Transportation Cost Modeling of International Containerized Soybean Exports in United States

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EXECUTIVE SUMMARY

What Is the Issue?

Containerized shipping is a small but growing niche in the export of agricultural commodities such as soybeans. Shipment through intermodal containers offers multiple advantages, particularly in terms of quality assurance, and can increase the attractiveness of United States exports in an increasingly competitive global market. The ability to maintain the competitiveness of domestic exports largely relies on the management of transportation costs. However, transportation cost management is a particularly complex task as the supply chain of soybeans and other domestic agricultural commodities is comprised of multiple transportation modes, complex networks, and various stakeholders.

A large majority of previous studies focus on estimating transportation cost for a single transportation mode, link, or route. A lack of "point-to-point" cost analysis that covers intermodal logistics impedes the evaluation of potential policy and operational changes to soybean exports originating from the United States. In addition, while past research efforts have concentrated on bulk transport, this research addresses the burgeoning container shipment market for agricultural transportation on an international scale. To help create a pathway for understanding the optimal strategies for improving the United States' economic competitiveness in the emerging market of containerized agricultural exports, this research develops a multi-modal transportation cost analysis modeling framework, with a focus on U.S. soybean container shipments. This transportation cost analysis and modeling framework provides a building block for a larger research effort that aims to develop strategies for improving freight transportation infrastructure and operations, in the evolving transportation industry and global market.

What Did the Study Find?

This study performs a cost analysis on Iowa soybeans outbound for Shanghai and Rotterdam. When considering transportation costs alone, shipments from Iowa to the Port of New Orleans via inland waterway barge mode are found to be the least expensive solution on a per metric tonnage basis. However, this route is also the longest in terms of travel time when compared to the other itineraries that utilize rail to transport soybeans from intermodal facilities in Iowa to domestic seaports.

Furthermore, we applied the Geospatial Intermodal Freight Transportation (GIFT) model to simulate the optimal flow from high production counties across the United States to various markets in Asia under two cost scenarios: low and high port-to-port ocean rates. By inputting market demand and U.S. domestic supply figures, the model is able to determine which domestically-produced soybeans should go to which foreign markets, and by what transport modes. In scenarios with low port-to-port ocean shipping rates, the model minimizes the usage of rail, instead favoring transport by barge or transport to ports that are closer in proximity. In scenarios with high port-to-port ocean shipping rates, the model favors shipping some soybeans through the Port of Long Beach/Los Angeles (LA/LB) via rail, instead of through the Port of New Orleans.

How Was the Study Conducted?

This study utilized various sources to model the domestic soybean supply chain. We referred to the USDA National Agriculture Service Database and Agricultural Marketing Service (AMS) Databases and Reports to determine soybean production and transportation trends. Based on each transport mode, different databases and programs were utilized to estimate transport costs. The National Transportation Atlas Database (NTAD), United States Army Corps of Engineers, and Bureau of Transportation Statistics (BTS) provide transportation network and intermodal facility data, while to develop truck and barge transport rates, the USDA Agricultural Marketing Service datasets, Grain Transportation Report, and Grain Truck and Ocean Rate Advisory (GTOR) were utilized. To analyze rail moves, the Uniform Rail Costing System (URCS) Phase 3 Railroad Cost Program of the Surface Transportation Board (STB) was utilized. First-hand data for ocean moves is difficult to obtain, as it is proprietary contract data. As a result, this research cross-checked data from multiple online resources so that the cost values could be estimated within reasonable ranges.

Based on the modal-specific transportation network and cost information, a Least Cost Market Analysis (LCMA)- based model estimates and compares the “point-to-point” transportation costs of alternative shipment routes from a domestic production site to a foreign port. For each candidate route, the analysis estimates the transportation time, distance, and cost for each modal segment. The study further employs this data to develop a transportation network optimization model, Geospatial Intermodal Freight Transportation (GIFT), aimed at optimizing the national flow of containerized soybeans.

