IMPACT OF THE PANAMA CANAL EXPANSION IN GLOBAL SUPPLY CHAIN: OPTIMIZATION MODEL FOR US CONTAINER SHIPMENT

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IMPACT OF THE PANAMA CANAL EXPANSION IN GLOBAL SUPPLY CHAIN: OPTIMIZATION MODEL FOR THE U.S. CONTAINER SHIPMENT

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

DOCTOR OF PHILOSOPHY

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ABSTRACT

The transportation of containerized shipments will continue to be a topic of interest in the world because it is the primary method for shipping cargo globally. The primary objective of this study is to analyze the impact of the Panama Canal Expansion (PCE) on the trade flows of containerized shipments between the United States and its trade partners for US exports and imports. The results show that the Panama Canal Expansion would affect the trade flows of US imports and exports significantly. The major findings are as follows: (1) the PCE affects not only US domestic trade flows, but also international trade flows since inland transportation and ocean transportation are interactive, (2) delay cost and toll rate at the Panama Canal do not have a significant impact on trade volume and flows of US containerized shipments after the Panama Canal Expansion mainly because delay cost and toll rate at the canal account for a small portion of the total transportation costs after the PCE, (3) West Coast ports would experience negative effects and East Coast ports would experience positive effects from the PCE, while Gulf ports would experience no effects from the PCE, and (4) an optimal toll rate is inconclusive in this study because changes in toll rate at the canal account for a small portion of the total transportation costs and the PNC competes with shipments to/from Asia shipping to the US West.

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were undeniably the bedrock upon which the past 10 years of my life in the United States have been built. Especially, all my honor goes to my dad, who is at rest since last May.

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CHAPTER 1. INTRODUCTION

1.1. Background of Problem Statement

The container shipping industry plays an important role in the transportation of freight. Between 1990 and 2008, containerization began to seriously impact global trade patterns. During the same period, a new class of Panamax containerships became a dominant vector of maritime shipping. Figure 1.1 shows the growth of world container traffic and throughput, full/empty containers, and transshipments from 1980 to 2013. The world container traffic was increased continuously from 28.7 million TEUs (twenty-foot equivalent units) in 1990 to 152.0 million TEUs in 2008, an increase of about 530%. This corresponds to an average annual compound growth of 9.5%. During the same period, container throughput, which includes TEUs at the port of origin, destination and transshipment, grew from 88 million to 530 million TEUs, an increase of 600%, equivalent to an average annual compound growth of 10.5%. The trend underlines a divergence between throughput and traffic as global supply chains became more complex. Consequently, the ratio of container traffic over container throughput was around 3.5 in 2008, whereas this ratio was 3.0 in 1990. However, the financial crisis of 2009-2010 had a significant impact on container flows, which experienced a drop of 49 million TEUs (9.3%) between 2008 and 2009 (WTO, 2013).

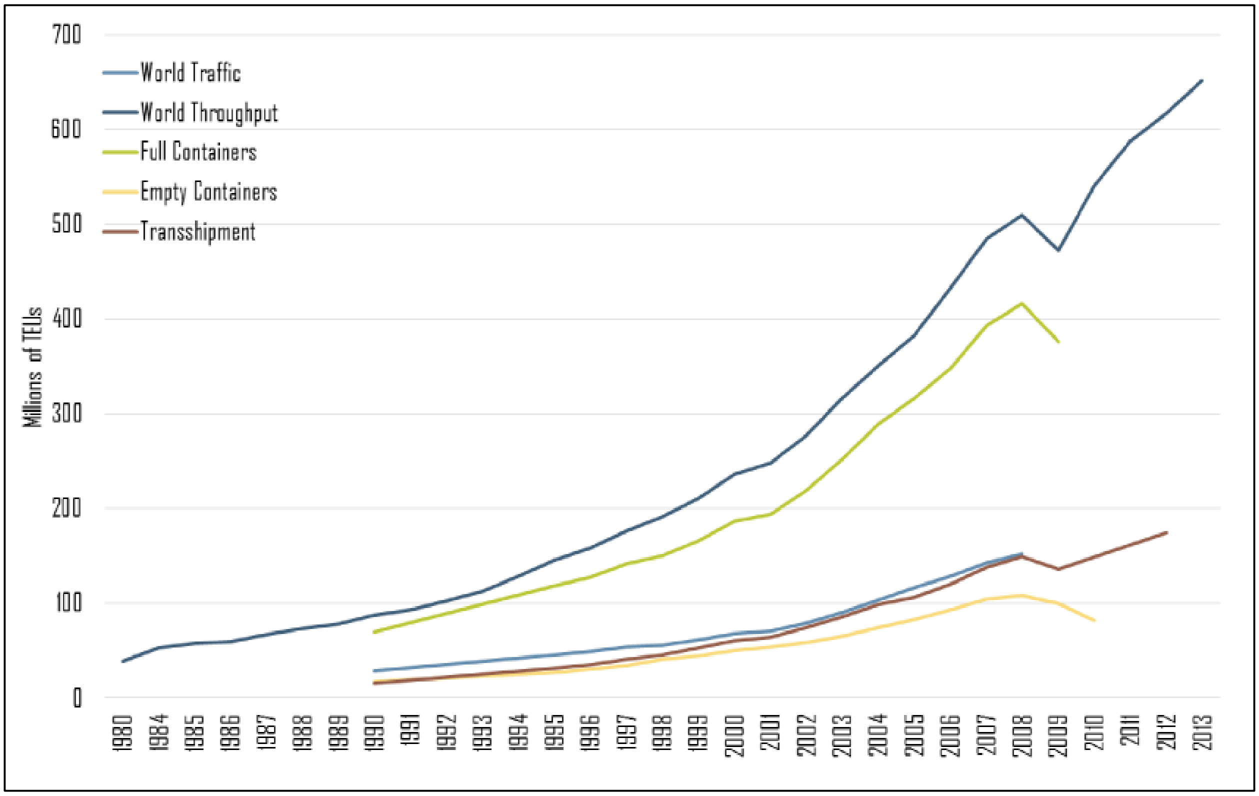


Figure 1.1. World container traffic and throughput (millions of TEU) (Drewry Shipping Consultants, 2014).

Figure 1.2 shows a correlation between global exports and global container throughput from 1980 to 2010 with R^2 of 0.97. Although this relation is proportional, Figure 1.2 shows that there is a direct relationship between the volume of world container throughput (TEU) and global exports as the number (TEU) of world container throughput increased when global exports increased during the same period. This implies that the trend of container traffic reflects world economic activity.

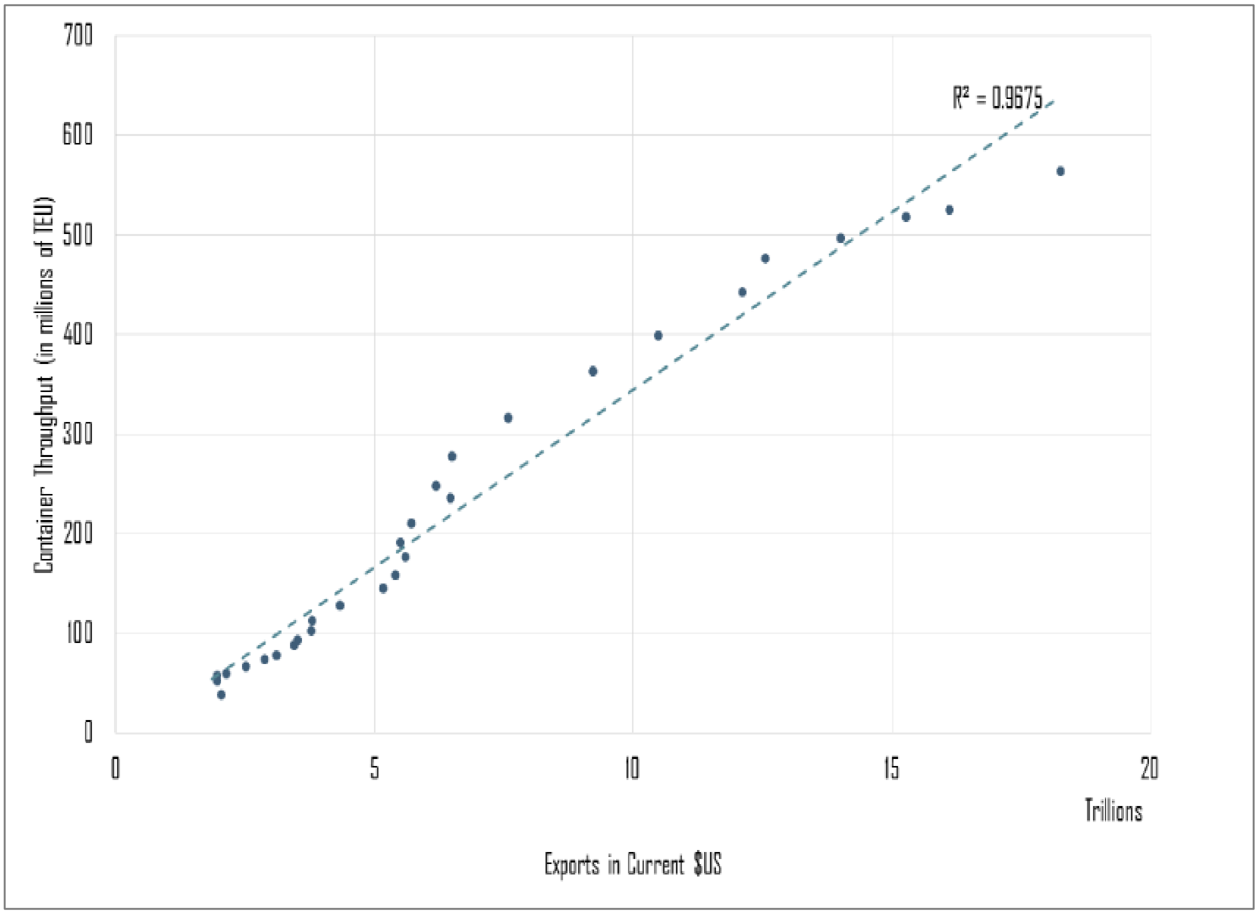


Figure 1.2. Global exports and container throughput (WTO and Drewry Shipping Consultants, 2013).

In the United States, container traffic with Asia and Europe, which are major global container flows, were more than doubled in volume from 10.9 million TEUs in 1995 to 26.9 million TEUs in 2008, and declined to about 22 million TEUs in 2009 (UNCTAD, Review of Maritime Transport, 2013). This implies that the trend of container traffic reflects US and world economic activity. In addition, the US Department of Transportation also reported that a comparison of annual growth in percentage between US loaded container TEUs and real GDP represents a correlation between the trend of container trade and general economic cycles. US container ports serve as water gateways for containerized imports and exports. Most of the container ports in the United States handle more import containers than exports, implying that the US has been facing a trade deficit in container shipments. About 60% of the international container trade is for imports and more than 80% of import containers are handled by US major container ports in 2012. However, most currently, US waterborne container export is 11.9 million TEUs in 2012, a 4% increase from the 10.7 million TEUs in 2007 (US Maritime Administration, 2013).

Since 60% of containerized exports in the United States are from its top 15 trading partners from Northeast Asia and Europe. The total number of containers export to the top 15 partners from US ports is about 7.5 million TEUs (Figure 1.3). Likewise, 80% of containerized imports in the United States are from its top 15 trading partners and the majority of these countries are located in Northeast Asia and Europe although some trading partners are from other continents.

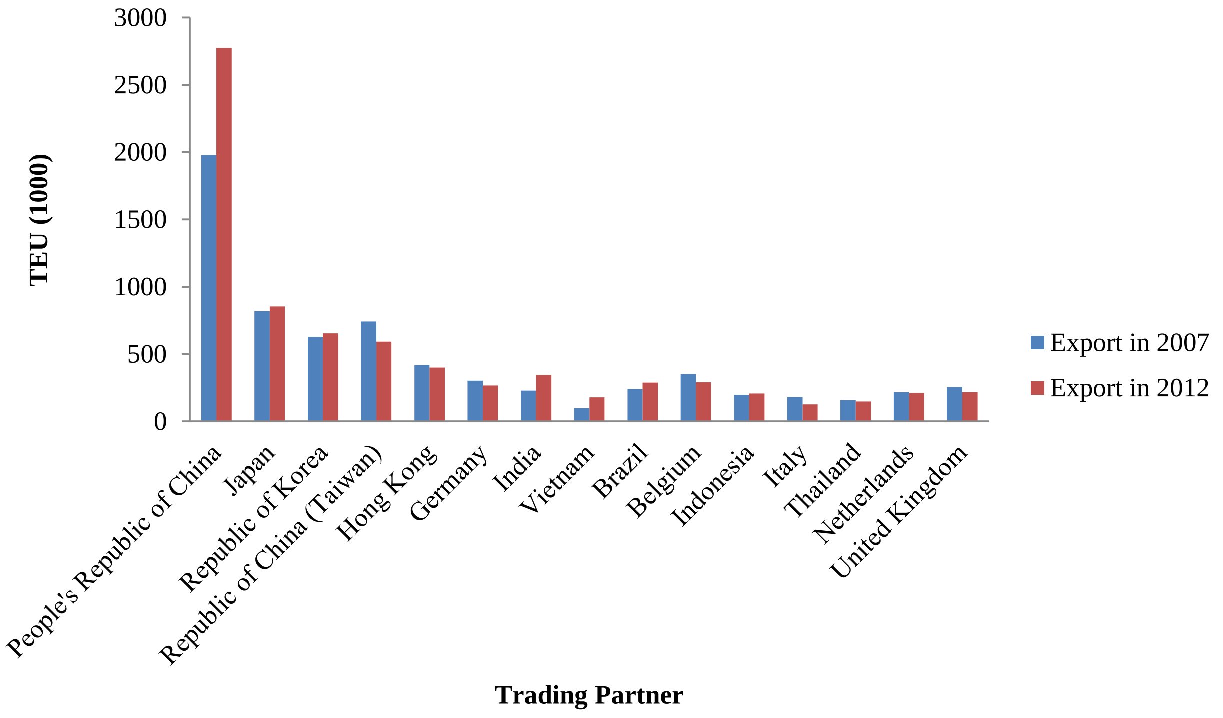


Figure 1.3. Top 15 trading partners for US containerized exports (US Maritime Administration, 2013).

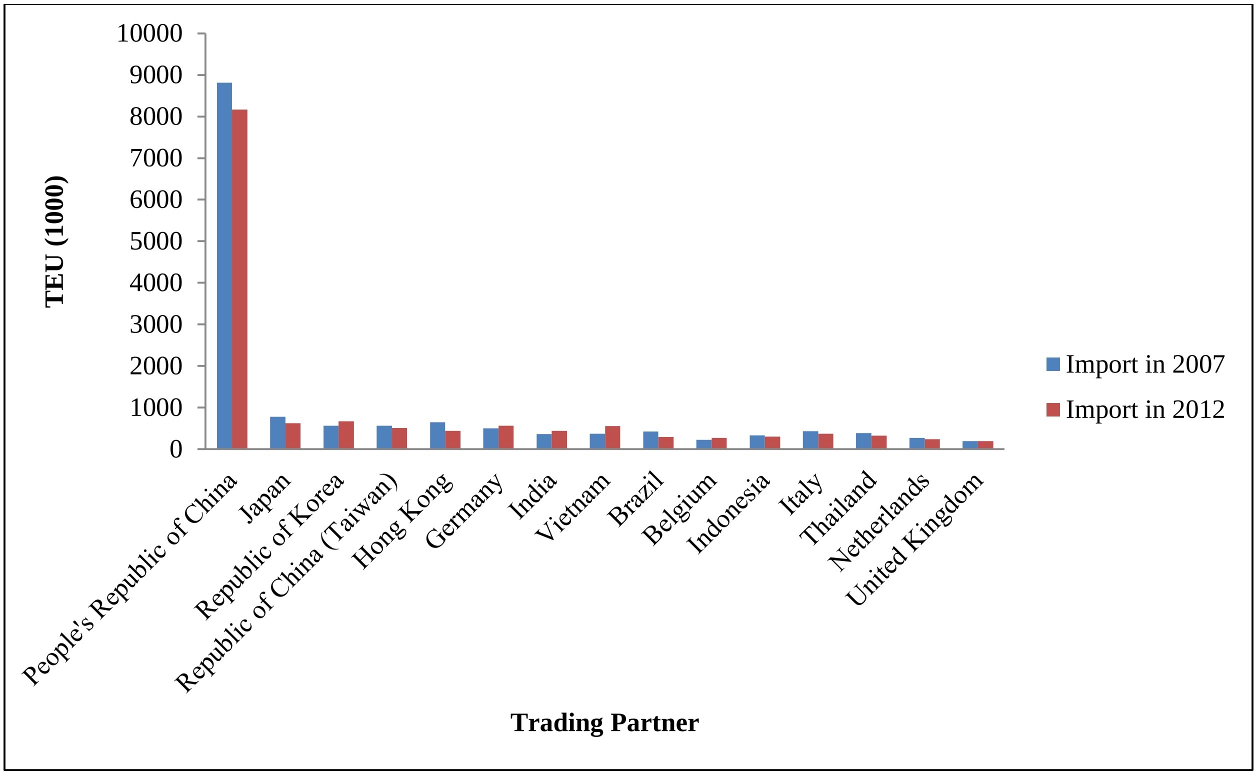


Figure 1.4. Top 15 trading partners for US containerized imports (US Maritime Administration, 2013).

Containerized imports to all US ports from these top 15 trade partners is about 13.9 million TEUs which is about 80% of the total imports in the United States (Figure 1.4). The People's Republic of China (hereafter, China) is the biggest trade partner for containerized shipments in the United States, since more than 35% of container shipments, among these top 15 exporters, is exported to China from the US and 60% of container shipments, among these top 15 importers, is imported from China to the US. Trade volume between the US and China is overwhelmingly larger than trade volume between the US and other countries.

Figure 1.5 shows export trends of container shipments at different US coasts. Between 2008 and 2009, exports of container shipments at US West Coast ports decreased by 0.3 million TEUs, exports of container shipments at US East Coast ports decreased by 0.5 million TEUs, and exports of container shipments at US Gulf Coast ports remained about same. On the other hand, between 2008 and 2012, exports of container shipments from both the US West Coast ports and

East Coast ports increased by 0.3 million TEUs, whereas exports of container shipments from US Gulf Coast ports increased by 0.1 million TEUs.

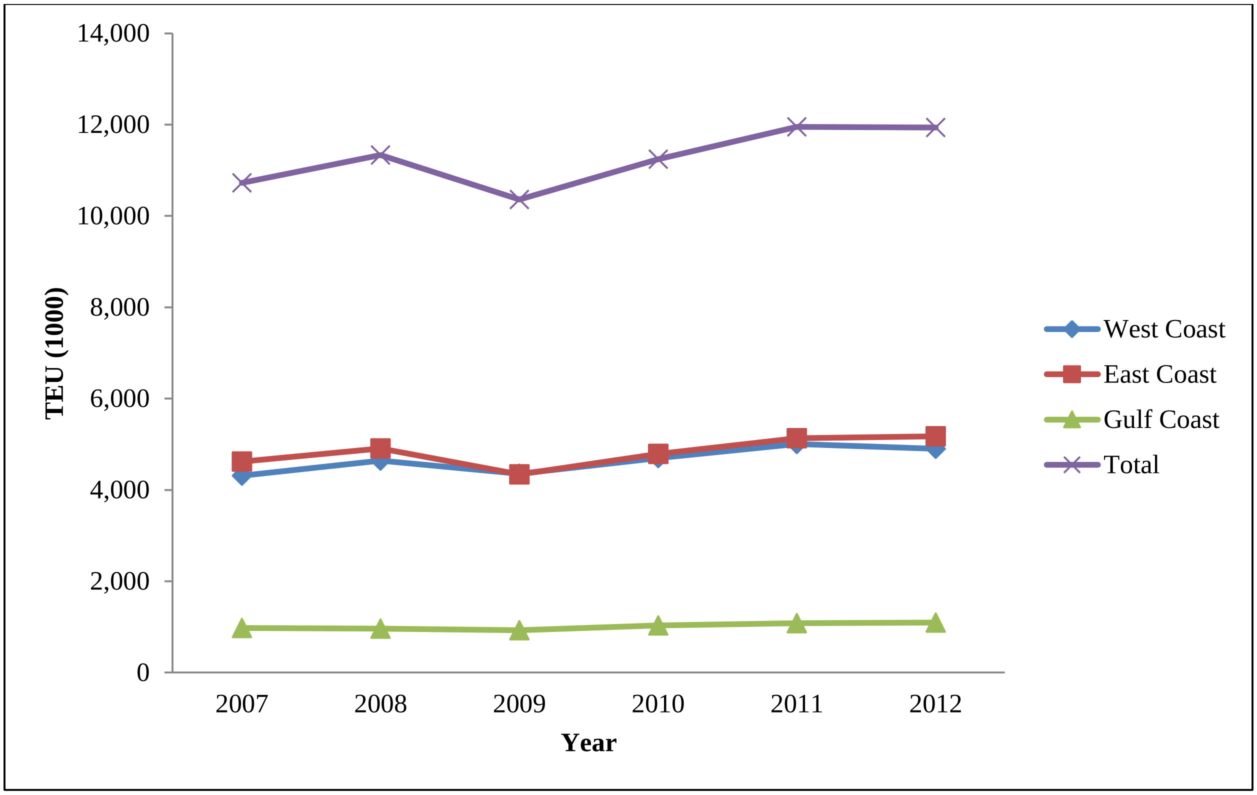


Figure 1.5. Container export trends at US coasts (US Maritime Administration, 2012).

Figure 1.6 represents that import trends of container shipments at different US coasts. Between 2007 and 2009, imports of container shipments at the US West Coast ports decreased by 2.6 million TEUs. Imports of container shipments at US East Coast ports decreased by 1.2 million TEUs, whereas imports of container shipments at US Gulf Coast ports decreased by 0.1 million TEUs. However, from 2009 to 2012, imports of container shipments at US West Coast ports increased by 1.5 million TEUs, increased by 1.2 million TEUs at US East Coast ports, and also increased by 0.1 million TEUs at US Gulf Coast ports. As a result, trades of container shipments at US West Coast ports decreased 1.1 million TEUs, while trades of container shipments at US East Coast and Gulf Coast ports remained about same from 2007 to 2012

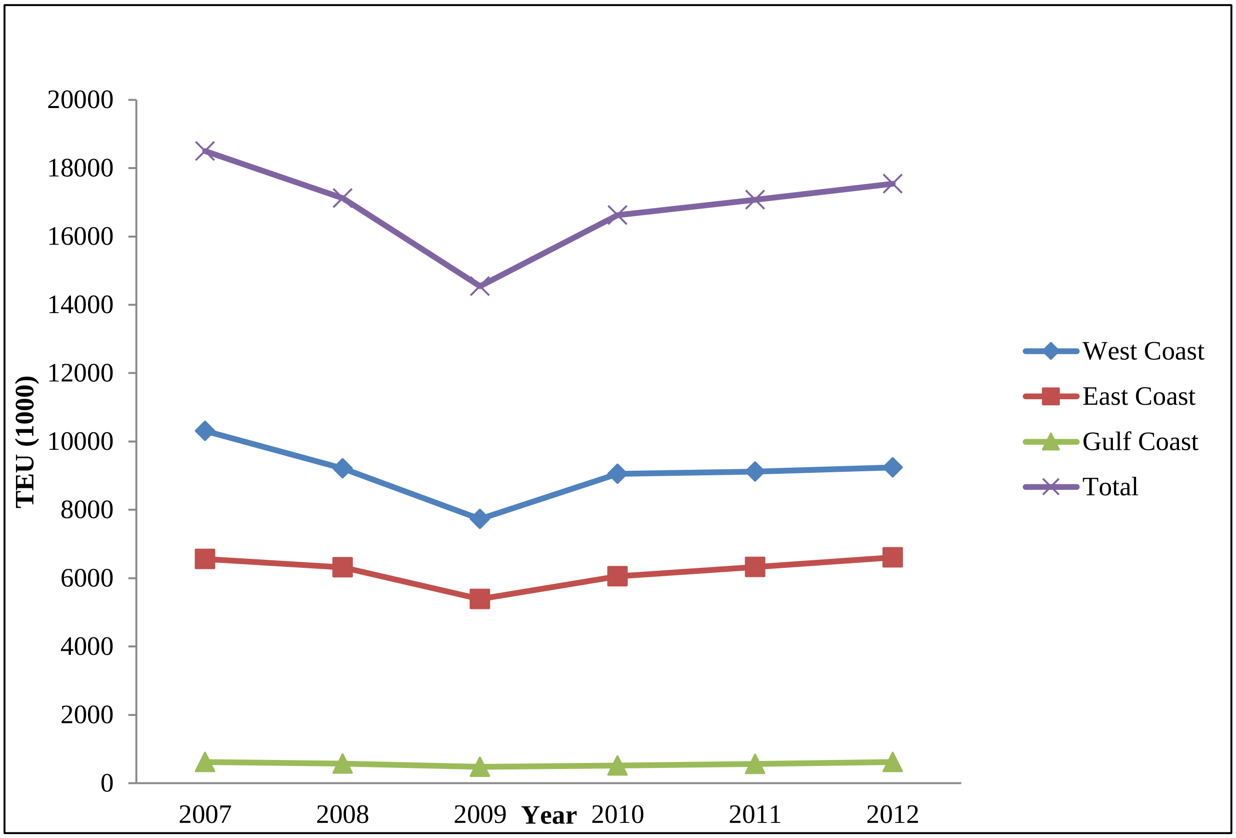


Figure 1.6. Container import trends at US coasts (US Maritime Administration, 2012).

More than 95% of US cargo imports arrived by ships (US Department of Transportation, 2009). To accommodate this situation in global trade, shipbuilders are making larger vessels. However, the larger Panamax vessels require deeper and wider shipping canals, greater overhead clearance, and larger cranes and shore infrastructure (US Department of Transportation, 2009). Some ports in the United States, such as the ports of Long Beach, Savanah, Oakland, Charleston, and Seattle, can receive New Panamax vessels. However, the efficiency of these ports is reduced by congestion caused by inland rail and road chokepoints (US Department of Transportation, 2009). Congestion affects the service reliability of the US transportation system and is critical for economic growth (Panama Canal Authority, 2006).

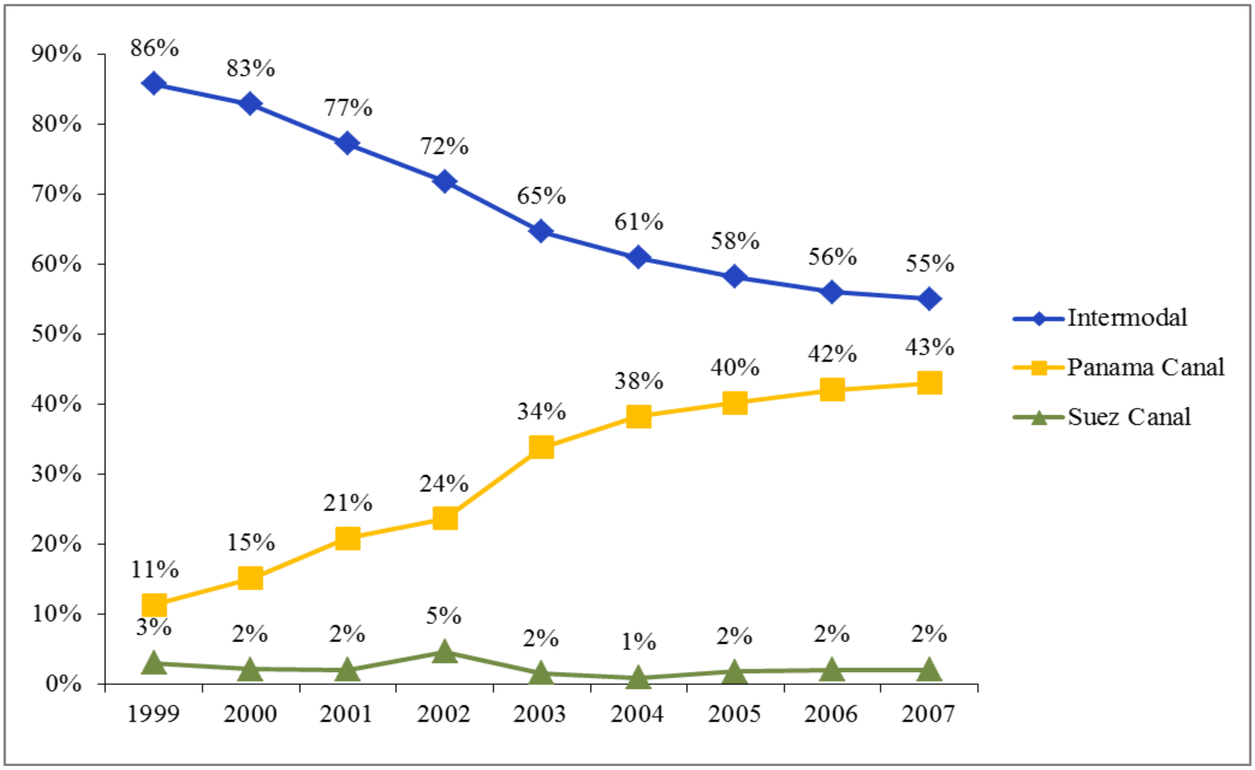


Figure 1.7. Shares of container flows between Northeast Asia and US East Coast ports (Panama Canal Authority, 2010).

There has been a significant drop in the share of intermodal rail servicing between the US West Coast and East Coast to the advantage of the Panama Canal route (all-water route). Figure 1.7 provides a snapshot of container flows between East Coast of the United States and its trading partners in Northeast Asia from 1999 to 2007. In 1999, intermodal rail between the US West Coast and East Coast accounted for 85.7% of the container traffic between Northeast Asia and the US East Coast, while the Panama and Suez canals route respectively accounted for 11.3% and 3% of the total container traffic. In 2007, the share of intermodal rail between the US West Coast and East Coast dropped to 55%, while Panama and Suez all-water routes accounted for 43% and 2% of the total traffic (US Surface Transportation Board, 2010). Thus, more container shipments between the US East Coast and Northeast Asia moved via the Panama Canal in recent years.

More than 1 million vessels have transited through the Panama Canal since it opened in 1914. The Panama Canal has served as a pathway for major world commodities and the importance of the Panama Canal continues to grow due to increases in trade between the United States and Asia. Container shipments have become the major type of commodities through the canal, although bulk shipments used to be major commodities through the canal in its history.

Now the canal is under the construction to expend the existing canal system. The Panama Canal is an efficient route between the US Gulf /East Coasts and Northeast Asia, but is reaching its maximum capacity. However, this problem would be resolved in 2016 when the Panama Canal expansion project is completed. Most currently, the Panama Canal Authority reported 86% of the expansion project was completed on February 2015. Figure 1.8 shows details of the existing locks and the new locks being built at the Panama Canal. As shown in Figure 1.8, major parts of the expansion project include dredging and the building of new locks. Dredging is the largest part of the expansion project since it will be able to allow New Panamax vessels to move through the Canal. The locks will be 38 feet wider, 18 feet deeper, and 401 feet longer than the current locks (Panama Canal Autuhority, 2012). The new locks will allow New Panamax vessels to move through the Canal. Since New Panamax vessels carry 12,500 TEUs of container shipments, while current Panamax vessels carry only 4,500 TEUs of container shipments, the expansion project will lead to more than a doubled capacity of the Canal. Therefore, the expansion project will accommodate growing trade volumes of container shipments and reduce congestion.

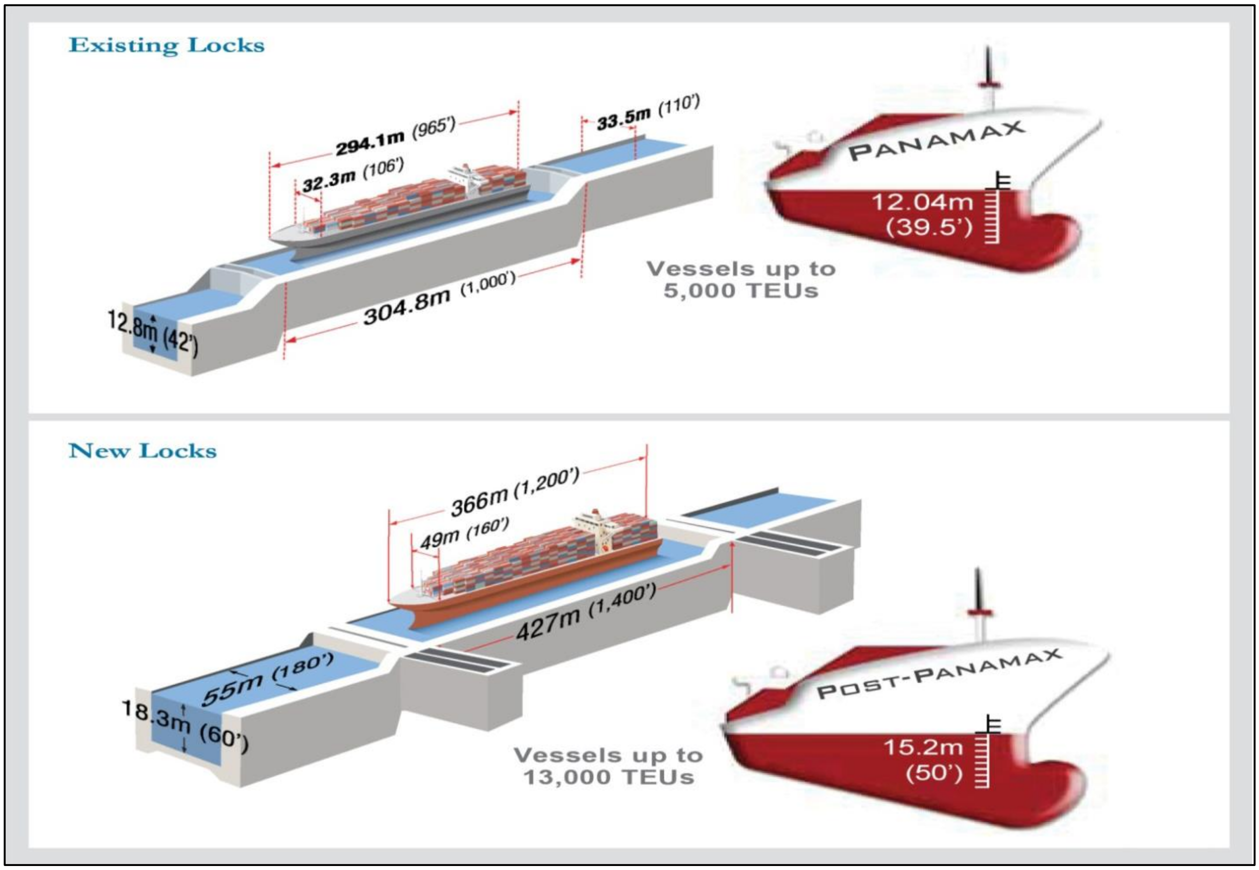


Figure 1.8. General information about the new locks at PNC (Panama Canal Authority, 2012)

1.2. Statements of the Problem

International trade is based on the ability of countries' productions, which differs based on resource endowments and technology and affects world economy growth potential. Global supply chain management is the single most significant element affecting volumes of goods from one nation to another. Therefore, there has been tremendous improvement in the global supply chain over the past couple of decades. One of the fastest growing segments of world trade is transporting container shipment. The United States is one of the leaders in container shipments with a growth rate of about 10% annually, while the average growth rate of the US GDP is 3.2% per year (US Bureau of Economic Analysis, 2014), implying that the United States is one of the fastest and largest growing markets of container shipments. Since containers transit through US seaports, container shipments have a significant impact on seaports, as well as intermodal transportation networks between the ports and inland.

Transportation costs of shipping containerized cargo from shipping origins in exporting countries to shipping destinations in importing countries consist of ocean transportation costs, inland transportation costs, cargo handling charges for loading and unloading at ports in exporting and importing countries, tolls at the canal (if the shipping route includes the canal), and delay costs (at the canal). Domestic transportation in an exporting country and international transportation cannot be separated and examined individually because they are interdependent.

There are interactions between domestic and international transportation. Domestic transportation costs affect international trade flows, as well as domestic trade flows in an exporting country. Inland transportation systems in exporting countries are another concern. How effectively inland transportation systems deliver containerized cargo from shipping origins to the export ports in exporting countries may be a critical measurement of countries' competitiveness in the world trade of container shipments.

The US railroad industry experiences intramodal and intermodal competition. Intramodal competition among railroad operators stimulates efficiency of rail transportation and reduces freight rates. Since railroads compete with barges in shipping containerized cargo from shipping origins to the US Gulf Coast ports, intermodal competition between rail and barge transportation also plays an important role in reducing rail freight rates. While the rail industry increases its efficiency to compete with barges, the barge industry loses its efficiency by decrepitude and erosion of dams and locks on river systems.

Global economics is driving the use of large vessels with their economies of scale. Ports that can handle these large vessels are expected to increase their market shares. Container traffic in the United States tends to be highly concentrated and is becoming even more so as larger vessels call on ports that are capable of handling them. As a result of these concentrations, increases in container shipping capacity (particularly enroute between Northeast Asia and the United States), and the escalation in vessel sizes, substantial strain or perception of future strain on capacity at most US ports is felt as well as in associated transportation corridors.

Changes in ocean transportation costs; toll, and delay costs at the Panama Canal; and port capacity after the PCE in exporting and importing countries are the most significant factors determining world container trade flows. A change in these factors is favorable to some exporting and importing countries, but not favorable to all. It is also necessary to evaluate how the changes in these factors affect the world trade of container shipments and individual exporting and importing countries.

