA_OAK	0.00
21_C2_R1_E_LA_OAK	0.00
21_C2_R2_E_OKC_SEA	0.00
21_C2_R2_E_WA_SEA	0.00
21_C2_R2_E_LA_SEA	0.00
21_C2_R1_I_LGB_OAK	0.00
21_C2_R1_E_OAK_LGB	0.00
22_C2_R1_I_SH_LGB	42000.00

22_C2_R2_I_SH_SEA	3984.15
22_C2_R1_E_LGB_SH	3466.04
22_C2_R2_E_SEA_SH	6434.99
22_C2_R1_I_LGB_OKC	0.00
22_C2_R1_I_LGB_WA	0.00
22_C2_R1_I_LGB_LA	42000.00
22_C2_R1_I_OAK_OKC	0.00
22_C2_R1_I_OAK_WA	0.00
22_C2_R1_I_OAK_LA	0.00
22_C2_R2_I_SEA_OKC	0.00
22_C2_R2_I_SEA_WA	3984.15
22_C2_R2_I_SEA_LA	0.00
22_C2_R1_E_OKC_LGB	3466.04
22_C2_R1_E_WA_LGB	0.00
22_C2_R1_E_LA_LGB	0.00
22_C2_R1_E_OKC_OAK	0.00
22_C2_R1_E_WA_OAK	0.00
22_C2_R1_E_LA_OAK	0.00
22_C2_R2_E_OKC_SEA	0.00
22_C2_R2_E_WA_SEA	6434.99
22_C2_R2_E_LA_SEA	0.00
22_C2_R1_I_LGB_OAK	0.00
22_C2_R1_E_OAK_LGB	0.00
23_C2_R1_I_SH_LGB	0.00
23_C2_R2_I_SH_SEA	3984.15
23_C2_R1_E_LGB_SH	4402.06
23_C2_R2_E_SEA_SH	0.00
23_C2_R1_I_LGB_OKC	0.00
23_C2_R1_I_LGB_WA	0.00
23_C2_R1_I_LGB_LA	0.00
23_C2_R1_I_OAK_OKC	0.00
23_C2_R1_I_OAK_WA	0.00
23_C2_R1_I_OAK_LA	0.00
23_C2_R2_I_SEA_OKC	0.00
23_C2_R2_I_SEA_WA	3984.15
23_C2_R2_I_SEA_LA	0.00
23_C2_R1_E_OKC_LGB	4402.06
23_C2_R1_E_WA_LGB	0.00
23_C2_R1_E_LA_LGB	0.00
23_C2_R1_E_OKC_OAK	0.00
23_C2_R1_E_WA_OAK	0.00
23_C2_R1_E_LA_OAK	0.00
23_C2_R2_E_OKC_SEA	0.00

23_C2_R2_E_WA_SEA	0.00
23_C2_R2_E_LA_SEA	0.00
23_C2_R1_I_LGB_OAK	0.00
23_C2_R1_E_OAK_LGB	0.00
31_C3_R1_I_SH_LGB	0.00
31_C3_R2_I_SH_LGB	0.00
31_C3_R1_E_SEA_SH	6434.99
31_C3_R2_E_LGB_SH	0.00
31_C3_R1_I_LGB_OKC	0.00
31_C3_R1_I_LGB_WA	0.00
31_C3_R1_I_LGB_LA	0.00
31_C3_R1_I_OAK_OKC	0.00
31_C3_R1_I_OAK_WA	0.00
31_C3_R1_I_OAK_LA	0.00
31_C3_R1_I_SEA_OKC	0.00
31_C3_R1_I_SEA_WA	0.00
31_C3_R1_I_SEA_LA	0.00
31_C3_R2_I_LGB_OKC	0.00
31_C3_R2_I_LGB_WA	0.00
31_C3_R2_I_LGB_LA	0.00
31_C3_R1_E_OKC_LGB	0.00
31_C3_R1_E_WA_LGB	0.00
31_C3_R1_E_LA_LGB	0.00
31_C3_R1_E_OKC_OAK	0.00
31_C3_R1_E_WA_OAK	0.00
31_C3_R1_E_LA_OAK	0.00
31_C3_R1_E_OKC_SEA	0.00
31_C3_R1_E_WA_SEA	6434.99
31_C3_R1_E_LA_SEA	0.00
31_C3_R2_E_OKC_LGB	0.00
31_C3_R2_E_WA_LGB	0.00
31_C3_R2_E_LA_LGB	0.00
31_C3_R1_I_LGB_OAK	0.00
31_C3_R1_I_OAK_SEA	0.00
31_C3_R1_E_LGB_OAK	0.00
31_C3_R1_E_OAK_SEA	0.00
32_C3_R1_I_SH_LGB	10793.25
32_C3_R2_I_SH_LGB	0.00
32_C3_R1_E_SEA_SH	0.00
32_C3_R2_E_LGB_SH	0.00
32_C3_R1_I_LGB_OKC	3607.85
32_C3_R1_I_LGB_WA	0.00
32_C3_R1_I_LGB_LA	7185.40

32_C3_R1_I_OAK_OKC	0.00
32_C3_R1_I_OAK_WA	0.00
32_C3_R1_I_OAK_LA	0.00
32_C3_R1_I_SEA_OKC	0.00
32_C3_R1_I_SEA_WA	0.00
32_C3_R1_I_SEA_LA	0.00
32_C3_R2_I_LGB_OKC	0.00
32_C3_R2_I_LGB_WA	0.00
32_C3_R2_I_LGB_LA	0.00
32_C3_R1_E_OKC_LGB	0.00
32_C3_R1_E_WA_LGB	0.00
32_C3_R1_E_LA_LGB	0.00
32_C3_R1_E_OKC_OAK	0.00
32_C3_R1_E_WA_OAK	0.00
32_C3_R1_E_LA_OAK	0.00
32_C3_R1_E_OKC_SEA	0.00
32_C3_R1_E_WA_SEA	0.00
32_C3_R1_E_LA_SEA	0.00
32_C3_R2_E_OKC_LGB	0.00
32_C3_R2_E_WA_LGB	0.00
32_C3_R2_E_LA_LGB	0.00
32_C3_R1_I_LGB_OAK	0.00
32_C3_R1_I_OAK_SEA	0.00
32_C3_R1_E_LGB_OAK	0.00
32_C3_R1_E_OAK_SEA	0.00
33_C3_R1_I_SH_LGB	48994.13
33_C3_R2_I_SH_LGB	0.00
33_C3_R1_E_SEA_SH	6434.99
33_C3_R2_E_LGB_SH	0.00
33_C3_R1_I_LGB_OKC	4743.72
33_C3_R1_I_LGB_WA	0.00
33_C3_R1_I_LGB_LA	44250.40
33_C3_R1_I_OAK_OKC	0.00
33_C3_R1_I_OAK_WA	0.00
33_C3_R1_I_OAK_LA	0.00
33_C3_R1_I_SEA_OKC	0.00
33_C3_R1_I_SEA_WA	0.00
33_C3_R1_I_SEA_LA	0.00
33_C3_R2_I_LGB_OKC	0.00
33_C3_R2_I_LGB_WA	0.00
33_C3_R2_I_LGB_LA	0.00
33_C3_R1_E_OKC_LGB	0.00
33_C3_R1_E_WA_LGB	0.00

33_C3_R1_E_LA_LGB	0.00
33_C3_R1_E_OKC_OAK	0.00
33_C3_R1_E_WA_OAK	0.00
33_C3_R1_E_LA_OAK	0.00
33_C3_R1_E_OKC_SEA	0.00
33_C3_R1_E_WA_SEA	6434.99
33_C3_R1_E_LA_SEA	0.00
33_C3_R2_E_OKC_LGB	0.00
33_C3_R2_E_WA_LGB	0.00
33_C3_R2_E_LA_LGB	0.00
33_C3_R1_I_LGB_OAK	0.00
33_C3_R1_I_OAK_SEA	0.00
33_C3_R1_E_LGB_OAK	0.00
33_C3_R1_E_OAK_SEA	0.00
C1_vessel_1	30.00
C1_vessel_2	0.00
C1_vessel_3	0.00
C2_vessel_1	21.00
C2_vessel_2	6.00
C3_vessel_1	30.00
C3_vessel_2	0.00

Appendix 6: Main Routine Code

```
import com.dashoptimization.*;

import java.io.*;
import java.util.ArrayList;
import java.util.HashMap;
import java.util.List;
import java.util.Map;

public class test_new {
   static final float oCost = 0.2F;
   static final float iCost = 1.0F;
   static final float[][] oProfit = {{0f, 0.2f, 0.2f}, {0.2f, 0f, 0.2f}, {0.2f, 0.2f, 0f}};
   //static final  double []  savingamount = { 793998.87f, 794435.02f, 802643.75f};