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1 Introduction

The supply chain of soybeans is complex, encompassing multiple production sites and multiple modes of transportation. As a result, multiple factors affect the supply chain including weather, seasonality, price, equipment availability, congestion, modal delay, cargo ownership, and requirements pertaining to sustainability or product quality (Clott et al., 2014). The United States is a leading producer and a major exporter of soybeans. Although most soybean exports are shipped in bulk, shipment by intermodal containers is increasing in popularity. Container transportation currently represents a relatively small share of total U.S. soybean transport but is emerging as a growing niche market that is attracting interest from government and industry sectors (Clott et al., 2015). Container shipping is advantageous in the domains of operating efficiency, security, and value-added service. Containers can be easily loaded onto truck-beds or railroad cars for movement out of the port without time lost unloading (Parola and Sciomachen, 2005). Additionally, container shipping can reduce the possibility of soybeans commingling with other cargo during delivery and prevent contamination in transit while offering more transparent traceability of producers or shippers. This is particularly important for transporting non-GMO products to meet the standard for product segregation during handling and shipping (Marathon et al., 2006).

High productivity rates and a reputation for quality ensure high demand for United States soybeans. However, there is increasing competition from other producing countries, such as Brazil, in the global market. In the 1990s the U.S. accounted for almost 70% of all exported soybeans. In 2013, however, Brazil surpassed the United States as the leading global exporter with a market share of almost 50% (Salin and Somwaru, 2015). On the other hand, the expansion of the Panama Canal completed in 2016 will allow for more efficient exports from the Midwest, via Gulf and East Coast ports, to key destinations in East Asia where demand presently outpaces agricultural production such as China, Japan, Taiwan, and Indonesia. As a result, ocean liners are now deploying larger vessels, upwards of 15,000 twenty-foot equivalent units (TEUs) in order to achieve increased economies of scale and to benefit from the Panama Canal and Suez Canal expansions.

Lower international ocean freight costs resulting from canal expansions and larger vessel sizes may be partly offset by freight costs that have increased due to a variety of other factors. These factors include the constrained capacities of inland waterways, difficulties attracting sufficient numbers of truck drivers, rising rail rates from intermodal cargo shifts between waterway and roadway, and the increasing foreign exchange rate of the United States dollar. A number of industry coalitions and government agencies have identified these issues, such as Ken et al. (2010) and Meade et al. (2016). The Departments of Commerce, Transportation, Energy, and Agriculture, acting on instructions from the President of the United States, are collaborating to identify critical issues that stand in the way of increased exports (TPCC, 2012). The consensus of this collaboration is that transportation costs must decline in order to enhance U.S. agricultural export competitiveness.

It is of keen interest for the United States soybean exporters to identify optimal pathways and to assess the impacts of any existing or emerging changes in the freight industry (e.g., ocean liner vessel sharing agreements) on soybean exports and transportation. Understanding transportation cost is a stepping-stone toward making optimal decisions to further the improvement of the United States' economic competitiveness in exporting soybeans. However, doing so poses immense challenges. For instance, the international movement of containerized soybeans is operated by multiple modes of transport (truck, rail, barge, containership), each of which has its own unique cost structure and estimation method. Furthermore, there is more than one possible route from almost every origin point in the U.S. to every destination point in a foreign nation.

In order to maintain the competitiveness of the United States in containerized soybean exportation, the USDA funded Rutgers University to study freight cost by modeling the total cost across multiple modes of transportation for soybean exports from the United States. This study departed from past efforts, which largely focus on soybean bulk transportation, by uniquely targeting the emerging container transportation market for agricultural exports. Built upon an integrated analysis of transportation-mode-specific cost structures and up-to-date data, the study results provide a step-by-step, practice-ready calculation tool by which analysts may estimate the transportation cost from the origin of production to the destination port for soybean container exports. The analysis framework also includes a network optimization model to compute optimal freight flow assignment, route choice and intermodal transhipment in order to strategically minimize the total transportation cost nation-wide. The study results can be further used to evaluate the transportation cost, performance, and bottlenecks of other agricultural products, thereby aiding in prioritizing future investments that enhance the economic competitiveness of the United States agricultural industry.

The remainder of this report proceeds as follows: Section 2 reviews relevant literature on U.S. soybean economic analysis and supply chain modeling, identifies knowledge gaps, and states the research objectives of this study. Section 3 provides a brief overview of the current soybean supply chain and transportation in the United States. Section 4 introduces the overall methodologies and data sources of the models. In Section 5, a least cost market analysis model is presented and illustrated through examples of soybean exports to Shanghai or Rotterdam. Section 6 develops and conducts a spatial transportation network optimization model for soybean flow from the U.S to Southeast Asia. Section 7 discusses insights into and applications of the proposed models and recommends strategies for future improvement. Lastly, concluding remarks are provided in Section 8.