The Panama Canal Expansion (PCE) may positively affect container shipment trade in the United States since the canal is a gateway for transporting containerized cargo between the United States and Asia. By completion of the expansion, transportable vessel size through the canal will increase from current Panamax size (4,500 TEUs) to a new Panamax size (12,500 TEUs) and efficiency of canal operation and its operation costs would increase. As a result, toll rates may be increased by the Panama Canal Authority, which has rights for operations and maintenance, to maximize its revenue from the canal.

1.3. Research Objective

The main objective of this study is to analyze the impacts of the Panama Canal Expansion (PCE) on the flows of containerized shipments from shipping origins in the United States to its export destinations and its impact on flows of containerized cargo from ports in exporting countries to shipping destinations in the US, with special interest in the flows of container shipments between the United States and Northeast Asia and Europe. More specifically, the study is designed to examine the following scenarios: (1) investigate the impacts of PCE on the transportation costs of US container shipments, (2) evaluate the impacts of the PCE on the trade volume and flows of container shipments through analyzing US container shipments comparing pre-PCE to after, (3) investigate impacts of delay cost at the PNC on the trade volume and flows of containerized shipments for US exports and imports, (4) examine the impacts of alternative toll rates in the Panama Canal on the flows of container shipments to ports in the United States and ocean shipping routes, (5) estimate an optimal toll rate to maximize the Panama Canal's revenue after PCE, (6) estimate throughput of container shipments at the Panama Canal after PCE, and (7) estimate port handling capacity in the United States after PCE.

The primary focus of this research is US trade of container shipments with Northeast Asia and Europe. Since Northeast Asia has a large trade volume of container shipments, the area of interest is whether more US container shipments will be shipped through the US Gulf and East Coast ports via the Panama Canal or if US container shipments will be shipped through US West Coast ports such as the Pacific Northwest (PNW) or Los Angeles/Long Beach (LA/LB). The major contributions of this study are that it evaluates impacts of toll rates at the Panama Canal due to the expansion of container trade flows, it estimates the economic value of the canal expansion in the world container trade, and estimates further needs of ocean and inland transportation infrastructures.

1.4. Assumptions

The model developed for this study is based on the following assumptions.

(1) The values of containerized cargo are ignored, mainly because the container is the equipment used for the shipping of commodities/products between shipping origin and destination.

(2) It is assumed that every container is fully loaded, while its total weight is 24 tons with 22 tons of net load. In this general situation, for normal or low value cargo, most shippers and carriers would not leave any wasted space inside containers because most ocean carriers (liners) charge shipping costs based on TEU rather than tonnage for containerized shipments. Although shipping rates are differentiated by container type, such as frozen, empty, and loaded, it does not charge based on cargo weight.

(3) US containerized shipments are moved by rail, truck, and barge between shipping origins/destinations. Trucks transit containerized shipments within less than 250 miles between shipping origins/destinations, and rail is used for distances greater than 250 miles. Truck and barge combinations are also used on the U.S. river systems.

(4) From the 1990s to 2000s, barge liners operated their services to transit containerized shipments between the Gulf ports and river ports along the US river systems because there were enough shipments for liner services and it was competitive with rail operations for long hauling. However, many barge liners quit operating their services for containers mainly because of the backhaul shortage at the end of 2000s. In other words, they had enough

shipments from the Gulf ports to river ports along the river systems for US imports, but there were not enough shipments on a return trip from river ports to the Gulf ports. This implies that the United States is a trade deficit country. In the United States, only one barge carrier still transports containers on barge service now and their service is based on contract rather than line service (Koenning, 2014). Therefore, it is assumed that container service is available at all river ports with their unlimited port capacities in the United States for barge service.

1.5. Organization

The introduction to the study, a background, the importance of container shipment trade, statement of the problem and objectives, and major assumptions were outlined previously. The remainder of this dissertation is organized as follows. Chapter 2 presents an extensive review of relevant literature on linear programing models, transportation cost models, container activity, and the Panama Canal expansion. The foundation of the study and insights on theory and methodology were built up through review of similar studies in this chapter. Chapter 3 outlines the theoretical foundation and background for model development and structure. The deterministic of base optimization model is developed. The major model parameter estimation and assumptions are explored in this chapter.

Data collection for this study is represented in Chapter 4. Chapter 4 describes details and procedures of data collection and development for supply and demand, transportation cost estimation, and the PNC delay cost. Chapter 5 presents the results found in regards to the trade flows and transportation costs associated with US containerized shipments under the base and alternative models. The results are also used to comparatively analyze the impacts of the Panama

Canal Expansion (PCE) on US trade. Chapter 6 summarizes and concludes and provides overall major findings and contributions for this dissertation. Finally, nine appendixes are included. Appendix A shows export demand and import supply (TEUs) for US exports. Appendix B presents export demand and import supply (TEUs) for US imports. Appendix C represents cargo handling costs (US$) at ports in exporting and importing countries. Appendix D shows cargo handling capacities of the Panama Canal and US container ports (TEUs). Appendix E represents inland transportation networks used for this study. Appendix F shows ocean transportation networks used for this study. Appendix G represents the quantities of exports and imports in the 49 states of the US mainland (TEUs). Appendix H shows Q&A during a personal interview with an expert in the barge industry in a phone interview. Appendix I shows GAMS code for the base model of this study.

CHAPTER 2. LITERATURE REVIEW

The study of the use of container shipments has been active, especially during recent decades of global booming trade. There exists a large body of research on spatial optimization modeling, spatial equilibrium modeling, transportation cost modeling, traffic flow optimization, infrastructure planning, intermodal simulation, empty container allocation problem, ocean ship scheduling, freight security, and freight network modeling. This chapter reviews current and previous research on the container shipping industry. The review covers literatures ranging from general research on global container trade, to supply chain network planning, to relevant mathematic methodology.

2.1. Spatial Optimization Models

Koo and Thompson (1982) developed a spatial optimization model using a linear programming algorithm to optimize US grain distribution systems. The objective function of this model is to minimize transportation and handling costs associated with transportation activities for the US grain trade. The authors found that the capacity constraints of transportation modes determine the flow of grain from shipping origins to destinations. The capacity constraints of transportation modes do not affect the flow when using shorter shipping distances and changes in grain flow to domestic markets. On the other hand, changes in costs of transportation modes affect intermodal transportation systems from origins to destinations since demand for barge service has more price elasticity than for rail services.

Koo, et al. (1988) used a spatial optimization model to optimize domestic and international grain flows. The authors found that international grain flow is influenced more by changes in ocean transportation costs at a particular port rather than by uniform changes at all ports. The reallocation of export shipments from the Gulf to other ports results in high freight rates for several importing regions because domestic transportation costs from major shipping origins are lower to US Gulf ports than to other US ports. The cheapest transportation mode for long distance transport to US Gulf ports is barge along the Mississippi River system. In addition, once ocean transportation costs from the Gulf ports to East Asia increase, quantities of grain shipped from the US West Coast to East Asia substantially increase.

Wilson, Koo, Taylor, and Dahl (2005) developed a large-scale spatial optimization model based on a longer-term competitive equilibrium to make projections in the world grain trade. The spatial distribution of grain flows are affected by changes in world grain trade. The changes in world grain trade are influenced by many factors, including production, consumption (which is impacted by tastes, population and income growth), and agricultural and trade policies. In addition, relative costs of production, interior shipping, handling and ocean transportation costs all have an impact on trade and competitiveness. Six major grains (wheat, corn, soybean, barley, sorghum, and rice) were identified for this study and very detailed data was generated. According to this study, world trade should increase by about 47%, with the fastest growth occurring in imports to China and Pakistan. Japan and the European Union (EU), traditionally large markets, are expected to have the slowest growth. Most of the increases are expected in soybeans (49%), followed by corn (26%), and most of US exports growth is expected through the US Gulf.

Wilson, Koo, Taylor, and Dahl (2005) developed a detailed spatial optimization model of the world grain trade in order to analyze the potential impacts of the Panama Canal expansion on the world grain trade. The model has the objective of minimizing production costs in exporting countries, and marketing costs from shipping origins in exporting countries to shipping destinations and importing countries. The objective is minimized subject to meeting demands at importing countries and regions, available supplies and production potential in each of the exporting countries and regions, and currently available shipping costs and technologies. The model is solved jointly for each of the six grains (wheat, corn, soybean, barley, sorghum, and rice). The model also contains 13 exporting countries and 26 importing countries with each type of grain and oilseed having different sets of exporting and importing countries. In the United States, there were 10 shipping origins and destinations, conforming to traditional production/consumption regions, and 3 export ports. Canada had 5 shipping origins and 2 possible export ports, in addition to shipping through the United States. Transportation modes included truck, rail, and barges for inland transportation and ocean vessels for ocean transportation. The model contains 16 ports in exporting countries and 32 ports in importing countries for transit of grains and oilseeds from shipping origins in exporting countries to shipping destinations in importing countries. The authors expected that the range of trade through the Panama Canal (after expansion) for those grains would be an increase from 35 mmt to 59 mmt in 2025, while the range in world grain trade in 2025 for these grains would be an increase from 270 mmt to 360 mmt (all grains, Canal and non-Canal). An expanded Canal would allow for larger vessel sizes used for grains, varying by markets, and would result in reduced shipping costs.

2.2. Transportation Costs and Container Shipment Trade

Limao and Venables (2001) investigated the dependence of transportation costs on geography and infrastructure. Transportation costs and trade volumes depend on many complex details of geography, infrastructure, administrative barriers, and the structure of the shipping industry. The authors used several sources of evidence to explain transportation costs and trade flows in terms of geography and the infrastructure of the trading countries. Two different data sources for transportation costs were used. The first is shipping company quotes for the cost of transporting a standard container from Baltimore, Maryland, to selected destinations. A second data set used a cross section of the ratio of carriage, insurance, and freight (CIF) to free on board (FOB) values that the International Monetary Fund (IMF) reported for bilateral trade between countries. Analysis of bilateral trade data confirmed the importance of these variables in determining trade and enabled the computation of estimates of the elasticity of trade flows with respect to transportation costs. They found that this elasticity is large, with a 10% increase in transportation costs typically reducing trade volumes by approximately 20%. They also found that the deterioration of infrastructure from the median to the 75th percentile raised transportation costs by 12% and reduced trade volumes by 28%. In addition, the authors extended the quantitative implications of their findings by applying them to the Sub-Saharan African trade, a real case study.

Behar and Venables (2010) studied not only the impact of transportation costs on the volume and nature of international trade but also the determinants of international transportation costs. Transportation costs also influence modal choice, the commodity composition of trade, and the organization of production, particularly as ‘just-in-time’ methods get extended to the global level. The authors found that transportation costs affect international trade and vice versa. Both are influenced by considerations of geography, technology, infrastructure, fuel costs, and policy towards trade facilitation. Distance is not the only significant geographical factor. Being landlocked increases trade costs by 50% and reduces trade volumes by 30-60%. Over time, technical change and the price of fuel have influenced transportation costs and trade volumes.

Binkley and Harrer (1981) explained that trade volume is of approximately equal importance with distance in determining rates through the econometric analysis of ocean grain rates suggests that ship size and trade volume. The authors developed a cross-section model to investigate the determinants of ocean freight rates for grain. Large ships reduce ocean transportation costs, but larger ships appear to incur higher port costs such as loading and unloading costs. They found that policies to improve shipping technology and increase trade volume can lead to lower rates, reduce geographic differences among exporters, and generate more competitive markets. This implies that the role of transportation in trade analysis should not be ignored.

Park and Koo (2004) evaluated structural changes and price differentials in ocean freight rates for grain shipments from US ports to various, major importing countries using a cross-sectional econometric model. Ocean freight rates fluctuate widely because of unbalanced traffic, low probability of backhaul shipments, and a lake of economic regulations in ocean transportation industries. The authors found that not only cost factors, such as distance and the ship size, but also the geographical location of the port play an important role in determining ocean freight rates. Ocean freight rates depend on types of commodities. In addition, there were seasonality and changes in structure for grain shipments during the 1987-1998 period.

Hummels (2007) used regression analysis to investigate the role of cost shocks and technological and compositional change in shaping the time series in transportation costs and then draw out implications of these trends for the changing nature of trade and integration. The author concentrated on international shipping trends of ocean and air transportation from 1950 to 2004. He found that ocean shipping constituted 99 percent of world trade by weight and a majority of world trade by value also experienced a technological revolution in the form of container shipping, but dramatic price declines are not in evidence. Instead, prices for ocean shipping exhibited little change from 1952–1970, substantial increases from 1970 through the mid-1980s, followed by a steady 20-year decline. Trade using container lowers shipping costs from 3% to 13%. However, ocean freight costs began to increase with the rising cost of crude and port congestion at the end of 1980s.

Korinek and Sourdin (2010) attempted to investigate the role that maritime freight costs play in determining ocean–shipped agricultural imports by using the newly-compiled Organization for Economic Co-operation and Development (OECD) Maritime Transportation Costs database. The authors found that transportation costs significantly and negatively impact agricultural imports, even after controlling for shipping distance. Analysis of the new dataset on maritime transportation costs underscored the importance of shipping in determining agricultural trade flows. The cost of shipping represented 10% of the overall cost of importing goods worldwide in 2007, and maritime transportation costs are even higher for some products, for example grains and oilseeds, and some countries, particularly small, developing countries. Lower income, net food-importing countries paid particularly dearly for imports of staple foods. The shipping costs of importing grains to some of these countries were 20–30% of their 2008 import value.

Koo and Uhm (2008) applied the theory of rail rates for cargo shipments to the United States and Canadian grain movements for both domestic and export destinations. The authors attempted to analyze that grain freight rates in US are significantly determined by distance, shipment size, frequency of shipments, intermodal competition, and geographical characteristics of route origins and destinations. For domestic grain, the rail-rate equation was estimated on the basis of 523 origin-destination routes where grain flows are heavy. 200 observations for wheat and 323 observations for corn and soybean movements were used. The total number of observations to estimate export grain rail-rate equation was 432 origin-destination routes, while

187 observations were used for wheat and 245 observations were used for corn and soybean movements. A comparison of US export rates with Canada's statutory rate revealed that US rate levels, in 1979, were 4.3 and 2.9 times higher for hauling distances of 200 and 1,000 miles respectively in the lowest-rate route; while it was about 7.8 and 7.5 times higher for the same mileage in the highest-rate route. It is concluded that if deregulation stimulates competition between rail and other inland transportation modes and among the railroads themselves, the expectation is of a lowering of freight rates in the Corn Belt, the Eastern, and Southern states. In contrast, in the Northern Plains, where railways face only limited competition from barge and truck transportation freight rates were already the highest in the United States. There was not seasonality on the demand for grain for domestic and export markets, although seasonal rates might be beneficial to both producers and consumers if they have the effect of moderating seasonal fluctuations in demand.

2.3. Operation of the Current Panama Canal and Its Expansion

Fuller, Makus, and Gallimore (1984) evaluated the ability of Panama Canal management to extract additional toll revenues from the transportation of United States grain and determined the effect of increasing toll rates on United States grain flows to port regions. A multi-commodity, multi-period, and cost-minimizing spatial model was used to conduct the analysis. Authors found that there is a relatively inelastic relationship between toll rate levels and the quantity of United States grain traveling through the Panama Canal. Therefore, there appears to be substantial opportunity for increasing toll rates and revenues if Canal management adopted a revenue maximizing philosophy. They also found that the revenue maximizing toll rates on soybeans, sorghum, and corn would range from 6 to 24 cents per bushel between 1975 and 1982.

Revenue maximizing tolls would be greatest when the Gulf and Pacific port ship rates to Asia are similar and smallest when the Gulf port rates to Asia are relatively high.

Pagano, Light, Sánchez, Ungo, and Tapiero (2012) investigated the economic impact of the Panama Canal expansion on the economy of Panama since the Panama Canal is the most significant resource, and a key industry in Panama. Authors found that the economic impact of the Panama Canal expansion on the Panama national economy must be considered based on its impact on export generation by using an Input-Output model. A gravity model was used to estimate the economies of agglomeration and network effects that result from the canal on the Panama Canal Trade in Logistics Services Cluster. In Panama, with its own small, open economy, exports are essential to maintain dynamic economic growth by linking the country to larger markets. 82% of Panama's economy and 33% of its exports are comprised of services. More than 75% of exports are services exported by the activities of the Cluster in the Interoceanic Transit Region, most of which are related to canal activity. It is concluded that Panama's economic growth depends, to an extent, on the Cluster's service exports.

Ungo and Sabonge (2012) analyzed the competitiveness of Panama Canal routes. The competitiveness of routes that use the Panama Canal against alternative routes based on total transportation cost for different type of vessels was computed by developing the Panama Canal Route Competitive Analysis Model. Fuel costs, operating costs, capital costs, charter rates, port costs, handling costs, and canal costs were used for ocean transportation costs, while inland transportation costs for truck, rail, and barge were based on market rates. The main finding is that the value of Panama Canal routes increases in times of heightened fuel prices.

Fan, Wilson, and Dahl (2012) analyzed spatial competition, congestion, and flows of container imports into the United States by developing a comprehensive intermodal network flow model. The model determines optimal ship sizes, routes, vessel-strings, container flows, and congestion costs and evaluates the value of increasing capacity at individual ports, as well as the impact of expanding all ports simultaneously. Authors found that there are fairly significant changes including the near-simultaneous expansion of water-routes serving the United States markets, as well as either new ports or expanded ports which are pending at many US ports. The results represent that channeling expansion decisions to conform to long-term optimal results should be a priority and ports should explore pricing and assess the feasibility of adopting varying forms of congestion pricing as a mechanism to even out flows.

Pagano, Wang, Sánchez, and Ungo (2013) evaluated impacts of privatization on port efficiency and effectiveness using Panama and US ports as examples. The results provide an estimate of the savings and effectiveness gains from privatization through a comparison between Panama and US ports using financial econometric techniques. Authors found that there is significant relationship of between port efficiency and various variables, which represent the type of operation indicates that privatization can have a positive impact on port efficiency for privatized ports to be more effective than publicly run operations.

The US Department of Transportation (DOT) and Maritime Administration (MARAD) (2013) reported on the Panama Canal expansion study which focus on examining the anticipated economic and infrastructure impacts of the Panama Canal expansion on US ports and port-related freight transportation infrastructure. The report presented information in four key areas: (1) the Panama Canal Expansion and its potential effects, (2) major factors that shape impacts on US ports and infrastructure, (3) impacts on US trade, and (4) impacts of the Panama Canal expansion on US regions. First, the Panama Canal is an important link in global trade, accommodating an estimated 5% of the world's total cargo volume. The Panama Canal expansion will double the Canal capacity and allow the passage of much larger ships than those currently able to transit the Canal. Second, the use of larger ships will increase the volume of containers that must be moved at each port of call to make the port of call profitable for the carrier. This will likely lead to fewer and more concentrated ship calls at larger ports, especially for vessel deployments serving between Northeast Asia and the US East and Gulf coasts trade. Third, the transition from 5,000 TEU vessels to 13,000 TEU vessels on Northeast Asia-US East/Gulf Coasts routes will result in significant gross cost savings, but a significant portion of these savings are expected to be absorbed by transportation service providers, rather than be passed on to the cargo owners. Last, cost reductions will be derived from volumes of cargo switched from the US West Coast routing to all-water service to the US East and Gulf Coasts. Shifts in shipments from the West Coast to East Coast ports may occur due to per-TEU cost reductions, but these shifts will be limited, relatively, by the already high current Panama Canal shares. As the US East Coast region already receives a large share of its imported goods (particularly for lower value products) via the Panama Canal, it will benefit the most from cost reductions associated with the Canal expansion. Both the use of the Panama Canal for shipments inland through the East Coast ports and the absolute cost reduction benefits related to current cargo flows will likely be small relative to intermodal service from West Coast ports.

Most recently, the Panama Canal Authority (2015) proposed to increase toll rates at the canal once the expanded canal begins operations. Previous toll rates are based on the concept of “one price fits all” where, for a merchant vessel, toll calculations are based on their volumetric capacity, measured using the Panama Canal/Universal Measurement System (PC/UMS) Net Tonnage, which only differed if the vessel transited laden or ballast, and in the case of other floating craft, including dredges, dry docks and warships, which were charged tolls on the basis of displacement tonnage (the weight of sea water that the vessel displaces). However, the Panama Canal Authority implemented a change in its admeasurement system applicable only to full container vessels and those vessels with container-carrying capacity on-deck in 2005. After that, the adjustment modified the traditional measure utilized as the charge basis for these vessels, from PC/UMS Net Ton to a twenty feet container, or TEU and established the total TEU capacity, including on-deck, adjusted for the visibility restrictions of the canal, as it has been changed several times until 2011. The current toll rate per TEU at the canal is $74 and the proposed toll rate is $90 per TEU, an approximately 22% increase.

CHAPTER 3. MODEL DEVELOPMENT

A large number of factors impact world trade in container shipments, the distribution of container shipments, and container shipments through the Panama Canal. These include supply and demand in individual countries and regions, ocean and inland transportation costs, cargo handling costs, delay costs, and tolls at a canal. To analysis these, a spatial optimization model of world trade in container shipments was developed. This chapter provides a detailed description of the development of an optimization model for container supply chain activity, minimizing total transportation costs subject to meeting demands in importing countries and regions. Section 3.1 provides a theoretical foundation, Section 3.2 presents a basic structure of container shipment modeling, and Section 3.3 provides a detailed description of the mathematic formulation.

3.1. Theoretical Foundation

Figure 3.1 represents effects of transportation costs from an exporting country to an importing country. Figure 3.1 (a) shows domestic demand and supply in an importing country and Figure 3.1 (c) represents domestic demand and supply in an exporting country. Figure 3.1 (b) shows export supply and import demand in international market. In Figure 3.1 (b), an international equilibrium price of goods without transportation costs is P and the quantity traded is OQ. Transportation costs are represented by distance ab, which is equal to (P_1 - P_2). Given this transportation cost, the price in the importing country increases from P to P_1, and the price in the exporting country decreases from P to P_2. The price difference between the two countries, (P_1 - P_2), is transportation costs in a free market system. Since the price of goods in the importing country increases and the price of goods in exporting country decreases, the trade volume decreases from Q to Q_I. This trade volume is equal to country's imports and country's exports. The decrease in the price of goods in the exporting country is the portion of transportation costs that producers pay in the exporting country. The increase in price of goods in the importing country is the portion of transportation costs that consumers pay in the importing country. This implies that transportation costs are shared between the two countries, depending upon the price elasticity of export supply and import demand. However, transportation costs are measured by TEU, rather than the actual price of goods because it is not possible to evaluate the value of goods in containers for every containerized shipment. Therefore, the value of goods in containers is ignored for this study since various types of cargo are containerized.

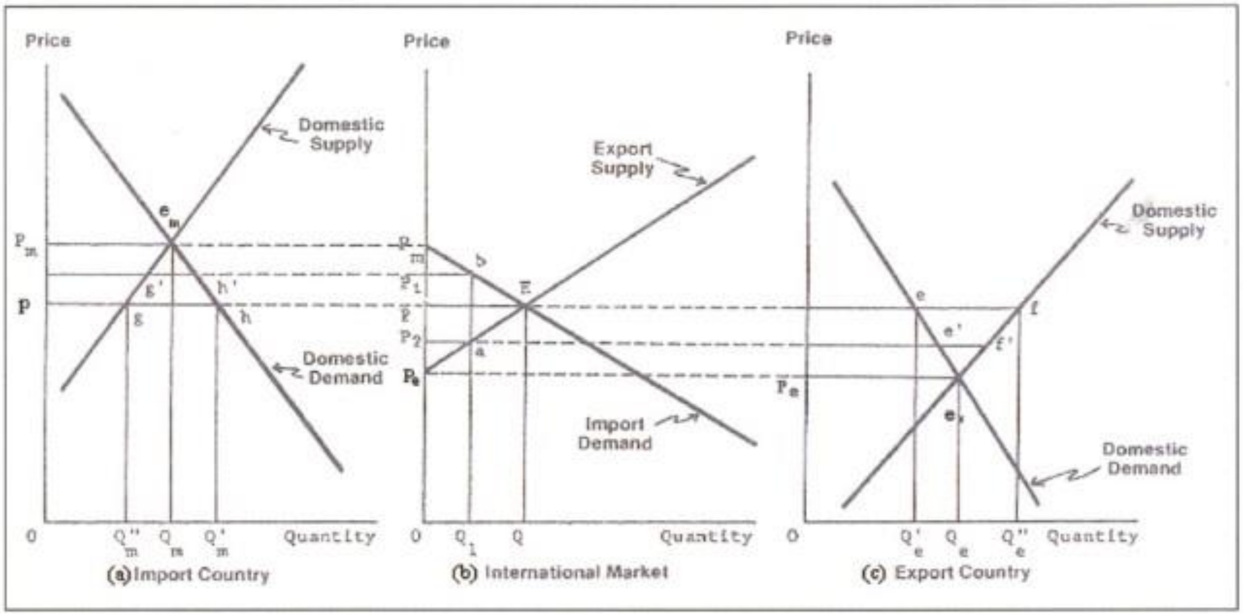
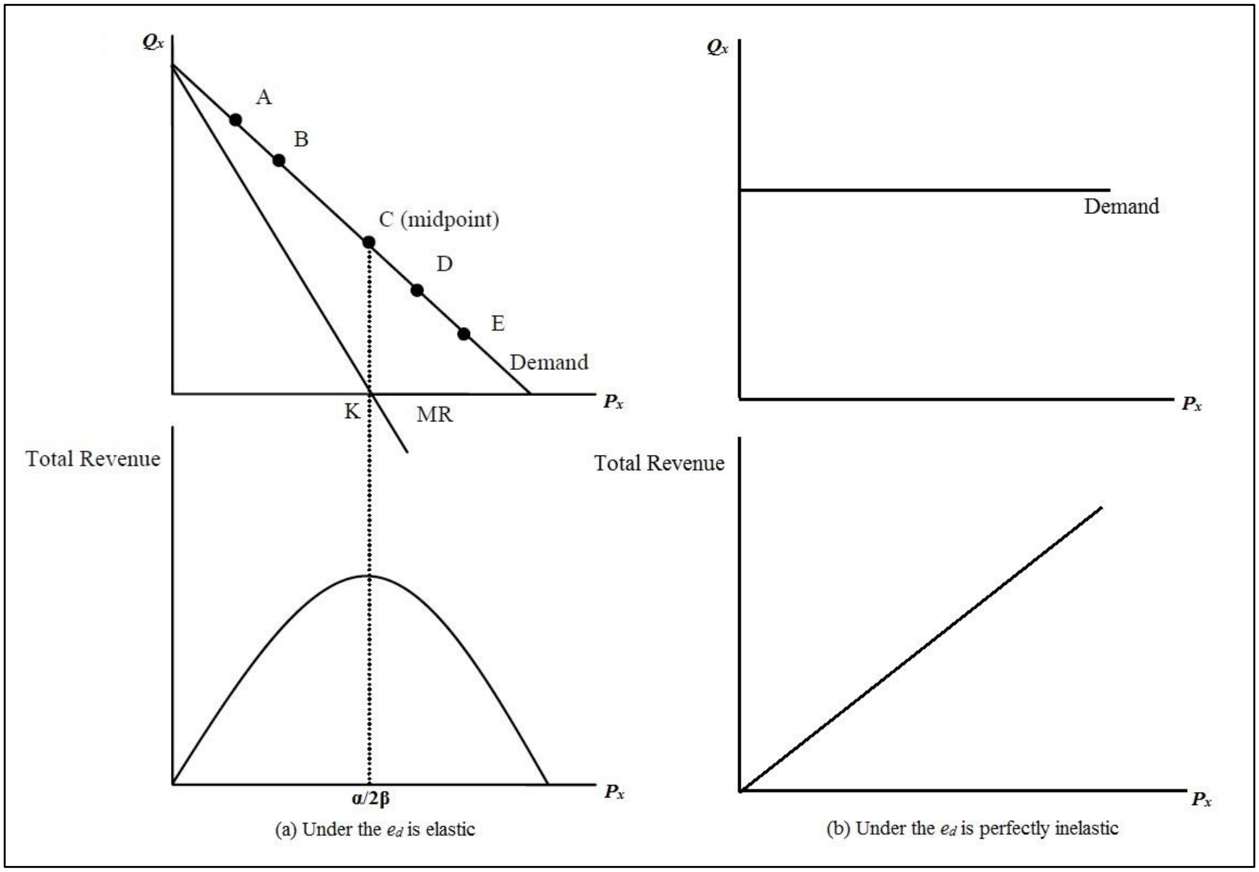


Figure 3.1. Effects of Transportation Cost (Koo, 1984).

Figure 3.2 shows the relationship between trade volume and toll rate at the Panama Canal through demand and total revenue curves. Figure 3.2 (a) shows the relationship under the elasticity of demand (e_d) is elastic and Figure 3.2 (b) indicates the relationship under the elasticity of demand (e_d) is perfectly inelastic. In Figure 3.2 (a), *MR* is marginal revenue which is the extra revenue associated with one additional TEU increase through the canal. P_x is toll rate at the canal and Q_x is quantity of TEUs through the canal. For $Q_x < K$, as long as *MR* is positive, meaning every additional TEU will increase the total revenue. However, MR gets smaller as output increases. Thus, the total revenue increases at a decreasing rate. Eventually, at the midpoint (C) of the linear demand curve, $MR = 0$. This implies that the total revenue neither increases nor decreases. For $Q_x > K$, $MR < 0$, indicating that every additional TEU will decrease the total revenue. In Figure 3.2 (b), since changes in quantity are not sensitive to changes in price, the total revenue increases as the price increases. Marginal revenue (MR) is equal to demand. As a result, an optimal price to maximize the total revenue is inconclusive when the elasticity of demand is perfectly inelastic.



(a) Under the e_d is elastic

(b) Under the e_d is perfectly inelastic

Figure 3.2. Relationship between trade volume and toll rate at the Panama Canal.

Throughput demand through the PNC (Figure 3.2 (a)) can be expressed as follows:

$$Q_x = \alpha - \beta P_x \tag{3.1}$$

where Q_x is the quantity shipped through the PNC and P_x is toll rate at the canal.

$$TR = P_x * Q_x = (\alpha - \beta P_x) * P_x = \alpha P_x - \beta P_x^2 \tag{3.2}$$

MR is obtained by taking partial derivative of TR with respect to P_x as follows:

$$\frac{\partial TR}{\partial (P_x)} = \alpha - 2\beta(P_x) \tag{3.3}$$

To find the toll rate to maximize TR, set $MR = 0$ as follows:

$$\alpha - 2\beta(P_x) = 0 \tag{3.4}$$

$$P_x = \frac{\alpha}{2\beta} \tag{3.5}$$

3.2. Basic Structure of Container Shipment Model

The model used for this study is developed on the basis of a mathematical programming model based on a linear programming algorithm. The objective of the model is to minimize transportation and handling costs of containers from shipping origin to destination. The objective function is optimized subject to a set of linear equations, representing the supply of containerized cargo at shipping origins in exporting countries and demand for the cargo in importing countries. Inland transportation modes used in this study are rail, truck, and barge. In general, trucks are the cheapest transportation mode for shipping containers short distances, followed by rail (Figure 3.3). For this reason, trucks and rails will be used to ship domestic containers from shipping origins/destinations to/from container ports in the United States. Since barges are the cheapest mode of transportation for long distances, rail and barges will be used for long-distance hauling.

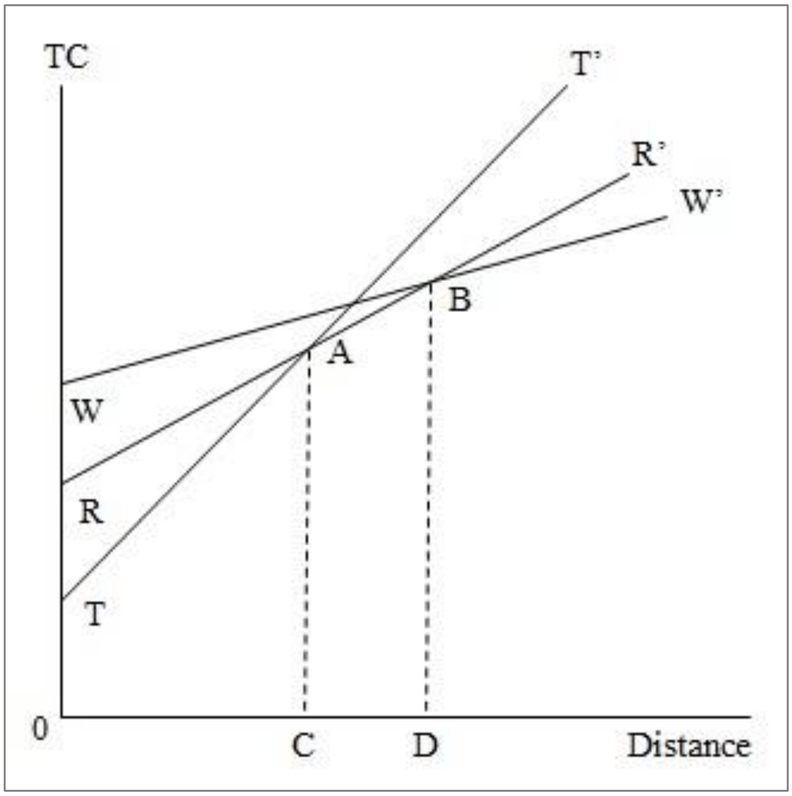


Figure 3.3. Hypothetical trip cost curves for rail (RR'), truck (TT'), and barge (WW') modes of transportation for a given origin/destination (Koo, Tolliver, and Bitzan, 1993).

In Figure 3.3, the industry has a comparative advantage in section OC, railways in section CD, and barges in distances greater than OD. Container vessels are the primary ocean transportation mode for shipping containers from ports in exporting countries to ports in importing countries. Figure 3.4 shows the classification of container ship by its capacity. As shown in Figure 3.4, the maximum container vessel size through the Panama Canal will increase from 4,500 TEUs to 12,500 TEUs, three times larger than the current Panamax allowance.

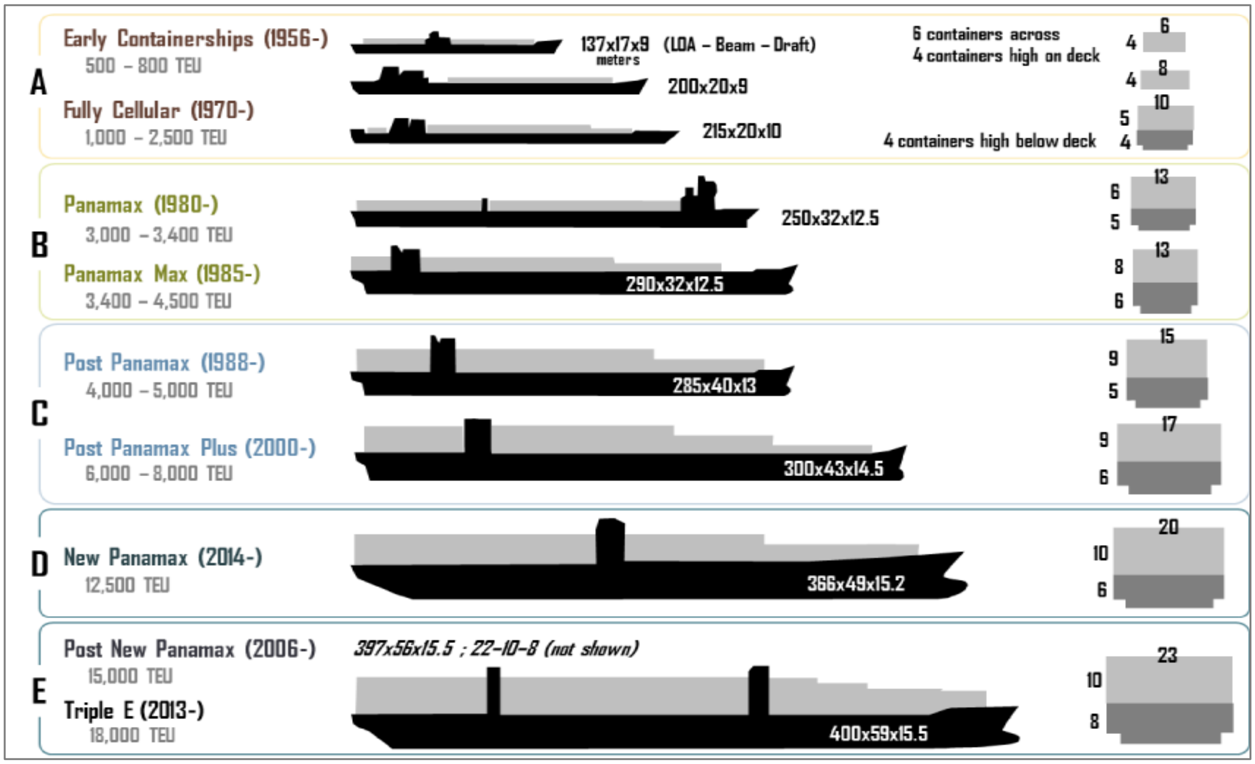


Figure 3.4. Classification of container vessel by its capacity (in meters) (Ashar and Rodrigue, 2012).