   static final float[][] iProfit = {};
   static final int vCost = 10000;
   static final int vSize = 2000;
   static final int MAXFLOW = 10000;
   static final int MAXROUTE = 20;
   static final int MAXVESSEL = 30;
   int companyNo;
   static XPRB bcl;
   static final String[] EMPTY_ARRAY = new String[0];
   static final String[] LPSTATUS = {"not loaded", "optimal", "infeasible",
         "worse than cutoff", "unfinished", "unbounded", "cutoff in dual",
         "unsolved", "nonconvex"};
   static final String[] MIPSTATUS = {"not loaded", "LP not optimal", "LP optimal",
         "no solution found", "solution found and incomplete global search", "infeasible", "optimal
solution found",
         "unbounded"};
   HashMap<String, Float> importAmt = new HashMap<String, Float>();
   HashMap<String, Float> exportAmt = new HashMap<String, Float>();
   HashMap<String, Float> oceanDis = new HashMap<String, Float>();
   HashMap<String, Float> inlandDis = new HashMap<String, Float>();
   HashMap<Integer, List<String[]>> comImRout = new HashMap<Integer, List<String[]>>();
   HashMap<Integer, List<String[]>> comExRout = new HashMap<Integer, List<String[]>>();
   HashMap<Integer, List<String[]>> comIntRout = new HashMap<Integer, List<String[]>>();
   HashMap<Integer, List<String[]>> comExtRout = new HashMap<Integer, List<String[]>>();
   HashMap<Integer, List<String[]>> comImInland = new HashMap<Integer, List<String[]>>();
   HashMap<Integer, List<String[]>> comExInland = new HashMap<Integer, List<String[]>>();
   HashMap<Integer, List<String>> comVar = new HashMap<Integer, List<String>>();
   String resultFile = "c:\\work\\result.csv";
   String sinRsltFile = "c:\\work\\result0.csv";

   public static void main(String[] args) {

      try {
         bcl = new XPRB();              /* Initialize BCL */
      } catch (XPRBlicenseError e) {
         System.out.println("Initialization failed (licensing problem).");
         System.exit(1);
      } catch (XPRBerror e) {
         System.out.println("Initialization failed.");
         System.exit(1);
```

```
    }
    //data file
    String fileName = "c:\\work\\data.csv";
    //String fileName = "c:\\work\\data.txt";
    test_new Testme = new test_new();
    //read date
    int companyNo = Testme.ReadData(fileName);
    double[] comCost = new double[companyNo];
    //Testme.solveProb(2);
    //solve individual problem
    for (int i = 1; i <= companyNo; i++) {
       comCost[i - 1] = Testme.solveProb(i);
    }
    // solve cooperation problem
    Testme.solveProb(comCost);
}

//method to solve cooperation problem
public void solveProb(double eachcost[])

{
    final int noComp = eachcost.length;
    XPRBprob p;
    p = bcl.newProb(noComp + " Companies: Coordination");
    XPRBvar[][][] flow;
    XPRBvar[][] vessel;
    List<String> rteDisMap, conRoute;
    XPRBexpr cost = new XPRBexpr();
    XPRBexpr eq1, eq2, eq3, eq4, leq5, leq6, leq7, leq8, leq15, cmpCost;
    HashMap<Integer, Integer> crMap = new HashMap<Integer, Integer>();
    HashMap<Integer, Integer> rtMap = new HashMap<Integer, Integer>();
    String[] port;
    int noVessel = 0;
    List<String[]> vrte;
    int nRoute;
    //variables
    flow = new XPRBvar[noComp][noComp][MAXFLOW];
    vessel = new XPRBvar[noComp][MAXROUTE];

    for (int i = 0; i < noComp; i++) {
       nRoute = 0;
       rteDisMap = new ArrayList<String>();
       conRoute = new ArrayList<String>();
       vrte = new ArrayList<String[]>();
       vrte = comImRout.get(i + 1);

       int cPort = 0;
       String rteKey;
       for (String[] x : vrte) {
          nRoute++;
          for (String y : x) {
             rteKey = "C" + (i + 1) + "_" + "R" + Integer.toString(nRoute) + "_" + "I" + "_" + y;
             rteDisMap.add(rteKey);
          }
       }
```

```
nRoute = 0;
vrte = comExRout.get(i + 1);
for (String[] x : vrte) {
   nRoute++;
   for (String y : x) {
      rteKey = "C" + (i + 1) + "_" + "R" + Integer.toString(nRoute) + "_" + "E" + "_" + y;
      rteDisMap.add(rteKey);
   }
}

nRoute = 0;
vrte = comImInland.get(i + 1);
for (String[] x : vrte) {
   nRoute++;
   for (String y : x) {
      rteKey = "C" + (i + 1) + "_" + "R" + Integer.toString(nRoute) + "_" + "I" + "_" + y;