2 Literature Review and Research Objectives

Soybeans are one of the most important commercial crops in the worldwide market. With strong demand for soybeans in Europe, Asia, and North Africa, and with production centered primarily in the Americas, transportation plays a crucial role in the decisions associated with importing and exporting soybeans. In order to make an effective transportation plan for soybeans, as well as for other exported crops, it is important to focus on supply-chain logistics. This section reviews relevant literature on soybean economic analysis and agricultural logistics modeling, discusses knowledge gaps, states our research objectives and scope, and presents the overall structure of this report.

2.1 Literature on Soybean and Agricultural Logistics

The existing literature covered various aspects of the soybean and agricultural commodity supply chain. For example, in regard to soybean transportation demand and supply chain configuration, DaSilva and Agosto (2013) developed a model to estimate origin-destination (O-D) matrices for soybean exports. The model involves transportation from production fields to the processing warehouse and finally to the port of exit. Shen and Wang (2013) develop binary logit and regression models to study cereal grain movement by truck and rail transportation throughout the United States. The model is useful for estimating modal split between truck and rail based on observed data, but it neither incorporates the intermodal system including inland waterway and ocean links nor estimates the total cost from a holistic point of view. Danao and Zandonandi (2015) developed a probe to monitor environmental conditions and logistics information during transportation. Through this methodology, soybean quality is assured, but transportation costs are increased. Lee et al. (2009) provided a method for monitoring the occurrence of genetically modified soybeans in cultivated fields and along transportation routes. They used a statistical method to monitor and detect outliers during the process. In addition, Informa Economics (2012) comprehensively evaluated United States soybean supply chains, tracing the routes from farm to market. They also assessed the impacts of transportation infrastructure on the U.S. agriculture industry. As for containerized soybean shipping, they recognized its promise of expanding, and the importance of close proximity of a transloader or container yard to farms in order for consistent utilization of containers. Salin and Somwaru (2015) quantitatively examined the decline in demand for U.S. soybeans, citing the need for improved farm-to-port transportation infrastructure. Whereas these models analyze soybean supply chain within the U.S., they rarely consider international shipping costs which is a significant factor in comparing container movement across different routes.

Other studies have focused more on specific aspects of agricultural transportation. For example, Keith (2013) provided an assessment of the U.S. freight railroad system and its ability to handle current and future commodities demand. Wetzstein (2016) investigated the supply-and-demand dynamics of agricultural commodity barge transportation and additionally produced spatial forecasts of barge rates along the Mississippi River, a major corridor for agricultural commodity transport. Such work attempts to look at the U.S. agricultural commodity export economy by focusing on a single key transportation mode of the supply chain. Friend and Lima (2011) focused on the national level policy aspect, analyzing the strength and competitiveness of U.S. and Brazilian soybean production according to each country's transportation policies.

Methodology-wise, freight network optimization has been an active research area for modeling soybean and agricultural transportation decision-making processes. Besides the Clott and Herman (2015)'s study that optimizes containerized soybean supply chain, Reis and Leal (2015) built deterministic models regarding the tactical planning of the soybean supply chain to aid with temporal and spatial decisions. For other agricultural and general freight commodities, Quètica (2016) assessed freight network demand and capacity, and developed an optimization model for the State of Iowa including exportation of freight in containers. Nourbakhsh et al. (2016) developed an optimization model to optimize supply chain network design for reducing grain post-harvest loss. Similarly, Fan et al. (2010) developed an optimization model that integrates international and North America inland transport networks to determine optimal ship size, route, port, and interior shipping corridors. Another stream of freight network modeling research applies Geographic Information Systems (GIS) models or integrate optimization approaches into GIS to simulate intermodal freight flow and analyze policy impacts, such as Macharis et al. (2010), Lim & Lee (2013). Winebrake et al. (2008) provides a good overview of such methodology and develops a GIFT model that connects highway, rail, and marine shipping networks through ports, rail yards, and other transfer facilities to create an intermodal freight transportation network. Furthermore, Pekin et al. (2013) modeled various factors that influencing the cost structure, such as value of time, in the intermodal supply chain. Despite these existing efforts, there has been little prior research of exactly the scope of intermodal containerized agricultural export problem on national scale, focusing on route, modal choice and transloading location.