3.3. Model Description

Set:

SO = set of shipping origins for US exports in the United States

EP_e = set of export ports for US exports in the United States

RP_e = set of river ports for US exports in the United States

IP_e = set of import ports for US exports in importing countries

EP_i = set of export ports for US imports in exporting countries

IP_i = set of import ports for US imports in the United States

RP_i = set of river ports for US imports in the United States

SD = set of shipping destinations for US imports in the United States

Parameters:

D_q = demand of TEUs for US exports in importing countries, $q \in IP_e$

Q_i = supply of TEUs for US exports in shipping origins, $i \in SO$

D_d = demand of TEUs for US imports in shipping destinations, $d \in SD$

Q_f = supply of TEUs for US imports in exporting countries, $f \in EP_i$

PC_p = cargo handling capacity (TEUs) at export ports in the United States, $p \in EP_e$

PC_u = cargo handling capacity (TEUs) at import ports in the United States, $u \in IP_i$

PC = aggregated cargo handling capacity (TEUs) at ports in the United States

PCC = cargo handling capacity (TEUs) at the Panama Canal

T^t = truck freight rate per TEU in the United States

T^r = rail freight rate per TEU in the United States

T^b = barge freight rate per TEU in the United States

T^o = ocean freight rate per TEU without the Panama Canal

T^{oc} = ocean freight rate per TEU through the Panama Canal

h = cargo handling charge per TEU at ports in exporting and importing countries

ρ = toll rate per TEU at the Panama Canal

σ = delay cost per TEU at the Panama Canal

Decision variables:

Q^t = the quantity of TEUs shipped by truck

Q^r = the quantity of TEUs shipped by rail

Q^b = the quantity of TEUs shipped by barge

Q^o = the quantity of TEUs shipped by container vessel without the Panama Canal

Q^{oc} = the quantity of TEUs shipped by container vessel through the Panama Canal

3.4. Spatial Optimization Model for US Exports

The model developed for US exports includes shipping origins and export ports in the United States and major container ports in importing countries, especially Northeast Asia and Europe. Shipping origin of each is identified based on workforce. Major container importing countries are chosen on the basis of their import volume from the United States. The model includes several inland transportation modes in the United States to evaluate the effects of intermodal competition on optimal container shipments for export in the United States. The model also includes major container ports in the United States for international trade. These ports will be used in the transit of containers from shipping origins in the United States to ports in importing countries.

Figure 3.5 represents the supply chain of container shipments from shipping origins to export ports and from export ports to ports in importing countries either with or without the Panama Canal. Rails and trucks are considered as transportation for shipping containers from shipping origins to export ports and a truck-barge combination is also considered as an inland transportation mode in the United States. The truck-barge combination consists of transiting containers from shipping origins to the river ports by truck and from the river ports to the US Gulf ports by barge. Container vessels are available for the ocean transportation mode and it navigates on a route either with or without the Panama Canal. Different sizes of container vessels are used for this study because the Panama Canal and container ports of exporting and importing countries have a size limitation of vessel that can be handled at their facilities.

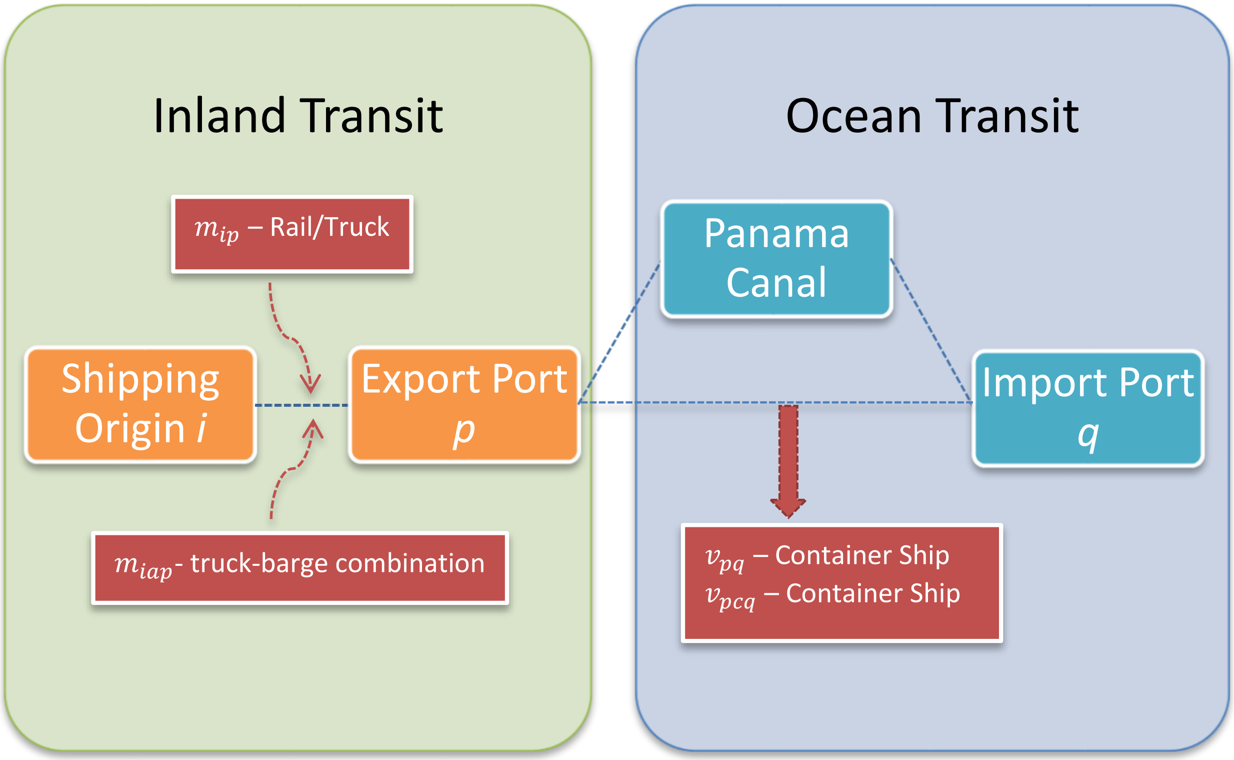


Figure 3.5. Regions associated with container trade and transportation modes for US exports.

The domestic transportation system in the United States is optimized by using a linear programing model. The objective function of the spatial optimization model is to minimize transportation and handling costs in shipping containers from shipping origins to export ports in the United States. The objective function is specified as follows:

$$W_{el} = \sum_{i=1}^{I}\sum_{p=1}^{P} Q_{ip}^{t} T_{ip}^{t} + \sum_{i=1}^{I}\sum_{p=1}^{P} Q_{ip}^{r} T_{ip}^{r} + \sum_{i=1}^{I}\sum_{a=1}^{A} Q_{ia}^{t} T_{ia}^{t} + \sum_{a=1}^{A}\sum_{p=1}^{P} Q_{ap}^{b} T_{ap}^{b} \qquad (3.6)$$

where *i* is an index for shipping origins in the United States, *p* is an index for export ports in the United States, *t* is an index for truck transportation mode, *r* is an index for rail transportation mode, *b* is an index for barge transportation mode, *a* is an index for barge access points, and *T* represents transportation costs. Q_{ip}^{t} is containers (TEUs) shipped from shipping origin *i* to export port p by trucks, Q_{ip}^{r} is containers (TEUs) shipped from shipping origin *i* to export port *p* by rails,

Q_{ia}^{t} is containers (TEUs) shipped from shipping origin *i* to barge access point *a* by trucks, Q_{ap}^{b} is containers (TEUs) shipped from barge point *a* to export port *p* by barges, T_{ip}^{t} is transportation costs from shipping origin *i* to export port *p* by trucks, T_{ip}^{r} is transportation costs from shipping origin *i* to export port *p* by rails, T_{ia}^{t} is transportation costs from shipping origin *i* to barge access point *a* by trucks, and T_{ap}^{b} is transportation costs from barge access point *a* to export port *p* by barges.

Inland transportation costs in the United States consist of costs from shipping origins to export ports. When several transportation modes are available, the least expensive mode is chosen for container shipments. The first and second terms of Equation 3.6 represent the sum of transportation costs in shipping containers from shipping origins to export ports by trucks and rails, respectively; the third term represents shipment of containers from shipping origins to barge access points by truck; and the last term represents shipment of containers from barge access points to export ports by barge.

The international transportation system from the United States to importing countries is optimized by using a linear programing model. The objective function of the spatial optimization model is to minimize transportation and handling costs in shipping containers from US origins to import ports. The objective function is specified as follows:

$$W_{eo} = \sum_{p=1}^{P}\sum_{q=1}^{Q} Q_{pq}^{o}(T_{pq}^{o} + h_{pq}) + \sum_{p=1}^{P}\sum_{q=1}^{Q} Q_{pq}^{oc}\left(T_{pq}^{oc} + \rho + \sigma\right) \tag{3.7}$$

where *p* is index for major container ports in the United States, *q* is an index for major container ports in importing countries, Q_{pq}^{o} is containers (TEUs) shipped from US port *p* to import port *q* without the Panama Canal, Q_{pq}^{oc} is containers (TEUs) shipped from US port *p* to import port *q* through the Panama Canal, T_{pq}^{o} is ocean transportation costs by ship size from US port *p* to import port q without using the canal, T_{pq}^{oc} is ocean transportation costs by ship size from US port p to import port q through the canal, h_{pq} is the handling charge at ports p and q, ρ is the toll rate per TEU at the Panama Canal, and σ is the delay cost per TEU at the Panama Canal.

Ocean transportation costs between the United States and importing countries consist of costs from US ports to import ports. Since two ocean routes for container shipments are available, the least expensive route is chosen for container shipments. The first term of Equation 3.7 represents the sum of transportation costs from US ports to import ports without using the Panama Canal and handling costs at ports in US and it trade partners. The next term indicates the sum of transportation costs from US ports to import ports through the Panama Canal, handling costs at the ports in the US and its importing countries, the PNC toll rate, and the delay cost at the Panama Canal.

Since the objective of this study is to optimize container flows from shipping origins in the United States to import ports in importing countries, under the spatial optimization and the objective function of the spatial optimization model for US export the sum of equations 3.7 and 3.8 is as follows:

$$\begin{aligned} W_e = {} & \sum_{i=1}^{I}\sum_{p=1}^{P} Q_{ip}^{t} T_{ip}^{t} + \sum_{i=1}^{I}\sum_{p=1}^{P} Q_{ip}^{r} T_{ip}^{r} + \sum_{i=1}^{I}\sum_{a=1}^{A} Q_{ia}^{t} T_{ia}^{t} + \sum_{a=1}^{A}\sum_{p=1}^{P} Q_{ap}^{b} T_{ap}^{b} \\ & + \sum_{p=1}^{P}\sum_{q=1}^{Q} Q_{pq}^{o}(T_{pq}^{o} + h_{pq}) + \sum_{p=1}^{P}\sum_{q=1}^{Q} Q_{pq}^{oc}\left(T_{pq}^{oc} + \rho + \sigma\right) \end{aligned} \tag{3.8}$$

Transportation costs are divided into domestic transportation and ocean transportation costs. Ocean shipments are divided into shipments from the United States to importing countries whether the shipments pass through the Panama Canal. Handling charges such as loading and unloading, at the ports in exporting and importing countries, the PNC toll, and the delay cost at the canal are included in the objective function.

Major constraints of the model are domestic supply in the United States, import demand in importing countries, cargo handling capacities of U.S ports and the Panama Canal and the inventory-clearing condition at export and import ports. The constraints are presented as follows:

$$\sum_{p=1}^{P} Q_{pq}^{o} + \sum_{p=1}^{P} Q_{pq}^{oc} \geq D_q \tag{3.9}$$

$$\sum_{p=1}^{P} Q_{ip}^{t} + \sum_{p=1}^{P} Q_{ip}^{r} + \sum_{a=1}^{A} Q_{ia}^{t} \leq Q_i \tag{3.10}$$

$$\sum_{i=1}^{I} Q_{ip} \leq PC_p \tag{3.11}$$

$$\sum_{p=1}^{P} \sum_{q=1}^{Q} Q_{pq}^{oc} \leq PCC \tag{3.12}$$

$$Q_q = \sum_{q=1}^{Q} Q_{pq}^{o} + \sum_{q=1}^{Q} Q_{pq}^{oc}, \qquad q = 1,2,\ldots,Q \tag{3.13}$$

$$Q_p = \sum_{i=1}^{I} Q_{ip}^{t} + \sum_{i=1}^{I} Q_{ip}^{r} + \sum_{i=1}^{I} Q_{ap}^{b}\ , \qquad p = 1,2,\ldots,P \tag{3.14}$$

$$Q_{aGulf}^{b} = \sum_{i=1}^{I} Q_{ia}^{t}\ , \qquad a = 1,2,\ldots,A \ and \ a \in RP_e \tag{3.15}$$

$$Q_p = \sum_{p=1}^{P} Q_{pq}^{o} + \sum_{p=1}^{P} Q_{pq}^{oc}\ , \qquad p = 1,2,\ldots,P \tag{3.16}$$

where Q_q is the number of containers (TEUs) at import port q, Q_p is the number of containers (TEUs) at export port p, and Q_{aGulf}^{b} is the number of containers for the Gulf ports at barge access points *a*. Other variables are defined previously. Equations 3.9 and 3.10 represent import demand and export supply constraints respectively. Equation 3.9 represents the import demand constraints in importing countries. Equation 3.10 indicates that the total containers shipped from each shipping origins in the United States should be equal to or smaller than the quantities of containers shipped to the export ports. Equations 3.11 and 3.12 represent container handling capacities at ports in the United States and the Panama Canal, respectively. The total quantities of containers handled by each port and the Panama Canal should be equal to or smaller than handling capacities at their facilities. Equation 3.13 indicates that the quantity of containers imported in import port *q* is equal to the sum of containers shipped from export ports. Equation 3.14 describes that the quantity of container exported in port *p* is equal to quantity of containers received from either shipping origins by truck and rail or barge access points by barge. Equation 3.15 is an inventory clearing condition at barge access points indicating that the quantity of containers received in each barge access points by truck should be equal to the quantity shipped out by barge to the Gulf ports. Equation 3.16 also describes an inventory-clearing condition at ports, indicating that the container quantities received by each export port from shipping origins must equal to the container quantities shipped to each import port.

3.5. Spatial Optimization Model for US Imports

The model developed for US imports includes major shipping destinations and container ports in the United States and ports in exporting countries. Major container shipping destinations will be identified as one of each states of the US mainland, based on population. Major container exporting countries are identified on the basis of US import volume. The model includes several inland transportation modes in the United States to evaluate the effects of intermodal competition on optimal container shipments in the United States. Ports in the United States will be used in the transit of containers from ports in exporting countries to shipping destinations in the United States.

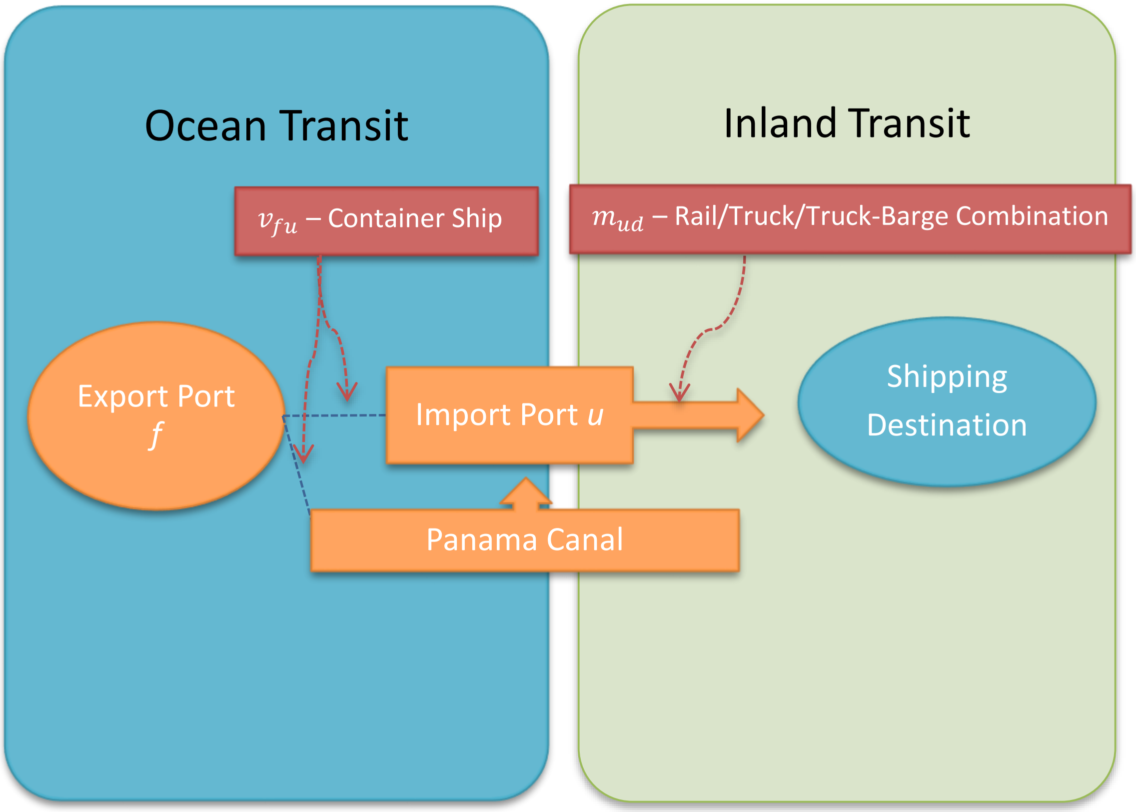


Figure 3.6. Regions associated with container trade and transportation modes for US imports.

Figure 3.6 represents the supply chain of container shipments from export ports in other countries to shipping destinations at US imports. Ocean vessels are the transportation mode used for shipping containers from ports in exporting countries to ports in the United States. The model for import includes barges, as one of the inland transportation modes, which are available to ship containers from the US Gulf ports to water access points along major US river systems. Since barges are the cheapest mode of inland transportation for long distances, barges are used for long-distance hauling. Containers imported in the Gulf ports in the United States can be moved to water access points by barge and then moved to shipping destinations by truck, called a truck-barge combination. For shipment from other US import ports, either rails or trucks are used to ship containers since trucks are the cheapest transportation mode for shipping containers short distances, followed by rail in general.

The international transportation system from exporting countries to the United States is optimized by using a linear programing model. The objective function of the spatial optimization model is to minimize transportation and handling costs in shipping containers from export ports to US ports. The objective function is specified as follows:

$$W_{io} = \sum_{f=1}^{F} \sum_{u=1}^{U} Q_{fu}^{o}(T_{fu}^{o} + h_{fu}) + \sum_{f=1}^{F} \sum_{u=1}^{U} Q_{fu}^{oc}\left(T_{fu}^{oc} + \rho + \sigma\right) \tag{3.17}$$

where *f* is the index for ports in exporting countries, *u* is an index for container ports in the United States, $Q_{fu}^{o}$is containers (TEUs) shipped from export port *f* to US port *u* without the Panama Canal, Q_{fu}^{oc} is containers (TEUs) shipped from export *f* to US port *u* through the Panama Canal, T_{fu}^{o} is ocean transportation costs by ship size from export port *f* to US port *u* without using the canal, T_{fu}^{oc} is ocean transportation costs by ship size from export port *f* to US port *u* through the canal, h_{fu} is handling charges at ports f and u , ρ is the toll rate per TEU at the Panama Canal, and σ is the delay cost per TEU at the Panama Canal.

Ocean transportation costs between exporting countries and the United States consist of costs from export ports to US ports. Since two ocean routes for container shipments are available, the least expensive route is chosen for container shipments. The first term of equation 3.17 represents the sum of ocean transportation costs from export ports to US ports without the Panama Canal and handling costs at the ports in exporting and importing countries. The next term indicates the sum of transportation costs from export ports to US ports through the Panama Canal, handling costs at ports, the PNC toll, and delay costs at the Panama Canal.

The domestic transportation system in the United States is optimized by using a linear programing model. The objective function of the spatial optimization model is to minimize transportation and handling costs in shipping containers from US ports to shipping destinations in the United States. The objective function is specified as follows:

$$W_{il} = \sum_{u=1}^{U}\sum_{d=1}^{D} Q_{ud}^{t}T_{ud}^{t} + \sum_{u=1}^{U}\sum_{d=1}^{D} Q_{ud}^{r}T_{ud}^{r} + \sum_{u=1}^{U}\sum_{e=1}^{E} Q_{ue}^{b}T_{ue}^{b} + \sum_{e=1}^{E}\sum_{d=1}^{D} Q_{ed}^{t}T_{ed}^{t} \qquad (3.18)$$

where *u* is an index for the import ports in the United States, *d* is an index for shipping destinations in the United States, *t* is an index for truck transportation mode, *r* is an index for rail transportation mode, *b* is an index for barge transportation mode, *e* is an index for barge access points, and *T* represents transportation costs. Q_{ud}^{t} is the containers (TEUs) shipped from import port *u* to destination *d* by trucks, Q_{ud}^{r} is the containers (TEUs) shipped from import port *u* to destination *d* by rails,Q_{ue}^{b} is containers (TEUs) shipped from import port *u* to barge point *e* by barges, Q_{ed}^{t} is containers (TEUs) shipped from barge access point *e* to destination *d* by trucks, T_{ud}^{t} is transportation costs from import port *u* to destination *d* by trucks, T_{ud}^{r} is transportation costs from import port *u* to destination *d* by rails, T_{ue}^{b} is transportation cost from import port *u* to barge access point *e* by barges. T_{ed}^{t} is transportation cost from barge access point *e* to destination *d* by trucks.

Inland transportation costs in the United States are accumulated from import ports to shipping destinations by multi-inland transportation modes. When more than one transportation mode is available, the least expensive mode is chosen for container shipments. The first and second terms of equation 3.18 represent the sum of transportation costs for shipping containers from import ports to shipping destinations by trucks and rails, respectively; the third term represents the sum of transportation costs from import ports to barge access points by barges.

The last term indicates the sum of the transportation costs from barge access points to shipping destinations by trucks.

Since one of the objectives of this study is to optimize container flows from exporting countries to the United States under the spatial optimization and the objective function of the spatial optimization model for US import the sum of equations 3.17 and 3.18 is as follows:

$$W_i = \sum_{f=1}^{F}\sum_{u=1}^{U} Q_{fu}^{o}(T_{fu}^{o} + h_{fu}) + \sum_{f=1}^{F}\sum_{u=1}^{U} Q_{fu}^{oc}\left(T_{fu}^{oc} + \rho + \sigma\right) + \sum_{u=1}^{U}\sum_{d=1}^{D} Q_{ud}^{t}T_{ud}^{t} + \sum_{u=1}^{U}\sum_{d=1}^{D} Q_{ud}^{r}T_{ud}^{r} + \sum_{u=1}^{U}\sum_{e=1}^{E} Q_{ue}^{b}T_{ue}^{b} + \sum_{e=1}^{E}\sum_{d=1}^{D} Q_{ed}^{t}T_{ed}^{t} \qquad (3.19)$$

Transportation costs are divided into ocean transportation and domestic transportation costs. Ocean shipments are divided into shipments from exporting countries to the United States, whether or not the shipments pass through the Panama Canal. Handling charges, such as loading and unloading charges, at the ports in exporting and importing countries, the PNC toll rate, and delay costs at the canal are included in the objective function.

Major constraints of the model are import demand in the United States, supply in exporting countries, cargo handling capacities of the U.S ports and the Panama Canal and the inventory-clearing condition at export and import ports. The constraints are presented as follows:

$$\sum_{u=1}^{U} Q_{ud}^{t} + \sum_{u=1}^{U} Q_{ud}^{r} + \sum_{e=1}^{E} Q_{ed}^{t} \geq D_d \qquad (3.20)$$

$$\sum_{u=1}^{U} Q_{fu}^{o} + \sum_{u=1}^{U} Q_{fu}^{oc} \leq Q_f \qquad (3.21)$$

$$\sum_{f=1}^{F} Q_{fu}^{o} + \sum_{f=1}^{F} Q_{fu}^{oc} \leq PC_u \qquad (3.22)$$

$$\sum_{f=1}^{F}\sum_{u=1}^{U} Q_{fu}^{oc} \leq PCC \tag{3.23}$$

$$Q_u = \sum_{u=1}^{U} Q_{fu}^{o} + \sum_{u=1}^{U} Q_{fu}^{oc} \ , \qquad u = 1,2,\ldots,U \tag{3.24}$$

$$Q_d = \sum_{d=1}^{D} Q_{ud}^{t} + \sum_{d=1}^{D} Q_{ud}^{r} + \sum_{d=1}^{D} Q_{ed}^{t} \ , \qquad d = 1,2,\ldots,D \tag{3.25}$$

$$Q_u = \sum_{d=1}^{D} Q_{ud}^{t} + \sum_{d=1}^{D} Q_{ud}^{r} + \sum_{d=1}^{D} Q_{ue}^{b} \ , \qquad u = 1,2,\ldots,U \tag{3.26}$$

$$Q_{Gulf,e}^{b} = \sum_{d=1}^{D} Q_{ed}^{t} \ , \qquad e = 1,2,\ldots,E \ and \ e \in RP_i \tag{3.27}$$

where Q_u is the number of containers (TEUs) at import port *u*, Q_d is the number of containers (TEUs) at destination *d*, $Q_{Gulf,e}^{b}$ is the number of containers from the Gulf ports to barge access points *e*. Other variables are defined previously.

Equations 3.20 and 3.21 represent import demand and export supply constraints respectively. Equation 3.20 represents the import demand constraints in the United States. Equation 3.21 indicates that the total containers shipped from ports in exporting countries should be equal to or smaller than the quantities of containers shipped to the United States. Equations 3.22 and 3.23 represent container handling capacities at ports in the United States and the Panama Canal, respectively. The total quantities of containers handled by each port and the Panama Canal should be equal to or smaller than their annual handling capacities. Equation 3.24 indicates that the quantity of containers received at import port *u* is equal to the sum of containers shipped from export ports. Equation 3.25 describes that the quantity of containers received at destination *d* is equal to sum of the containers from import ports and barge access points. Equation 3.26 describes an inventory-clearing condition at ports, indicating that the container quantities received by each import port from exporting countries must equal to sum of containers shipped to destinations and barge access points. Equation 3.27 is an inventory clearing condition at barge access points indicating that the quantity of containers received in each barge access point by barge from the Gulf ports should be equal to the quantity shipped out through trucks to destinations.

3.6. Spatial Optimization Model for US Container Trade

Since a primary objective of this study is to optimize overall flows of containerized shipment in the United States, export and import were considered at the same time. Therefore, the objective function of the spatial optimization model for this study is developed by combining equations 3.8 and 3.19 as follows:

$$\begin{aligned} W_c = {} & \sum_{i=1}^{I}\sum_{p=1}^{P} Q_{ip}^{t}T_{ip}^{t} + \sum_{i=1}^{I}\sum_{p=1}^{P} Q_{ip}^{r}T_{ip}^{r} + \sum_{i=1}^{I}\sum_{a=1}^{A} Q_{ia}^{t}T_{ia}^{t} + \sum_{a=1}^{A}\sum_{p=1}^{P} Q_{ap}^{b}T_{ap}^{b} \\ & + \sum_{u=1}^{U}\sum_{d=1}^{D} Q_{ud}^{t}T_{ud}^{t} + \sum_{u=1}^{U}\sum_{d=1}^{D} Q_{ud}^{r}T_{ud}^{r} + \sum_{u=1}^{U}\sum_{e=1}^{E} Q_{ue}^{b}T_{ue}^{b} \\ & + \sum_{e=1}^{E}\sum_{d=1}^{D} Q_{ed}^{t}T_{ed}^{t} + \sum_{p=1}^{P}\sum_{q=1}^{Q} Q_{pq}^{o}(T_{pq}^{o} + h_{pq}) \\ & + \sum_{p=1}^{P}\sum_{q=1}^{Q} Q_{pq}^{oc}\left(T_{pq}^{oc} + \rho + \sigma\right) + \sum_{f=1}^{F}\sum_{u=1}^{U} Q_{fu}^{oc}\left(T_{fu}^{oc} + \rho + \sigma\right) \\ & + \sum_{f=1}^{F}\sum_{u=1}^{U} Q_{pq}^{o}(T_{fu}^{o} + h_{fu}) \end{aligned} \tag{3.28}$$

The first through fourth terms represent inland transportation costs for US exports and the fifth through eighth terms are inland transportation costs for US imports. The last four terms represent ocean transportation costs of containerized shipments for US exports and imports and those include cargo handling charges at ports in exporting and importing countries, the PNC toll rate, and the delay cost at the Panama Canal.

Major constraints of the model are import demand in importing countries, supply in exporting countries, cargo handling capacity at US ports and the Panama Canal, and the inventory-clearing condition at US ports. The constraints are presented as follows:

$$\sum_{p=1}^{P} Q_{pq}^{o} + \sum_{p=1}^{P} Q_{pq}^{oc} \geq D_q \tag{3.29}$$

$$\sum_{u=1}^{U} Q_{ud}^{t} + \sum_{u=1}^{U} Q_{ud}^{r} + \sum_{e=1}^{E} Q_{ed}^{t} \geq D_d \tag{3.30}$$

$$\sum_{p=1}^{P} Q_{ip}^{t} + \sum_{p=1}^{P} Q_{ip}^{r} + \sum_{a=1}^{A} Q_{ia}^{t} \leq Q_i \tag{3.31}$$

$$\sum_{u=1}^{U} Q_{fu}^{o} + \sum_{u=1}^{U} Q_{fu}^{oc} \leq Q_f \tag{3.32}$$

$$\sum_{i=1}^{I} Q_{ip} + \sum_{a=1}^{A} Q_{ap} + \sum_{f=1}^{F} Q_{fu}^{o} + \sum_{f=1}^{F} Q_{fu}^{oc} \leq PC\,, \qquad p = u \tag{3.33}$$

$$\sum_{p=1}^{P} \sum_{q=1}^{Q} Q_{pq}^{oc} + \sum_{f=1}^{F} \sum_{u=1}^{U} Q_{fu}^{oc} \leq PCC \tag{3.34}$$

$$Q_q = \sum_{p=1}^{P} Q_{pq}\ , \qquad q = 1,2,\dots,Q \tag{3.35}$$

$$Q_p = \sum_{i=1}^{I} Q_{ip}^{t} + \sum_{i=1}^{I} Q_{ip}^{r} + \sum_{i=1}^{I} Q_{ap}^{b}\ , \qquad p = 1,2,\dots,P \tag{3.36}$$

$$Q^b_{aGulf} = \sum_{i=1}^{I} Q^t_{ia} \ , \qquad a = 1,2,\dots,A \ and \ a \in RP_e \qquad (3.37)$$

$$Q_p = \sum_{q=1}^{Q} Q_{pq} \ , \qquad p = 1,2,\dots,P \qquad (3.38)$$

$$Q_u = \sum_{f=1}^{F} Q_{fu} \ , \qquad u = 1,2,\dots,U \qquad (3.39)$$

$$Q_d = \sum_{d=1}^{D} Q^t_{ud} + \sum_{d=1}^{D} Q^r_{ud} + \sum_{d=1}^{D} Q^t_{ed} \ , \qquad d = 1,2,\dots,D \qquad (3.40)$$

$$Q_u = \sum_{d=1}^{D} Q^t_{ud} + \sum_{d=1}^{D} Q^r_{ud} + \sum_{d=1}^{D} Q^b_{ue} \ , \qquad u = 1,2,\dots,U \qquad (3.41)$$

$$Q^b_{Gulf,e} = \sum_{d=1}^{D} Q^t_{ed} \ , \qquad e = 1,2,\dots,E \ and \ e \in RP_i \qquad (3.42)$$

where PC is annual handling capacity of container ports in the United States. Other variables are defined previously.

Equations 3.29 and 3.30 represent import demands in importing countries for US exports and the United States for US imports, respectively. Equations 3.31 and 3.32 represent export supply constraints in the United States for US exports and exporting countries for US imports, respectively. Equations 3.33 and 3.34 represent containers handling capacities at US ports and the Panama Canal, respectively. The total quantities of containers handled by each port and the Panama Canal should be equal to or smaller than their annual handling capacities. Equation 3.35 indicates that the quantity of containers for export in import port q is equal to the sum of containers exported at US ports. Equation 3.36 describes that the quantity of container exported at US port p is equal to the quantity of containers received from shipping origins by rail and truck and from barge access points by barge. Equation 3.37 is an inventory clearing condition for US exports at barge access points indicating that the quantity of containers received in each barge access points by truck should be equal to the quantity shipped out by barge to the Gulf ports. Equation 3.38 also describes an inventory-clearing condition at US ports, indicating that the container quantities received by each US port from shipping origins must equal to the container quantities exported at US port to import port. Equation 3.39 indicates that the quantity of containers imported at US port *u* is equal to the sum of containers shipped from export ports. Equation 3.40 describes that the quantity of containers received at shipping destination *d* is equal to the sum of the containers from import ports by truck and rail and from barge access points by truck in the United States. Equation 3.41 describes an inventory-clearing condition for US imports at US ports, indicating that the container quantities received by each import port from exporting countries must be equal to the sum of containers shipped to shipping destinations by truck and rail and to barge access points by barge. Equation 3.42 is also an inventory clearing condition for US imports at barge access points, indicating that the quantity of containers received in each barge access point from the Gulf ports by barge should be equal to the quantity shipped out through trucks to destinations.

CHAPTER 4. DATA COLLECTION

Data used for this study are container shipments demand in shipping destinations, container shipments supply in shipping origins, the total quantities (TEUs) of containerized shipments for US exports and imports through the Panama Canal, and transportation costs in shipping container shipments from shipping origins to destinations, which consist of inland and ocean transportation costs. In addition, cargo handling charges at container ports in exporting and importing countries, delay costs and toll rates at the Panama Canal were included as well.

4.1. Supply and Demand

Since the model used for this study includes containerized shipments for US exports and imports, supply and demand for US exports and imports are developed separately. The quantities in TEUs of US exports and imports are calculated by using a weighted arithmetic average under the assumption that regardless of the cargo value in the containers, an average of three years (2011 through 2013) of TEUs for US exports and imports were used for this study.

4.1.1. US Exports

An annual trade volume in TEU between the US and its trade partners from 2008 to 2013 is used as a proxy for measuring supply and demand for US exports. They were found in the US Container Trade by Trading Partners Report which is published by the US Maritime Administration. An annual trade value in US dollars from the 49 states of the US mainland to its trade partners in the world are used as a proxy for measuring the supply and demand for US exports. This data was found at 2013 NAICS Total All Merchandise Exports and Imports published by the International Trade Administration of the US Department of Commerce. This study assumes that the value of the cargo in the containers is ignored, and every container is fully loaded, because shippers and carriers do not want to waste space in containers in general.

Therefore, the trade volume in TEU is converted from value to volume by using a weighted arithmetic average. Then, an average of three years of trade volume from 49 mainland states of the US to its trade partners is used as proxy for supply and demand for US exports for this study.

4.1.2. US Imports

An annual trade volume in TEU between the US and its trade partners from 2008 to 2013 is used as a proxy for measuring supply and demand for US imports. They were found in the US Container Trade by Trading Partners Report, which is published by the US Maritime Administration. An annual trade value in US dollars from US trade partners in the world to the 49 mainland states of US are used as a proxy for measuring the supply and demand for US imports and they were found at 2013 NAICS Total All Merchandise Exports and Imports published by the International Trade Administration of the US Department of Commerce. Like US exports, the trade volume in TEU is converted from value to volume by using a weighted arithmetic average. Then, an average of three years of trade volume from US trade partners to the 49 mainland states of US is used as a proxy for supply and demand for US imports for this study.

4.2. Shipping Origins and Destinations

Since the majority of US exports and imports are shipped from/to the US mainland, this study is focused on supply and demand for containerized shipments in the US mainland. One shipping origin of each state is identified in the US mainland for US exports, while the top 15 importing countries for US exports are identified. 49 shipping origins are used for US exports and it is based on workforce. The workforce of each county/city in the United States is used as a proxy for shipping origin because it would be one of the biggest producing areas in each state. 18 container ports in importing countries consist of one container port in each country and one additional container port in China, Japan, and Germany, respectively. Most of the 18 container ports are ranked on the top in each country, while they are ranked in the top 50 container ports in the world (World Shipping Council, 2014).

For US imports, one shipping destination of each state is identified in the US mainland for US imports, while the top 15 exporting countries for US imports are identified. 49 shipping destinations are used for US exports and it is based on population. The population of each county/city in the United States is used as a proxy for shipping destinations because it would be the biggest consumer in each state. 18 container ports in exporting countries consist of one container port in each country and one additional container port in China, Japan, and Germany, respectively. Most of those 18 container ports are ranked on the top in each country, while they are ranked in the top 50 container ports in the world (World Shipping Council, 2014).

4.3. Transportation Costs

Transportation in this study is divided into inland transportation and ocean transportation. Inland transportation modes used in this study are rail and truck. Barges are used as an inland transportation mode between barge access points and the US Gulf ports. Container vessels are used as an ocean transportation mode in shipping container shipments from ports in exporting countries to ports in importing countries.

4.3.1. Ocean Transportation Costs

Ocean freight rates are specified as a function of the size of vessel, the ocean distance between ports, oil price, and characteristics of the destination and origin as the function developed by Park and Koo (2004). The ocean freight rate function for this study is re-specified as follows:

$$OR_{pqt} = f\left(S_{pqt}, M_{pqt}\right) \tag{4.1}$$

where OR_{pqt} is the ocean freight rate per TEU in shipping containers from export port p to import port q in a time period t, S_{pqt} is the size of the vessel shipping containers from export port p to import port q in a time period t, M_{pqt} is the ocean distance from export port p to import port q in a time period t. It is expected that a variable for the size of the vessel has a negative relationship with the ocean freight rates function, which means that ocean freight costs decrease as the size of the vessel increases. The coefficient of the ocean distance variable is expected to be positive, which means that ocean freight costs per TEU per nautical mile increases as the distance between origin and destination increases.

Monthly average ocean freight rates per TEU from December 2009 to October 2013 are used to estimate ocean freight and they were collected from the Shipping Intelligence Network at Clarkson Research. Container vessel size on a route is measured by maximum size port the container vessel can access and smaller vessel size between importing and exporting port facilities was chosen as maximum vessel size. These were found using research from Port Authority on each of its ports in the US and its trading partners. Ocean distance used for this study is measured by using an ocean distance calculator, which is available on a website as an open source, http://www.sea-distances.org. Since ocean distance from the ocean distance calculator is based on nautical miles, ocean distances used for this study were converted from nautical miles to standard miles.