      rteDisMap.add(rteKey);
   }
}

nRoute = 0;
vrte = comExInland.get(i + 1);
for (String[] x : vrte) {
   nRoute++;
   for (String y : x) {
      rteKey = "C" + (i + 1) + "_" + "R" + Integer.toString(nRoute) + "_" + "E" + "_" + y;
      rteDisMap.add(rteKey);
   }
}
nRoute = 0;
vrte = comIntRout.get(i + 1);
for (String[] x : vrte) {
   nRoute++;
   for (String y : x) {
      cPort++;
      rteKey = "C" + (i + 1) + "_" + "R" + Integer.toString(nRoute) + "_" + "I" + "_" + y;
      System.out.println(rteKey);
      rteDisMap.add(rteKey);
      conRoute.add(rteKey);
   }
}
nRoute = 0;
vrte = comExtRout.get(i + 1);
for (String[] x : vrte) {
   nRoute++;
   for (String y : x) {
      cPort++;
      rteKey = "C" + (i + 1) + "_" + "R" + Integer.toString(nRoute) + "_" + "E" + "_" + y;
      System.out.println(rteKey);
      rteDisMap.add(rteKey);
      conRoute.add(rteKey);
   }
}
//vessel
if (nRoute > MAXROUTE) {
   System.out.println("ROUTE has reached MAX no, Need to update ");
```

```
            return;
        } else {
            rtMap.put(i, nRoute);
        }
        noVessel = nRoute;
        //vessel      initialization
        for (int j = 0; j < noVessel; j++) {
            vessel[i][j] = p.newVar("C" + (i + 1) + "_vessel_" + (j + 1), XPRB.UI, 0, XPRB.INFINITY);
        }
        int nItems = rteDisMap.size();

        if (nItems > MAXFLOW) {
            System.out.println("Flow way has reached MAX no, Need to update ");
            return;
        } else {
            crMap.put(i, nItems);
        }

        //variables initialization
        for (int k = 0; k < noComp; k++) {
            for (int j = 0; j < nItems; j++) {
                flow[i][k][j] = p.newVar(Integer.toString(i + 1) + Integer.toString(k + 1) + "_" +
rteDisMap.get(j), XPRB.PL, 0, XPRB.INFINITY);
            }
        }


        for (int k = 0; k < noComp; k++) {
            for (int j = 0; j < nItems; j++) {
                if (oceanDis.containsKey(flow[i][k][j].getName().substring(11)))
{//System.out.println(flow[j].getName().substring(8));
                    cost.add(flow[i][k][j].mul(oceanDis.get(flow[i][k][j].getName().substring(11)) * oCost));
                } else if (inlandDis.containsKey(flow[i][k][j].getName().substring(11))) {
                    // System.out.println(flow[j].getName().substring(8));
                    cost.add(flow[i][k][j].mul(inlandDis.get(flow[i][k][j].getName().substring(11)) * iCost));
                }
            }
        }

        for (int j = 0; j < noVessel; j++) {
            cost.add(vessel[i][j].mul(vCost));
        }

        //vessel constraint

        for (int x = 0; x < noVessel; x++) {
            leq5 = new XPRBexpr();
            leq6 = new XPRBexpr();
            leq7 = new XPRBexpr();
            for (int k = 0; k < noComp; k++) {
                for (int j = 0; j < nItems; j++) {
                    if (flow[i][k][j].getName().contains("R" + (x + 1)) &&
flow[i][k][j].getName().contains("_I_") && !conRoute.contains(flow[i][k][j].getName())) {
                        if (oceanDis.containsKey(flow[i][k][j].getName().substring(11)))

                        {
```

```
                        leq5.add(flow[i][k][j].mul(-1));
                        leq6.add(flow[i][k][j].mul(-1));
                        //eq1[xx].add(flow[j].mul(1));
                    }

                }

                if (flow[i][k][j].getName().contains("R" + (x + 1)) &&
flow[i][k][j].getName().contains("_E_") && !conRoute.contains(flow[i][k][j].getName())) {
                    if (oceanDis.containsKey(flow[i][k][j].getName().substring(11)))

                    {
                        leq7.add(flow[i][k][j].mul(-1));

                        //eq1[xx].add(flow[j].mul(1));
                    }

                }
            }
        }
        leq5.add(vessel[i][x].mul(vSize));
        leq7.add(vessel[i][x].mul(vSize));
        leq6.add((vessel[i][x].add(-1)).mul(vSize));
        p.newCtr("C" + (i + 1) + "_vessel5", leq5.gEql(0));
        p.newCtr("C" + (i + 1) + "_vessel7", leq7.gEql(0));
        p.newCtr("C" + (i + 1) + "_vessel6", leq6.lEql(0));

    }

    //vessel  total constraint.