2.2 Knowledge Gaps

Although soybean transportation research has received growing attention in recent years, several fundamental questions have yet to be addressed. First, a large majority of previous studies focused on estimating transportation cost on a single transportation mode, either nationally or on a given international leg. To our knowledge, no published study has concentrated on total cost analysis across multiple modes, especially for containers, from any specific production site in the U.S. to the destination port in a foreign country. A lack of this "point-to-point" cost analysis impedes the evaluation of potential policy and operational changes to soybean logistics originating from the United States. Second, while past research efforts concentrated on bulk transport, this research addresses the burgeoning container shipment market for agricultural transportation on an international scale. Our proposed methodology builds on existing research by assessing the transportation costs associated with intermodal links from farm-to-port, expanding to include links to international markets, and providing recommendations on how to reduce the costs of such links using network optimization modeling.

2.3 Research Objective and Scope

Built upon an understanding of the literature and knowledge gaps, we develop a modeling framework specific to containerized agricultural commodities, with a focus on soybeans. Specifically, this research seeks to accomplish the following research objectives:

- Develop a flexible, comprehensive methodology for assessing the total transportation cost of containerized soybean shipping from any point in the United States to a foreign port, including a detailed, step-by-step, practice-ready calculation procedure that synthesizes the best available data for industry personnel and other relevant stakeholders.

- Develop a mathematical model for optimizing system-wide logistics operations to improve the cost-effectiveness of soybean containerized exports for U.S. producers and shippers.

- Draw economic insights relevant to the current practice and recommend infrastructure investment strategies for improving the long-term economic viability and competitiveness of U.S. soybean containerized exports.

With these methodologies and tools in hand, decision makers can evaluate freight performance, identify infrastructure bottlenecks, and prioritize infrastructure investment in order to improve the efficiency of the containerized soybean supply chain. As the first step in a larger research trust, this research provides the essential cost information for initiating a series of follow-up studies. These studies, once completed, would potentially enhance the competitiveness of U.S. soybean containerized exports in the world market and will provide insights into the optimal investment strategy portfolio for improving the long-term economic viability and competitiveness of the U.S. agriculture industry.

3 Overview of U.S. Soybean Transportation and Export Market

First, the domestic soybean supply chain of the United States is examined in this Section, beginning with locations of production. Next, the transportation of soybeans from the production site is examined, including modal shares and transport costs. Lastly, for export-bound soybeans, port-of-exit and destination trends are analyzed. The overall goal of this section is to assess the current state of the supply chain in advance of any cost analysis or optimization modeling.

3.1 Soybean Production

The United States is the world's largest soybean producer, and until 2013 it was also the largest exporter of soybean (Denicoff et al., 2014). According to the USDA National Agricultural Statistics Service (NASS) data, soybean production within the United States is primarily concentrated in the Corn Belt, including the Upper Midwest, portions of the Great Plains, and the Mississippi River Delta. Overall the largest share of soybean production occurs in the North Plains region (including Iowa, Minnesota, North Dakota South Dakota). In 2015 the largest soybean-producing states were Illinois, Iowa, Indiana, Minnesota, and Nebraska. Together, these five states accounted for 49% of United States soybean production. Figure 1, below, shows soybean production in 2015 on county level, and highlights how soybean production ranges across a wide expanse of the eastern United States.