4.3.2. Barge Transportation Costs

Barge freight rates are estimated with diesel oil prices. The barge freight rate function is specified as follows:

$$BR_t = f(O_t) \tag{4.2}$$

where BR_t is an average barge freight rate per ton-mile in time period *t* and O_t is an average diesel oil price per gallon at time period *t*. The coefficient of the diesel oil price is expected to be positive, which means that the barge rate per ton-mile increases as the diesel oil price increases. An annual average of real revenue of barge per ton-mile from 1995 to 2004 is used to estimate barge rates and they were found on Table 3-21 at the Bureau of Transportation Statistics published by the US Department of Transportation. Annual average diesel retail prices per gallon from 1995 to 2012 are used to estimate barge rates and they were found at US Energy Information Administration’s main website.

4.3.3. Rail Transportation Costs

Rail freight rates are estimated with diesel oil prices and fixed distance ranges. The rail freight rate function is specified as follows:

$$RR_t = f(O_t, D_t) \tag{4.3}$$

where RR_t is an average rail freight rate per ton-mile in time period *t*, O_t is an average diesel oil price per gallon, and D_t is the fixed distance range. It is expected that a variable for the diesel oil price has a positive relationship with the rail freight rate function, which means that rail freight costs decrease as diesel oil prices increase. The coefficient of the fixed rail distance variable is expected to be positive, which means that rail freight costs increase as the fixed distance range increases. Fixed distance ranges have four different distance ranges, as follows: (1) rail distance less than 500 miles, (2) rail distance between 501 and 1,000 miles, (3) rail distance between 1,001 and 1,500 miles, (4) distance longer than 1,501 miles. The longest distance in each range is used for this study.

An annual average of real revenue of class I rail per ton-mile from 1995 to 2007 is used to estimate rail rates and they were collected from the Bureau of Transportation Statistics at the

US Department of Transportation. Annual average diesel retail price per gallon from 1995 to 2012 is used to estimate barge rates and they were found at the US Energy Information Administration. Distance for rail is calculated by PC Miler Rail 19 BatchPro and it is measured based on Standard Point Location Code (SPLC). In addition, if there is more than one class I railroad operations on the same route, the shortest distance was chosen. If there is more than one shortest distance, then the distance with the fewer number of transfers or railroad operations was chosen for this study.

4.3.4. Truck Transportation Costs

Truck freight rates are estimated with diesel oil prices. The truck freight rate function is specified as follows:

$$TR_t = f(O_t) \tag{4.2}$$

where TR_t is an average truck freight rate per ton-mile in time period *t*, and O_t is an average diesel oil price per gallon at time period *t*. The coefficient of the diesel oil price is expected to be positive, which means that the truck rate per ton-mile increases as the diesel oil price increases. An annual average of real revenue of truck per ton-mile from 1995 to 2007 is used to estimate truck rates and they were found on Table 3-21 at the Bureau of Transportation Statistics published by the US Department of Transportation. An annual average of diesel retail price per gallon from 1995 to 2012 is used to estimate barge rates and they were found at the US Energy Information Administration.

4.3.5. Summary

In this study, railroad, truck, and barge operations for containerized shipments are considered inland transportation modes in the United States and container vessel operation is a mode of ocean transportation. Railroad is an inland transportation mode in shipping container shipments from shipping origins to export ports in the US for US exports and it operates its service from the import ports to shipping destinations in the US for US imports. This study assumed that railroads operate their services for transiting containerized shipments longer than 250 miles of the total travel distance, while trucks operate their services for containers no longer than 250 miles of the total travel distance. Also, trucks are the only inland transportation mode to transit containers between barge access points and shipping origins/destinations in the United States and then barges are the only inland transportation mode between river access points to US Gulf ports, called truck-barge combination hereafter. Under the assumption of a fully loaded container, rate per TEU for this study was calculated by multiplying with 24 tons of inland transportation rates per ton-mile which is maximum weight of a single container.

4.4. Cargo Handling Charges at Container Ports

Cargo handling costs are included in the model to the estimate efficiency of port operation. Efficiency of operation consists of loading and unloading cargo, time to transit, and time for loading and unloading. Handling costs at ports in the United States and its trading partners are included. Cargo handling charges at 15 US container ports are found at the Local Haulage Surcharges, Orient Overseas Container Line, Ltd, (OOCL), and 18 container ports in 15 US trade partners are collected from the Landside Tariff Surcharge at Mitsui O.S.K. Lines, Ltd, (MOL). Currencies were converted to US dollars when costs were in local currency.

4.5. Delay Costs and Toll Rates at the Panama Canal

Delay costs and toll rates are included in the model to estimate the efficiency of the Canal’s operation. Delay time at the Panama Canal could be decreased by the Panama Canal Expansion, since the expansion project includes building new locks. Congestion in the Canal will be reduced because of larger capacity of the Canal due to the PCE. The delay cost at the PNC is developed for this study. An annual average of fuel consumption for Panamax accounts for 46% of an annual average of total operating costs (Drewry Shipping Consultants, Ltd., 2013) and 20% of fuel consumption is required to maintain the vessel without navigating (Report for NC DOT by AECOM, 2012). Most current delay time at the PNC is 23 hours (Panama Canal Authority, 2013). Delay cost at the PNC was calculated by using those three references. Toll rate at the Panama Canal could be decreased by the Panama Canal Expansion since the Panama Canal Expansion will allow bigger sized vessels to transit through the Canal. Most current toll rate at the PNC is $74 per TEU and it is used for this study.

4.6. Cargo Handling Capacity of US Ports and the Panama Canal

Cargo handling capacities of the US ports and the Panama Canal are considered in this study because they actually have limited capacity at their facilities. These facilities would investigate needs of port expansion in US mainly due to the Panama Canal Expansion. Most recent throughput at port in the United States is used as a proxy for measuring port capacity, because most of major container ports handle more than their capacities. This information was collected from the Port Authority at each port in the US, Current capacity of the PNC is used for its capacity and it is found at the Panama Canal Authority.

CHAPTER 5. EMPIRICAL RESULTS

This chapter presents the results found in regards to the trade flows and transportation costs associated with US containerized shipments under the base and alternative models. The results are also used to comparatively analyze the impacts of the Panama Canal Expansion (PCE) on US trade.

The model has 15 importing and exporting countries for US exports and imports, respectively. For US exports, each state of the US mainland, including the District of Columbia, has a shipping origin (a total of 49 shipping origins). This study also identifies nine river ports along the Mississippi, Arkansas, Ohio, Illinois, Wisconsin, and Missouri River System, 15 US container ports, and 18 import ports in other countries are identified. For US imports, 18 export ports in other countries, 15 US container ports, and 9 river ports along the Mississippi, Arkansas, Ohio, Illinois, Wisconsin, and Missouri River System in the US are identified. Each state of the mainland US, including the District of Columbia, has a shipping destination (a total of 49 shipping destinations).

Four issues are examined in this chapter: optimal trade flows for US containerized shipments under the most current trade circumstances, the impacts of the Panama Canal Expansion on US containerized shipments, the impacts of the Panama Canal and US port expansion on US containerized shipments, and the effects of delay cost and toll rate at the Panama Canal on US containerized shipments.

5.1. Spatial Optimization under the Base Model vs. the Panama Canal and the US Port Expansion

This section analyzes results for the base model and the models including the Panama Canal and US port facilities, with the same toll rates for each model. Delay costs at the canal are expected to be decreased or eliminated when the Panama Canal is expanded. Since the PCE allows a larger handling capacity and larger vessel size at the PNC, congestion (waiting time) at the PNC could be reduced. Therefore, delay costs after the Panama Canal Expansion are assumed as follows: (1) delay costs are decreased by 50% after the PCE and (2) delay costs are eliminated after the PCE. The base model is based on the current handling capacity of the Panama Canal and US ports, estimated transportation costs, current cargo handling charges at port, current delay costs, and toll rates at the Panama Canal. The base model determines optimal trade flows for US containerized shipments in current trade situations.

The base model is compared to conditions under completion of the PCE to investigate which changes occur in the transportation of US containerized shipments, under the same Panama Canal toll rate and two different delay costs. This comparative analysis between current canal conditions and post PCE is conducted by eliminating the canal capacity from the model constraints and by increasing the vessel size that can go through the expanded canal using the ocean freight rate. This represents lower ocean freight rates associated with economies of scale, due to the increase in vessel size for hauling containerized shipments and simultaneously foreshadowing the Panama Canal’s ability to handle larger vessels.

The base model is also being compared to conditions after the PCE and US port expansion, which allows a 50% increase of port capacity, to investigate what changes occur in the transportation of US containerized shipments, under the same Panama Canal toll rates and two different delay costs. This comparative analysis between current canal conditions and post PCE with US port expansion is conducted by eliminating the canal capacity and increasing US port capacity by 50% in the model constraints by increasing vessel size that can go through expanded canals charged the ocean freight rate. This represents the lower ocean freight rates associated with economies of scale due to the increase in vessel size for the hauling of containerized shipments and simultaneously foreshadowing the Panama Canal and US Ports' abilities to handle larger vessels.

The base and alternative models are minimized as follows:

The base model – the current Panama Canal capacity with the existing delay cost and toll rate.

Model 1 – the expanded canal capacity with reduced delay costs and existing toll rate.

Model 2 – the expanded canal capacity with eliminated delay costs and existing toll rate.

Model 3 – the expanded canal and US port capacities with reduced delay costs and existing toll rate.

Model 4 – the expanded canal and US port capacities with eliminated delay costs and existing toll rate.

5.1.1. Trade Volume of Containerized Shipments for US Exports

Table 5.1 shows the average of trade volume between US shipping origins and its top 15 trade partners for US exports from 2011 to 2013. The total quantities of containerized shipments for US exports are over 7.4 million TEUs. California is the largest production state for containerized shipments in the United States since approximately 1.2 million TEUs are exported from California, 16.15% of the total US exports. Texas is the second largest production state since more than 860,000 TEUs are exported from Texas, which is 11.61% of the total US exports. Washington, New York, and Louisiana are the third, fourth, and fifth largest production states, respectively. Those five states account for 48% of the total US exports. China is the largest importing country, which imports about 2.7 million TEUs of US containerized shipments, accounting for 36.78% of the total US exports. Japan and South Korea are the second and third largest importing countries for US exports. They imports more than 814,000 TEUs and 649,000

TEUs, which accounts for 10.99% and 8.76% of the total US exports, respectively. Taiwan and Hong Kong are the fourth and fifth largest importing countries for US exports, respectively. Those five importing countries account for 69.75% of the total US exports.

Table 5.1. An average of actual trade volume between US shipping origins and its top 15 trade partners from 2011 to 2013 (TEUs).

Shipping origin	**Importing Country**															
	Belgium	Brazil	China	Germany	Hong Kong	India	Indonesia	Italy	Japan	Netherlands	South Korea	Taiwan	Thailand	United Kingdom	Viet Nam	The total
Alabama	2,567	4,570	59,741	12,491	2,196	3,466	970	1,579	9,400	1,193	8,096	4,447	2,144	2,762	1,610	117,233
Arkansas	1,597	1,573	15,103	840	2,063	737	1,185	487	2,618	265	2,889	2,159	521	681	937	33,655
Arizona	987	2,579	27,742	4,047	4,101	1,320	1,009	1,562	11,124	1,841	4,525	7,938	6,468	3,504	1,891	80,639
California	28,830	19,058	369,930	29,366	80,707	63,577	22,820	16,042	165,401	23,569	131,642	160,211	24,010	18,248	44,136	1,197,546
Colorado	1,454	1,096	16,395	1,547	2,281	1,812	1,315	563	5,365	1,570	4,376	4,045	1,100	923	1,584	45,428
Connecticut	3,559	2,416	24,171	7,889	2,167	2,222	1,285	1,169	7,163	2,703	8,455	2,802	1,130	2,795	1,247	71,173
District of Columbia	14	81	111	56	12	320	11	286	46	4	22	62	3	140	9	1,175
Delaware	4,200	760	11,055	1,494	382	554	331	160	4,014	1,150	1,908	2,476	191	3,031	386	32,093
Florida	4,371	36,652	31,975	8,087	10,804	14,006	3,604	3,992	13,217	5,171	8,164	7,518	2,826	4,765	4,064	159,217
Georgia	7,015	7,706	88,104	6,048	8,045	8,079	7,578	4,357	16,977	3,537	13,360	14,966	2,964	5,060	11,151	204,946
Iowa	888	4,168	16,106	3,574	1,298	1,296	1,923	830	12,059	1,313	5,017	2,508	646	1,448	1,741	54,816
Idaho	90	391	11,124	183	3,240	285	1,389	162	3,706	346	9,331	16,408	338	367	777	48,138
Illinois	16,935	17,439	114,210	14,660	7,116	15,560	13,529	3,789	25,858	6,741	14,067	24,423	5,134	8,344	12,266	300,070
Indiana	4,805	6,427	31,834	11,170	4,172	4,063	1,716	5,652	20,622	4,626	12,066	5,621	1,686	4,640	1,561	120,662
Kansas	1,061	3,526	29,185	2,014	1,324	1,183	1,886	1,014	9,733	449	3,796	3,664	599	1,979	3,206	64,620
Kentucky	5,017	8,072	27,557	4,385	6,598	1,958	1,330	1,447	15,409	3,279	8,228	6,829	1,540	6,758	971	99,378
Louisiana	11,382	15,575	204,102	5,876	663	9,582	14,618	3,903	44,467	16,094	24,193	11,139	5,185	4,503	4,549	375,832
Massachusetts	7,113	3,066	49,413	10,510	11,161	4,772	1,190	4,209	24,659	6,054	15,567	21,528	2,586	10,138	1,814	173,781

Table 5.1. An average of actual trade volume between US shipping origins and its top 15 trade partners from 2011 to 2013 (TEUs) (continued).

Shipping origin	**Importing Country**															
	Belgium	Brazil	China	Germany	Hong Kong	India	Indonesia	Italy	Japan	Netherlands	South Korea	Taiwan	Thailand	United Kingdom	Viet Nam	The total
Maryland	3,499	2,261	14,873	1,540	1,402	3,867	1,762	1,707	5,761	2,003	5,618	2,684	1,064	2,057	953	51,051
Maine	569	171	6,197	310	263	241	205	335	1,513	358	1,398	423	99	274	100	12,455
Michigan	7,356	5,284	83,941	10,054	2,421	3,603	2,130	3,663	17,473	1,775	15,826	4,501	3,711	2,984	1,106	165,830
Minnesota	6,585	2,448	49,444	4,115	4,580	3,088	2,642	2,073	15,136	2,364	10,694	11,043	3,755	2,224	3,117	123,306
Missouri	4,529	2,159	26,215	1,816	1,381	2,144	2,909	1,511	7,878	1,517	9,320	2,417	1,340	1,363	1,262	67,762
Mississippi	3,555	2,955	16,920	1,001	900	1,203	725	462	2,454	1,680	2,047	1,204	575	788	1,148	37,618
Montana	596	30	2,648	198	42	358	95	107	670	110	2,984	1,708	45	103	138	9,833
No. Carolina	6,801	5,333	65,405	5,844	8,117	5,283	5,728	1,901	21,581	3,549	10,062	7,128	2,058	3,927	6,319	159,037
North Dakota	792	222	535	292	27	490	184	159	412	31	272	155	45	135	115	3,867
Nebraska	987	637	12,112	790	1,826	341	846	910	6,687	1,001	4,978	2,344	631	258	2,392	36,741
New Hampshire	231	480	7,300	1,236	1,619	474	170	604	1,399	863	1,393	1,062	460	681	281	18,253
New Jersey	10,348	8,477	40,452	7,611	8,663	7,928	3,645	5,064	20,238	10,700	18,701	13,578	2,384	9,118	2,786	169,692
New Mexico	238	226	2,188	404	222	257	440	123	649	104	340	245	326	235	136	6,133
Nevada	1,078	408	13,126	698	1,819	16,850	392	427	3,117	367	1,798	1,045	433	586	305	42,447
New York	28,042	7,084	114,587	13,154	91,165	37,598	3,913	7,704	29,173	9,034	25,050	23,984	10,195	25,151	4,676	430,510
Ohio	4,931	11,267	74,469	7,690	4,487	7,904	5,766	3,887	19,426	3,994	13,979	9,842	4,274	6,341	3,082	181,338
Oklahoma	851	1,303	9,390	1,210	615	1,145	1,254	320	5,003	646	1,399	744	797	548	501	25,726

Table 5.1. An average of actual trade volume between US shipping origins and its top 15 trade partners from 2011 to 2013 (TEUs) (continued).

Shipping origin	**Importing Country**															
	Belgium	Brazil	China	Germany	Hong Kong	India	Indonesia	Italy	Japan	Netherlands	South Korea	Taiwan	Thailand	United Kingdom	Viet Nam	The total
Oregon	1,100	2,840	76,674	2,433	3,915	2,291	5,271	994	20,216	1,142	16,607	18,267	2,053	1,322	17,771	172,897
Pennsylvania	9,963	9,306	77,834	9,833	4,720	8,326	4,190	5,156	21,773	8,771	16,594	12,320	2,180	6,470	2,114	199,551
Rhode Island	289	103	2,195	1,168	354	209	58	783	588	126	473	1,611	324	295	216	8,793
So. Carolina	4,427	4,684	92,529	20,203	2,849	7,229	2,160	2,037	8,443	2,115	7,838	6,377	1,809	5,749	3,393	171,842
South Dakota	367	129	1,637	134	181	29	127	71	641	20	280	165	81	75	134	4,072
Tennessee	11,897	5,054	53,205	4,229	3,622	4,089	5,121	2,838	23,216	4,965	10,176	7,681	2,475	3,725	5,363	147,655
Texas	43,466	73,267	266,972	15,462	16,484	33,030	25,297	9,858	60,415	48,736	121,499	89,184	17,294	16,877	22,870	860,711
Utah	2,099	750	21,151	1,490	46,453	10,018	1,055	1,291	6,803	948	4,217	13,606	8,900	19,561	678	139,019
Virginia	4,086	4,919	46,860	4,767	2,397	4,266	6,597	1,955	6,553	2,373	5,309	10,500	1,424	4,419	4,465	110,890
Vermont	244	44	15,486	312	2,990	181	208	161	1,899	205	2,317	3,703	705	221	211	28,887
Washington	4,035	7,973	350,174	9,967	24,053	21,537	48,490	1,977	95,803	5,407	49,177	37,272	10,544	8,813	9,459	684,682
Wisconsin	3,855	3,669	38,161	4,258	2,923	5,577	2,086	2,353	10,758	1,988	6,601	4,695	2,687	2,674	2,358	94,642
West Virginia	3,052	4,482	15,973	1,700	774	8,839	294	4,912	6,519	4,041	6,305	1,055	363	1,909	363	60,581
Wyoming	87	837	241	13	13	62	2,169	3	633	221	679	953	442	93	383	6,828
Total	271840	303954	2726751	258174	389609	333248	213618	116547	814673	201060	649634	590242	142542	209061	192100	

Figure 5.1 shows official regions and divisions of the United States and it is used for measurement of trade volumes and flows by US regions and divisions. The northeast region of the United States produces 15.02% of the total US exports, the Midwest region of the United States exports 16.43% of the total US exports, the South region of the United States produces 35.73% of the total US exports, and the West region of the United States exports 32.83% of the total US exports. On the other hand, approximately, 77.15% of the total US containerized shipments are imported by countries in Asia, while 18.75% and 4.1% of the total US containerized shipments are imported by countries in Europe and South America, respectively.

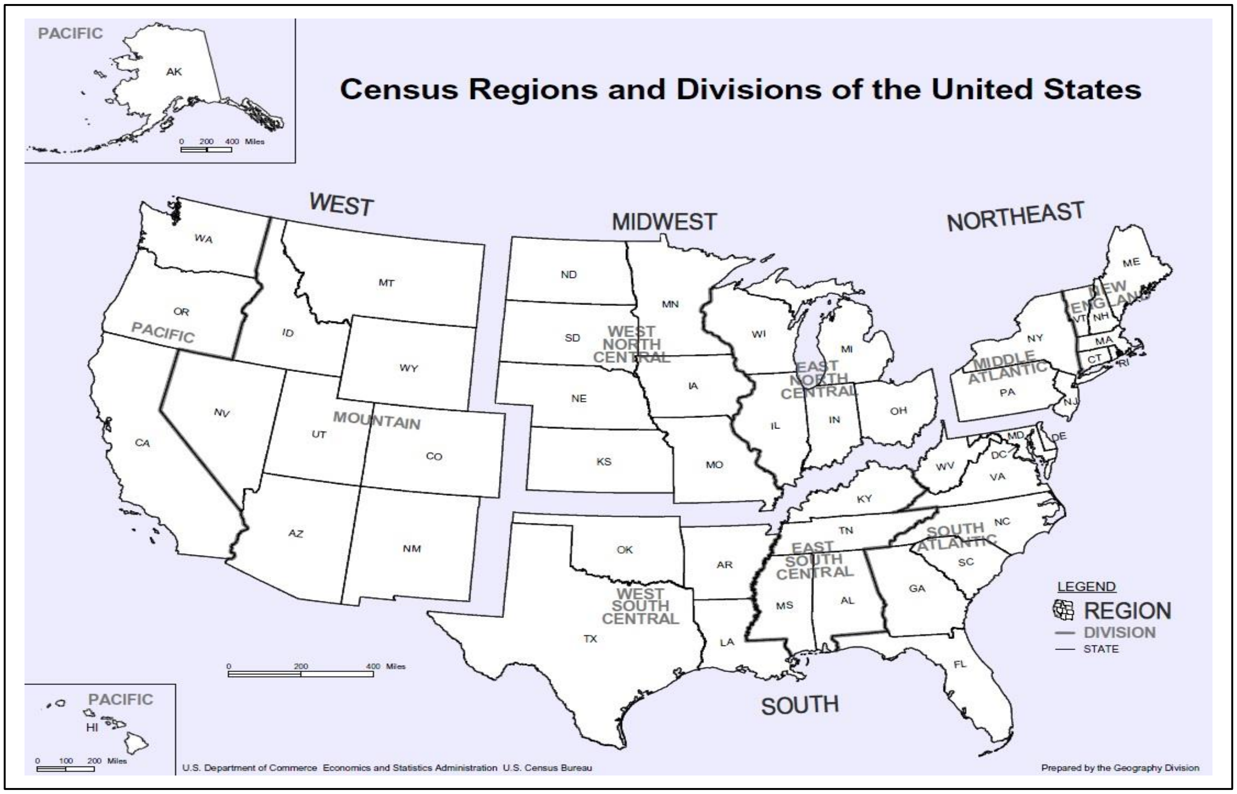


Figure 5.1. Official regions of the United States. Source: US Census (2015).

5.1.2. Trade Volume of Containerized Shipments for US Imports

Table 5.2 shows the average trade volume between US shipping destinations and its top 15 trade partners for US imports from 2011 to 2013. The total quantities of containerized shipments for US imports are over 14.4 million TEUs. California is the largest consumption state for containerized shipments in the United States. California imports approximately 3.7 million TEUs, accounting for 25.63% of the total US imports. Texas and New York are the second and third largest consumption states. They import approximately 1.3 million TEUs and 1 million TEUs, respectively, which account for 9.39% and 7.43% of the total US imports. Illinois and New Jersey are the fourth and fifth largest consumption states, respectively. Those five states account for 53% of the total US imports.

China, as the largest exporting country, exports more than 8.6 million TEUs of containerized shipments, accounting for 59.77% of the total US imports. South Korea and Japan are the second and third largest exporting countries to the US, which imports more than 695,000 TEUs and 619,000 TEUs, respectively, accounting for 4.82% and 4.29% of the total US imports. Vietnam and Germany are the fourth and fifth largest exporting countries to the US, respectively. Those five exporting countries account for 76.33% of the total US imports. The northeast region of the United States consumes 19.16 of the total US imports. The Midwest region of the United States imports 16.94% of the total US imports, the south region of the United States consumes 32.7% of the total US imports, and the west region of the United States imports 31.2% of the total US imports. Approximately 83.99% of the total containerized shipments for US imports are from countries in Asia, while 14.08% and 1.94% of the total containerized shipments for US imports are from countries in Europe and South America, respectively.

Table 5.2. An average of actual trade volume between US shipping destinations and its top 15 trade partners from 2011 to 2013 (TEUs)

Shipping destination	**Exporting Country**															
	Belgium	Brazil	China	Germany	Hong Kong	India	Indonesia	Italy	Japan	Netherlands	South Korea	Taiwan	Thailand	United Kingdom	Viet Nam	Total
Alabama	1166	15898	40452	14102	837	986	1458	3476	5437	976	44770	1827	644	640	3831	136500
Arkansas	335	242	43350	1780	844	2518	521	905	610	555	1482	1644	1045	299	1004	57135
Arizona	382	943	52661	3086	7463	1784	1233	1794	6617	2992	3366	6748	3188	1548	1626	95432
California	7788	24696	2604119	60280	86888	34120	79124	28665	183998	12314	148000	148506	114294	12127	154326	3699245
Colorado	669	531	39427	3024	3442	4307	530	2683	945	1536	3055	2793	1043	903	4052	68940
Connecticut	2808	2995	56027	7894	3641	2302	1574	5116	4529	13820	1947	3705	1380	6482	3773	117991
District of Columbia	43	78	396	235	61	177	9	241	161	367	136	13	30	131	37	2115
Delaware	14977	2524	10481	1589	435	1271	129	823	473	3197	178	415	46	9042	195	45775
Florida	4713	31140	237016	10287	20842	9670	8852	15265	18195	12087	14987	13716	10028	7279	27180	441257
Georgia	6208	7162	331080	61604	16111	15578	13267	13115	20444	8045	68015	13639	16616	6925	20686	618495
Iowa	465	1160	26230	3173	531	1682	224	3040	1768	737	1552	2439	557	370	1034	44962
Idaho	28	77	15925	388	548	119	278	3216	1979	348	4285	9167	71	77	574	37081
Illinois	8770	6823	526970	25575	11878	13167	11264	15860	38875	33159	63928	29327	13780	6844	21873	828092
Indiana	2170	4214	126175	11163	2746	4352	3093	6540	23039	4356	3744	11361	7320	4092	8456	222822
Kansas	1396	1532	44095	3955	1983	866	2201	2584	1112	781	2591	16580	794	1567	7136	89173
Kentucky	4458	2667	132175	9294	6769	8587	7670	14587	20858	2620	8161	19947	7598	3665	11009	260064
Louisiana	17276	18129	21214	3223	1097	4447	8984	2340	1490	5224	6888	1104	1675	2932	2584	98608

Table 5.2. An average of actual trade volume between US shipping destinations and its top 15 trade partners from 2011 to 2013 (TEUs) (continued)

Shipping destination	**Exporting Country**															
	Belgium	Brazil	China	Germany	Hong Kong	India	Indonesia	Italy	Japan	Netherlands	South Korea	Taiwan	Thailand	United Kingdom	Viet Nam	Total
Massachusetts	2746	1636	98926	9067	6469	3165	4776	6460	4097	7401	4236	7975	4850	8161	6983	176948
Maryland	3103	7796	60704	25864	2352	5695	6638	6496	5638	2619	1936	2164	10243	4035	6256	151541
Maine	173	60	7368	2433	285	240	92	346	227	697	235	290	692	416	1198	14753
Michigan	2280	6190	137812	19867	3554	10318	3140	9182	18726	2335	23256	8785	8714	2453	3014	259628
Minnesota	1018	2601	205753	4783	2980	2265	1016	3938	2280	1475	2130	8033	2343	1300	2705	244621
Missouri	4629	1185	83320	5744	2071	3716	995	2471	1598	1320	2838	4601	1423	1336	2709	119956
Mississippi	179	10984	65871	2775	1014	2674	301	970	3297	1791	1250	2963	1137	3269	3338	101813
Montana	41	29	2138	742	46	79	5	93	36	36	177	168	25	68	18	3701
North Carolina	3691	8655	207937	16930	4679	12559	12235	13673	13293	5685	9103	10722	6727	7714	18384	351987
North Dakota	58	116	2907	706	16	700	59	375	357	54	523	179	174	112	562	6898
Nebraska	900	272	17947	1679	505	365	112	1253	1169	132	344	810	649	175	986	27299
New Hampshire	159	158	18512	2374	708	1370	748	1069	423	1462	533	2297	998	673	1020	32504
New Jersey	33721	9017	346173	37686	14925	57592	20981	52518	42894	21701	31507	20565	14185	23797	23833	751093
New Mexico	261	36	15899	546	189	174	39	140	474	1627	159	479	533	267	67	20890
Nevada	648	940	59571	711	1900	1013	993	682	413	340	14863	4191	1378	460	1314	89418
New York	67117	12426	460945	19333	190866	104875	20513	50558	13459	10161	20194	31277	17461	15531	36940	1071657
Ohio	3739	5872	243296	23400	4637	10915	11421	9942	26445	4169	13015	14987	7942	3529	27961	411269
Oklahoma	1582	340	45714	1777	1697	1821	1429	1061	2081	347	823	2813	1328	680	1629	65122
Oregon	268	726	58654	3009	2106	1606	3019	1123	16530	1918	16289	4431	3121	419	7477	120697
Pennsylvania	22006	9598	346053	25147	6136	11873	6679	14399	9271	8641	32592	11495	4992	9372	16054	534309

Table 5.2. An average of actual trade volume between US shipping destinations and its top 15 trade partners from 2011 to 2013 (TEUs) (continued)

Shipping destination	**Exporting Country**															
	Belgium	Brazil	China	Germany	Hong Kong	India	Indonesia	Italy	Japan	Netherlands	South Korea	Taiwan	Thailand	United Kingdom	Viet Nam	Total
Rhode Island	1130	655	25101	16676	584	1467	209	819	633	3049	358	748	1320	2170	429	55348
South Carolina	5738	6267	111239	34886	1722	8713	14398	10882	7921	7435	4595	4846	6770	4445	10208	240064
South Dakota	33	1055	2581	137	68	47	9	218	71	48	103	252	107	30	97	4857
Tennessee	11893	4082	435571	13076	4578	14862	17810	7598	39750	2961	5375	10632	9604	4477	28981	611252
Texas	19538	57407	825238	35917	18671	51829	17627	30721	32085	23693	99929	43821	38308	16894	42944	1354621
Utah	143	837	34627	945	2106	671	427	791	632	279	689	3768	362	269	1183	47728
Virginia	2611	5053	90504	9065	2281	9405	9528	7000	8726	2324	2138	3333	2730	3228	10185	168112
Vermont	43	69	5546	555	188	672	510	417	228	106	414	352	78	213	783	10174
Washington	1547	2914	179038	4168	5179	3616	5404	5484	28719	4489	25037	28346	7079	5441	10570	317032
Wisconsin	1221	1230	117034	6395	4192	6799	6770	7104	3560	1839	3760	6723	1376	1018	16965	185985
West Virginia	484	253	5289	896	101	1347	114	542	4203	125	122	434	82	158	922	15071
Wyoming	18	6	2260	164	48	133	12	22	37	23	64	53	9	80	47	2977
Total	266367	279279	8627320	548105	452968	438508	308421	368599	619803	223395	695674	525462	336851	187116	555145	

5.1.3. Trade Volume and Total Toll Revenue of Containerized Shipments at the Panama Canal

Table 5.3 shows the trade volume of containerized shipments between the United States and its trade partners through the Panama Canal (PNC), and it also contains the total toll revenue at the PNC. Prior to the Panama Canal Expansion (PCE), more than 2 million TEUs of containerized shipments are exported from US export ports to import ports in other countries through the PNC, while more than 4.5 million TEUs of containerized shipments are imported from export ports in other countries to US import ports through the PNC. In other words, 27% of the total US exports and 32% of the total US imports are shipped via the PNC.

The total toll revenue at the PNC is about $488 million dollars, with existing delays costing $6.34 per TEU and a toll rate at $74 per TEU. These were factored into the base model. After the PCE with a 50% reduced delay cost and without delay costs at the canal, it is expected that more than 2.6 million TEUs of containerized shipments will be exported from US export ports to import ports in other countries through the PNC, while more than 4.9 million TEUs of containerized shipments will be imported from export ports in other countries to US import ports through the PNC. In other words, 36% of the total US exports and 34% of the total US imports are anticipated to be shipped via the PNC.

The total toll revenue at the PNC is about $563 million dollars with a 50% reduced delay cost ($3.17 per TEU) in Model 1 and the same without delay cost at the canal with same toll rate in Model 2. Since traffic volume at the PNC increases by 31% for US exports and 8% for US imports, respectively in Models 1 and 2, the total toll revenue at the PNC increases by more than 15%. After the PCE and US port expansion (50% increased capacity) with 50% reduced delay cost (Model 3) and no delay cost (Model 4) at the Canal, more than 3 million TEUs of containerized shipments will be exported from US export ports to import ports in other countries through the PNC, while more than 6.2 million TEUs of containerized shipments are expected to be imported from export ports in other countries to US import ports through the PNC. In other words, 41% of the total US exports and 43% of the total US imports will be shipped via the PNC.

Table 5.3. Trade volume and the total toll revenue of containerized shipments at the Panama Canal.

		Base Model	Model 1	Model 2	Model 3	Model 4
Trade Volume (TEUs) at the PNC	US Export	2,021,409	2,640,077	2,648,310	3,046,233	3,046,233
	US Import	4,584,475	4,964,146	4,964,146	6,202,617	6,202,618
Trade Volume (%) at the PNC	US Export	27%	36% (31%↑)	36% (31%↑)	41% (51%↑)	41% (51%↑)
	US Import	32%	34% (8%↑)	34% (8%↑)	43% (35%↑)	43% (35%↑)
Toll Revenue (US $) at the PNC		$488,835,416	$562,712,502	$563,321,744	$684,414,900	$684,414,974
% Change in Toll Revenue			15.11% ↑	15.24% ↑	40% ↑	40% ↑

The total toll revenue at the PNC is about $684 million dollars with both 50% reduced delay cost ($3.17 per TEU) and no delay cost at the canal with same toll rate in Models 3 and 4. Since trade volume at the PNC increases by 51% for US exports and 35% for US imports respectively, the total toll revenue at the PNC increases by 40%.Thus, after the Panama Canal is expanded, more containerized shipments for US export and import will be moved through the PNC because of the lower ocean freight rates associated with vessel size for the hauling of containerized shipments. For instance, ocean freight rate between the Port of Shanghai in China and the port of Houston, Texas in the United States by Panamax vessel with current capacity at the PNC is $3,101 per TEU, excluding port handling charges at export and import ports, delay costs and the toll rate at the canal. However, the ocean freight rate on the same route by a New Panamax vessel with an unlimited capacity after the expanded PNC is finished is $1,972 per TEU. The ocean freight rate on this route decreases to $1,129 when the Panama Canal is expanded. Therefore, the PCE affects trade volume and the total toll revenue at the PNC. If the Panama Canal and US Ports are expanded, even more containerized shipments for US exports and imports are shipped through the PNC, because larger port capacity allows US ports in the East and the Gulf Coast to handle more shipments for US exports and imports. Although the Panama Canal and US port expansion have very significant impacts on trade volume and the total toll revenue at the canal, delay costs at the canal do not affect trade volume and the total toll revenue at the canal, mainly because delay costs at the PNC accounts for a small portion of the total transportation costs.

5.1.4. Trade Volume and Flows at Container Ports in the United States

Table 5.4 shows trade volume and flows at US major container ports. In Table 5.4, coastal regions in the United States are divided into 6 regions: (1) Pacific Northwest (PNW) including major US container ports in Washington and Oregon, (2) Los Angeles and Long Beach (LA/LB) including major container ports in California, (3) the West side of the Gulf of Mexico (West Gulf) including major US container ports in Texas, (4) the East side of the Gulf of Mexico (East Gulf) including major US container ports in Louisiana, Mississippi, Alabama, the South side of Georgia, and the West side of Florida, (5) the South Atlantic including major US container ports in the East side of Florida, the Southeast side of Georgia, South Carolina and North Carolina, and (6) the Mid-Atlantic including major US container ports in Virginia, Maryland, Delaware, Pennsylvania, New York and New Jersey. Since none of the container ports are ranked as the top 15 US container ports in the North Atlantic, this study is focused on six coastal regions in the United States.

Table 5.4. Trade volume and flows at container ports in the United States.

		Base Model				Model 2				Model 4			
Coastal Region	Port	US Export (TEUs)	US Import (TEUs)	Total (TEUs)	Port Usage (%)	US Export (TEUs)	US Import (TEUs)	Total (TEUs)	Port Usage (%)	US Export (TEUs)	US Import (TEUs)	Total (TEUs)	Port Usage (%)
PNW	Seattle, WA	663493	0	663493	50.90	257771	0	257771	19.78	0	0	0	0
	Tacoma, WA	259993	730945	990938	100	505529	485409	990938	100	742653	417232	1159885	78.03
	Portland, OR	0	0	0	0	156117	0	156117	100	172897	61279	234176	100
LA/LB	Los Angeles, CA	2560654	5402679	7963333	100	2203826	5471672	7675498	96.39	1543766	4240098	5783864	48.42
	Long Beach, CA	0	203128	203128	2.68	0	0	0	0	0	0	0	0
West Gulf	Freeport, TX	52704	0	52704	100	0	52704	52704	100	0	79056	79056	100
	Houston, TX	0	1475997	1475997	100	450117	1025880	1475997	100	884305	1329691	2213996	100
East Gulf	Gulfport, MS	70939	103179	174118	100	0	174118	174118	100	16556	244621	261177	100
	Mobile, AL	87997	41201	129198	100	0	129198	129198	100	0	193797	193797	100
	New Orleans, LA	299518	0	299518	100	78438	221080	299518	100	22406	426871	449277	100
South Atlantic	Charleston, SC	117233	136500	253733	21.76	160254	336851	497105	42.63	117233	136500	253733	14.51
	Miami, FL	159217	441257	600474	82.19	285807	444823	730630	100	159217	936728	1095945	100
	Savannah, GA	889616	1389539	2279155	100	963677	1315478	2279155	100	1650949	1767784	3418733	100
Mid-Atlantic	New York, NY	1655519	3844481	5500000	100	1677706	3822294	5500000	100	1304558	3632934	4937492	59.85
	Norfolk, VA	596165	664106	1260271	77.45	673806	953505	1627311	100	798508	966421	1764929	72.3

Container ports in PNW handle approximately 923,000 TEUs for US exports and 730,000 TEUs for US imports and meet 67.51% of their current capacities in the base model. Container ports in PNW handle more shipments for US exports than imports. While PNW continues to handle more shipments for US exports than imports, the total containerized shipments at PNW decrease by 15.09% when the PNC is expanded and decrease by 15.74% when the PNC and its port capacity are expanded. Unlike PNW, container ports in LA/LB handle approximately 2.5 million TEUs for US exports and 5.6 million TEUs for US imports and meet 52.53% of their current capacities in the base model. Container ports in LA/LB handle more shipments for US imports than exports. While LA/LB continues to handle more shipments for US imports than exports, the total containerized shipments at LA/LB decreases by 6.01% when the PNC is expanded and decreases by 29.18% when the PNC and US port capacities are expanded.