    leq15 = new XPRBexpr();
    for (int k = 0; k < noVessel; k++) {

        leq15.add(vessel[i][k]);

    }
    p.newCtr("C" + (i + 1) + "_vessel number", leq15.lEql(MAXVESSEL));


    //flow in = flow out
    for (int x = 0; x < noVessel; x++)

    {
        for (int k = 0; k < noComp; k++) {
            eq3 = new XPRBexpr();
            eq4 = new XPRBexpr();
            for (int j = 0; j < nItems; j++) {
                if (flow[i][k][j].getName().contains("R" + (x + 1)) &&
flow[i][k][j].getName().contains("_I_") && !conRoute.contains(flow[i][k][j].getName().substring(3))) {
                    if (oceanDis.containsKey(flow[i][k][j].getName().substring(11)))

                        eq3.add(flow[i][k][j]);
                        //eq1[xx].add(flow[j].mul(1)); }

                    else if (inlandDis.containsKey(flow[i][k][j].getName().substring(11)))
```

```
                        //
                        // eq1[2*x].add(flow[j].mul(-1));
                        eq3.add(flow[i][k][j].mul(-1));
                    } else if (flow[i][k][j].getName().contains("R" + (x + 1)) &&
flow[i][k][j].getName().contains("_E_") && !conRoute.contains(flow[i][k][j].getName().substring(3))) {
                        if (oceanDis.containsKey(flow[i][k][j].getName().substring(11)))
                            //eq1[2*x+1].add(flow[j]);
                            eq4.add(flow[i][k][j]);
                        else if (inlandDis.containsKey(flow[i][k][j].getName().substring(11)))
                            //eq1[2*x+1].add(flow[j].mul(-1));
                            eq4.add(flow[i][k][j].mul(-1));
                    }
                }

                p.newCtr("C" + (i + 1) + "R" + (x + 1) + "_Flow in", eq3.eql(0));
                p.newCtr("C" + (i + 1) + "R" + (x + 1) + "_Flow out", eq4.eql(0));

            }

        }

        //connecting port equation

        eq2 = new XPRBexpr();
        vrte = new ArrayList<String[]>();
        vrte = comIntRout.get(i + 1);
        nRoute = 0;
        for (String[] x : vrte) {
            nRoute++;
            for (String y : x) {
                leq8 = new XPRBexpr();
                port = y.split("_");
                for (int k = 0; k < noComp; k++) {
                    eq2 = new XPRBexpr();
                    for (int j = 0; j < nItems; j++) {
                        if (flow[i][k][j].getName().contains("R" + nRoute) &&
flow[i][k][j].getName().endsWith(port[0]) && flow[i][k][j].getName().contains("_I_")
                                && oceanDis.containsKey(flow[i][k][j].getName().substring(11))) {
                            eq2.add(flow[i][k][j]);
                        }
                        if (flow[i][k][j].getName().contains("R" + nRoute) &&
flow[i][k][j].getName().substring(11).startsWith(port[0]) && flow[i][k][j].getName().contains("_I_")
                                && oceanDis.containsKey(flow[i][k][j].getName().substring(11))) {
                            eq2.add(flow[i][k][j].mul(-1));
                        }

                        if (flow[i][k][j].getName().contains("R" + nRoute) &&
flow[i][k][j].getName().substring(11).startsWith(port[0]) && flow[i][k][j].getName().contains("_I_")
                                && inlandDis.containsKey(flow[i][k][j].getName().substring(11))) {
                            eq2.add(flow[i][k][j].mul(-1));
                        }

                        if (flow[i][k][j].getName().contains("R" + nRoute) &&
flow[i][k][j].getName().substring(11).equals(y)
                                && oceanDis.containsKey(flow[i][k][j].getName().substring(11))) {
                            leq8.add(flow[i][k][j].mul(-1));
```

```
                    }
                }
                p.newCtr("C" + (i + 1) + "__" + (k + 1) + "_Import connecting constraint", eq2.eql(0));
            }
            leq8.add(vessel[i][nRoute - 1].mul(vSize));
            p.newCtr("C" + (i + 1) + "_Vessel", leq8.gEql(0));
        }
    }

    vrte = comExtRout.get(i + 1);
    nRoute = 0;
    for (String[] x : vrte) {
        nRoute++;
        for (String y : x) {
            port = y.split("_");
            for (int k = 0; k < noComp; k++) {
                eq2 = new XPRBexpr();
                for (int j = 0; j < nItems; j++) {
                    if (flow[i][k][j].getName().contains("R" + nRoute) &&
flow[i][k][j].getName().endsWith(port[1]) && flow[i][k][j].getName().contains("_E_")
                            && oceanDis.containsKey(flow[i][k][j].getName().substring(11))) {
                        eq2.add(flow[i][k][j]);

                    }
                    if (flow[i][k][j].getName().contains("R" + nRoute) &&
flow[i][k][j].getName().substring(11).startsWith(port[1]) && flow[i][k][j].getName().contains("_E_")
                            && oceanDis.containsKey(flow[i][k][j].getName().substring(11))) {
                        eq2.add(flow[i][k][j].mul(-1));

                    }

                    if (flow[i][k][j].getName().contains("R" + nRoute) &&
flow[i][k][j].getName().substring(11).endsWith(port[1]) && flow[i][k][j].getName().contains("_E_")
                            && inlandDis.containsKey(flow[i][k][j].getName().substring(11))) {
                        eq2.add(flow[i][k][j]);
                    }
                }
                p.newCtr("C" + (i + 1) + "__" + (k + 1) + "_Export connecting constraint", eq2.eql(0));
            }
        }
    }
}

for (Map.Entry<String, Float> pair : importAmt.entrySet()) {
    port = pair.getKey().split("_");
    for (int i = 0; i < noComp; i++) {
        eq1 = new XPRBexpr();
        for (int j = 0; j < crMap.get(i); j++) {
            if (flow[i][i][j].getName().substring(11).endsWith(port[1]) &&
flow[i][i][j].getName().contains("_I_")
                    && inlandDis.containsKey(flow[i][i][j].getName().substring(11))) {
                eq1.add(flow[i][i][j]);
            }
        }

        for (int k = 0; k < noComp; k++) {
```

```
                if (k != i) {
                    for (int j = 0; j < crMap.get(k); j++) {
                        if (flow[k][i][j].getName().substring(11).endsWith(port[1]) &&
flow[k][i][j].getName().contains("_I_")
                                && inlandDis.containsKey(flow[k][i][j].getName().substring(11))) {
                            eq1.add(flow[k][i][j]);
                        }
                        // if(oceanDis.containsKey(flow[k][i][j].getName().substring(11)) &&
flow[k][i][j].getName().contains("_I_") )
                        //
sinCost[i].add(flow[k][i][j].mul(oceanDis.get(flow[k][i][j].getName().substring(11))*oProfit[k][i]));
                    }
                }

            }