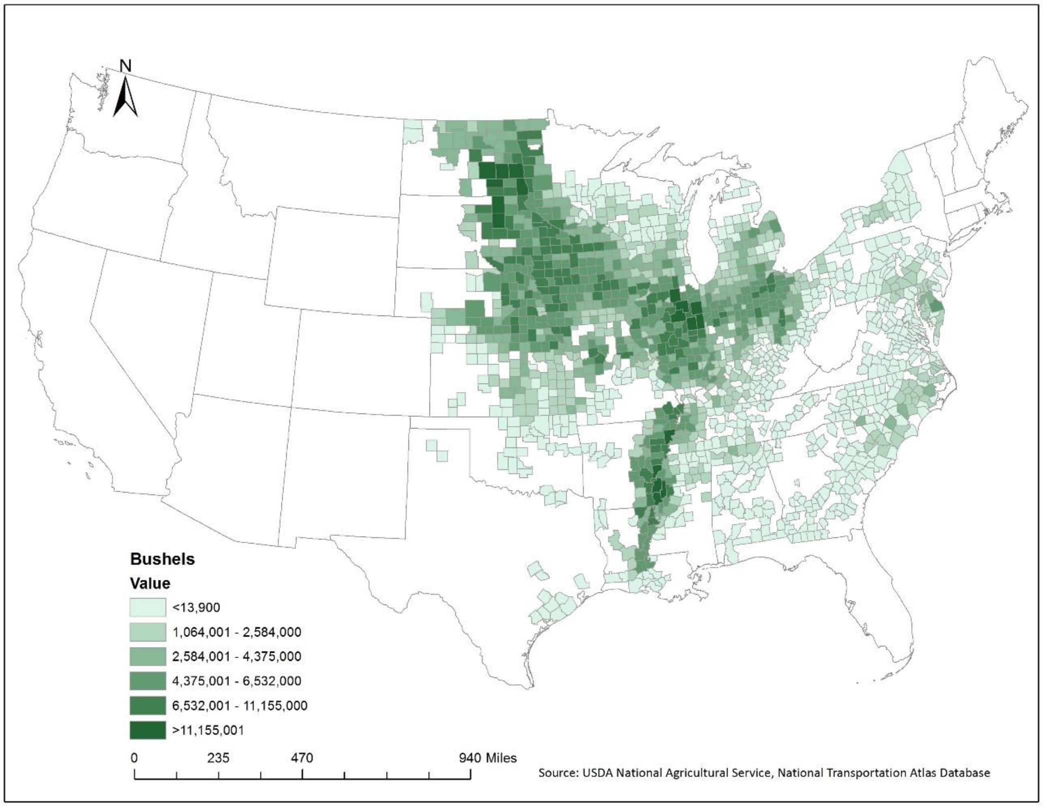


Figure 1 2015 Soybean Production Distribution by County

3.2 Soybean Transportation Modal Share

Transportation plays a significant role in the versatility of the United States soybean market. The nation's well-developed multimodal transportation system, which results in lowered shipping costs, is one of the major reasons for the competitiveness of the soybean export industry. Using data from the USDA AMS (Denicoff et al., 2014; Sparger and Marathon, 2015), this subsection further describes the use of truck, rail, and barge in the United States soybean supply chain.

Figure 2 below breaks down total transported soybean tonnage between 2003 and 2013, an eleven-year period. As the Figure shows, the modal share of truck transport makes up between two and three times the share of rail and barge transport. These figures remain relatively consistent across the eleven-year period. Furthermore, the modal shares for both rail and barge remained very similar, given a slight increase in tonnage from 2008 through 2010, before dropping slightly in 2011 and then again increasing in 2012.