More than 1.5 million TEUs are handled by container ports in the West Gulf, which meets 100% of current port capacities in the base model. In this area, container ports handle the majority of their shipments for US imports about 96.55% of the total throughput at the West Gulf is come from other countries. However, when the PNC is expended, 29.44% of the total throughput at the West Gulf is shipped out and 70.56% is from other countries, while container ports in the West Gulf fully use their current capacities. If ports in the West Gulf expand their capacity by 50% of their current capacity with the PCE, the total throughput at the West Gulf increases by 50%, which means ports in that area fully meet their new capacities as well. About 38.56% and 61.44% of the total throughput at the West Gulf are US exports and imports, respectively.

In the East Gulf, 76.05% of the total throughput at the East Gulf is US exports, while 23.95% is US imports. Container ports in West Gulf handle more shipments for US exports than import. They meet 100% of their current capacities in the base model. On the other hand, 86.99% of the total throughput at the West Gulf is from other countries and 13.01% is shipped out after the PCE. They meet 100% of their current capacities in Model 2 as well. If ports in that area expanded their capacities with the PCE, they would handle 95.69% of the total throughput as shipments for US imports, while they would fully use their expanded capacities.

Under the current status of port facilities in the South Atlantic, about 3.1 million TEUs are shipped through these ports. About 62.79% of the total throughput in the South Atlantic is from other countries and 37.21% is shipped out. Container ports in the South Atlantic meet 75.03% of their current capacities in the base model. Since quantities of containerized shipments in the South Atlantic increase after the PCE, container ports in the South Atlantic handle 11.92% more than prior to the changes. Usage of ports increases to 83.98% from 75.03% of current capacity in Model 2. In the South Atlantic, if ports and the PNC are expanded, the total throughput increases to 4.7 million TEUs from 3.1 million TEUs, which is 52.18% increase. Usage of ports is 76.13% of the new capacity.

Container ports in the Mid-Atlantic handle approximately 2.2 million TEUs for US exports and 4.5 million TEUs for US imports and meet 94.85% of their current capacities in the base model. Container ports in the Mid-Atlantic handle more shipments for US exports than imports. While the Mid-Atlantic continues to handle more shipments for US exports than imports, the total containerized shipments at the Mid-Atlantic increase by 5.43% and meets current port capacity when the PNC is expanded. However, the total containerized shipments at the Mid-Atlantic decreases by 0.86% and meets 62.69% of a new port capacity when the PNC and ports are expanded together.

Major container ports in the United States are characterized under given alternative scenarios in this section. Prior to the Panama Canal Expansion, all container ports by coastal regions in the United States use more than 50% of their current capacities. Container ports in the West Coast of the US use approximately 55%, container ports in the Gulf of Mexico use 100%, and container ports in the East Coast use about 88% of their current capacities. Although all container ports by coastal regions in the United States continue to use more than 50% of their current capacities, usage of ports in the West Coast decreases by 4%, as the total throughput decreases by 6%, while usage of ports in the East Coast increases by 7%, as the total throughput increases by 5%, and usage of ports and the total throughput in the Gulf Coast remains the same as before the PCE.

Thus, the Panama Canal Expansion will have significant impacts on the total throughput at ports in the United States. For instance, ports in the West Coast loses total throughput, but ports in the Gulf and East Coast have the same or more shipments after the PCE. Furthermore, ports in the Gulf Coast and East Coast may need to be expanded, because usage of these ports increase to 100% and 94%, respectively, after the PCE.

On the other hand, if the Panama Canal and major US container ports are expanded, usage of ports in the West Coast decreases by 28%, as the total throughput decreases by 29%, and usage of ports in the East Coast decreases by 20%, as the total throughput decreases by 1%. Since ports in the Gulf meet 100% of their capacities in all models, usage of ports in the Gulf Coast remains the same as the base case, while the total throughput increases by 50%. Under this new trade circumstance, in the United States, ports in the Gulf Coast need to be expanded by 50% of their current capacities and by even more than 50% since ports in the Gulf Coast fully use their new capacities. Ports in the East Coast also need to be expanded to handle more containerized shipments; however, it is not necessary to increase its capacity as much as 50% of their current capacities, because ports in the East Coast use 68% of their new capacities under the current volume of containerized shipments. However, ports in the West Coast should not expand their capacities because they will only use 27% of their new capacities if the PCE and ports are expanded.

5.1.5. Domestic Trade Volume and Flows of Containerized Shipments in the United States

Table 5.5 shows domestic trade volume and flows of containerized shipments by trucks in the United States. Prior to the PCE, approximately 1.2 million TEUs of containerized shipments for US exports are transited from shipping origins in California to the ports of Los Angeles or Long Beach, and 3.7 million TEUs of containerized shipments for US imports are shipped from the ports of Los Angeles or Long Beach to shipping destinations in California by truck. In New York and its neighbor states such as New Jersey or Connecticut, more than 430,000 TEUs, 169,000 TEUs, and 71,000 TEUs of containerized shipments for US exports are delivered to the port of New York from their shipping destinations by truck, respectively. Shipping destinations in New York, New Jersey, and Connecticut receive about 1 million TEUs, 751,000 TEUs, and 117,000 TEUs of containerized shipments for US imports from the port of New York by truck, respectively. Washington and Oregon are shipped more than 684,000 TEUs and 172,000 TEUs of containerized shipments for US exports from their shipping origins to the ports of Seattle or Tacoma by truck and shipping destinations in Washington and Oregon receive more than 317,000 TEUs and 120,000 TEUs of containerized shipments for US imports from the ports of Seattle or Tacoma by truck, respectively. Shipping origin in Florida ships out 159,000 TEUs of containerized shipments for US exports to the port of Miami and 441,000 TEUs of containerized shipments are moved from the port of Miami to Florida by truck. In Virginia, 71,000 TEUs of containerized shipments for US exports are transited from its shipping origin to the port of Norfolk, while its shipping destination receives about 118,000 TEUs from the port of

Norfolk by truck. Those eight shipping origins and destinations are connected with five container ports in the United States in the base model.

Table 5.5. Domestic trade volume and flows of containerized shipments by truck in the United States (TEUs).

	US Export			US Import		
	Shipping origin	Container Port	Volume (TEUs)	Container Port	Shipping destination	Volume (TEUs)
Base Model	California	LA/LB, CA	1,197,546	LA/LB, CA	California	3,699,245
	New York	New York, NY	430,510	New York, NY	New York	1,071,657
	Washington	Seattle/Tacoma, WA	684,682	Seattle/Tacoma, WA	Washington	317,032
	New Jersey	New York, NY	169,692	New York, NY	New Jersey	751,093
	Florida	Miami, FL	159,217	Miami, FL	Florida	441,257
	Oregon	Seattle/Tacoma, WA	172,897	Seattle/Tacoma, WA	Oregon	120,697
	Virginia	Norfolk, VA	110,890	Norfolk, VA	Virginia	168,112
	Connecticut	New York, NY	71,173	New York, NY	Connecticut	117,991
Model 2	California	LA/LB, CA	1,197,546	LA/LB, CA	California	3,699,245
	New York	New York, NY	430,510	New York, NY	New York	1,071,657
	Washington	Seattle/Tacoma, WA	684,682	Seattle/Tacoma, WA	Washington	317,032
	New Jersey	New York, NY	169,692	New York, NY	New Jersey	751,093
	Florida	Miami, FL	159,217	Miami, FL	Florida	441,257
	Oregon	Seattle/Tacoma, WA	16,780	Seattle/Tacoma, WA	Oregon	120,697
		Portland, OR	156,117			
	Virginia	Norfolk, VA	110,890	Norfolk, VA	Virginia	168,112
	Connecticut	New York, NY	71,173	New York, NY	Connecticut	117,991
	North Carolina	Charleston, SC	43,021	Charleston, SC	North Carolina	3,918

Table 5.5. Domestic trade volume and flows of containerized shipments by truck in the United States (TEUs) (continued).

	US Export			US Import		
	Shipping origin	Container Port	Volume (TEUs)	Container Port	Shipping destination	Volume (TEUs)
Model 4	California	LA/LB, CA	1,197,546	LA/LB, CA	California	3,699,245
	New York	New York, NY	430,510	New York, NY	New York	1,071,657
	Washington	Seattle/Tacoma, WA	684,682	Seattle/Tacoma, WA	Washington	317,032
	New Jersey	New York, NY	169,692	New York, NY	New Jersey	751,093
	Florida	Miami, FL	159,217	Miami, FL	Florida	441,257
	Oregon	Portland, OR	172,897	Portland, OR	Oregon	61,279
				Seattle/Tacoma, WA		59,418
	Virginia	Norfolk, VA	110,890	Norfolk, VA	Virginia	168,112
	Connecticut	New York, NY	71,173	New York, NY	Connecticut	117,991

When the Panama Canal is expanded, truck movements of containerized shipments in the United States will change. For instance, Oregon ships out 16,000 TEUs to the ports of Seattle or Tacoma and 156,000 TEUs to the port of Portland for US exports by truck, while its trade volume and flow for US imports remains the same as the base model. More than 43,000 TEUs of containerized shipments for US exports are transited from shipping origin in North Carolina to the port of Charleston by truck and about 4,000 TEUs of containerized shipments for US imports are moved to shipping destinations in North Carolina to the port of Charleston by truck. This new truck route occurs mainly due to the PCE. If the Panama Canal and US container ports are expanded, truck movements and its volume in the United States changes. More than 61,000 and TEUs of containerized shipments for US imports are shipped from the port of Portland to shipping destinations in Oregon and 59,000 TEUs of containerized shipments for US imports are transited from the ports of Seattle or Tacoma to shipping destinations in Oregon by truck. All other truck movements and volumes remain the same as the base case.

Table 5.6 shows domestic trade volume and flows of containerized shipments by truck-barge combinations in the United States. Under current trade movement of containerized shipments in the United States, shipping origins in Arkansas transits 33,000 TEUs of containerized shipments for US exports to the port of Freeport via the river port of Little Rock, Arkansas, by truck-barge combination and 57,000 TEUs of containerized shipments for US imports are shipped from the port of Houston to shipping destinations in Arkansas via the river port of Little Rock, Arkansas, by a truck-barge combination.

Illinois ships out more than 35,000 TEUs, 84,000 TEUs, and 19,000 TEUs of containerized shipments for US exports to the ports of Mobile, New Orleans, and Freeport via the river port of Chicago, Illinois, by a truck-barge combination. Shipping destinations in Illinois receive 728,000 TEUs from the port of Houston and 99,000 TEUs from the port of Gulfport via the river port of Chicago, Illinois, by a truck-barge combination for US imports.

More than 52,000 TEUs and 70,000 TEUs of containerized shipments for US exports are shipped to the ports of Mobile and the Gulfport via the river port of Minneapolis, Minnesota, from shipping origin in Minnesota, respectively and about 4,000 TEUs of containerized shipments of US imports are transited from the port of the Gulfport to Minnesota via the river port of Minneapolis, Minnesota, by a truck-barge combination.

In Missouri, more than 67,000 TEUs are moved to the port of New Orleans from its shipping origin via St. Louis, Missouri, for US exports and 78,000 TEUs and 41,000 TEUs of containerized shipments for the U.S import are transited from the ports of Houston and Mobile to its shipping destination via the river port of St. Louis, Missouri, by a truck-barge combination, respectively.

Table 5.6. Domestic trade volume and flows of containerized shipments by a truck-barge combination in the United States (TEUs).

	US Export				US Import			
	Shipping origin	River Port	Container Port	Volume (TEUs)	Container Port	River Port	Shipping destination	Volume (TEUs)
Base Model	Arkansas	Little Rock, AR	Freeport, TX	33,655	Houston, TX	Little Rock, AR	Arkansas	57,135
	Illinois	Chicago, IL	Mobile, AL	35,630	Houston, TX	Chicago, IL	Illinois	728,855
			New Orleans, LA	84,101	Gulfport, MS			99,237
			Freeport, TX	19,049				
	Minnesota	Minneapolis, MN	Mobile, AL	52,367	Gulfport, MS	Minneapolis, MN	Minnesota	3,942
			Gulfport, MS	70,939				
	Missouri	St. Louis, MO	New Orleans, LA	67,762	Houston, TX	St. Louis, MO	Missouri	78,755
					Mobile, AL			41,201
	Tennessee	Memphis, TN	New Orleans, LA	147,655	Houston, TX	Memphis, TN	Tennessee	611,252
Model 2	Arkansas	Little Rock, AR	Houston, TX	33,655	Houston, TX	Little Rock, AR	Arkansas	57,135
	Iowa	St. Louis, MO	New Orleans, LA	78,438	Mobile, AL	Kansas, KS	Iowa	44,962
					Freeport, TX		Kansas	89,173
	Kansas				New Orleans, LA	St. Louis, MO	Missouri	119,956
	Missouri		Houston, TX	145,501	Houston, TX	Chicago, IL	Illinois	601,693
	Nebraska				New Orleans, LA			30,621
	Minnesota	Minneapolis, MN	Houston, TX	123,306	Gulfport, MS	Minneapolis, MN	Minnesota	174,118
					New Orleans, LA			70,503
	Tennessee	Memphis, TN	Houston, TX	147,655	Houston, TX	Memphis, TN	Tennessee	367,052

Table 5.6. Domestic trade volume and flows of containerized shipments by a truck-barge combination in the United States (TEUs) (continued).

	US Export				US Import			
	Shipping origin	River Port	Container Port	Volume (TEUs)	Container Port	River Port	Shipping destination	Volume (TEUs)
Model 4	Arkansas	Little Rock, AR	Houston, TX	33,655	Freeport, TX	Little Rock, AR	Arkansas	57,135
	Iowa	St. Louis, MO	Houston, TX	223,939	New Orleans, LA	Kansas, KS	Iowa	44,962
	Kansas						Kansas	89,173
	Missouri						Nebraska	27,299
						St. Louis, MO	Missouri	119,956
	Nebraska					Louisville, KY	Kentucky	65,561
	Illinois	Chicago, IL	New Orleans, LA	22,406	Mobile, AL New Orleans, LA Freeport, TX Houston, TX	Chicago, IL	Illinois	828,092
	Wisconsin		Houston, TX	372,306			Wisconsin	185,985
	Minnesota	Minneapolis, MN	Gulfport, MS	16,556	Gulfport, MS	Minneapolis, MN	Minnesota	244,621
			Houston, TX	106,750				
	Tennessee	Memphis, TN	Houston, TX	147,655	Houston, TX	Memphis, TN	Tennessee	611,252

Tennessee uses a truck-barge combination to transit more than 147,000 TEUs of containerized shipments to the port of Houston via the river port of Memphis, Tennessee, for US exports and its shipping destination receives more than 611,000 TEUs of containerized shipments from the port of Houston via the river port of Memphis, Tennessee, by a truck-barge combination for US imports.

After the PCE, Iowa begins to use a truck-barge combination for US exports and imports since more than 54,000 TEUs and 44,000 TEUs of containerized shipments for US exports and import will be shipped to/from the ports in the Gulf of Mexico via the river ports of St. Louis, Missouri, and Kansas, Kansas, by a truck-barge combination, respectively. Although Nebraska continues to ship more than 36,000 TEUs to the ports of New Orleans or Houston via the river port of St. Louis, Missouri by a truck-barge combination for US exports, none of the containerized shipments in Nebraska are delivered by a truck-barge combination for US imports after the PCE. In Illinois, more than 601,000 TEUs and 30,000 TEUs of containerized shipments come from the ports of Houston and New Orleans via the river port of Chicago, Illinois by a truck-barge combination for US imports respectively, but Illinois does not use a truck-barge combination to ship containerized shipments for US exports after the PCE. Besides the states of Iowa, Illinois, and Nebraska, other states continue to use a truck-barge combination for US exports and import after the PCE.

If the Panama Canal and US ports are expanded, shipping destinations in Nebraska and Kentucky begin to receive more than 27,000 TEUs and 65,000 TEUs of containerized shipments for US imports from the port of New Orleans via the river port of Kansas, Kansas, and Louisville, Kentucky by a truck-barge combination, respectively. Wisconsin begins to use a truck-barge combination after the PCE and US port expansion since more than 372,000 TEUs of containerized shipments for US exports are shipped to the port of Houston via the river port of Chicago, Illinois and 185,000 TEUs of containerized shipments for US imports are transited from the ports of Mobile, New Orleans, Freeport or Houston via the river port of Chicago, Illinois by a truck-barge combination.

Table 5.7 shows domestic trade volume and flows of containerized shipments on the most sensitive route by rail in the United States. Those 15 selected rail routes are most sensitive in changes of trade situation in the United States. Before the PCE, more than 54,000 TEUs of containerized shipments for US exports are shipped to the ports of Los Angeles or Long Beach from Iowa by rail and 44,000 TEUs of US imports are delivered to its shipping destination from the Port of Los Angeles or Long Beach by rail. However, none of the containerized shipments are transited by rail in Iowa when neither the Panama Canal is expanded nor the Panama Canal and US ports are expanded.

In Illinois, 161 TEUs of containerized shipments for US exports are shipped from its shipping origin to the port of New York by rail, while no containerized shipments for US imports are moved by rail in the base case. Quantities of containerized shipments for US exports from Illinois to the port of New York increases by 300 TEUs and its shipping origin begins to receive 195,000 TEUs of containerized shipments for US imports from the port of New York by rail after the PCE. On the other hand, none of containerized shipments are transited by rail in Illinois if the Panama Canal and U.S ports are expanded. In Indiana, 120,000 TEUs of US exports and 222,000 TEUs of US imports are transited to/from the port of New York by rail before the PCE, and the PCE does not make any changes in trade volume and flows in Indiana since trade volume and flows of containerized shipments remain the same as the base case.

Table 5.7. Domestic trade volume and flows of containerized shipments by rail in the United States (TEUs).

	US Export			US Import		
	Shipping origin	Container Port	Volume (TEUs)	Container Port	Shipping destination	Volume (TEUs)
Model 2	North Dakota	Seattle/Tacoma WA	3,867	LA/LB, CA	Nebraska	27,299
	South Dakota	New York, NY	4,069	Savannah, GA	Mississippi	98,247
				Miami, FL		3,566
	Texas	LA/LB, CA	660,060	Norfolk, VA	North Carolina	348,069
		Miami, FL	126,590	Seattle/Tacoma, WA	North Dakota	6,898
		Savannah, GA	74,061	New York, NY	South Dakota	4,857
	Wisconsin	New York, NY	94,642	Charleston, SC	Tennessee	196,433
				LA/LB, CA	Texas	1,354,621
				New York, NY	Wisconsin	185,685
Model 4	Indiana	New York, NY	17,697	New York, NY	Indiana	185,505
		Norfolk, VA	102,965	Norfolk, VA		37,317
	Kentucky	Norfolk, VA	99,378	Norfolk, VA	Kentucky	194,503
	North Carolina	Norfolk, VA	159,037	Miami, FL	Louisiana	98,608
	North Dakota	New York, NY	3,867	Miami, FL	Mississippi	101,813
				Norfolk, VA	North Carolina	351,987

Table 5.7. Domestic trade volume and flows of containerized shipments by rail in the United States (TEUs) (continued).

	US Export			US Import		
	Shipping origin	Container Port	Volume (TEUs)	Container Port	Shipping destination	Volume (TEUs)
Base Model	Iowa	LA/LB, CA	54,816	LA/LB, CA	Iowa	44,962
	Illinois	New York, NY	161,290	New York, NY	Indiana	222,822
	Indiana	New York, NY	120,662	LA/LB, CA	Kansas	89,173
	Kansas	LA/LB, CA	64,620	Savannah, GA	Kentucky	260,064
	Kentucky	Savannah, GA	99,378	Savannah, GA	Louisiana	98,608
	North Carolina	Norfolk, VA	159,037	Seattle/Tacoma, WA	Minnesota	240,679
	North Dakota	Seattle/Tacoma, WA	3,867	Savannah, GA	Mississippi	101,813
	Nebraska	LA/LB, CA	36,741	Norfolk, VA	North Carolina	281,492
				Savannah, GA		70,495
	South Dakota	Seattle/Tacoma, WA	4,069	Seattle/Tacoma, WA	North Dakota	6,898
	Texas	LA/LB, CA	860,711	LA/LB, CA	Nebraska	27,299
				Seattle/Tacoma, WA	South Dakota	4,857
	Wisconsin	New York, NY	94,642	LA/LB, CA	Texas	1,354,621
				New York, NY	Wisconsin	185,685
Model 2	Illinois	New York, NY	300,070	New York, NY	Illinois	195,778
	Indiana	Norfolk, VA	120,662	Norfolk, VA	Indiana	222,822
	Kentucky	Savannah, GA	99,378	Savannah, GA	Kentucky	260,064
	North Carolina	Norfolk, VA	116,016	Savannah, GA	Louisiana	98,608
Model 2	North Dakota	Seattle/Tacoma, WA	3,867	LA/LB, CA	Nebraska	27,299
	South Dakota	New York, NY	4,069	Savannah, GA	Mississippi	98,247
				Miami, FL		3,566
	Texas	LA/LB, CA	660,060	Norfolk, VA	North Carolina	348,069
		Miami, FL	126,590	Seattle/Tacoma, WA	North Dakota	6,898
		Savannah, GA	74,061	New York, NY	South Dakota	4,857
	Wisconsin	New York, NY	94,642	Charleston, SC	Tennessee	196,433
				LA/LB, CA	Texas	1,354,621
				New York, NY	Wisconsin	185,685
Model 4	Indiana	New York, NY	17,697	New York, NY	Indiana	185,505
		Norfolk, VA	102,965	Norfolk, VA		37,317
	Kentucky	Norfolk, VA	99,378	Norfolk, VA	Kentucky	194,503
	North Carolina	Norfolk, VA	159,037	Miami, FL	Louisiana	98,608
	North Dakota	New York, NY	3,867	Miami, FL	Mississippi	101,813
				Norfolk, VA	North Carolina	351,987

Table 5.7. Domestic trade volume and flows of containerized shipments by rail in the United States (TEUs) (continued).

	US Export			US Import		
	Shipping origin	Container Port	Volume (TEUs)	Container Port	Shipping destination	Volume (TEUs)
Model 4	South Dakota	New York, NY	4,069	New York, NY	North Dakota	6,898
				New York, NY	South Dakota	4,857
	Texas	Savannah, GA	860,711	LA/LB, CA	Texas	150,346
				Miami, FL		295,050
				Savannah, GA		909,225

After the PCE and US port expansion, 17,000 TEUs and 102,000 TEUs of containerized shipments for US exports are delivered to the ports of New York and Norfolk from Indiana by rail respectively and 185,000 TEUs and 37,000 TEUs in shipping destination of Indiana are imported from the port of New York and Norfolk by rail, respectively. In Kansas, more than 64,000 TEUs of containerized shipments for US exports are shipped from its shipping origin to the port of Los Angeles or Long Beach and 89,000 TEUs of containerized shipments for US imports are transited to Kansas from the port of Savannah by rail in the base model. Shipping origin and destination in Kansas do not use rail to transit containerized shipments for US exports and import after the PCE and US port expansion.

Under the base model and Model 2, more than 99,000 TEUs of containerized shipments for US exports and 260,000 TEUs of containerized shipments for US imports in Kentucky are transited to/from the port of Savannah by rail. However, whole containerized shipments for US exports are shipped to the port of Norfolk, rather than Savannah Port by rail after the PCE and US port expansion. Quantities of containerized shipments for US imports in Kentucky decreases by 194,000 TEUs and they are shipped from the port of Norfolk by rail. In Louisiana, approximately 99,000 TEUs of containerized shipments for US imports are shipped from the port of Savannah to the shipping destination in the base model and Model 2, but the import port changes from Savannah to the port of Miami after the PCE and US port expansion, while trade volume remains the same as the base case. Louisiana does not use rail to transit containerized shipments for US exports.

Minnesota imports some of their containerized shipments from the ports of Settle or Tacoma, since 240,000 TEUs of US imports are shipped on this route by rail in the base model. After the PCE and US port expansion, none of the containerized shipments for US exports and import are transited by rail in Minnesota. In Mississippi, more than 101,000 TEUs of containerized shipments are imported from the port of Savannah to shipping destination by rail. When the Panama Canal is expanded, quantities of containerized shipments for US imports decreases by 98,000 TEUs, which comes from the port of Savannah by rail as the port of Miami begins to send 3,000 TEUs for US imports to Mississippi by rail. If the Panama Canal and US ports are expanded, all containerized shipments for US imports in Mississippi are shipped from Miami by rail.

In North Carolina, 159,000 TEUs of containerized shipments for US exports are shipped from shipping origin to the port of Norfolk by rail and 281,000 TEUs and 70,000 TEUs of containerized shipments for US imports are from the ports of Norfolk and Savannah by rail, respectively in the base case. Shipping origin exports 116 TEUs of containerized shipments for US exports to the port of Norfolk by rail and more than 378,000 TEUs of containerized shipments for US imports are delivered to shipping destination from the port of Norfolk by rail after the PCE. If the PCE and US port expansion are completed, 159,000 TEUs for the U.S, export and 351,000 TEUs for US imports are transited by rail to/from the port of Norfolk by rail.

In North Dakota, about 3,000 TEUs for US exports and 7,000 TEUs for US imports are transited to/from the port Seattle or Tacoma by rail in the base model and Model 2. However, all containerized shipments for US exports and imports in North Dakota are transited to/from the port of New York instead of Seattle or Tacoma Ports by rail when the Panama Canal and US ports are expanded. In Nebraska, 36,000 TEUs of containerized shipments for US exports are shipped from shipping origin to the port of Los Angeles or Long Beach by rail and 27,000 TEUs are delivered to shipping destination from the same port by rail before the PCE.

Although Nebraska continues to receive the same quantities of containerized shipments for US imports from the port of Los Angeles or Long Beach by rail after the PCE, none of the containerized shipments are exported and imported after the PCE and US port expansion. In South Dakota, about 4,000 TEUs and 5,000 TEUs containerized shipments for US exports and import are transited to/from the port of Seattle or Tacoma by rail in the base model; however, all containerized shipments for US exports and import are transited to/from the port of New York instead of Seattle and Tacoma ports, by rail, mainly when neither the PNC is expanded nor the PNC and US ports are expanded.

Texas, which is the largest state to use rail services for domestic freight movement in the United States, more than 860,000 TEUs of containerized shipments are shipped from shipping origin to the port of Los Angeles or Long Beach and 1.3 million TEUs of containerized shipments for US imports are transited to shipping destinations from the same port by rail prior to the PCE. Although trade volume and flow of containerized shipments for US imports after the PCE remain the same as the base case, trade volume and flows of containerized shipments for US exports change as 666,000 TEUs, 126,000 TEUs, and 74,000 TEUs are exported to the port of LA/LB, Miami, and Savannah by rail, respectively. If the Panama Canal and US ports are expanded, all containerized shipments for US exports are shipped from shipping origin to the port of Savannah, while trade volume and flows of containerized shipments for US imports changes as 150,000 TEUs, 295,000 TEUs, and 909,000 TEUs are imported from the port of LA/LB, Miami, and Savannah by rail, respectively.

Wisconsin exports more than 94,000 TEUs to the port of New York and this shipping destination receives more than 185,000 TEUs from the same port by rail in the base model and Model 2. None of the containerized shipments for US exports and import are shipped by rail if the Panama Canal and US port are expanded. Lastly, Tennessee receives approximately 196,000 TEUs of containerized shipments for US imports from the port of Charleston by rail when only the Panama Canal is expanded.

Details of domestic trade flows and shares of intermodal and intramodal systems in the United States are discussed in the next section. Competitiveness of domestic transportation modes by changes in international trade circumstance such as the Panama Canal Expansion is also discussed.

5.1.6. Impacts of the Panama Canal Expansion on the competitiveness of intermodal and intramodal systems in the United States

Table 5.8 shows shares of domestic transportation modes under given alternative scenarios in the United States. 40.42%, 6.9%, and 52.68% of the total containerized shipments for US exports are shipped from shipping origins to the export ports by truck, truck-barge combination, and rail respectively and 46.33%, 11.23%, and 42.44% of containerized shipments for US imports are transited to shipping destinations from import ports by truck, truck-barge combination, and rail respectively before the Panama Canal Expansion in the United States. Rail moves more containerized shipments for US exports than truck, but truck moves more containerized shipments for US imports than rail in the base model. In the total, rail moves more containerized shipments than trucks in the United States. Figure 5.2 shows distribution of domestic transportation modes prior to the PCE in the United States. In Figure 5.2, red dots indicate quantities of containerized shipments transited by trucks, blue dots indicate quantities of containerized shipments moved by a truck-barge combination, and green dots indicate quantities of containerized shipments transited by rail in the United States. In the base model, Washington, Oregon, California, Florida, Virginia, New Jersey, Connecticut, and New York are only the states to use truck services to transit their containerized shipments in the United States. Arkansas, Tennessee, Missouri, Minnesota, and Illinois use truck-barge services to transit their containerized shipments in the United States. All other states use rail services to transit their containerized shipments. Illinois is the only state that uses more than one domestic transportation mode for US exports and Minnesota is the only state that uses more than one domestic transportation mode for US imports.

Table 5.8. Shares of domestic transportation modes in the United States.

	Base Model			Model 2			Model 4		
Mode	Export	Import	Total	Export	Import	Total	Export	Import	Total
Truck	40.42%	46.33%	44.33%	41%	46.36%	44.54%	40.42%	46.33%	44.33%
Truck-Barge	6.9%	11.23%	9.76%	7.13%	11.11%	9.76%	12.45%	15.76%	14.64%
Rail	52.68%	42.44%	45.92%	51.87%	42.53%	45.70%	47.12%	37.91%	41.04%

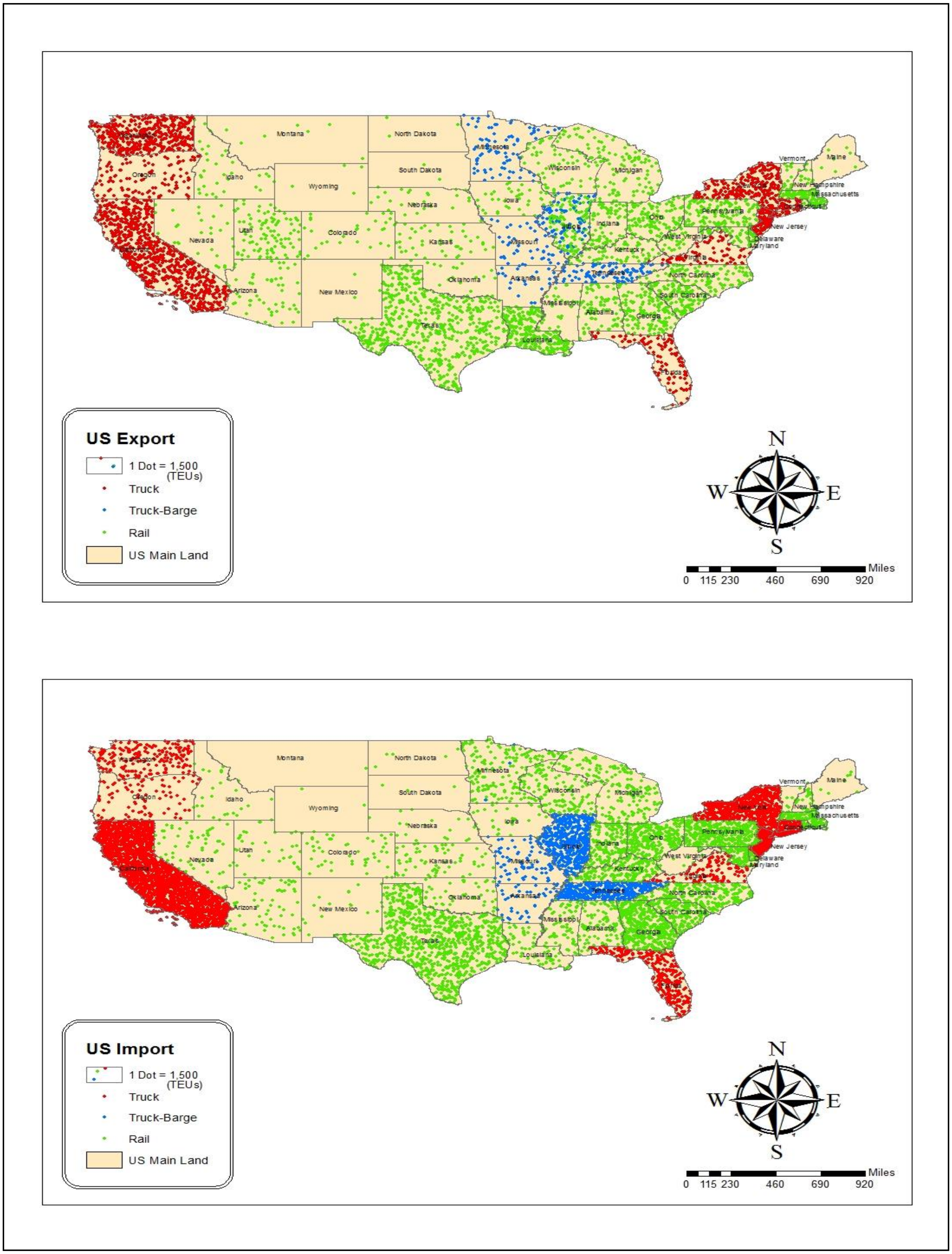


Figure 5.2. Distribution of domestic transportation modes prior to the Panama Canal Expansion in the United States.

Table 5.8 also shows shares of domestic transportation modes after the Panama Canal Expansion in the United States. Truck and truck-barge movements of containerized shipments for US exports increase by 0.58% and 0.23% respectively and rail movement for US exports decreases by 0.81% under the Panama Canal Expansion. Truck and truck-barge movements for US imports also increase by 0.03% and 0.12% and rail movement decreases by 0.09%. The total movements of truck increases by 0.21% as rail movement decreases by 0.21% and the total movements of the truck-barge combination remains the same as the base case.

Figure 5.3 shows distribution of domestic transportation modes after the PCE in the United States. In Figure 5.3, orange dots indicate quantities of containerized shipments transited by truck, sky blue dots indicate quantities of containerized shipments moved by a truck-barge combination, and green dots indicate quantities of containerized shipments transited by rail in the United States. Model 2, Washington, Oregon, California, Florida, North Carolina, Virginia, New Jersey, Connecticut, and New York are the states only to use truck services to transit their containerized shipments in the United States. Arkansas, Tennessee, Missouri, Minnesota, Kansas, and Iowa uses a truck-barge services to transit their containerized shipments in the United States, while Nebraska uses a truck-barge combination for US exports only and Illinois uses a truck-barge combination for US imports only. All other states use rail services to transit their containerized shipments in the United States. North Carolina is the only state that uses more than one domestic transportation mode for US exports and imports and Illinois and Tennessee use more than one domestic transportation mode for US imports.