            //p.newCtr("C"+ (i+1)+ "_Import_" +pair.getKey(),eq1.eql(pair.getValue()*noComp));
            p.newCtr("C" + (i + 1) + "_Import_" + pair.getKey(), eq1.eql(pair.getValue()));
        }
    }

    for (Map.Entry<String, Float> pair : exportAmt.entrySet()) {
        port = pair.getKey().split("_");
        for (int i = 0; i < noComp; i++) {
            eq1 = new XPRBexpr();
            for (int j = 0; j < crMap.get(i); j++) {
                if (flow[i][i][j].getName().substring(11).startsWith(port[0]) &&
flow[i][i][j].getName().contains("_E_")
                        && inlandDis.containsKey(flow[i][i][j].getName().substring(11))) {
                    eq1.add(flow[i][i][j]);
                }
            }
            for (int k = 0; k < noComp; k++) {
                if (k != i) {
                    for (int j = 0; j < crMap.get(k); j++) {
                        if (flow[k][i][j].getName().substring(11).startsWith(port[0]) &&
flow[k][i][j].getName().contains("_E_")
                                && inlandDis.containsKey(flow[k][i][j].getName().substring(11))) {
                            eq1.add(flow[k][i][j]);

                        }
                        //if(oceanDis.containsKey(flow[k][i][j].getName().substring(11)) &&
flow[k][i][j].getName().contains("_E_") )
                        //
sinCost[i].add(flow[k][i][j].mul(oceanDis.get(flow[k][i][j].getName().substring(11))*oProfit[k][i]));
                    }
                }
            }
            // p.newCtr("C"+ (i+1)+ "_Export_" +pair.getKey(),eq1.eql(pair.getValue()*noComp));
            p.newCtr("C" + (i + 1) + "_Export_" + pair.getKey(), eq1.eql(pair.getValue()));
        }
    }

    for (int i = 0; i < noComp; i++) {
        cmpCost = new XPRBexpr();
        for (int j = 0; j < rtMap.get(i); j++) {
```

```
            cmpCost.add(vessel[i][j].mul(vCost));
         }
         for (int k = 0; k < noComp; k++) {
            for (int j = 0; j < crMap.get(i); j++) {
               if (oceanDis.containsKey(flow[i][k][j].getName().substring(11)))
{//System.out.println(flow[j].getName().substring(8));
                  cmpCost.add(flow[i][k][j].mul(oceanDis.get(flow[i][k][j].getName().substring(11)) *
oCost));
                  cmpCost.add(flow[i][k][j].mul(oceanDis.get(flow[i][k][j].getName().substring(11)) *
oProfit[i][k] * (-1)));
               } else if (inlandDis.containsKey(flow[i][k][j].getName().substring(11))) {
                  // System.out.println(flow[j].getName().substring(8));
                  cmpCost.add(flow[i][k][j].mul(inlandDis.get(flow[i][k][j].getName().substring(11)) *
iCost));
               }
            }

            if (k != i) {
               for (int j = 0; j < crMap.get(k); j++) {
                  if (oceanDis.containsKey(flow[k][i][j].getName().substring(11)))
                     cmpCost.add(flow[k][i][j].mul(oceanDis.get(flow[k][i][j].getName().substring(11)) *
oProfit[k][i]));
               }
            }

         }
         //cmpCost.add(savingamount[i]);
         p.newCtr("Company cost constraint" + (i + 1), cmpCost.lEql(eachcost[i]));
         //p.newCtr("Company cost constraint" + (i + 1), cmpCost.eql(eachcost[i]));
      }

      p.setObj(cost);
      p.setSense(XPRB.MINIM);
      // p.lpOptimize("");
      p.mipOptimize("");
      System.out.println("Problem status: " + MIPSTATUS[p.getMIPStat()]);

      try {
         p.exportProb(XPRB.MPS, "company_co");
         p.exportProb(XPRB.LP, "company_co");
      } catch (IOException e) {
         System.err.println(e.getMessage());
         return;
         //To change body of catch statement use File | Settings | File Templates.
      }

      /* Solution printing */
      System.out.println("Total cost: " + p.getObjVal());
      StringBuilder contents = new StringBuilder();
      contents.append("Total cost: " + p.getObjVal() + System.getProperty("line.separator"));
      double cmpcost, abcost = 0;
      for (int i = 0; i < noComp; i++) {
         cmpcost = 0;

         for (int j = 0; j < rtMap.get(i); j++) {
```

```
            cmpcost = cmpcost + vessel[i][j].getSol() * vCost;
         }
         //System.out.println(cmpcost);
         for (int k = 0; k < noComp; k++) {
            for (int j = 0; j < crMap.get(i); j++) {
               if (oceanDis.containsKey(flow[i][k][j].getName().substring(11)))
{//System.out.println(flow[j].getName().substring(8));
                  cmpcost = cmpcost + flow[i][k][j].getSol() *
(oceanDis.get(flow[i][k][j].getName().substring(11)) * oCost);
                  cmpcost = cmpcost + flow[i][k][j].getSol() *
(oceanDis.get(flow[i][k][j].getName().substring(11)) * oProfit[i][k] * (-1));
               } else if (inlandDis.containsKey(flow[i][k][j].getName().substring(11))) {
                  // System.out.println(flow[j].getName().substring(8));
                  cmpcost = cmpcost + flow[i][k][j].getSol() *
(inlandDis.get(flow[i][k][j].getName().substring(11)) * iCost);
               }
            }
            if (k != i) {
               for (int j = 0; j < crMap.get(k); j++) {
                  if (oceanDis.containsKey(flow[k][i][j].getName().substring(11)))
                     cmpcost = cmpcost + flow[k][i][j].getSol() *
(oceanDis.get(flow[k][i][j].getName().substring(11)) * oProfit[k][i]);
               }
            }

         }
         System.out.println("C" + (i + 1) + "_Total cost:" + cmpcost + " Orignal Cost: " + eachcost[i]);
         contents.append("C" + (i + 1) + "_Total cost:" + cmpcost + " Orignal Cost: " + eachcost[i] +
System.getProperty("line.separator"));
         abcost = abcost + cmpcost;
      }

      for (int i = 0; i < noComp; i++)
         for (int k = 0; k < noComp; k++)
            for (int s = 0; s < crMap.get(i); s++) {
               System.out.println(flow[i][k][s].getName() + ": " + flow[i][k][s].getSol());
               contents.append(flow[i][k][s].getName() + ": " + flow[i][k][s].getSol() +
System.getProperty("line.separator"));
            }

      for (int i = 0; i < noComp; i++)
         for (int s = 0; s < rtMap.get(i); s++) {
            System.out.println(vessel[i][s].getName() + ": " + vessel[i][s].getSol());
            contents.append(vessel[i][s].getName() + ": " + vessel[i][s].getSol() +
System.getProperty("line.separator"));
         }

      // for (int i =0;i<noComp;i++)
      //System.out.println(p.getCtrByName("Company cost constraint" + (i + 1)));
      //System.out.println(p.getCtrByName("C" + (i+1)+"_Export connecting constraint").getAct());
      System.out.println(abcost - p.getObjVal());

      try {
         Writer output;
         output = new BufferedWriter(new FileWriter(resultFile));
         //FileWriter always assumes default encoding is OK!