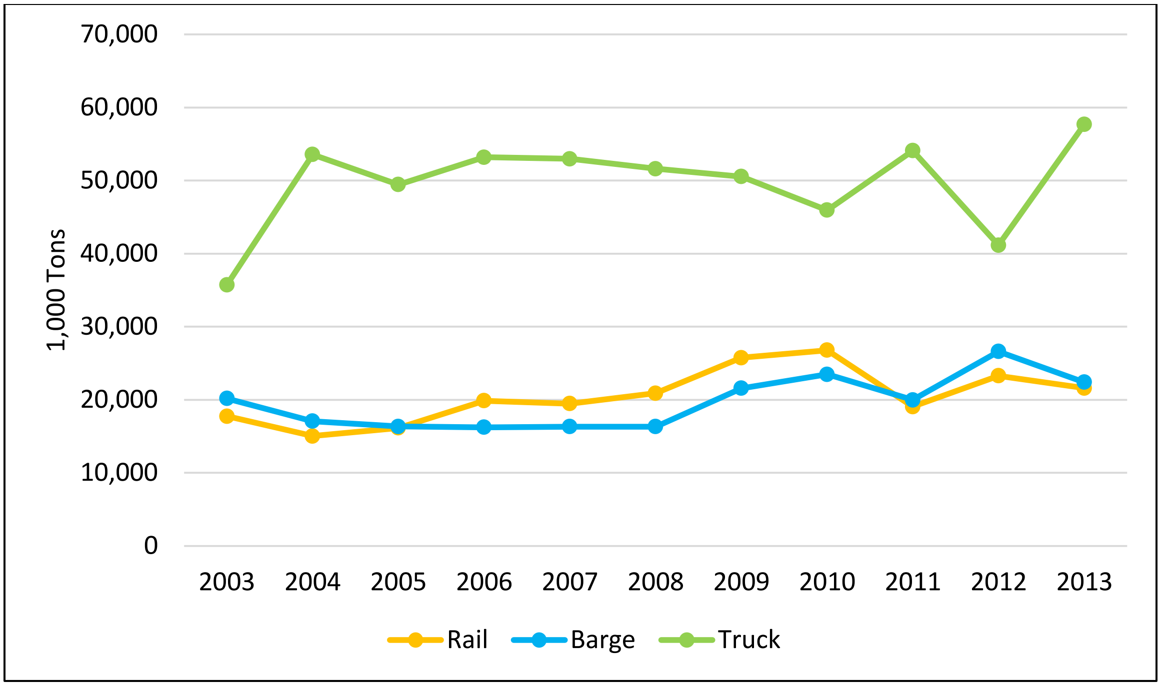


Figure 2 Tonnage of United States Soybean Transported by Mode, 2003-2013 (Sparger and Marathon, 2015)

Whereas Figure 2 describes all soy movement in the United States, Figure 3, Figure 4, and Figure 5 divide these numbers into exported and domestic-bound tonnage. Figure 3 breaks down the proportions of soybeans produced in the United States according to whether they are exported or domestic-bound. As Figure 3 shows, the proportion of soybeans exported appears to be on a slight upward trend, given how the exportation of between 35% and 40% of soybeans in the early-to-mid 2000s increases to almost 50% by the early-to-mid 2010s.