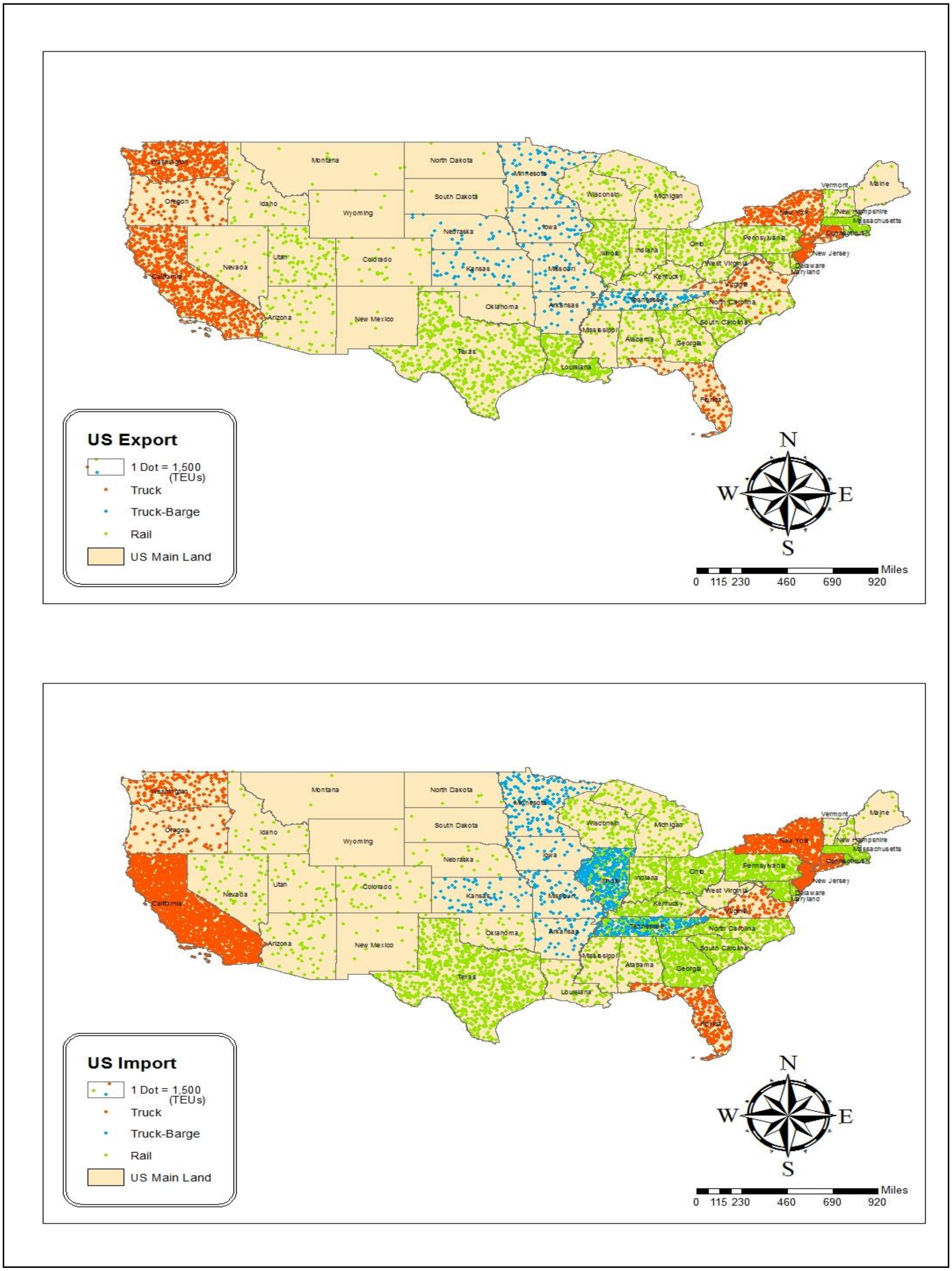


Figure 5.3. Distribution of domestic transportation modes after the Panama Canal Expansion in the United States.

Table 5.8 also shows shares of domestic transportation modes after the Panama Canal and US port expansion in the United States. Truck-barge movements of containerized shipments for US exports increase by 5.55%, while rail movement for US exports decreases by 5.55% because of the Panama Canal and US port expansion. Truck-barge movements for US imports also increase by 4.53%, while rail movement decreases by 4.53%. The total movements of truck-barge combination increase by 4.88% as rail movement decreases by 4.88%. This means that shares of truck movements in Model 4 remain the same as the base model.

Figure 5.4 shows distribution of domestic transportation modes after the Panama Canal and US port expansion in the United States. In Figure 5.4, dark yellow dots indicate quantities of containerized shipments transited by truck, dark blue dots indicate quantities of containerized shipments moved by a truck-barge combination, and green dots indicate quantities of containerized shipments transited by rail in the United States. In Model 4, Washington, Oregon, California, Florida, Virginia, New Jersey, Connecticut, and New York are only the states to use truck services to transit their containerized shipments in the United States. Arkansas, Tennessee, Missouri, Minnesota, Kansas, Iowa, Nebraska, Illinois, and Wisconsin use truck-barge services to transit their containerized shipment in the United States, and Kentucky uses a truck-barge combination to ship from import ports to shipping destinations for US imports.

Thus, the Panama Canal Expansion will affect intermodal and intramodal systems in the United States. Table 5.9 shows optimal choices for domestic transportation modes reflecting changes to international trade and indicates competitiveness of intermodal and intramodal systems in the United States. In Table 5.9, domestic transportation modes used to transit containerized shipments to/from US ports appear in parenthesis. Most of the states along US major river systems are the most competitive for the intermodal system in the United States since the optimal choices of domestic transportation modes in the states of Iowa, Illinois, Kansas, Kentucky, Minnesota, Nebraska, Tennessee, and Wisconsin are changed by the Panama Canal and US port expansion. In these states, truck-barge and rail services are highly competitive.

North Carolina is the only state that truck and rail services with compete each other. Washington, Oregon, and California are largest states to transit containerized shipments by truck; therefore, intramodal competition occurs in these states. Since more than one major US container port is located within 250 miles in those states, truck services are highly competitive to capture more containerized shipments in the market. Port is located within 250 miles in those states, truck services are highly competitive to capture more containerized shipments in the market.

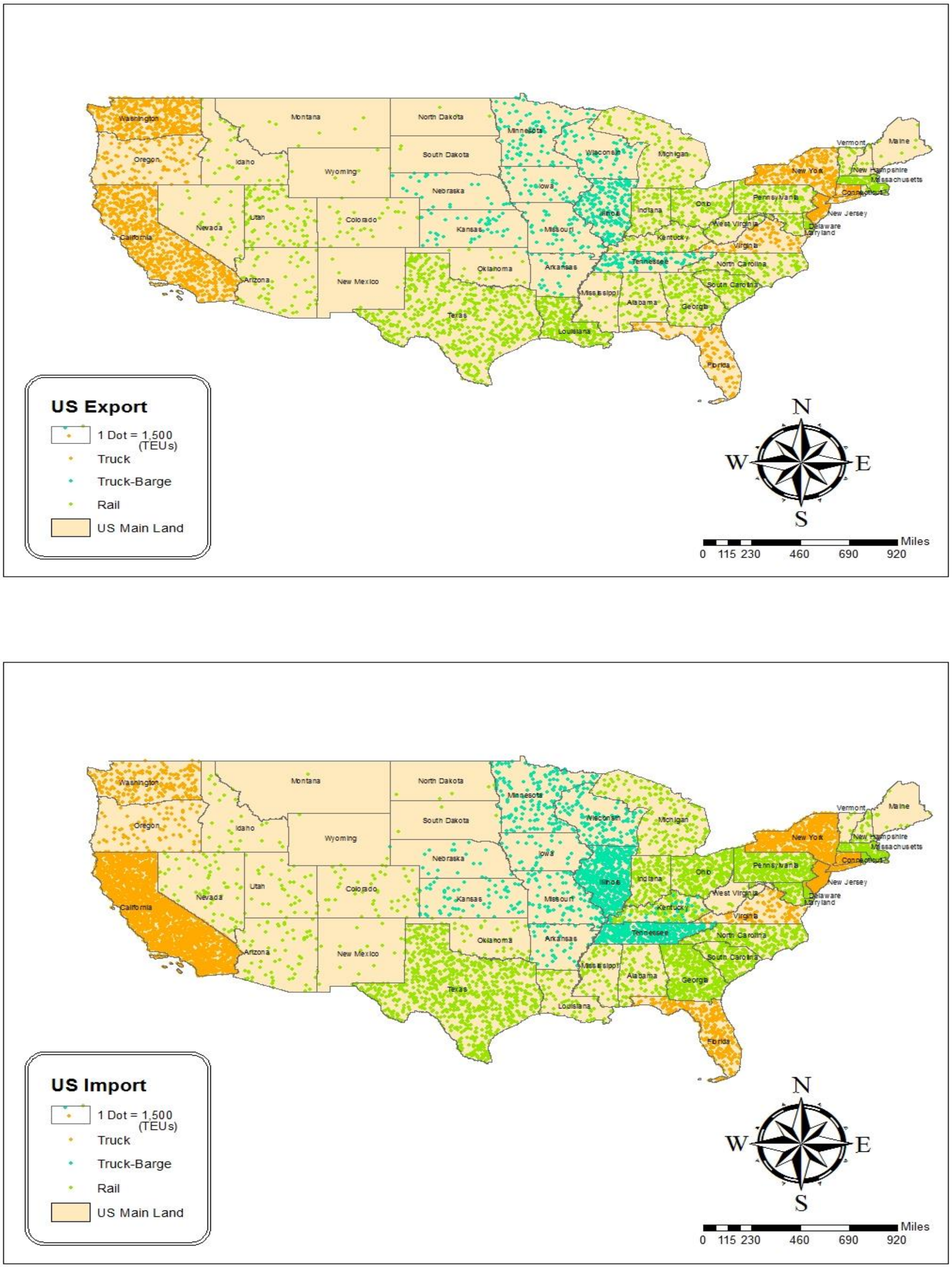


Figure 5.4. Distribution of domestic transportation modes after completion of the Panama Canal and US port expansion in the United States.

Table 5.9. Optimal choices of US domestic transportation mode in changes of international trade circumstance.

US Export				US Import			
State	Base Model	Model 2	Model 4	State	Base Model	Model 2	Model 4
				CA	LA/LB (T)	LA/LB (T)	LA/LB (T)
IA	LA/LB (R)	Gulf (T-B)	Gulf (T-B)	IA	LA/LB (R)	Gulf (T-B)	Gulf (T-B)
IL	Gulf (T-B) M-A (R)	M-A (R)	Gulf (T-B)	IL	Gulf (T-B)	Gulf (T-B) M-A (R)	Gulf (T-B)
				IN	M-A (R)	M-A (R)	M-A (R)
KS	LA/LB (R)	Gulf (T-B)	Gulf (T-B)	KS	LA/LB (R)	Gulf (T-B)	Gulf (T-B)
KY	S-A (R)	S-A (R)	M-A (R)	KY	S-A (R)	S-A (R)	Gulf (T-B) M-A (R)
				LA	S-A (R)	S-A (R)	S-A (R)
				MN	Gulf (T-B) PNW (R)	Gulf (T-B)	Gulf (T-B)
				MS	S-A (R)	S-A (R)	S-A (R)
NC	M-A (R)	M-A (R) S-A (T)	M-A (R)	NC	M-A (R) S-A (R)	M-A (R) S-A (T)	M-A (R)
ND	PNW (R)	PNW (R)	M-A (R)	ND	PNW (R)	PNW (R)	M-A (R)
NE	LA/LB (R)	Gulf (T-B)	Gulf (T-B)	NE	LA/LB (R)	LA/LB (R)	Gulf (T-B)
OR	PNW (T)	PNW (T)	PNW (T)	OR	PNW (T)	PNW (T)	PNW (T)
SD	PNW (R)	M-A (R)	M-A (R)	SD	PNW (R)	M-A (R)	M-A (R)
TX	LA/LB (R)	LA/LB (R) S-A (R)	S-A (R)	TX	LA/LB (R)	LA/LB (R)	LA/LB (R) S-A (R)
WA	PNW (T)	PNW (T)	PNW (T)	TN	Gulf (T-B)	Gulf (T-B) S-A (R)	Gulf (T-B)
WI	M-A (R)	Gulf (T-B)	M-A (R)	WI	M-A (R)	M-A (R)	Gulf (T-B)

Rail distance between shipping origin/destination in Indiana and export/import ports in the South-Atlantic and Mid-Atlantic are almost the same as each other; therefore, rail services are highly competitive in these areas. Louisiana and Mississippi are supposed to be competitive for truck movements, because more than one major US container port is located within states or interstate. However, these two states are highly competitive for rail services, since container ports in or near these states meet their port capacities for other states' shipments.

Containerized shipments in Arkansas and Missouri are always transited by a truck-barge combination under the given scenarios because the distance between shipping origins/destinations in those two states and export/import ports in the Gulf of Mexico could be the optimal distance to minimize total domestic transportation costs. Then, those two states will be able to use only a truck-barge combination. Lastly, since North and South Dakota are located right in the Mid-North of the United States, long hauling of containerized shipments is required. As a result, rail services are the only available choice for inland transportation mode in this study. However, these two states become highly competitive for rail services when the Panama Canal and US ports are expanded.

5.1.7. International Trade Volume and Flows of Containerized Shipments in the United States

International trade flows of containerized shipments for US exports and import show shipments between container ports in the United States and its trade partners in the world. Figure 5.5 shows ocean trade volume and flows of containerized shipments in the United States prior to the Panama Canal Expansion. In Figure 5.5, a bar chart indicates quantities of containerized shipments for US exports (green) and imports (red) on all possible ocean freight routes in the United States. Ocean trades route in the United States are divided into 5 routes: (1) an ocean trade route between US trade partners in Asia and the West Coast of the United States including container ports in the PNW and LA.LB areas; (2) an ocean trade route between US trade partners in Asia and the Gulf of Mexico including container ports in the West and East Gulf areas; (3) an ocean trade route between US trade partners in Europe/South America and the Gulf of Mexico including container ports in the West and East Gulf areas; (4) an ocean trade route between US trade partners in Asia and the East Coast of the United States, including container ports in the South Atlantic and Mid-Atlantic areas; and (5) an ocean trade route between US trade partners in Europe/South America and the East Coast, including container ports in the South Atlantic and

Mid-Atlantic areas. One additional ocean trade route, named PNC in Figure 5.5 shows the total volume of containerized shipments through the Panama Canal in the United States.

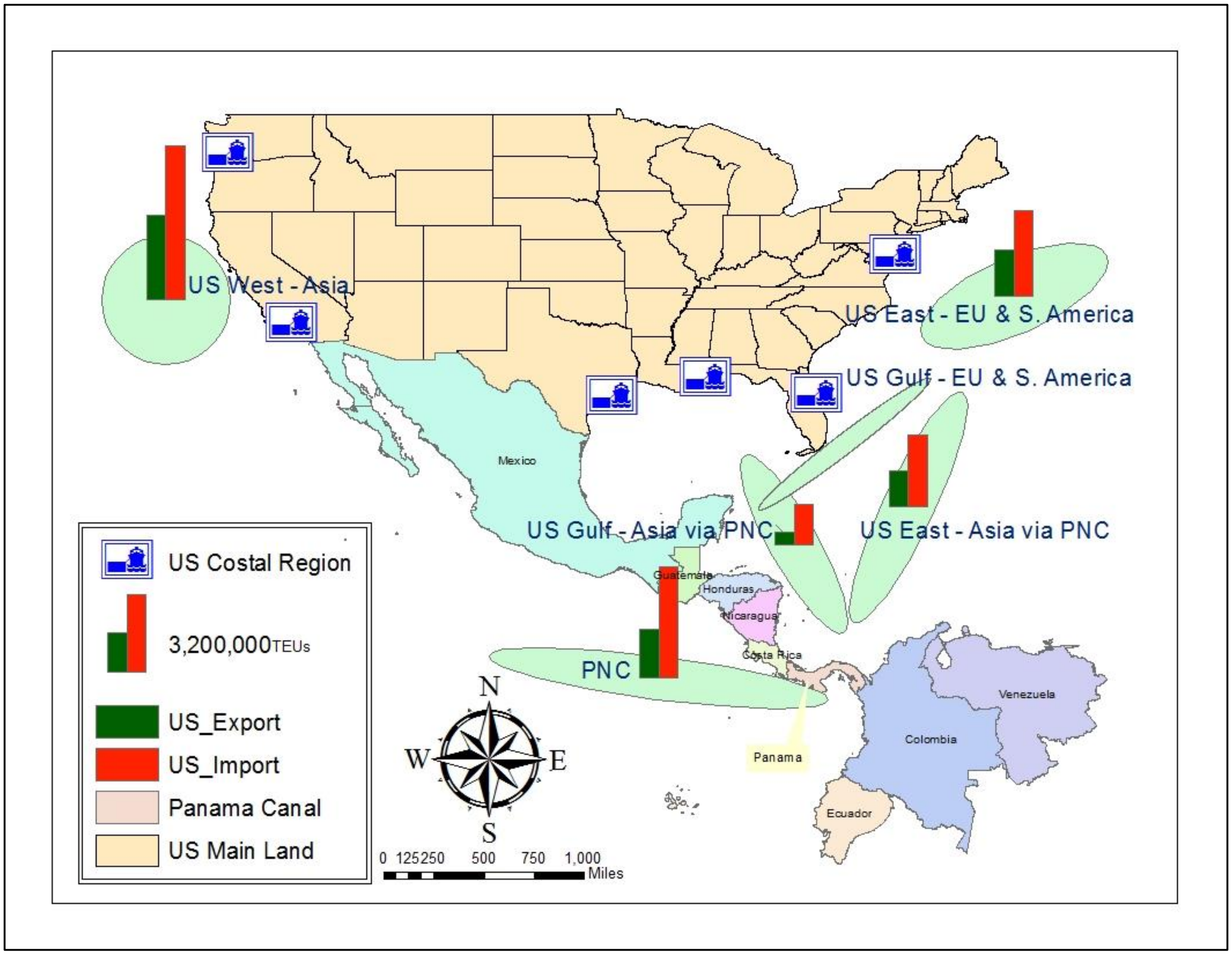


Figure 5.5. Ocean trade flows of containerized shipments in the United States.

Prior to the Panama Canal Expansion, more than 3.4 million TEUs of containerized shipments are exported from the West Coast to importing counties in Asia, and 6.3 million TEUs of containerized shipments are imported from exporting countries in Asia to the West Coast of the United States. For shipments between the Gulf of Mexico and Asia through the Panama Canal, more than 511,000 TEUs and 1.6 million TEUs of containerized shipments are transited for US exports and imports, respectively. None of the containerized shipments are traded between the Gulf of Mexico and US trade partners in Europe and South America in the base case. Approximately 1.5 million TEUs of containerized shipments are exported from importing countries in Asia to the East Coast of the United States through the Panama Canal and 2.9 million TEUs of containerized shipments are imported from exporting countries in Asia to the East Coast of the United States via the Panama Canal. More than 1.9 million TEUs are exported to importing countries in Europe and South America from the East Coast of the United States and 3.5 million TEUs of containerized shipments are imported from exporting countries in Europe and South America to the East Coast. 2 million TEUs and 4.5 million TEUs of containerized shipment for US exports and import are shipped through the Panama Canal.

Figure 5.6 shows ocean trade volume and flows of containerized shipments by container vessel in the United States after the Panama Canal Expansion. More than 3.1 million TEUs of containerized shipments are exported from the West Coast to importing counties in Asia and 5.9 million TEUs of containerized shipments are imported from exporting countries in Asia to the West Coast of the United States. For shipments between the Gulf of Mexico and Asia through the Panama Canal, more than 78,000 TEUs and 350,000 TEUs of containerized shipments are transited for US exports and import, respectively. 450 TEUs of containerized shipments are exported to importing countries in Europe and South America from the Gulf of Mexico and 125,000 TEUs are imported from exporting countries in those two continents to the Gulf of Mexico in the United States. More than 2.5 million TEUs of containerized shipments are exported from importing countries in Asia to the East Coast through the Panama Canal and 4.6 million TEUs of containerized shipments are imported from exporting countries in Asia to the East Coast via the Panama Canal. Approximately 1.2 million TEUs are exported to importing countries in Europe and South America from the East Coast and 2.2 million TEUs of containerized shipments are imported from exporting countries in Europe and South America to the East Coast. More than 2.6 million TEUs and 4.9 million TEUs of containerized shipment for US exports and import are transited through expanded Panama Canal.

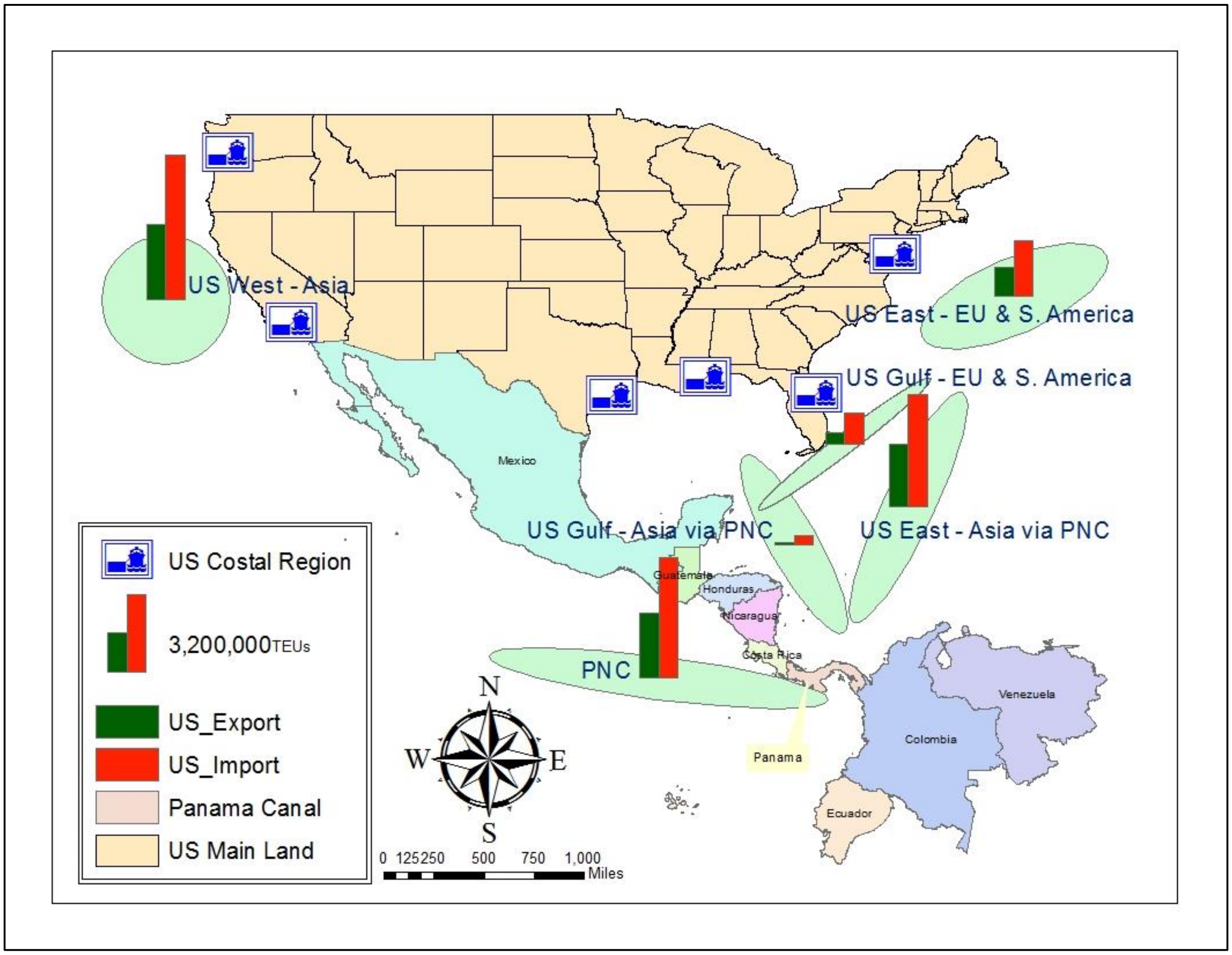


Figure 5.6. Ocean trade flows of containerized shipments after the Panama Canal Expansion in the United States.

Figure 5.7 shows ocean trade volume and flows of containerized shipments by container vessel in the United States after the Panama Canal and US port expansion. More than 2.4 million TEUs of containerized shipments are exported from the West Coast to importing counties in Asia and 4.7 million TEUs of containerized shipments are imported from exporting countries in Asia to the West Coast of the United States.

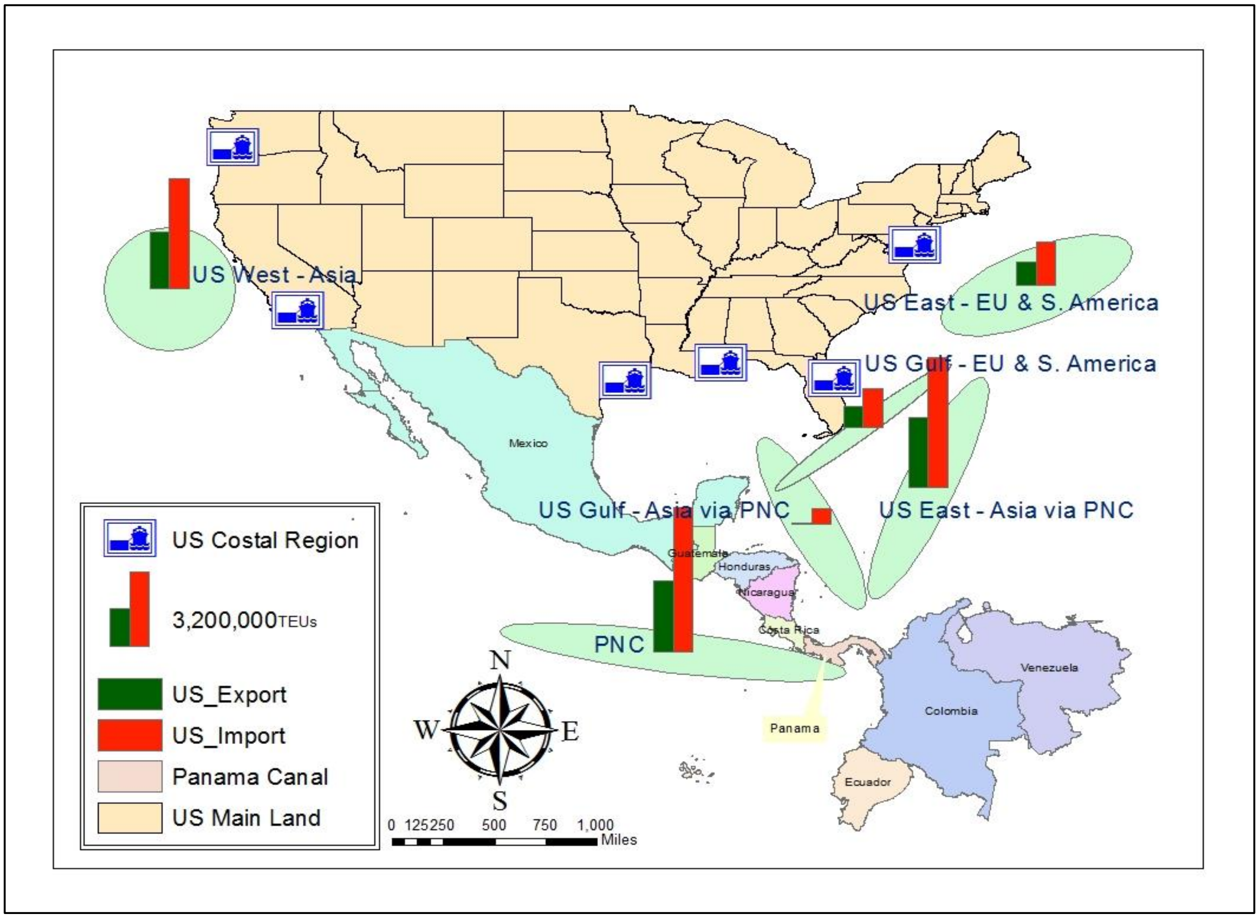


Figure 5.7. Ocean trade flows of containerized shipments after the Panama Canal and US port expansion in the United States.

For shipments between the Gulf of Mexico and Asia through the Panama Canal, more than 22,000 TEUs and 620,000 TEUs of containerized shipments are transited for US exports and import, respectively. 900 TEUs of containerized shipments are exported to importing countries in Europe and South America from the Gulf of Mexico and 1.6 million TEUs are imported from exporting countries in those two continents to the Gulf of Mexico in the United States. More than 3 million TEUs of containerized shipments are exported from importing countries in Asia to the East Coast of the United States through the Panama Canal and 5.5 million TEUs of containerized shipments are imported from exporting countries in Asia to the East Coast of the United States via the Panama Canal. Approximately 1 million TEUs are exported to importing countries in Europe and South America from the East Coast of the United States and 1.8 million TEUs of containerized shipments are imported from exporting countries in Europe and South America to the East Coast of the United States. More than 3 million TEUs and 6.2 million TEUs of containerized shipment for US exports and import are transited through the expanded Panama Canal.

As a result, Panama Canal Expansion affects international trade volume and flows of containerized shipments between US and Asia. Table 5.10 shows shares and changes in international trade volume of containerized shipments on selected routes in the United States. Under current international trade conditions, 44.95% of the total containerized shipments in the United States are traded between the West Coast of the United States and its trade partners in Asia, 9.76% are on a route between the Gulf of Mexico in the United States and its trade partners in Asia, 20.48% are on a route between East Coast of the United States and its trade partners in Asia, and 24.81% of the total containerized shipments in the United States are traded between the East Coast of the United States and its trade partners in Europe and South America. Shares of international containerized shipments for US exports and imports at the Panama Canal is 30.24%, since 27.21% of the total US export and 31.76% of the total US import are shipped through the canal in the base case.

After the Panama Canal Expansion, quantities of the total containerized shipments between the West Coast and Asia decrease to 41.57%, the total TEUs of containerized shipments between the Gulf and Asia decrease to 1.96%, and the volume of the total containerized shipments between the East Coast and EU/South America decreases to 15.79%. However, the total quantities of containerized shipments between the Gulf and EU/S. America increase to 7.79% and the total TEUs of containerized shipments between East Coast and Asia increase to 32.88%.

As a result, shares of containerized shipments at the PNC increase to 34.85%, since a large number of TEUs are transited between the East Coast and Asia after the PNC.

Table 5.10. Shares and changes of international trade volume of containerized shipments in the United States.

	Base Model			Model 2			Model 4		
c	Export	Import	Total	Export	Import	Total	Export	Import	Total
West Coast – Asia	47%	43.9%	44.95%	42.13% (10.36%↓)	41.27% (5.99%↓)	41.57% (7.54%↓)	33.18% (29.41%↓)	32.69% (25.54%↓)	32.86% (26.91%↓)
Gulf – Asia	6.9%	11.23%	9.76%	1.06% (84.65%↓)	2.43% (78.38%↓)	1.96% (79.89%↓)	0.3% (95.62%↓)	4.3% (61.7%↓)	2.94% (69.83%↓)
Gulf – EU/S. America	0	0	0	6.07% (6.07%↑)	8.68% (8.68%↑)	7.79% (7.79%↑)	12.15% (12.15%↑)	11.46% (11.46%↑)	11.69% (11.69%↑)
East Coast – Asia	20.37%	20.54%	20.48%	34.67% (70.16%↑)	31.97% (55.66%↑)	32.88% (60.55%↑)	40.79% (100.22%↑)	38.67% (88.32%↑)	39.39% (92.34%↑)
East Coast – EU/S. America	25.73%	24.33%	24.81%	16.07% (37.54%↓)	15.65% (35.67%↓)	15.79% (36.33%↓)	13.58% (47.23%↓)	12.88% (47.08%↓)	13.11% (47.13%↓)
PNC	27.21%	31.76%	30.24%	35.75% (31.01%↑)	34.39% (8.28%↑)	34.85% (15.24%↑)	41.09% (50.70%↑)	42.98% (35.3%↑)	42.34% (40%↑)

If the Panama Canal and US ports are expanded, bigger changes occur for international trade volume and flows of containerized shipments in the United States. The total quantities of containerized shipments between the West Coast and Asia decreases to 32.86%, the total TEUs of containerized shipments between the Gulf and Asia decreases to 2.94%, and the total TEUs of containerized shipments between the East Coast and EU/South America decrease to 13.11%. On the other hand, the total quantities of containerized shipments between the Gulf and EU/S. America increase to 11.69% and the total TEUs of containerized shipments between East Coast and Asia increase to 39.39%. Therefore, the total TEUs of containerized shipments at the PNC increase to 42.34% after the PCE and US port expansion.

Thus, 45.29% of the total TEUs in the United States are shipped through the East Coast and 44.95% of the total TEUs in the United States will be transited through the West Coast, while 9.76% of the total TEUs in the United States will be handled at the Gulf. East and West Coasts handle the majority of the containerized shipments in the United States evenly before the PCE. The East Coast has an advantage with the completion of the new PCE, since it handles 48.67% of the total TEUs in the United States. Shares of the total containerized shipments in West Coast will decrease from 44.95% to 41.75% after the PCE. However, the total quantities of containerized shipments at the Gulf remain the same in the base case because all container ports in the Gulf meet their capacities in all models. Therefore, although the total TEUs of containerized shipments between the Gulf and Asia decreases as the total TEUs between the Gulf and EU/South America increase, the total TEUs at the Gulf do not change before or after the PCE. At the Gulf of Mexico, the ports' capacities are relatively smaller than other container ports in the United States; therefore, they have very limited capacities to handle containerized shipments at ports under current trade conditions. If the Panama Canal and US ports are expanded, the Gulf has an advantage with the PCE since it handles 14.63% of the total TEUs of containerized shipments in the United States and the Gulf used to handle less than 10% of the total TEUs. In the East Coast, container ports share 52.5% of the total containerized shipments in the United States, while the West Coast loses their shipments dramatically. As a result, it is concluded that the PCE brings positive effects for container ports in the East Coast and negative effects on the ports in the West Coast, while no effects are felt by ports in the Gulf. The PCE and US port expansion are significantly harmful to the ports in the West Coast, while they are the most beneficial to the ports in the Gulf and the East Coast of the United States (Figure 5.8).

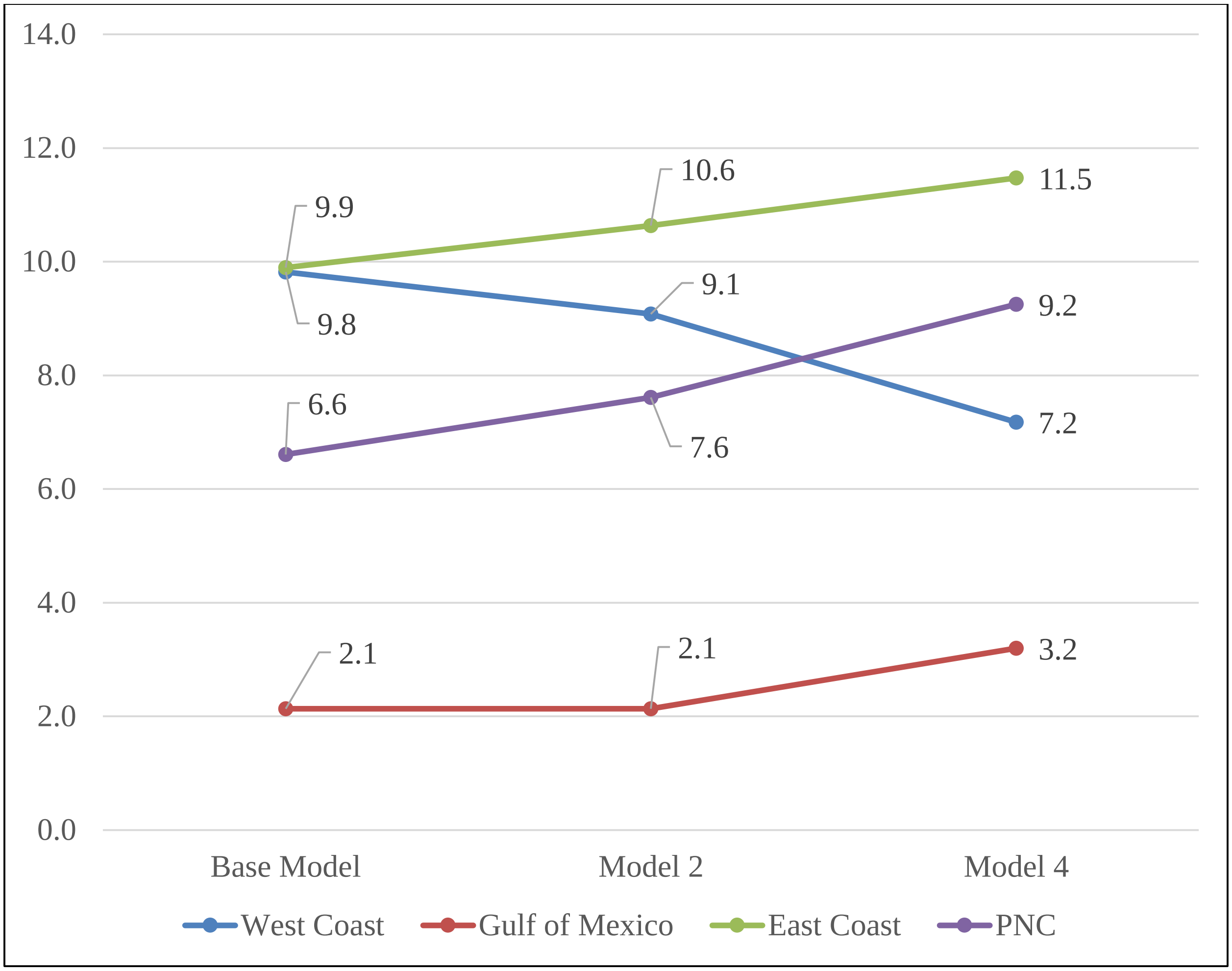


Figure 5.8. Total trade volume of containerized shipments by coastal regions in the United States.

5.1.8. Summary

The Panama Canal Expansion results in changes in international and domestic trade flows because it allows larger container vessels transit through the canal. According to the result of the ocean freight rate estimation, the ocean freight rate decreases as the vessel size increases. This represents the lower ocean freight rates associated with economies of scale due to the increase in vessel size for the hauling of containerized shipments. As a result, more containerized shipments are transited through the expanded Panama Canal with a reduced ocean freight rate from using larger vessel and eliminating delay by resolving congestion at the canal. However, the savings by eliminating delays is relatively small compared with the reduction in the ocean freight rate.

Therefore, the delay cost at the PNC does not affect trade volume and flows of containerized shipments in the United States under the Panama Canal Expansion.

Since more than one inland transportation mode is available in states along US major river systems, rail and barge-truck combinations are highly competitive in those states. Most major US export and import states are located near the ocean and have cost advantages for domestic transportation. In most coastal areas in the United States, more than one major container port is located within a couple of hundred miles and this encourages competitiveness of intermodal and intramodal systems. Since truck service has some advantages (cheaper cost and better reliability, and accessibility for short hauling), truck service competes with rail service, while it competes with other trucking services in the market. As a result, competitiveness of intermodal and intramodal systems occurs at the same time in those states.