```

```
            output.write(contents.toString());
            output.close();
        } catch (IOException e) {
            System.err.println(e.getMessage());
        }
    }

    // method  for  individual problem
    public double solveProb(int i) {
        XPRBprob p;
        p = bcl.newProb("Company:" + Integer.toString(i));
        XPRBvar[] flow, vessel;
        XPRBexpr cost;
        XPRBexpr[] eq;
        XPRBexpr eq1, eq2, eq3, eq4, leq5, leq6, leq7, leq8;
        List<String> rteDisMap = new ArrayList<String>();
        List<String> conRoute = new ArrayList<String>();
        List<String[]> vrte = new ArrayList<String[]>();
        vrte = comImRout.get(i);
        int nRoute = 0;
        int cPort = 0;
        String rteKey;
        for (String[] x : vrte) {
            nRoute++;
            for (String y : x) {
                rteKey = "C" + i + "_" + "R" + Integer.toString(nRoute) + "_" + "I" + "_" + y;
                rteDisMap.add(rteKey);
            }
        }

        nRoute = 0;
        vrte = comExRout.get(i);
        for (String[] x : vrte) {
            nRoute++;
            for (String y : x) {
                rteKey = "C" + i + "_" + "R" + Integer.toString(nRoute) + "_" + "E" + "_" + y;
                rteDisMap.add(rteKey);
            }
        }

        nRoute = 0;
        vrte = comImInland.get(i);
        for (String[] x : vrte) {
            nRoute++;
            for (String y : x) {
                rteKey = "C" + i + "_" + "R" + Integer.toString(nRoute) + "_" + "I" + "_" + y;
                rteDisMap.add(rteKey);
            }
        }

        nRoute = 0;
        vrte = comExInland.get(i);
        for (String[] x : vrte) {
            nRoute++;
            for (String y : x) {
                rteKey = "C" + i + "_" + "R" + Integer.toString(nRoute) + "_" + "E" + "_" + y;
```

```
            rteDisMap.add(rteKey);
        }
    }
    nRoute = 0;
    vrte = comIntRout.get(i);
    for (String[] x : vrte) {
        nRoute++;
        for (String y : x) {
            cPort++;
            rteKey = "C" + i + "_" + "R" + Integer.toString(nRoute) + "_" + "I" + "_" + y;
            System.out.println(rteKey);
            rteDisMap.add(rteKey);
            conRoute.add(rteKey);
        }
    }
    nRoute = 0;
    vrte = comExtRout.get(i);
    for (String[] x : vrte) {
        nRoute++;
        for (String y : x) {
            cPort++;
            rteKey = "C" + i + "_" + "R" + Integer.toString(nRoute) + "_" + "E" + "_" + y;
            System.out.println(rteKey);
            rteDisMap.add(rteKey);
            conRoute.add(rteKey);
        }
    }

    int noVessel = nRoute;
    vessel = new XPRBvar[noVessel];
    for (int j = 0; j < noVessel; j++) {
        vessel[j] = p.newVar("vessel_" + j, XPRB.UI, 0, XPRB.INFINITY);
    }

    int nItems = rteDisMap.size();
    flow = new XPRBvar[nItems];
    for (int j = 0; j < nItems; j++) {
        flow[j] = p.newVar(rteDisMap.get(j), XPRB.PL, 0, XPRB.INFINITY);
    }

    //objective
    cost = new XPRBexpr();
    for (int j = 0; j < nItems; j++) {
        if (oceanDis.containsKey(flow[j].getName().substring(8)))
{//System.out.println(flow[j].getName().substring(8));
            cost.add(flow[j].mul(oceanDis.get(flow[j].getName().substring(8)) * oCost));
        } else if (inlandDis.containsKey(flow[j].getName().substring(8))) {
            // System.out.println(flow[j].getName().substring(8));
            cost.add(flow[j].mul(inlandDis.get(flow[j].getName().substring(8)) * iCost));
        }
    }
    for (int j = 0; j < noVessel; j++)
        cost.add(vessel[j].mul(vCost));
    p.setObj(cost);

    //vessel constraint
```

```
      for (int x = 0; x < noVessel; x++) {
         leq5 = new XPRBexpr();
         leq6 = new XPRBexpr();
         leq7 = new XPRBexpr();
         for (int j = 0; j < nItems; j++) {
            if (flow[j].getName().contains("R" + (x + 1)) && flow[j].getName().contains("_I_")
&& !conRoute.contains(flow[j].getName())) {
               if (oceanDis.containsKey(flow[j].getName().substring(8))) {
                  leq5.add(flow[j].mul(-1));
                  leq6.add(flow[j].mul(-1));
                  //eq1[xx].add(flow[j].mul(1));
               }
            }
            if (flow[j].getName().contains("R" + (x + 1)) && flow[j].getName().contains("_E_")
&& !conRoute.contains(flow[j].getName())) {
               if (oceanDis.containsKey(flow[j].getName().substring(8)))

               {
                  leq7.add(flow[j].mul(-1));
                  //eq1[xx].add(flow[j].mul(1));
               }
            }
         }
         leq5.add(vessel[x].mul(vSize));
         leq7.add(vessel[x].mul(vSize));
         leq6.add((vessel[x].add(-1)).mul(vSize));
         p.newCtr(leq5.gEql(0));
         p.newCtr(leq7.gEql(0));
         p.newCtr(leq6.lEql(0));
      }

      //equation constraint
      // msa input, output
      for (int x = 0; x < nRoute; x++) {
         eq3 = new XPRBexpr();
         eq4 = new XPRBexpr();

         for (int j = 0; j < nItems; j++) {
            if (flow[j].getName().contains("R" + (x + 1)) && flow[j].getName().contains("_I_")
&& !conRoute.contains(flow[j].getName())) {
               if (oceanDis.containsKey(flow[j].getName().substring(8)))
                  eq3.add(flow[j]);
                  //eq1[xx].add(flow[j].mul(1)); }
               else if (inlandDis.containsKey(flow[j].getName().substring(8)))
                  //
                  // eq1[2*x].add(flow[j].mul(-1));