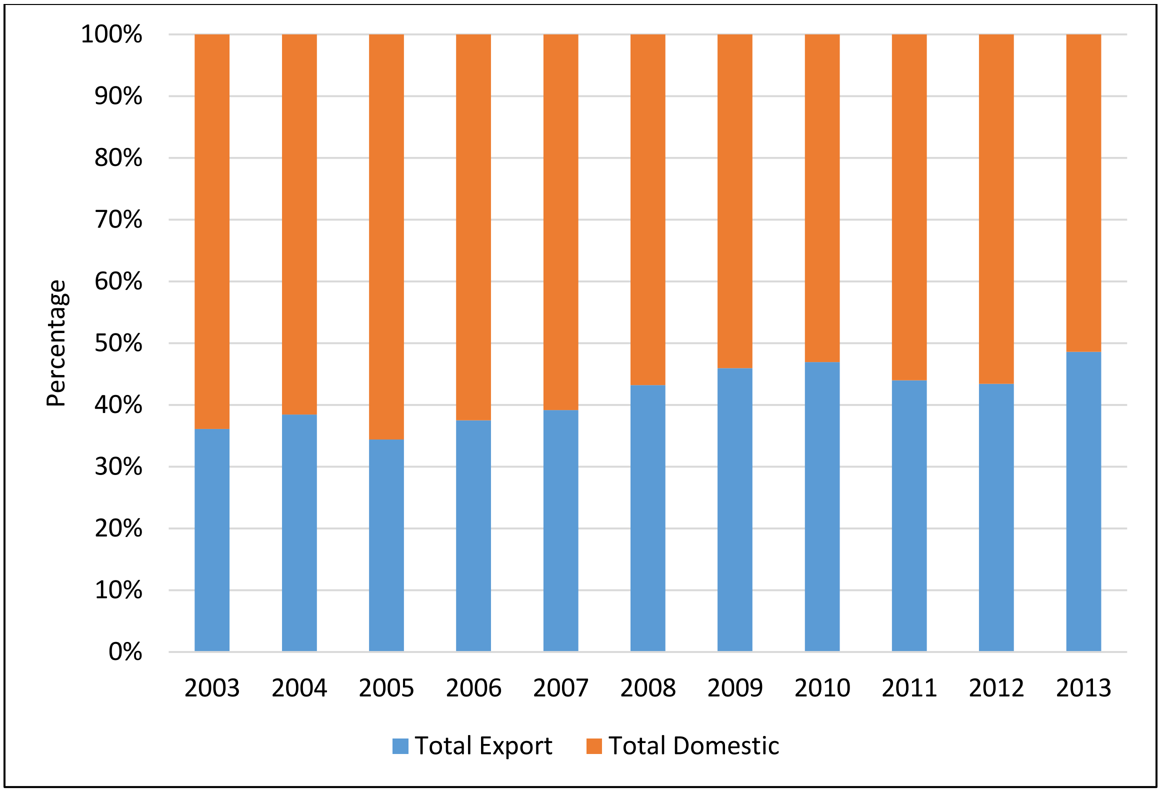


Figure 3 Soybean Movement to Domestic and Export Markets in United States, 2003-2013 (Sparger and Marathon, 2015)

As Figure 4 shows, barge transport accounted for the largest modal share of exported tonnage, followed by rail. Exported soybeans transported by rail and truck were likely bound for Mexico and/or Canada, as those countries share a land border with the United States. Given the fluctuating rail and truck tonnages, the two modes may compete with one another for this share of exportation, depending on the origins of each soybean shipment.

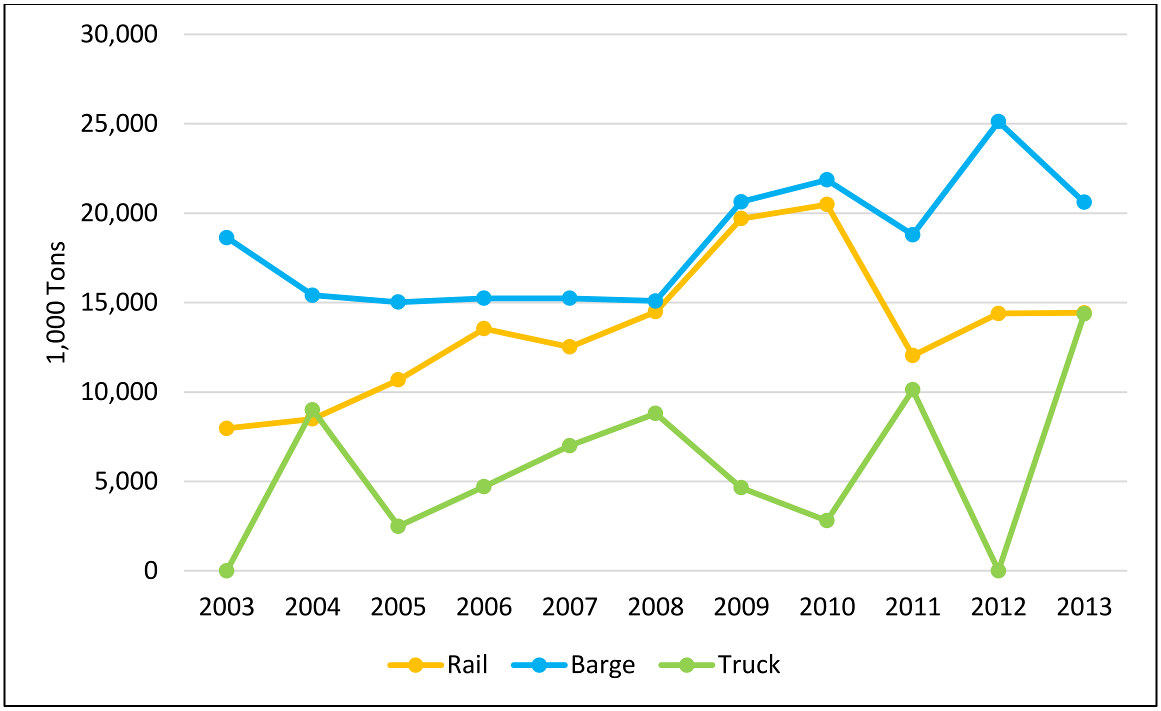


Figure 4 Tonnage of U.S. Export Soybean Transported by Mode, 2003-2013 (Sparger and Marathon, 2015)

Figure 5 shows how truck transport comprised the majority of domestic-bound United States soybean movements from 2003-2013. Such figures accounted for over 80% of all tonnage for the majority of the 11-year period. There is little reported change in modal share for rail and barge over this period.