Because container ports in the Gulf of Mexico meet 100% of their capacities before and after the PCE, trade volumes do not change. However, trade routes are changed significantly after the PCE and US port expansion. States in the mid-north part of the US mainland have only one choice for domestic transportation since distance between states and US sea ports are long. Rail service is the most popular domestic transportation mode in those states; however, they have choices of sea ports, depending on their international trade partners. Since those states could go to all coastal regions in the United States with comparable costs for inland transportation, states in the mid-north part of the US mainland are relatively more sensitive to inland transportation costs than other states. Lastly, the PCE changes international trade volume and flows dramatically. Most beneficial ports are located in the East Coast and the ports in the West Coast have negative effects on their shipments.

Thus, most of states in the United States are sensitive to the PCE and US port expansion. Competitiveness of intermodal and intramodal systems occurs in the United States. However, it is not necessary to expand port capacities in the West Coast, while ports in the East Coast should expand their capacities. Container ports in the Gulf should be or should not be expanded, under various, alternative scenarios for this study.

5.2. Impacts of Changes in Toll Rates at the Panama Canal

This section introduces alternative toll rates at the Panama Canal to examine the impact of changes in toll rates on trade flows of containerized shipments between the United States and its top 15 trade partners. The model determines the optimal toll rate to maximize revenue at the Panama Canal.

It is expected that the Panama Canal Authority (PCA) may increase or decrease toll rates to maximize canal revenue. An increase (or a decrease) of the canal toll rates reduces (or increases) the quantities of containerized shipments passing through the canal and also affects inland shipping in the United States. The toll rate in the base case is $74 per TEU; alternatives toll rates considered are decreases (and increases) of 5%, 10%, 15%, 20%, and 30%, respectively. This section analyzes the increases and decreases in toll rates and examines the resulting economic values of the Panama Canal Expansion.

5.2.1. Changes in Trade Volume of Containerized Shipments Transited through the Panama Canal

Changes in toll rates at the PNC influence the total quantities of containerized shipments at the canal. Table 5.11 shows changes in the total trade volume of containerized shipments between the United States and its trading partners using alternative toll rates. Prior to the Panama Canal Expansion, the US exports more than 2 million TEUs of containerized shipments to its trade partners through the PNC, which is 27% of the total containerized shipments for US exports. Approximately 4.5 million TEUs of containerized shipments are imported from other countries to the US via the PNC, which is 32% of the total containerized shipments for US imports. More than 6.6 million TEUs of the total containerized shipments are transited through the PNC for US exports and imports. When the Panama Canal is expanded, the total TEUs of containerized shipments for US exports through the PNC increase by 31% and, US imports through the PNC increase by 8%, with the PNC toll rate remaining the same as in the base model. The PNC handles more than 7.6 million TEUs of the total containerized shipments for US exports and imports.

Table 5.11. Changes in trade volume of containerized shipments at the Panama Canal by the PNC toll changes.

	Toll Change	Toll at the PNC ($)	Trade Volume (TEUs) at the PNC			Trade Volume (%) at the PNC		
			Export	Import	Total	Export	Import	Total
Base Model	-	$74 (-)	2,021,409	4,584,475	6,605,884	27%	32%	30%
Model 2	-	$74 (-)	2,648,310	4,964,146	7,612,456	36% (31%↑)	34% (8%↑)	34% (15%↑)
	Decrease	$71.78 (3%↓)	2,861,928	5,272,567	8,134,495	39% (8%↑)	37% (6%↑)	37% (6.9%↑)
		$70.3 (5%↓)	2,861,928	5,272,567	8,134,495	39% (8%↑)	37% (6%↑)	37% (6.9%↑)
		$66.6 (10%↓)	2,861,928	5,272,567	8,134,495	39% (8%↑)	37% (6%↑)	37% (6.9%↑)
		$62.9 (15%↓)	2,861,928	5,272,567	8,134,495	39% (8%↑)	37% (6%↑)	37% (6.9%↑)
		$59.2 (20%↓)	2,861,928	5,272,567	8,134,495	39% (8%↑)	37% (6%↑)	37% (6.9%↑)
		$51.8 (30%↓)	3,281,696	5,521,796	8,803,492	44% (24%↑)	38% (11%↑)	40% (15.6%↑)
	Increase	$77.4 (5%↑)	2,640,077	4,964,146	7,604,223	35% (.3%↓)	34% (-)	35% (0.1%↓)
		$81.4 (10%↑)	2,454,514	4,964,146	7,418,660	33% (7%↓)	34% (-)	34% (2.5%↓)

Table 5.11. Changes in trade volume of containerized shipments at the Panama Canal by the PNC toll changes (continued).

	Toll Change	Toll at the PNC ($)	Trade Volume (TEUs) at the PNC			Trade Volume (%) at the PNC		
			Export	Import	Total	Export	Import	Total
		$85.1 (15%↑)	2,454,514	4,964,146	7,418,660	33% (7%↓)	34% (-)	34% (2.5%↓)
Model 4	-	$74 (-)	3,046,233	6,202,618	9,248,851	41% (51%↑)	43% (35%↑)	42% (40%↑)
	Decrease	$70.3 (5%↓)	3,046,233	6,202,618	9,248,851	41% (-)	43% (-)	42% (-)
		$66.6 (10%↓)	3,046,233	6,352,964	9,399,197	41% (-)	44% (2.4↑)	43% (1.6%↑)
		$62.9 (15%↓)	3,046,233	6,352,964	9,399,197	41% (-)	44% (2.4↑)	43% (1.6%↑)
		$59.2 (20%↓)	3,046,233	6,352,964	9,399,197	41% (-)	44% (2.4↑)	43% (1.6%↑)
		$51.8 (30%↓)	3,046,233	6,352,964	9,399,197	41% (-)	44% (2.4↑)	43% (1.6%↑)
	Increase	$77.4 (5%↑)	3,046,233	6,202,618	9,248,851	41% (-)	43% (-)	42% (-)
		$81.4 (10%↑)	3,046,233	6,202,618	9,248,851	41% (-)	43% (-)	42% (-)
		$85.1 (15%↑)	3,046,233	6,202,618	9,248,851	41% (-)	43% (-)	42% (-)
		$88.8 (20%↑)	3,046,233	6,202,618	9,248,851	41% (-)	43% (-)	42% (-)
		$96.2 (30%↑)	3,046,233	6,202,618	9,248,851	41% (-)	43% (-)	42% (-)

As an inverse relationship between the PNC toll rate and quantities of containerized shipments through the PNC is expected, the quantity of containerized shipments through the PNC increases when the PNC toll rate decreases. For instance, if 3% of the current toll rate at the PNC decreases, TEUs of containerized shipments through the PNC increase by 6.9%. More than 8.1 million TEUs of containerized shipments are transited through the PNC when the toll is reduced to $71.78 per TEU. However, if the PNC toll rates decrease by 10%, 15%, and 20%, the total TEUs of containerized shipments through the PNC remains the same as that with the 3% decrease. Trade balance of US exports and import through the PNC does not change as well. However, if the PNC toll rate decreases from $74 to $51.8 (a 30% decrease), quantities of the total containerized shipments through the PNC increase by 15.6%. The total quantities of containerized shipments through the PNC for US exports and imports decrease by 0.1% with a 5% decrease in the PNC toll rate. On the other hand, if the PNC toll rates increase by 10%, 15%, 20%, and 30%, the total number of containerized shipments through the PNC decrease from 7.6 million TEUs to 7.4 million TEUs. This implies that toll rates are not sensitive to the volume of containerized shipments through the PNC.

If the Panama Canal and US ports are expanded, the total quantities of containerized shipments through the PNC increase, as shown in Table 5.10. However, changes in the PNC rate affect the total containerized shipments through the PNC only for US imports under some instances of toll changes. The total TEUs of containerized shipments increase by 40%, with a 51% increase for US exports and a 35% increase for US imports via the PNC after the PCE and US port expansion. In quantity, more than 9.2 million TEUs of containerized shipments are transited through the PNC after the PCE and US port expansion under the current toll rate. When the PNC toll rate decreases by 5%, the quantities of US exports and imports remain the same as those in the base case. However, if the PNC toll rates decrease by 10%, 15%, 20%, and 30%, quantities of containerized shipments through the PNC for US imports increase by 1.6% from 6.2 million TEUs to 6.3 million TEUs. Even if the PNC toll rates increase by 5%, 10%, 15%, 20%, and 30%, the quantities of containerized shipments through the PNC in the United States do not change. This implies that toll rates are not sensitive to the volume of containerized shipments through the canal.

The PCE and US port expansion influence quantities of containerized shipments through the Panama Canal significantly. In Model 2, four breaking points for the PNC toll rate are found in regard to changes in the quantity of containerized shipments. The total quantities of containerized shipments through the PNC increase with toll rate decreases in 3% and 30%, while quantities of TEUs remain the same with toll rate decreases ranging between more than 3% through 20%. The total quantities of containerized shipments through the PNC decrease with toll rate increases in 5% and 10%, while quantities of TEUs remain the same with toll rate increases ranging between more than 10% through 30%. On the other hand, in Model 4, only one breaking point for the PNC toll rate is found in regard to changes in the quantity of containerized shipments. The total quantity of containerized shipments through the PNC increases with a toll rate decrease of 10%, while quantities of TEUs remain the same with toll rate decreases of more than 10% through 30%. The total quantities of containerized shipments through the PNC do not change with toll increases ranging between 5% through 30%.

5.2.2. Economic Value of the Panama Canal Expansion

The Panama Canal plays an important role in transporting shipments between the United States and its trade partners in Asia. Without the canal, shipments between the Gulf of Mexico and the East Coast of the United States and countries in Asia are transited through either the Suez Canal, along the Atlantic Ocean or an alternative route along the Straits of Magellan. The Panama Canal saves not only ocean transit time, but also the ocean transportation cost of shipments passing between the Atlantic and Pacific Oceans. Since the Panama Canal has traffic congestion due to increased shipments through the canal, the Panama Canal Authority (PCA) decided to expand the canal.

Table 5.12 shows changes in the total toll revenue at the Panama Canal under alternative PNC toll rates. Prior to the Panama Canal Expansion with a current toll rate as of $74 per TEU, the total toll revenue is more than $488 million. When the PCE is completed, using the PNC toll rate at the current level, the total toll revenue is more than $563 million, 15.2% higher than that of the base model. If the PNC toll rate decreases by 3%, the total toll revenue at the PNC is approximately $584 million, 3.7% higher than that of Model 2 with the PCE and current toll rate. If the PNC toll rate decreases by 5%, the total toll revenue at the canal increases by 1.5%. However, if the PNC toll rates decrease by more than 5%, the total revenues at the PNC decrease. As a result, the total toll revenue at the PNC is maximized if the PNC toll rate decreases by 3% and the total toll revenues at the PNC decrease if the PNC toll rates decrease more than 3%. If the PNC toll rate decreases by more than 10%, the total revenues at the PNC are smaller than the total revenue after the PNC with the current toll rate. Therefore, a break- even point for the total toll revenue at the canal occurs at the PNC rates somewhere between decreases of 5% and 10%. On the other hand, if the PNC toll rate increases, the total toll revenue at the canal increases consistently, as seen in Model 2.

Table 5.12. Changes in the total toll revenue at the Panama Canal by the PNC toll changes.

	Toll Change	**Toll at the PNC ($)**	**Total throughput at the PNC (TEUs)**	**Total toll revenue at the PNC ($)**
Base Model	-	$74 (-)	6,605,884	$ 488,835,426
Model 2	-	$74 (-)	7,612,456	$ 563,321,744 (15.2%↑)
	Decrease	$71.78 (3%↓)	8,134,495	$ 583,894,051 (3.7%↑)
		$70.30 (5%↓)	8,134,495	$ 571,854,999 (1.5%↑)
		$66.6 (10%↓)	8,134,495	$ 541,757,367 (3.8%↓)
		$62.9 (15%↓)	8,134,495	$ 511,659,736 (9.2%↓)
		$59.2 (20%↓)	8,134,495	$ 481,562,104 (14.5%↓)
		$51.8 (30%↓)	8,803,492	$ 456,020,886 (19%↓)
	Increase	$77.40 (5%↑)	7,604,223	$ 588,566,860 (4.48%↑)
		$81.4 (10%↑)	7,418,660	$ 603,878,924 (7.2%↑)
		$85.1 (15%↑)	7,418,660	$ 631,327,966 (12.1%↑)

Table 5.12. Changes in the total toll revenue at the Panama Canal by the PNC toll changes (continued).

	Toll Change	Toll at the PNC ($)	Total throughput at the PNC (TEUs)	Total toll revenue at the PNC ($)
		$88.8 (20%↑)	7,418,660	$ 658,777,008 (17%↑)
		$96.2 (30%↑)	7,418,660	$ 713,675,092 (26.7%↑)
Model 4	-	$74 (-)	9,248,851	$ 684,414,974 (40%↑)
	Decrease	$70.3 (5%↓)	9,248,851	$ 650,194,225 (15.4%↑)
		$66.6 (10%↓)	9,399,197	$ 625,986,520 (11.1%↑)
		$62.9 (15%↓)	9,399,197	$ 591,209,491 (5%↑)
		$59.2 (20%↓)	9,399,197	$ 556,432,462 (1.2%↓)
		$51.8 (30%↓)	9,399,197	$ 486,878,405 (13.6%↓)
	Increase	$77.4 (5%↑)	9,248,851	$ 715,861,067 (27.1%↑)
		$81.4 (10%↑)	9,248,851	$ 752,856,471 (33.6%↑)
		$85.1 (15%↑)	9,248,851	$ 787,077,220 (40%↑)
		$88.8 (20%↑)	9,248,851	$ 821,297,969 (45.8%↑)
		$96.2 (30%↑)	9,248,851	$ 889,739,466 (58%↑)

In Model 4, the total toll revenue at the PNC increases by 40%, mainly due to the Panama Canal and US port expansion, while the toll rate at $74. Compare to Model 4, which includes the PCE and US port expansion with the current toll rate, if the PCA decreases the toll rate at the canal by 5%, 10%, and 15%, total revenues increase by 15.4%, 11.1%, and 5%, respectively although changes in percentage are decreased. The total revenue decreases if the PNC toll rates decrease by more than 20%. However, if the PNC toll rate increases, the total toll revenue at the canal increases as well in Model 4.

Thus, if the Panama Canal Authority does not decrease the toll rate more than 5% or the PCA increases the toll rate by any amount less than 30%, the total toll revenue increases consistently after the Panama Canal Expansion. If the PCA decreases the toll rate less than 15%, the total revenue at the canal also increases, while the total revenue increases consistently as the toll rate increase at the canal after the Panama Canal and US port expansion. As a result, although the PCE and US port expansion results in changes of the total toll revenue at the canal associated with the total quantities of containerized shipments through the canal and the toll rate at the canal, the total quantities of containerized shipments through the canal in the United States are not sensitive to changes of the toll rate at the canal. In addition, the PNC toll changes would account for a small portion of total ocean transportation costs and it will not affect the quantities of shipments through the expanded canal significantly.

5.2.3. Summary

An optimal toll rate after the Panama Canal and US port expansion, to maximize the total toll revenue at the PNC, is inconclusive. Theoretically, expansions would decrease the PNC toll rate due to the economies of scale by use of larger container vessels after the PCE. However, an optimal toll rate cannot be found in this study mainly because the toll rate is not sensitive to the quantity of containers shipped through the canal. The toll rate at the PNC accounts for a small portion of total transportation cost to transit containerized shipments between the United States and its trading partners.

Figure 5.9 shows changes in the total volume (upper side) and toll revenue (lower side) under alternative toll rates at the Panama Canal. In Figure 5.9, the blue line indicates volume of containerized shipments with the current and alternative toll rates (Model 2) and the Panama Canal Expansion. The red line indicates those under Model 4, which includes the Panama Canal and US port expansion. Figure 5.9 also includes the total volume and revenue at the PNC for the base model with current toll rate at $74*. The total volume of containerized shipments through the Panama Canal either increases as the PNC toll rate decreases and the total volume decreases as toll rate increases in Model 2. More specifically, the total quantities of containerized shipments through the PNC does not change when the PNC toll rates change from 3% to 20% decreases and from 10% to 30% increases. In Model 4, the total volume through the PNC increases as the PNC toll decreases slightly and the total volume remains when the PNC toll rate increases. The total volume of containerized shipments through the PNC remains the same with the toll rate decreased from 10% to 30%.

The total toll revenue at the Panama Canal consistently increases as the PNC toll rate increases in both Models 2 and 4 because the total volume at the canal either remains or slightly decreases. The total revenue at the canal decreases as the toll rate decreases in Model 4. On the other hand, the total revenue increases when the PNC toll rate decreases by less than 5% and the total revenue begins to decrease somewhere between 5% and 10% decreases of the PNC toll rate in Model 2. As a result, the Panama Canal Authority will earn more revenue from the toll unless they decrease the toll rate by less than 5% of the current toll rate at the canal.

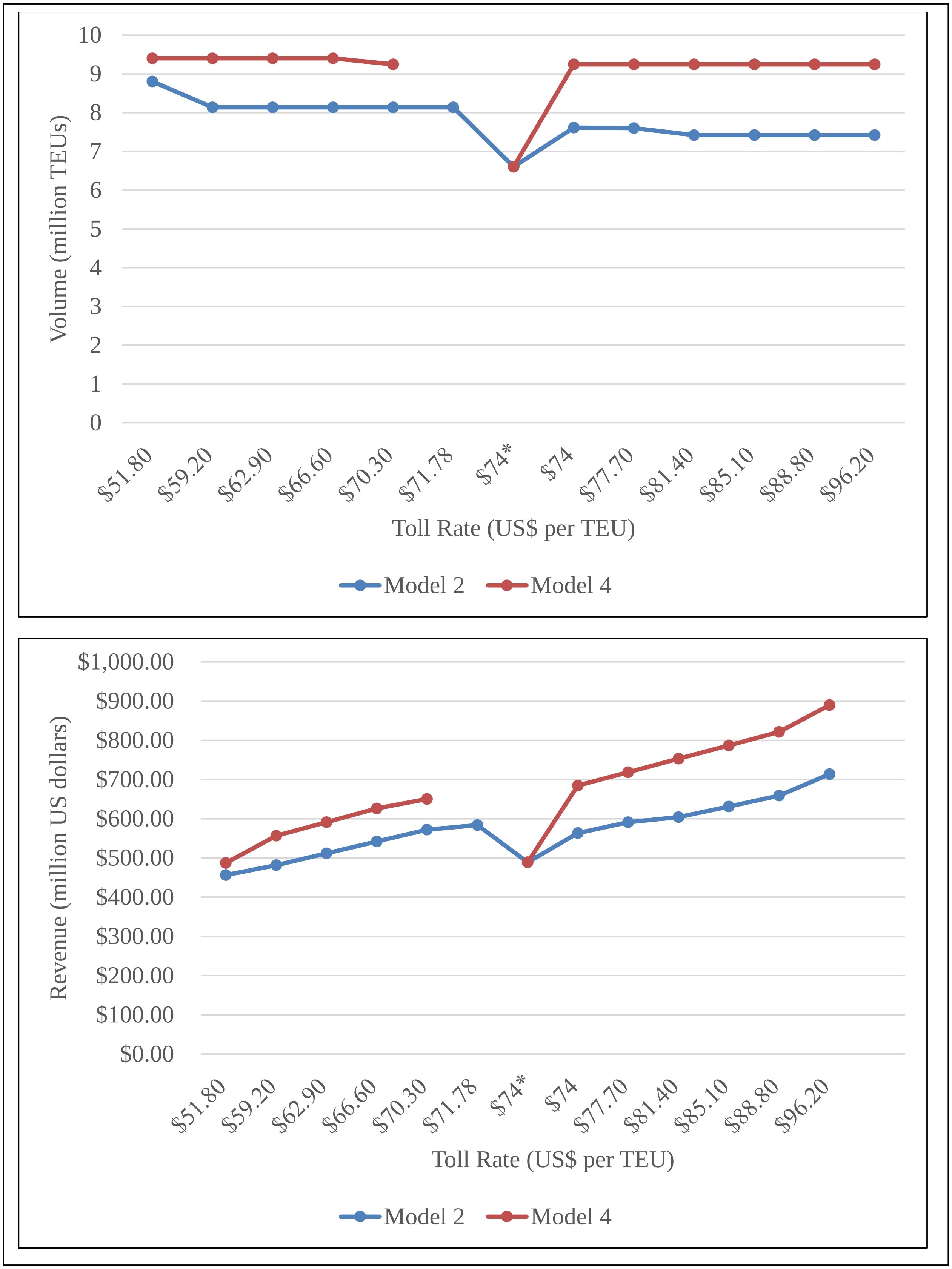


Figure 5.9. Total volume and toll revenue in changes of toll rate at the Panama Canal.

CHAPTER 6. SUMMARY AND CONCLUSIONS

The transportation of containerized shipments will continue to be a topic of interest in the world because it is the major method used to ship various cargo globally. The reason for continuous studies on the topic of transportation of containerized shipments is due mainly to a significant increase in world container traffic since 1990. The majority of cargo is containerized mainly due to advancement in the technology of container design. Since the United States is one of the leaders in global trade, a large number of containerized shipments are exported and imported in the United States.

In the United States, 80% of containerized shipments are imported from its top 15 exporting countries and 60% of containerized shipments are exported to its top 15 importing countries. The majority of these countries are located in Northeast Asia and Europe, although some trading partners are in other continents. Since the United States is a trade deficit country in containerized shipments, most major container ports in the United States handle more import shipments than export shipments. Furthermore, more than 95% of US cargo imports arrive on d by ships (US Department of Transportation, 2009). Factors determining costs for shipping containerized shipments between the US and its trading partners include domestic transportation costs, ocean transportation costs, cargo handling charges at ports, and other costs (such as the toll at the Panama Canal when vessel is required to navigate via the canal).

The Panama Canal is being expanded to reduce traffic congestions, stemming from the increase in global trade between countries. The growth of world trade has led to the greater cargo hauling of container vessels, and the increase in the number of these larger vessels being manufactured. Fleets of a new class of Panamax ships continue to rise to satisfy a continuous increase in containerized shipments under globalization.

The primary objective of this paper is to evaluate the impact of the Panama Canal Expansion on the domestic and international trade flows of containerized shipments from shipping origins in the US to ports in its importing countries for US exports and from the ports in exporting countries to shipping destinations in the US for US imports. Special attention is given to flows of containerized shipments between the US and its trade partners in Asia. More specifically, the study is designed to undertake the following issues: (1) analyze the optimal trade flows for US containerized shipments under the current shipping conditions, (2) estimate the impact of the Panama Canal Expansion on the trade flows of US containerized shipments, (3) estimate the impact of the Panama Canal and US port expansion on US containerized shipments, (4) examine the effects of delay cost and toll rate at the Panama Canal for US containerized shipments, and (5) evaluate the economic value of the Panama Canal Expansion.

Many studies have analyzed transportation of containerized shipments and its impacts on trade flows among nations. The studies are, in general, focused on a spatial optimization of containerized shipments. A spatial optimization model based on a linear programming algorithm was developed to optimize trade flows by either minimizing costs or maximizing volumes. Most of the previous studies were focused on US imports.

This study developed a spatial optimization model based on a mathematical programming algorithm to examine the economic effects of the PCE on US trade with its trading partners, especially those in Asia. The model minimizes total transportation costs associated with the transportation of containerized shipments, in order to get them from their shipping origins to US export ports and then also from export ports to the ports in importing countries for US exports and from the ports in exporting countries to US import ports and then also from the import ports to the shipping destinations in US for US imports. The objective function is minimized subject to a system of linear constraints.

This study shows that there would be a significant change in the quantity of containerized shipments transited through the canal and the toll revenue at the canal after its expansion. The East Coast of the United States receives the most benefit under the Panama Canal Expansion mainly because a decrease in ocean transportation costs from ports in the East Coast to Asia leads to more domestic shipments to the East Coast from other ports in the US. Therefore, ports in the East Coast of the United States would be beneficial if the ports expand their capacities to handle increased shipments in the future. On the other hand, the ports in the West Coast would lose quantities of containerized shipments after the Panama Canal Expansion because more shipments would change domestic transportation routes from the West Coast to either the Gulf of Mexico or the East Coast of the United States. This implies that the ports in the West Coast of the United States would see a negative impact under the Panama Canal Expansion.

The Panama Canal Expansion will have no effect on US containerized shipments to ports in the Gulf of Mexico because of two reasons: (1) ports in the Gulf Coast meet 100% of their port capacities before and after the Panama Canal Expansion and (2) the majority of their shipments are transited to/from ports in Asia through the PNC before the PCE, but many shipments are transited to/from the ports in either Europe or South America after the PCE. In other words, containerized shipments between the US Gulf Coast and either Europe or South America fully replace lost quantities between the US Gulf Coast and Asia under the Panama Canal Expansion. As a result, Gulf Coast ports may or may not need expansion of their port capacities.

This study is inconclusive in determining the optimal toll rate at the canal which maximizes its revenue. This may be mainly because the delay cost and toll rate at the canal account for a small portion of the total transportation costs to transit containerized shipments through the expanded canal. The sensitivity analysis indicates that changes in the toll rate ranging between 5% and 30% are not sensitive to shipments via the canal, including that the PNC should increase the toll rate to maximize its revenue under the assumption that US freight rates, such as the rail rate, remain constant. Since shipping routes from shipping origins in most states in the US to Asia through the West Coast competes with those through the PNC, changes in domestic transportation costs (e.g., rail rate) to the West Coast may be an important factor affecting containerized shipments via the Canal. Therefore, increases in the PNC toll rate to maximize its revenue should be constrained by US shipments through the West Coast. This is also true for containerized shipments for US imports from Asia.

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APPENDIX A. EXPORT DEMAND AND IMPORT SUPPLY FOR US EXPORTS (TEUs)

Table A1. Export Demand and Import Supply for US Exports (TEUs)

Shipping Origin	**Importing Countries**															**Supply**
	Belgium	Brazil	China	Germany	Hong Kong	India	Indonesia	Italy	Japan	Netherlands	South Korea	Taiwan	Thailand	United Kingdom	Viet Nam	
Alabama	2567	4570	59741	12491	2196	3466	970	1579	9400	1193	8096	4447	2144	2762	1610	117233
Arkansas	1597	1573	15103	840	2063	737	1185	487	2618	265	2889	2159	521	681	937	33655
Arizona	987	2579	27742	4047	4101	1320	1009	1562	11124	1841	4525	7938	6468	3504	1891	80639
California	28830	19058	369930	29366	80707	63577	22820	16042	165401	23569	131642	160211	24010	18248	44136	1197546
Colorado	1454	1096	16395	1547	2281	1812	1315	563	5365	1570	4376	4045	1100	923	1584	45428
Connecticut	3559	2416	24171	7889	2167	2222	1285	1169	7163	2703	8455	2802	1130	2795	1247	71173
District of Columbia	14	81	111	56	12	320	11	286	46	4	22	62	3	140	9	1175
Delaware	4200	760	11055	1494	382	554	331	160	4014	1150	1908	2476	191	3031	386	32093
Florida	4371	36652	31975	8087	10804	14006	3604	3992	13217	5171	8164	7518	2826	4765	4064	159217
Georgia	7015	7706	88104	6048	8045	8079	7578	4357	16977	3537	13360	14966	2964	5060	11151	204946
Iowa	888	4168	16106	3574	1298	1296	1923	830	12059	1313	5017	2508	646	1448	1741	54816
Idaho	90	391	11124	183	3240	285	1389	162	3706	346	9331	16408	338	367	777	48138
Illinois	16935	17439	114210	14660	7116	15560	13529	3789	25858	6741	14067	24423	5134	8344	12266	300070
Indiana	4805	6427	31834	11170	4172	4063	1716	5652	20622	4626	12066	5621	1686	4640	1561	120662
Kansas	1061	3526	29185	2014	1324	1183	1886	1014	9733	449	3796	3664	599	1979	3206	64620
Kentucky	5017	8072	27557	4385	6598	1958	1330	1447	15409	3279	8228	6829	1540	6758	971	99378
Louisiana	11382	15575	204102	5876	663	9582	14618	3903	44467	16094	24193	11139	5185	4503	4549	375832
Massachusetts	7113	3066	49413	10510	11161	4772	1190	4209	24659	6054	15567	21528	2586	10138	1814	173781
Maryland	3499	2261	14873	1540	1402	3867	1762	1707	5761	2003	5618	2684	1064	2057	953	51051
Maine	569	171	6197	310	263	241	205	335	1513	358	1398	423	99	274	100	12455
Michigan	7356	5284	83941	10054	2421	3603	2130	3663	17473	1775	15826	4501	3711	2984	1106	165830
Minnesota	6585	2448	49444	4115	4580	3088	2642	2073	15136	2364	10694	11043	3755	2224	3117	123306
Missouri	4529	2159	26215	1816	1381	2144	2909	1511	7878	1517	9320	2417	1340	1363	1262	67762
Mississippi	3555	2955	16920	1001	900	1203	725	462	2454	1680	2047	1204	575	788	1148	37618
Montana	596	30	2648	198	42	358	95	107	670	110	2984	1708	45	103	138	9833

Table A1. Export Demand and Import Supply for US Exports (TEUs) (continued).

Shipping Origin	**Importing Countries**															**Supply**
	Belgium	Brazil	China	Germany	Hong Kong	India	Indonesia	Italy	Japan	Netherlands	South Korea	Taiwan	Thailand	United Kingdom	Viet Nam	
North Carolina	6801	5333	65405	5844	8117	5283	5728	1901	21581	3549	10062	7128	2058	3927	6319	159037
North Dakota	792	222	535	292	27	490	184	159	412	31	272	155	45	135	115	3867
Nebraska	987	637	12112	790	1826	341	846	910	6687	1001	4978	2344	631	258	2392	36741
New Hampshire	231	480	7300	1236	1619	474	170	604	1399	863	1393	1062	460	681	281	18253
New Jersey	10348	8477	40452	7611	8663	7928	3645	5064	20238	10700	18701	13578	2384	9118	2786	169692
New Mexico	238	226	2188	404	222	257	440	123	649	104	340	245	326	235	136	6133
Nevada	1078	408	13126	698	1819	16850	392	427	3117	367	1798	1045	433	586	305	42447
New York	28042	7084	114587	13154	91165	37598	3913	7704	29173	9034	25050	23984	10195	25151	4676	430510
Ohio	4931	11267	74469	7690	4487	7904	5766	3887	19426	3994	13979	9842	4274	6341	3082	181338
Oklahoma	851	1303	9390	1210	615	1145	1254	320	5003	646	1399	744	797	548	501	25726
Oregon	1100	2840	76674	2433	3915	2291	5271	994	20216	1142	16607	18267	2053	1322	17771	172897
Pennsylvania	9963	9306	77834	9833	4720	8326	4190	5156	21773	8771	16594	12320	2180	6470	2114	199551
Rhode Island	289	103	2195	1168	354	209	58	783	588	126	473	1611	324	295	216	8793
South Carolina	4427	4684	92529	20203	2849	7229	2160	2037	8443	2115	7838	6377	1809	5749	3393	171842
South Dakota	367	129	1637	134	181	29	127	71	641	20	280	165	81	75	134	4072
Tennessee	11897	5054	53205	4229	3622	4089	5121	2838	23216	4965	10176	7681	2475	3725	5363	147655
Texas	43466	73267	266972	15462	16484	33030	25297	9858	60415	48736	121499	89184	17294	16877	22870	860711
Utah	2099	750	21151	1490	46453	10018	1055	1291	6803	948	4217	13606	8900	19561	678	139019
Virginia	4086	4919	46860	4767	2397	4266	6597	1955	6553	2373	5309	10500	1424	4419	4465	110890
Vermont	244	44	15486	312	2990	181	208	161	1899	205	2317	3703	705	221	211	28887
Washington	4035	7973	350174	9967	24053	21537	48490	1977	95803	5407	49177	37272	10544	8813	9459	684682
Wisconsin	3855	3669	38161	4258	2923	5577	2086	2353	10758	1988	6601	4695	2687	2674	2358	94642
West Virginia	3052	4482	15973	1700	774	8839	294	4912	6519	4041	6305	1055	363	1909	363	60581
Wyoming	87	837	241	13	13	62	2169	3	633	221	679	953	442	93	383	6828
Demand	271840	303954	2726751	258174	389609	333248	213618	116547	814673	201060	649634	590242	142542	209061	192100	

APPENDIX B. EXPORT DEMAND AND IMPORT SUPPLY FOR US IMPORTS (TEUs)

Table B1. Export Demand and Import Supply for US Imports (TEUs)

	Exporting Countries															
Shipping Destination	Belgium	Brazil	China	Germany	Hong Kong	India	Indonesia	Italy	Japan	Netherlands	South Korea	Taiwan	Thailand	United Kingdom	Viet Nam	**Demand**
Alabama	1166	15898	40452	14102	837	986	1458	3476	5437	976	44770	1827	644	640	3831	136500
Arkansas	335	242	43350	1780	844	2518	521	905	610	555	1482	1644	1045	299	1004	57135
Arizona	382	943	52661	3086	7463	1784	1233	1794	6617	2992	3366	6748	3188	1548	1626	95432
California	7788	24696	2604119	60280	86888	34120	79124	28665	183998	12314	148000	148506	114294	12127	154326	3699245
Colorado	669	531	39427	3024	3442	4307	530	2683	945	1536	3055	2793	1043	903	4052	68940
Connecticut	2808	2995	56027	7894	3641	2302	1574	5116	4529	13820	1947	3705	1380	6482	3773	117991
District of Columbia	43	78	396	235	61	177	9	241	161	367	136	13	30	131	37	2115
Delaware	14977	2524	10481	1589	435	1271	129	823	473	3197	178	415	46	9042	195	45775
Florida	4713	31140	237016	10287	20842	9670	8852	15265	18195	12087	14987	13716	10028	7279	27180	441257
Georgia	6208	7162	331080	61604	16111	15578	13267	13115	20444	8045	68015	13639	16616	6925	20686	618495
Iowa	465	1160	26230	3173	531	1682	224	3040	1768	737	1552	2439	557	370	1034	44962
Idaho	28	77	15925	388	548	119	278	3216	1979	348	4285	9167	71	77	574	37081
Illinois	8770	6823	526970	25575	11878	13167	11264	15860	38875	33159	63928	29327	13780	6844	21873	828092
Indiana	2170	4214	126175	11163	2746	4352	3093	6540	23039	4356	3744	11361	7320	4092	8456	222822
Kansas	1396	1532	44095	3955	1983	866	2201	2584	1112	781	2591	16580	794	1567	7136	89173
Kentucky	4458	2667	132175	9294	6769	8587	7670	14587	20858	2620	8161	19947	7598	3665	11009	260064
Louisiana	17276	18129	21214	3223	1097	4447	8984	2340	1490	5224	6888	1104	1675	2932	2584	98608
Massachusetts	2746	1636	98926	9067	6469	3165	4776	6460	4097	7401	4236	7975	4850	8161	6983	176948
Maryland	3103	7796	60704	25864	2352	5695	6638	6496	5638	2619	1936	2164	10243	4035	6256	151541
Maine	173	60	7368	2433	285	240	92	346	227	697	235	290	692	416	1198	14753
Michigan	2280	6190	137812	19867	3554	10318	3140	9182	18726	2335	23256	8785	8714	2453	3014	259628
Minnesota	1018	2601	205753	4783	2980	2265	1016	3938	2280	1475	2130	8033	2343	1300	2705	244621
Missouri	4629	1185	83320	5744	2071	3716	995	2471	1598	1320	2838	4601	1423	1336	2709	119956
Mississippi	179	10984	65871	2775	1014	2674	301	970	3297	1791	1250	2963	1137	3269	3338	101813
Montana	41	29	2138	742	46	79	5	93	36	36	177	168	25	68	18	3701

Table B1. Export Demand and Import Supply for US Imports (TEUs) (continued).

Shipping Destination	**Exporting Countries**															**Demand**
	Belgium	Brazil	China	Germany	Hong Kong	India	Indonesia	Italy	Japan	Netherlands	South Korea	Taiwan	Thailand	United Kingdom	Viet Nam	
North Carolina	3691	8655	207937	16930	4679	12559	12235	13673	13293	5685	9103	10722	6727	7714	18384	351987
North Dakota	58	116	2907	706	16	700	59	375	357	54	523	179	174	112	562	6898
Nebraska	900	272	17947	1679	505	365	112	1253	1169	132	344	810	649	175	986	27299
New Hampshire	159	158	18512	2374	708	1370	748	1069	423	1462	533	2297	998	673	1020	32504
New Jersey	33721	9017	346173	37686	14925	57592	20981	52518	42894	21701	31507	20565	14185	23797	23833	751093
New Mexico	261	36	15899	546	189	174	39	140	474	1627	159	479	533	267	67	20890
Nevada	648	940	59571	711	1900	1013	993	682	413	340	14863	4191	1378	460	1314	89418
New York	67117	12426	460945	19333	190866	104875	20513	50558	13459	10161	20194	31277	17461	15531	36940	1071657
Ohio	3739	5872	243296	23400	4637	10915	11421	9942	26445	4169	13015	14987	7942	3529	27961	411269
Oklahoma	1582	340	45714	1777	1697	1821	1429	1061	2081	347	823	2813	1328	680	1629	65122
Oregon	268	726	58654	3009	2106	1606	3019	1123	16530	1918	16289	4431	3121	419	7477	120697
Pennsylvania	22006	9598	346053	25147	6136	11873	6679	14399	9271	8641	32592	11495	4992	9372	16054	534309
Rhode Island	1130	655	25101	16676	584	1467	209	819	633	3049	358	748	1320	2170	429	55348
South Carolina	5738	6267	111239	34886	1722	8713	14398	10882	7921	7435	4595	4846	6770	4445	10208	240064
South Dakota	33	1055	2581	137	68	47	9	218	71	48	103	252	107	30	97	4857
Tennessee	11893	4082	435571	13076	4578	14862	17810	7598	39750	2961	5375	10632	9604	4477	28981	611252
Texas	19538	57407	825238	35917	18671	51829	17627	30721	32085	23693	99929	43821	38308	16894	42944	1354621
Utah	143	837	34627	945	2106	671	427	791	632	279	689	3768	362	269	1183	47728
Virginia	2611	5053	90504	9065	2281	9405	9528	7000	8726	2324	2138	3333	2730	3228	10185	168112

Table B1. Export Demand and Import Supply for US Imports (TEUs) (continued).