                  eq3.add(flow[j].mul(-1));
            } else if (flow[j].getName().contains("R" + (x + 1)) && flow[j].getName().contains("_E_")
&& !conRoute.contains(flow[j].getName())) {
               if (oceanDis.containsKey(flow[j].getName().substring(8)))
                  //eq1[2*x+1].add(flow[j]);
                  eq4.add(flow[j]);
               else if (inlandDis.containsKey(flow[j].getName().substring(8)))
                  //eq1[2*x+1].add(flow[j].mul(-1));
                  eq4.add(flow[j].mul(-1));
```

```
            }
        }
        p.newCtr(eq3.eql(0));
        p.newCtr(eq4.eql(0));
    }

    //connecting port equation
    eq2 = new XPRBexpr();
    String[] port;
    vrte = comIntRout.get(i);
    nRoute = 0;
    for (String[] x : vrte) {
        nRoute++;
        for (String y : x) {
            eq2 = new XPRBexpr();
            leq8 = new XPRBexpr();
            port = y.split("_");
            for (int j = 0; j < nItems; j++) {
                if (flow[j].getName().contains("R" + nRoute) && flow[j].getName().endsWith(port[0]) &&
flow[j].getName().contains("_I_")
                        && oceanDis.containsKey(flow[j].getName().substring(8))) {
                    eq2.add(flow[j]);
                }
                if (flow[j].getName().contains("R" + nRoute) &&
flow[j].getName().substring(8).startsWith(port[0]) && flow[j].getName().contains("_I_")
                        && oceanDis.containsKey(flow[j].getName().substring(8))) {
                    eq2.add(flow[j].mul(-1));
                }

                if (flow[j].getName().contains("R" + nRoute) &&
flow[j].getName().substring(8).startsWith(port[0]) && flow[j].getName().contains("_I_")
                        && inlandDis.containsKey(flow[j].getName().substring(8))) {
                    eq2.add(flow[j].mul(-1));
                }

                if (flow[j].getName().contains("R" + nRoute) && flow[j].getName().substring(8).equals(y)
                        && oceanDis.containsKey(flow[j].getName().substring(8))) {
                    leq8.add(flow[j].mul(-1));
                }
            }
            leq8.add(vessel[nRoute - 1].mul(vSize));
            p.newCtr(leq8.gEql(0));
            p.newCtr(eq2.eql(0));
        }
    }

    vrte = comExtRout.get(i);
    nRoute = 0;
    for (String[] x : vrte) {
        nRoute++;
        for (String y : x) {
            eq2 = new XPRBexpr();
            port = y.split("_");
            for (int j = 0; j < nItems; j++) {
                if (flow[j].getName().contains("R" + nRoute) && flow[j].getName().endsWith(port[1]) &&
flow[j].getName().contains("_E_")
```

```
                    && oceanDis.containsKey(flow[j].getName().substring(8))) {
                eq2.add(flow[j]);
            }
            if (flow[j].getName().contains("R" + nRoute) &&
flow[j].getName().substring(8).startsWith(port[1]) && flow[j].getName().contains("_E_")
                    && oceanDis.containsKey(flow[j].getName().substring(8))) {
                eq2.add(flow[j].mul(-1));
            }

            if (flow[j].getName().contains("R" + nRoute) &&
flow[j].getName().substring(8).endsWith(port[1]) && flow[j].getName().contains("_E_")
                    && inlandDis.containsKey(flow[j].getName().substring(8))) {
                eq2.add(flow[j]);
            }
        }
        p.newCtr(eq2.eql(0));
    }
}

for (Map.Entry<String, Float> pair : importAmt.entrySet()) {
    eq1 = new XPRBexpr();
    port = pair.getKey().split("_");
    for (int j = 0; j < nItems; j++) {
        if (flow[j].getName().substring(8).endsWith(port[1]) && flow[j].getName().contains("_I_")
                && inlandDis.containsKey(flow[j].getName().substring(8))) {
            eq1.add(flow[j]);
        }
    }
    p.newCtr(eq1.eql(pair.getValue()));  // tmp change
}

for (Map.Entry<String, Float> pair : exportAmt.entrySet()) {
    eq1 = new XPRBexpr();
    port = pair.getKey().split("_");
    for (int j = 0; j < nItems; j++) {
        if (flow[j].getName().substring(8).startsWith(port[0]) && flow[j].getName().contains("_E_")
                && inlandDis.containsKey(flow[j].getName().substring(8))) {
            eq1.add(flow[j]);
        }
    }
    p.newCtr(eq1.eql(pair.getValue()));
}

/****SOLVING + OUTPUT****/
p.setSense(XPRB.MINIM);
// p.lpOptimize("");
p.mipOptimize("");
System.out.println("Problem status: " + MIPSTATUS[p.getMIPStat()]);
try {
    p.exportProb(XPRB.MPS, "company_" + i);
    p.exportProb(XPRB.LP, "company_" + i);
} catch (IOException e) {
    System.err.println(e.getMessage());
    return 0;
    //To change body of catch statement use File | Settings | File Templates.
}
```

```
      /* Solution printing */
      StringBuilder contents = new StringBuilder();
      contents.append("Total cost: " + p.getObjVal() + System.getProperty("line.separator"));
      System.out.println("Total cost: " + p.getObjVal());
      for (int s = 0; s < nItems; s++) {
         System.out.println(flow[s].getName() + ": " + flow[s].getSol());
         contents.append(flow[s].getName() + ": " + flow[s].getSol() +
System.getProperty("line.separator"));
      }
      for (int s = 0; s < noVessel; s++) {
         System.out.println(vessel[s].getName() + ": " + vessel[s].getSol());
         contents.append(vessel[s].getName() + ": " + vessel[s].getSol() +
System.getProperty("line.separator"));
      }

      try {
         Writer output;
         output = new BufferedWriter(new FileWriter(sinRsltFile));
         //FileWriter always assumes default encoding is OK!
         output.write(contents.toString());
         output.close();
      } catch (IOException e) {
         System.err.println(e.getMessage());
      }

      return p.getObjVal();
   }

   //method for reading data
   public int ReadData(String fileName) {
      long lineNum = 0;
      int companyNo = 0;
      List<String[]> imRoute = new ArrayList<String[]>();
      List<String[]> exRoute = new ArrayList<String[]>();
      List<String[]> intRoute = new ArrayList<String[]>();
      List<String[]> extRoute = new ArrayList<String[]>();
      List<String[]> iminland = new ArrayList<String[]>();
      List<String[]> exinland = new ArrayList<String[]>();
      List<String> msa = new ArrayList<String>();
      int noMsa;
      String line = null;
      String delim = ",";
      char[] delimiter = delim.toCharArray();
      int sepData = 0;

      try {
         File file = new File(fileName);
         if (!file.exists()) {
            System.out.println("File " + file.getAbsolutePath() + " does not exist!");
            return 0;
         }
         BufferedReader in = new BufferedReader(new FileReader(file));
         //String str;
         while ((line = in.readLine()) != null && !line.startsWith("%")) {
            lineNum++;
```

```
            String[] list = line.split(delim);
            if (sepData == 1 && list.length > 1) {
               importAmt.put(list[0].trim() + "_" + list[1].trim(), Float.parseFloat(list[2].trim())); //temp
change
               if (!msa.contains(list[1].trim()))
                  msa.add(list[1].trim());
            }
            if (sepData == 2 && list.length > 1) {
               exportAmt.put(list[0].trim() + "_" + list[1].trim(), Float.parseFloat(list[2].trim()));
            }
            if (sepData == 3 && list.length > 1) {
               if (!oceanDis.containsKey(list[0].trim() + "_" + list[1].trim()))
                  oceanDis.put(list[0].trim() + "_" + list[1].trim(), Float.parseFloat(list[2].trim()));
               if (!oceanDis.containsKey(list[1].trim() + "_" + list[0].trim()))
                  oceanDis.put(list[1].trim() + "_" + list[0].trim(), Float.parseFloat(list[2].trim()));
            }
            if (sepData == 4 && list.length > 1) {
               if (!inlandDis.containsKey(list[0].trim() + "_" + list[1].trim()))
                  inlandDis.put(list[0].trim() + "_" + list[1].trim(), Float.parseFloat(list[2].trim()));
               if (!inlandDis.containsKey(list[1].trim() + "_" + list[0].trim()))
                  inlandDis.put(list[1].trim() + "_" + list[0].trim(), Float.parseFloat(list[2].trim()));
            }

            if (sepData >= 5 && list.length > 1) {
               String[] imrt = new String[1];
               String[] intrt;
               String[] extrt;
               String[] exrt = new String[1];
               String[] imland;
               String[] exland;
               noMsa = msa.size();
               if (list[0].trim().equals(list[list.length - 1].trim())) {
//                   imrt = new String[list.length - 2];
//                   exrt = new String[list.length - 2];
                  imrt[0] = list[0].trim() + "_" + list[1].trim();
                  exrt[0] = list[list.length - 2].trim() + "_" + list[list.length - 1].trim();
                  imland = new String[(list.length - 2) * noMsa];
                  exland = new String[(list.length - 2) * noMsa];
                  if (list.length > 3) {
                     intrt = new String[list.length - 3];
                     extrt = new String[list.length - 3];
                     for (int x = 0; x < list.length - 3; x++) {
                        intrt[x] = list[x + 1].trim() + "_" + list[x + 2].trim();
                        extrt[x] = list[x + 1].trim() + "_" + list[x + 2].trim();
                     }
                  } else {
                     intrt = EMPTY_ARRAY;
                     extrt = EMPTY_ARRAY;
                  }
                  for (int x = 0; x < list.length - 2; x++) {
//                      imrt[x] = list[x].trim() + "_" + list[x + 1].trim();
//                      exrt[x] = list[x + 1].trim() + "_" + list[x + 2].trim();
                     for (int j = 0; j < noMsa; j++) {
                        imland[x * noMsa + j] = list[x + 1].trim() + "_" + msa.get(j);
                        exland[x * noMsa + j] = msa.get(j) + "_" + list[x + 1].trim();
                     }
```

```
        }
    } else {
        //imrt = new String[list.length - 1];
        //exrt = new String[list.length - 1];
        imrt[0] = list[0].trim() + "_" + list[1].trim();
        exrt[0] = list[1].trim() + "_" + list[0].trim();
        imland = new String[(list.length - 1) * noMsa];
        exland = new String[(list.length - 1) * noMsa];
        if (list.length > 2)

        {
            intrt = new String[list.length - 2];
            extrt = new String[list.length - 2];
            for (int x = 0; x < list.length - 2; x++) {
                intrt[x] = list[x + 1].trim() + "_" + list[x + 2].trim();
                extrt[x] = list[x + 2].trim() + "_" + list[x + 1].trim();
            }
        } else {
            intrt = EMPTY_ARRAY;
            extrt = EMPTY_ARRAY;
        }
        for (int x = 0; x < list.length - 1; x++) {
            // imrt[x] = list[x].trim() + "_" + list[x + 1].trim();
            //exrt[x] = list[x + 1].trim() + "_" + list[x].trim();
            for (int j = 0; j < noMsa; j++) {
                imland[x * noMsa + j] = list[x + 1].trim() + "_" + msa.get(j);
                exland[x * noMsa + j] = msa.get(j) + "_" + list[x + 1].trim();
            }
        }
    }
    imRoute.add(imrt);
    exRoute.add(exrt);
    iminland.add(imland);
    exinland.add(exland);
    intRoute.add(intrt);
    extRoute.add(extrt);
}

if (line.toLowerCase().contains("import")) {
    sepData++;
}
if (line.toLowerCase().contains("export")) {
    sepData++;
}
if (line.toLowerCase().contains("ocean")) {
    sepData++;
}
if (line.toLowerCase().contains("inland")) {
    sepData++;
}
if (line.toLowerCase().contains("route")) {
    sepData++;
    companyNo++;
    if (companyNo > 1) {
        comImRout.put(companyNo - 1, imRoute);
        comExRout.put(companyNo - 1, exRoute);
```

```
                    comImInland.put(companyNo - 1, iminland);
                    comExInland.put(companyNo - 1, exinland);
                    comExtRout.put(companyNo - 1, extRoute);
                    comIntRout.put(companyNo - 1, intRoute);
                    //route.Clear();
                    imRoute = new ArrayList<String[]>();
                    exRoute = new ArrayList<String[]>();
                    iminland = new ArrayList<String[]>();
                    exinland = new ArrayList<String[]>();
                    intRoute = new ArrayList<String[]>();
                    extRoute = new ArrayList<String[]>();
                }
            }
          }
          in.close();
          comImRout.put(companyNo, imRoute);
          comExRout.put(companyNo, exRoute);
          comImInland.put(companyNo, iminland);
          comExInland.put(companyNo, exinland);
          comExtRout.put(companyNo, extRoute);
          comIntRout.put(companyNo, intRoute);
        } catch (IOException e) {
          System.out.println(e.toString());
        }
        return companyNo;
    }
}
```