Shipping Destination	**Exporting Countries**															**Demand**
	Belgium	Brazil	China	Germany	Hong Kong	India	Indonesia	Italy	Japan	Netherlands	South Korea	Taiwan	Thailand	United Kingdom	Viet Nam	
Vermont	43	69	5546	555	188	672	510	417	228	106	414	352	78	213	783	10174
Washington	1547	2914	179038	4168	5179	3616	5404	5484	28719	4489	25037	28346	7079	5441	10570	317032
Wisconsin	1221	1230	117034	6395	4192	6799	6770	7104	3560	1839	3760	6723	1376	1018	16965	185985
West Virginia	484	253	5289	896	101	1347	114	542	4203	125	122	434	82	158	922	15071
Wyoming	18	6	2260	164	48	133	12	22	37	23	64	53	9	80	47	2977
Supply	266367	279279	8627320	548105	452968	438508	308421	368599	619803	223395	695674	525462	336851	187116	555145	

APPENDIX C. CARGO HANDLING COSTS (US$) AT PORTS IN EXPORTING AND IMPORTING COUNTRIES

Table C1. Cargo Handling Costs (US$) at Ports in Exporting and Importing Countries

	US Port														
Foreign Port	Mobile, AL	LA, CA	LB, CA	Miami, FL	Savannah, GA	New Orleans, LA	Gulfport, MS	NY, NY	Portland, OR	Charleston, SC	Freeport, TX	Houston, TX	Norfolk, VA	Seattle, WA	Tacoma, WA
Shanghai, China	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Shenzhen, China	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Tokyo, Japan	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Yokohama, Japan	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Busan, Korea	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Kaohsiung, Taiwan	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Hong Kong, Hong Kong	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Hamburg, Germany	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Bremen/Bremerhaven, Germany	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Jawaharlal Nehru, India	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Ho Chi Minh, Vietnam	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Santos, Brazil	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Antwerp, Belgium	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Tanjung Priok, Indonesia	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Gioia Tauro, Italy	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Laem Chabang, Thailand	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Rotterdam, Netherlands	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43
Felixstowe, UK	68.52	30.32	74.25	36.2	109.2	79.3	52.12	27.12	134.68	42	224.8	63.06	61.25	145.08	91.43

APPENDIX D. CARGO HANDLING CAPACITIES OF THE PANAMA CANAL AND US PORTS (TEUs)

Table D1. Cargo Handling Capacities of the Panama Canal and US Ports (TEUs)

Port	Capacity
Panama Canal	7200000
Mobile, AL	129198
LA, CA	7963333
LB, CA	7583333
Miami, FL	730630
Savannah, GA	2279155
New Orleans, LA	299518
Gulfport, MS	174118
NY, NY	5500000
Portland, OR	156117
Charleston, SC	1166102
Freeport, TX	52704
Houston, TX	1475997
Norfolk, VA	1627311
Seattle, WA	1303482
Tacoma, WA	990938

APPENDIX E. INLAND TRANSPORTATION NETWORKS IN THE UNITED STATES

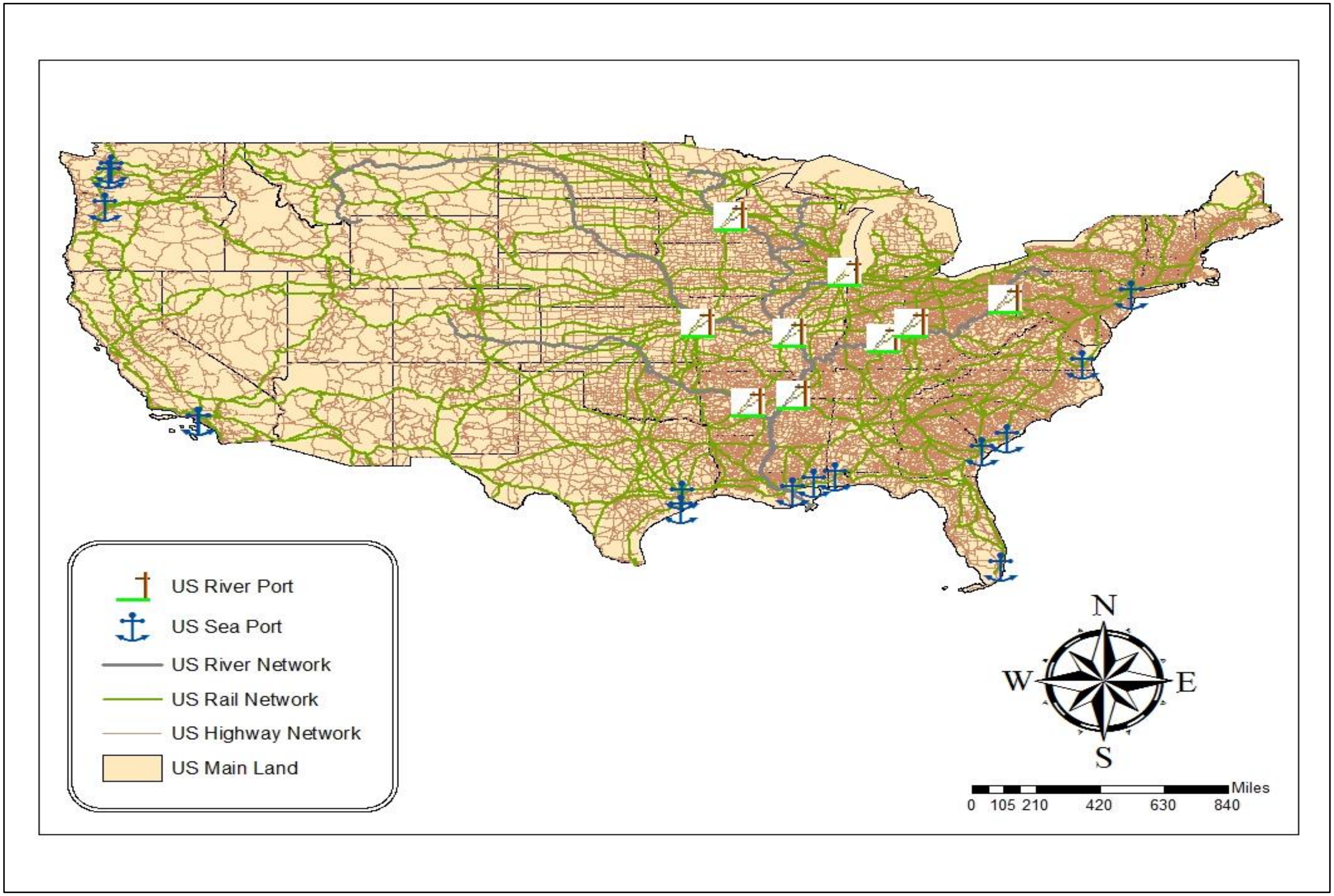

Figure E1. Inland Transportation Networks in the United States

APPENDIX F. OCEAN TRANSPORTATION NETWORKS IN THE UNITED STATES

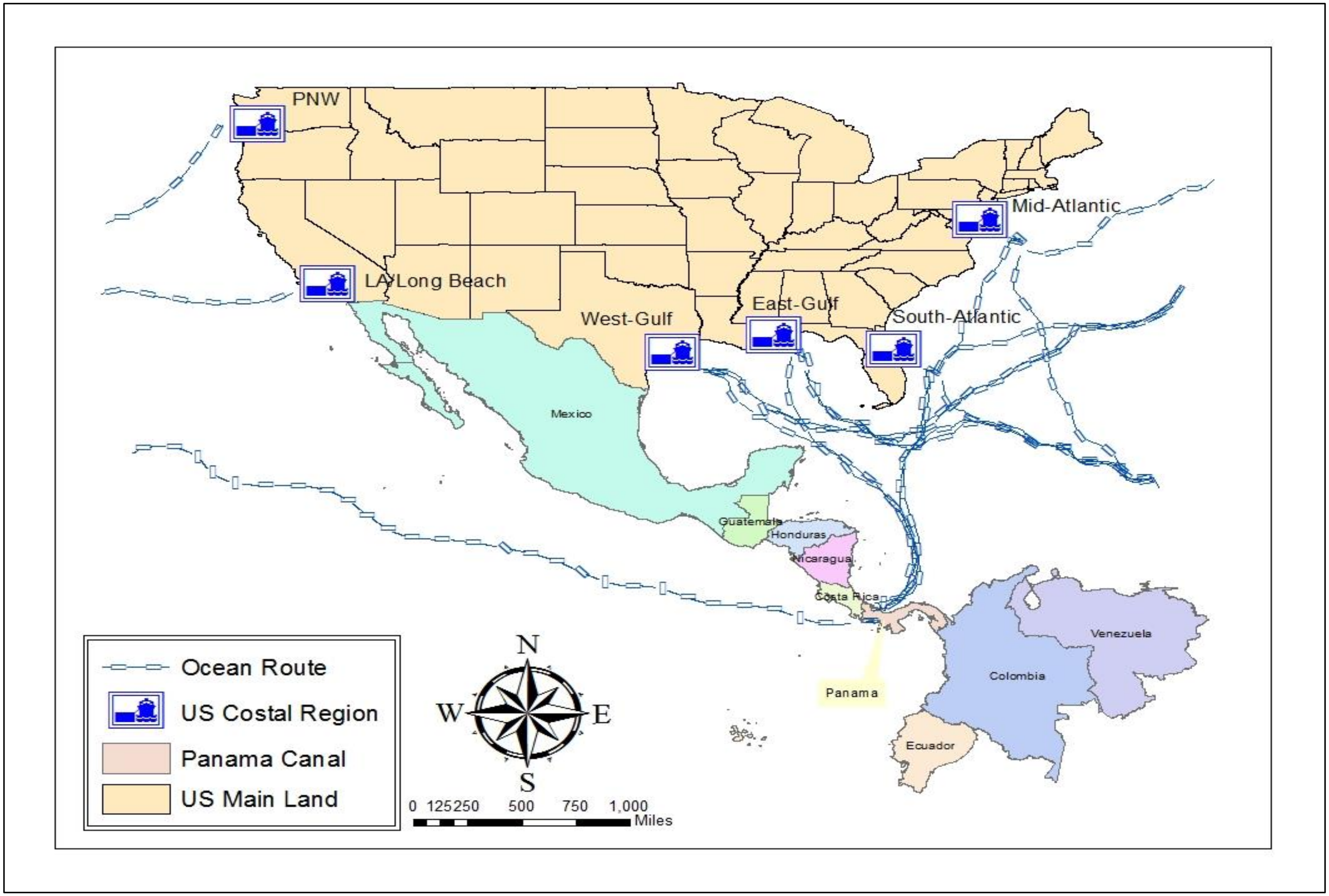

Figure F1. Ocean Transportation Networks in the United States

APPENDIX G. QUANTITIES OF EXPORTS AND IMPORTS IN 49 STATES OF US MAINLAND (TEUs)

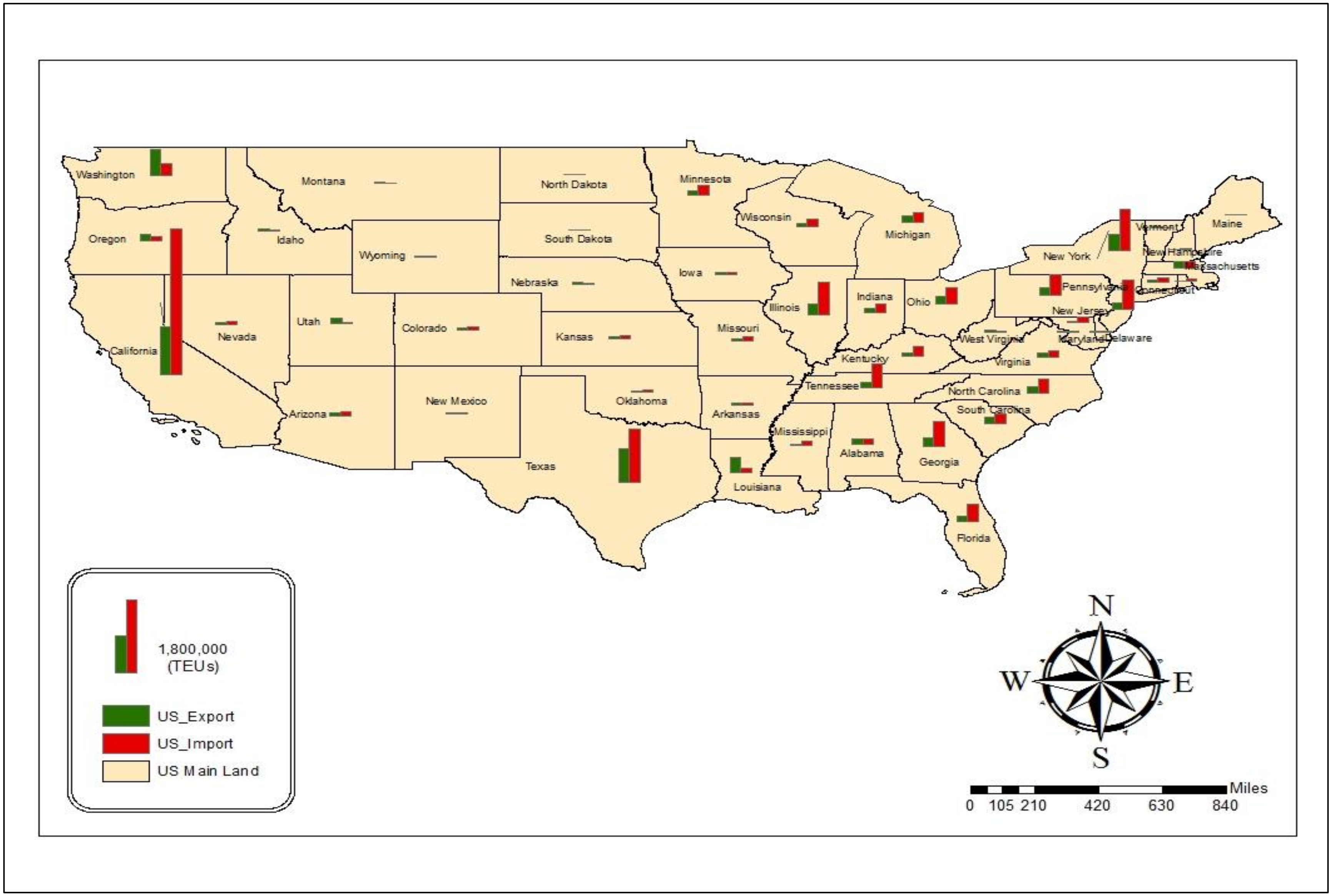

Figure G1. Quantities of Exports and Imports in 49 States of US Mainland (TEUs)

APPENDIX H. Q&A FROM PERSONAL INTERVIEW

Interviewee: Mr. Les Koenning, Account Manager and Operations at Osprey Line LLC.

Date: 2 p.m. on July 24th 2014

Question 1: Does your company operate container-on-barge (COB) service as liner along the US river systems, now?

Answer: No, we used to operate COB as liner service from 1990s to 2000s. We do not serve COB as liner service since 2009. COB as liner service is no longer profitable mainly due to the shortage of backhaul because there had not been enough shipments on the return trip though there was enough shipments for US imports.

Questions 2: Then, how does your company still operate COB service?

Answer: We serve COB as project which is based on contract.

Question 3: Is there enough demand in the market?

Answer: No, we occasionally have customer for COB.

Question 4: Could you please explain general procedure of COB, now and how do you think COB services at your company in the future?

Answer: We have our own barge for container which can carry 120 TEUs; however, any river port facilities have equipment (crane) to handle containers; therefore, we use crane truck to unload containers. Frankly, in these days, COB has very limited operation system and infrastructure. I do not think we will be back to COB service as liner until shipments of COB are balanced.

APPENDIX I. GAMS CODE

```
*this program computes optimal trade flows of containerized shipments
*between the US and its top trade partners in the world. The model is a
*spatial optimization model based on a linear programming algorithm. The objective
*function of the model is to minimize transport costs from shipping origins to destinations via
*various means of transportation modes. The objective function is optimized subject to a
*set of linear constraints.
*Base avg 2011, 2012, 2013


*The model contains containerized shipments regardless of cargo types and value,
*49 shipping origins in the US and 15 importing countries for US exports
*and 49 shipping destinations in the US and 15 exporting countries for US imports,
*15 ports in the US and 18 ports in other countries for US exports and imports,
*and 9 river ports in the US for truck-barge combination.

OPTION limrow=0; OPTION limcol=0;



SETS
I PRODUCING REGIONS IN THE US FOR US EXPORT / ALP, ARP, AZP, CAP, COP, CTP,
DCP, DEP, FLP, GAP,
IAP, IDP, ILP, INP, KSP, KYP, LAP, MAP, MDP, MEP, MIP, MNP, MOP, MSP, MTP, NCP,
```

NDP, NEP, NHP, NJP, NMP, NVP, NYP, OHP, OKP, ORP, PAP, RIP, SCP, SDP, TNP, TXP, UTP, VAP, VTP, WAP, WIP, WVP, WYP /

A RIVER PORTS IN THE US FOR US EXPORT / ELi, ECh, ELo, EMi, ESt, EKa, ECi, EPi, EMe /

P SEA PORTS IN THE US / MO, LA, LB, MI, SV, NO, GP, NY, PO, CH, FP, HU, NF, SE, TA /

Q IMPORT PORTS IN OTHER COUNTRIES FOR US EXPORT / ImCH1, ImCH2, ImJP1, ImJP2, ImKO, ImTW, ImHK, ImGR1, ImGR2, ImIN, ImVT, ImBR, ImBL, ImID, ImIT, ImTH, ImNE, ImUK /

D EXPORT PORTS IN OTHER COUNTRIES FOR US IMPORT / ExCH1, ExCH2, ExJP1, ExJP2, ExKO, ExTW, ExHK, ExGR1, ExGR2, ExIN, ExVT, ExBR, ExBL, ExID, ExIT, ExTH, ExNE, ExUK /

F RIVER PORTS IN THE US FOR US IMPORT / ILi, ICh, ILo, IMi, ISt, IKa, ICi, IPi, IMe /

G CONSUMTION REGIONS IN THE US FOR US IMPORT / CAL, CAR, CAZ, CCA, CCO, CCT, CDC, CDE, CFL, CGA,

CIA, CID, CIL, CIN, CKS, CKY, CLA, CMA, CMD, CME, CMI, CMN, CMO, CMS, CMT, CNC, CND, CNE,

```
CNH, CNJ, CNM, CNV, CNY, COH, COK, COR, CPA, CRI, CSC, CSD, CTN, CTX, CUT,

CVA, CVT, CWA,

CWI, CPWV, CWY /


PARAMETERS

      S(I) PRODUCTION IN THE US FOR US EXPORT

         /   ALP    117233

             ARP    33655

             AZP    80639

             CAP    1197546

             COP    45428

             CTP    71173

             DCP    1175

             DEP    32093

             FLP    159217

             GAP    204946

             IAP    54816

             IDP    48138

             ILP    300070

             INP    120662

             KSP    64620

             KYP    99378

             LAP    375832
```

MAP	173781
MDP	51051
MEP	12455
MIP	165830
MNP	123306
MOP	67762
MSP	37618
MTP	9833
NCP	159037
NDP	3867
NEP	36741
NHP	18253
NJP	169692
NMP	6133
NVP	42447
NYP	430510
OHP	181338
OKP	25726
ORP	172897
PAP	199551
RIP	8793
SCP	171842
SDP	4072

```
      TNP   147655

      TXP   860711

      UTP   139019

      VAP   110890

      VTP   28887

      WAP   684682

      WIP   94642

      WVP   60581

      WYP   6828  /


T(P) PORT CAPACITY IN THE US

   /  MO    129198

      LA    7963333

      LB    7583333

      MI    730630

      SV    2279155

      NO    299518

      GP    174118

      NY    5500000

      PO    156117

      CH    1166102

      FP    52704

      HU    1475997
```

```
            NF      1627311

            SE      1303482

            TA      990938  /


U(Q) CONSUMPTION IN IMPORTING COUNTRY FOR US EXPORT

        /   ImCH1       1363375

            ImCH2       1363375

            ImJP1       407336

            ImJP2       407336

            ImKO        649634

            ImTW        590242

            ImHK        389609

            ImGR1       129087

            ImGR2       129087

            ImIN        333245

            ImVT        192100

            ImBR        303954

            ImBL        271840

            ImID        213618

            ImIT        116547

            ImTH        142542

            ImNE        201060

            ImUK        209061  /
```

```
J(D) PRODUCTION IN OTHER COUNTRIES FOR US IMPORT

    /   ExBL      266367

        ExBR      279279

        ExCH1     4313660

        ExCH2     4313660

        ExGR1     274052

        ExGR2     274052

        ExHK      452968

        ExIN      438508

        ExID      308421

        ExIT      368599

        ExJP1     309902

        ExJP2     309902

        ExNE      223395

        ExKO      695674

        ExTW      525462

        ExTH      336851

        ExUK      187116

        ExVT      555145  /


K(G) COMSUMPTION IN THE US FOR US IMPORT

    /   CAL       136500
```

CAR	57135
CAZ	95432
CCA	3699245
CCO	68940
CCT	117991
CDC	2115
CDE	45775
CFL	441257
CGA	618495
CIA	44962
CID	37081
CIL	828092
CIN	222822
CKS	89173
CKY	260064
CLA	98608
CMA	176948
CMD	151541
CME	14753
CMI	259628
CMN	244621
CMO	119956
CMS	101813

CMT	3701
CNC	351987
CND	6898
CNE	27299
CNH	32504
CNJ	751093
CNM	20890
CNV	89418
CNY	1071657
COH	411269
COK	65122
COR	120697
CPA	534309
CRI	55348
CSC	240064
CSD	4857
CTN	611252
CTX	1354621
CUT	47728
CVA	168112
CVT	10174
CWA	317032
CWI	185985

```
          CPWV     15071
          CWY      2977    /


*Read the following data from C-drive
TABLE IT1(I,A) SHIPPING RATE FROM PRODUCTUIN REGION TO RIVER PORT BY TRUCK (USD)
$include "C:\Users\Jude\Desktop\GAMS\New Table\Base_Model\TFR_US_Export_to_BAP_Base_250.txt" ;


TABLE IT2(I,P) SHIPPING RATE FROM PRODUCTION REGION TO EXPORT PORT BY TRUCK (USD)
$include "C:\Users\Jude\Desktop\GAMS\New Table\Base_Model\TFR_US_Export_to_ESP_Base_250.txt" ;


TABLE IB(A,P) SHIPPING RATE FROM RIVER PORT TO EXPORT PORT BY BARGE (USD)
$include "C:\Users\Jude\Desktop\GAMS\New Table\Base_Model\BFR_US_Export_Base_250.txt" ;


TABLE NG3(A,P) NO-GO MATRIX
$include "C:\Users\Jude\Desktop\GAMS\New Table\Base_Model\ng3_01.txt" ;
```

```
TABLE IR(I,P) SHIPPING RATE FROM PRODUCTION REGION TO EXPORT PORT BY
RAIL (USD)
$include "C:\Users\Jude\Desktop\GAMS\New
Table\Base_Model\RFR_US_Export_Base_250_01.txt" ;

TABLE OT1(P,Q) SHIPPING RATE FROM EXPORT PORT TO IMPORT PORT WITHOUT
PNC BY VESSEL (USD)
$include "C:\Users\Jude\Desktop\GAMS\New
Table\Base_Model\OFR_US_Export_no_PNC_01.txt" ;

TABLE NG5(P,Q) NO-GO MATRIX
$include "C:\Users\Jude\Desktop\GAMS\New Table\Base_Model\ng5_01.txt" ;

TABLE OT2(P,Q) SHIPPING RATE FROM EXPORT PORT TO IMPORT PORT VIA PNC
BY VESSEL (USD)
$include "C:\Users\Jude\Desktop\GAMS\New
Table\Base_Model\OFR_US_Export_thu_PNC_01.txt" ;

TABLE NG6(P,Q) NO-GO MATRIX
$include "C:\Users\Jude\Desktop\GAMS\New Table\Base_Model\ng6_01.txt" ;

TABLE TC(P,Q) TERMINAL HANDLING CHARGE AT EXPORT AND IMPORT PORT
FOR US EXPORT (USD)
```

```
$include "C:\Users\Jude\Desktop\GAMS\New Table\Base_Model\ESP_THC_01.txt" ;

TABLE PT(P,Q) PANAMA CANAL TOLL RATE FOR US EXPORT (USD)
$include "C:\Users\Jude\Desktop\GAMS\New Table\Base_Model\US_Ex_PNC_TOL_01.txt" ;

TABLE PH(P,Q) PANAMA CANAL HANDLING CHARGE FOR US EXPORT (USD)
$include "C:\Users\Jude\Desktop\GAMS\New Table\Base_Model\US_Ex_PNC_THC_01.txt" ;

TABLE PD(P,Q) PANAMA CANAL DELAY COST FOR US EXPORT (USD)
$include "C:\Users\Jude\Desktop\GAMS\New Table\Base_Model\US_Ex_PNC_DEL_01.txt" ;

TABLE OTI1(D,P) SHIPPING RATE FROM FOREIGN EXPORT PORT TO US IMPORT
PORT WITHOUT PNC BY VESSEL (USD)
$include "C:\Users\Jude\Desktop\GAMS\New
Table2\Base_Model\OFR_USIMPORT_NO_PNC_01.txt" ;

TABLE NG12(D,P) NO-GO MATRIX
$include "C:\Users\Jude\Desktop\GAMS\New Table2\Base_Model\ng12_01.txt" ;

TABLE OTI2(D,P) SHIPPING RATE FROM FOREIGN EXPORT PORT TO US IMPORT
PORT VIA PNC BY VESSEL (USD)
$include "C:\Users\Jude\Desktop\GAMS\New
Table2\Base_Model\OFR_USIMPORT_thu_PNC_01.txt" ;
```

```
TABLE NG13(D,P) NO-GO MATRIX
$include "C:\Users\Jude\Desktop\GAMS\New Table2\Base_Model\ng13_01.txt" ;

TABLE IBI(P,F) SHIPPING RATE FROM US IMPORT PORT TO US IMPORT RIVER
PORT BY BARGE (USD)
$include "C:\Users\Jude\Desktop\GAMS\New
Table2\Base_Model\BFR_US_Import_Base_250.txt" ;

TABLE NG9(P,F) NO-GO MATRIX
$include "C:\Users\Jude\Desktop\GAMS\New Table2\Base_Model\ng9_01.txt" ;

TABLE ITI1(F,G) SHIPPING RATE FROM US IMPORT RIVER PORT TO US
CONSUMPTION REGION BY TRUCK (USD)
$include "C:\Users\Jude\Desktop\GAMS\New
Table2\Base_Model\TFR_US_Import_from_BAP_Base_250.txt" ;

TABLE ITI2(P,G) SHIPPING RATE FROM US IMPORT PORT TO US CONSUMPTION
REGION BY TRUCK (USD)
$include "C:\Users\Jude\Desktop\GAMS\New
Table2\Base_Model\TFR_US_Import_from_ISP_Base_250.txt" ;
```

```
TABLE IRI(P,G) SHIPPING RATE FROM US IMPORT PORT TO US CONSUMPTION REGION BY RAIL (USD)
$include "C:\Users\Jude\Desktop\GAMS\New Table2\Base_Model\RFR_US_Import_Base_250_01.txt" ;

TABLE TCI(D,P) TERMINAL HANDLING CHARGE AT EXPORT AND IMPORT PORT FOR US IMPORT (USD)
$include "C:\Users\Jude\Desktop\GAMS\New Table2\Base_Model\US_IMP_THC_01.txt" ;

TABLE PTI(D,P) PANAMA CANAL TOLL RATE FOR US IMPORT (USD)
$include "C:\Users\Jude\Desktop\GAMS\New Table2\Base_Model\US_IM_PNC_TOL_01.txt" ;

TABLE PHI(D,P) PANAMA CANAL HANDLING CHARGE FOR US IMPORT (USD)
$include "C:\Users\Jude\Desktop\GAMS\New Table2\Base_Model\US_IM_PNC_THC_01.txt" ;

TABLE PDI(D,P) PANAMA CANAL DELAY COST FOR US IMPORT (USD)
$include "C:\Users\Jude\Desktop\GAMS\New Table2\Base_Model\US_IM_PNC_DEL_01.txt" ;
```

```
PARAMETERS
        IT1(I,A)  TRUCK FREIGHT RATE FROM I TO A IN DOLLARS
        IT2(I,P)  TRUCK FREIGHT RATE FROM I TO P IN DOLLARS
        IB(A,P)   BARGE FREIGHT RATE FROM A TO P IN DOLLARS
        IR(I,P)   RAIL FREIGHT RATE FROM I TO P IN DOLLARS
        OT1(P,Q)  OCEAN FREIGHT RATE FROM P TO Q WITHOUT PNC IN DOLLARS
        OT2(P,Q)  OCEAN FREIGHT RATE FROM P TO Q VIA PNC IN DOLLARS
        TC(P,Q)   TERMINAL HANDLING CHARGE AT PORT FOR US EXPORT
        PT(P,Q)   PANAMA CANAL TOLL FOR US EXPORT IN DOLLARS
        PH(P,Q)   PANAMA CHNAL HANDLING CHARGE FOR US EXPORT IN
            DOLLARS
        PD(P,Q)   PANAMA CHNAL DELAY COST FOR US EXPORT IN DOLLARS
        OTI1(D,P) OCEAN FREIGHT RATE FROM D TO E WITHOUT PNC IN DOLLARS
        OTI2(D,P) OCEAN FREIGHT RATE FROM D TO E VIA PNC IN DOLLARS
        IBI(P,F)  BARGE FREUGHT RATE FROM E TO F IN DOLLARS
        ITI1(F,G) TRUCK FREIGHT RATE FROM F TO G IN DOLLARS
        ITI2(P,G) TRUCK FREIGHT RATE FROM E TO G IN DOLLARS
        IRI(P,G)  RAIL FREIGHT RATE FROM E TO G IN DOLLARS
        TCI(D,P)  TERMINAL HANDLING CHARGE AT PORT FOR US IMPORT
        PTI(D,P)  PANAMA CANAL TOLL IN DOLLARS FOR US IMPORT
        PHI(D,P)  PANAMA CHNAL HANDLING CHARGE FOR US EXPORT IN
            DOLLARS
        PDI(D,P)  PANAMA CANAL DELAY COST FOR US IMPORT (USD) ;
```

```
VARIABLES

        costs

        x(I,A)  QUANTITY FROM PRODUCING REGION TO RIVER PORT

        m(A,P)  QUANTITY FROM RIVER PORT TO EXPORT PORT

        n(I,P)  QUANTITY FROM PRODUCING REGION TO EXPORT PORT

        o(P,Q)  QUANTITY FROM EXPORT PORT TO IMPORT PORT WITHOUT
            PNC

        r(P,Q)  QUANTITY FROM EXPORT PORT TO IMPORT PORT VIA PNC

        h1(D,P) QUANTITY FROM PRODUCING COUNTRY TO US IMPORT PORT
            WITHOUT PNC FOR US IMPORT

        h5(D,P) QUANTITY FROM PRODUCING COUNTRY TO US IMPORT PORT
            VIA PNC FOR US IMPORT

        h2(P,F) QUANTITY FROM US IMPORT PORT TO US IMPORT RIVER PORT

        h3(F,G) QUANTITY FROM US IMPORT RIVER PORT TO CONSUMING
            REGION

        h4(P,G) QUANTITY FROM US IMPORT PORT TO CONSUMING REGION


POSITIVE VARIABLES x, m, n, o, r, h1, h2, h3, h4, h5 ;


EQUATIONS

        Obj             costs

        SUPPLY(I)       OBSERVE SUPPLY LIMIT AT PRODUCING REGION I
```

```
        DEMAND(Q)       SATISFY DEMAND AT IMPORTING COUNTRY Q

        PORTBALANCE1(A)  RIPORT CLEARING

        PORTBALANCE2(P)  EXPORT CLEARING

        ISUPPLY(D)      OBSERVE SUPPLY LIMIT AT PRODUCING REGION D

        IDEMAND(G)      SATISFY DEMAND IN THE US G

        IPORTBALANCE1(P) IMPORT CLEARING

        IPORTBALANCE2(F) IRIPORT CLEARING

        PORTCAP(P)      PORT CAPACITY

        PNCAP           PNC CAPACITY ;


obj..     costs =E= SUM((I,A),x(I,A) * IT1(I,A))

               + SUM((A,P),m(A,P) * IB(A,P))

               + SUM((I,P),n(I,P) * IT2(I,P))

               + SUM((I,P),n(I,P) * IR(I,P))

               + SUM((P,Q),o(P,Q) * (OT1(P,Q) + TC(P,Q)))

               + SUM((P,Q),r(P,Q) * (OT2(P,Q) + TC(P,Q)

                  + PT(P,Q) + PH(P,Q) + PD(P,Q)))

               + SUM((D,P),h5(D,P) * (OTI2(D,P) + TCI(D,P)

                  + PTI(D,P) + PHI(D,P) + PDI(D,P)))

               + SUM((D,P),h1(D,P) * (OTI1(D,P) + TCI(D,P)))

               + SUM((P,F),h2(P,F) * IBI(P,F))

               + SUM((F,G),h3(F,G) * ITI1(F,G))

               + SUM((P,G),h4(P,G) * ITI2(P,G))
```

```
                + SUM((P,G),h4(P,G) * IRI(P,G)) ;

SUPPLY(I)..        SUM(A,x(I,A)) + SUM(P,n(I,P)) =L= S(I) ;

DEMAND(Q)..        SUM(P,o(P,Q)) + SUM(P,r(P,Q)) =G= U(Q) ;

PORTBALANCE1(A)..   SUM(I,x(I,A)) =E= SUM(P,m(A,P)) ;

PORTBALANCE2(P)..   SUM(A,m(A,P)) + SUM(I,n(I,P)) =E= SUM(Q,o(P,Q)) +
SUM(Q,r(P,Q)) ;

ISUPPLY(D)..       SUM(P,h1(D,P)) + SUM(P,h5(D,P)) =L= J(D) ;

IDEMAND(G)..       SUM(F,h3(F,G)) + SUM(P,h4(P,G)) =G= K(G) ;

IPORTBALANCE1(P)..  SUM(D,h1(D,P)) + SUM(D,h5(D,P)) =E= SUM(F,h2(P,F)) +
SUM(G,h4(P,G)) ;

IPORTBALANCE2(F)..  SUM(P,h2(P,F)) =E= SUM(G,h3(F,G)) ;

PORTCAP(P)..       SUM(A,m(A,P)) + SUM(I,n(I,P)) + SUM(D,h1(D,P)) + SUM(D,h5(D,P))
=L= T(P) ;
```

```
PNCAP..              SUM((P,Q),r(P,Q)) + SUM((D,P),h5(D,P)) =L= 7200000 ;



Loop((A,P)$(NG3(A,P)EQ 0),

 m.fx(A,P)=0 ;

);


Loop((P,Q)$(NG5(P,Q)EQ 0),

 o.fx(P,Q)=0 ;

);


Loop((P,Q)$(NG6(P,Q)EQ 0),

 r.fx(P,Q)=0 ;

);


Loop((D,P)$(NG12(D,P)EQ 0),

 h1.fx(D,P)=0 ;

);


Loop((D,P)$(NG13(D,P)EQ 0),

 h5.fx(D,P)=0 ;

);
```

```
Loop((P,F)$(NG9(P,F)EQ 0),

 h2.fx(P,F)=0 ;

);




MODEL TRANSPORT /ALL/;

SOLVE TRANSPORT USING LP MINIMIZING costs ;


FILE out /C:\Users\Jude\Desktop\GAMS\Test\Base_Model_Final.prn/;

put out;


put "Trade flows from PROD Region to River Port for US Export"

put /;

loop((I,A)$x.l(I,A),

put I.tl,A.tl,x.l(I,A)

put /;

);


put "Trade flows from River Port to Export Port for US Export"

put /;

loop((A,P)$m.l(A,P),

put A.tl,P.tl,m.l(A,P)

put /;
```

```
);

put "Trade flows from PROD Region to Export Port for US Export"
put /;
loop((I,P)$n.l(I,P),
put I.tl,P.tl,n.l(I,P)
put /;
);

put "Trade flows from Export Port to Import Port without PNC for US Export"
put /;
loop((P,Q)$o.l(P,Q),
put P.tl,Q.tl,o.l(P,Q)
put /;
);

put "Trade flows from Export Port to Import Port via PNC for US Export"
put /;
loop((P,Q)$r.l(P,Q),
put P.tl,Q.tl,r.l(P,Q)
put /;
);
```

```
put "Trade flows from PROD Country to US Import Port without PNC for US Import"
put /;
loop((D,P)$h1.l(D,P),
put D.tl,P.tl,h1.l(D,P)
put /;
);

put "Trade flows from PROD Country to US Import Port via PNC for US Import"
put /;
loop((D,P)$h5.l(D,P),
put D.tl,P.tl,h5.l(D,P)
put /;
);

put "Trade flows from US Import port to US Import river port for US Import"
put /;
loop((P,F)$h2.l(P,F),
put P.tl,F.tl,h2.l(P,F)
put /;
);

put "Trade flows from US Import river port to consuming region for US Import"
put /;
```

```
loop((F,G)$h3.l(F,G),
put F.tl,G.tl,h3.l(F,G)
put /;
);

put "Trade flows from US Import port to consuming region for US Import"
put /;
loop((P,G)$h4.l(P,G),
put P.tl,G.tl,h4.l(P,G)
put /;
);
```