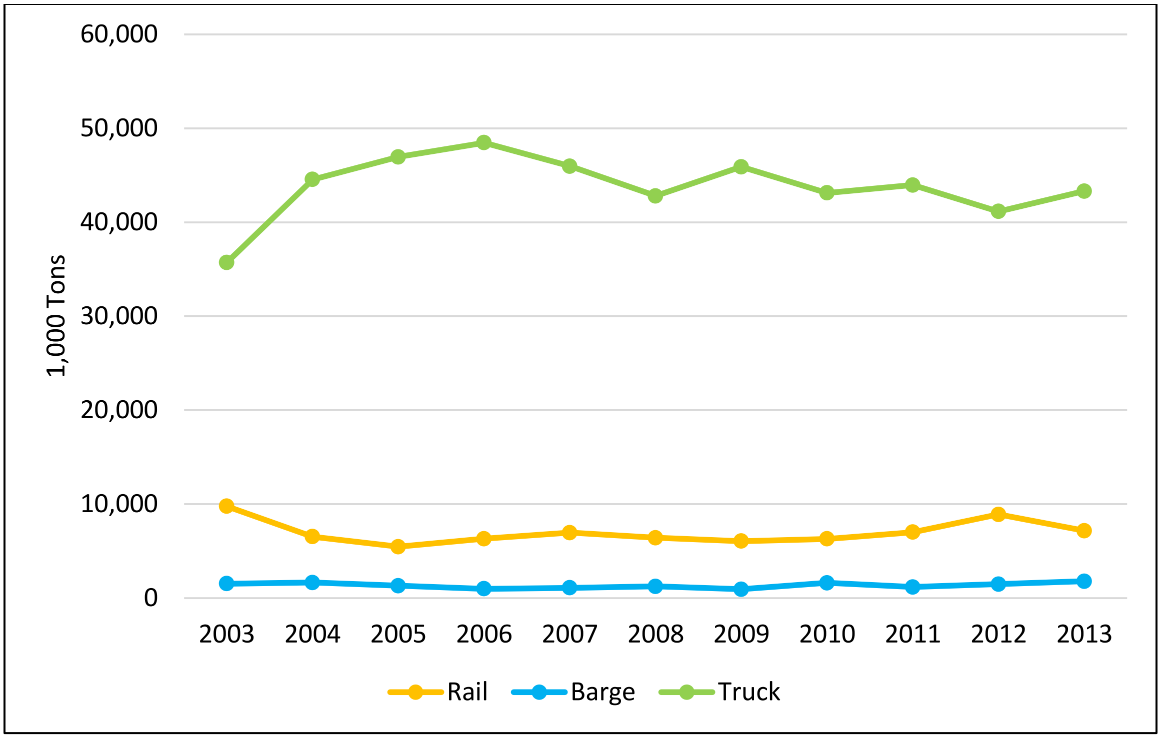


Figure 5 Tonnage of United States Domestic-Bound Soybean Transported by Mode, 2003-2013 (Sparger and Marathon, 2015)

3.3 Transportation Cost and Market Trends

In this section, transportation cost trends are examined using the baseline year of 2002. These figures are determined using the Grain Transportation Cost Indicator (USDA, 2015), which can be used to compare truck, rail, and barge transportation costs. Categorized into quarterly figures, as Figure 6 shows, the transportation cost index indicates increasing transportation costs relative to the base year values in 2000, even when accounting for cost decreases resulting from the global economic recession of 2008. Diesel fuel costs are additionally overlaid onto the Graph. CPI adjusted diesel prices relative to the 2013 value are also calculated based on data from the U.S. Bureau of Labor Statistics. The rising value of the transportation cost index is likely attributable in significant part to rising fuel costs, which rose from about $1.80 per gallon in 2002 (adjusted value) to about $4 per gallon in 2013, a 122% increase.

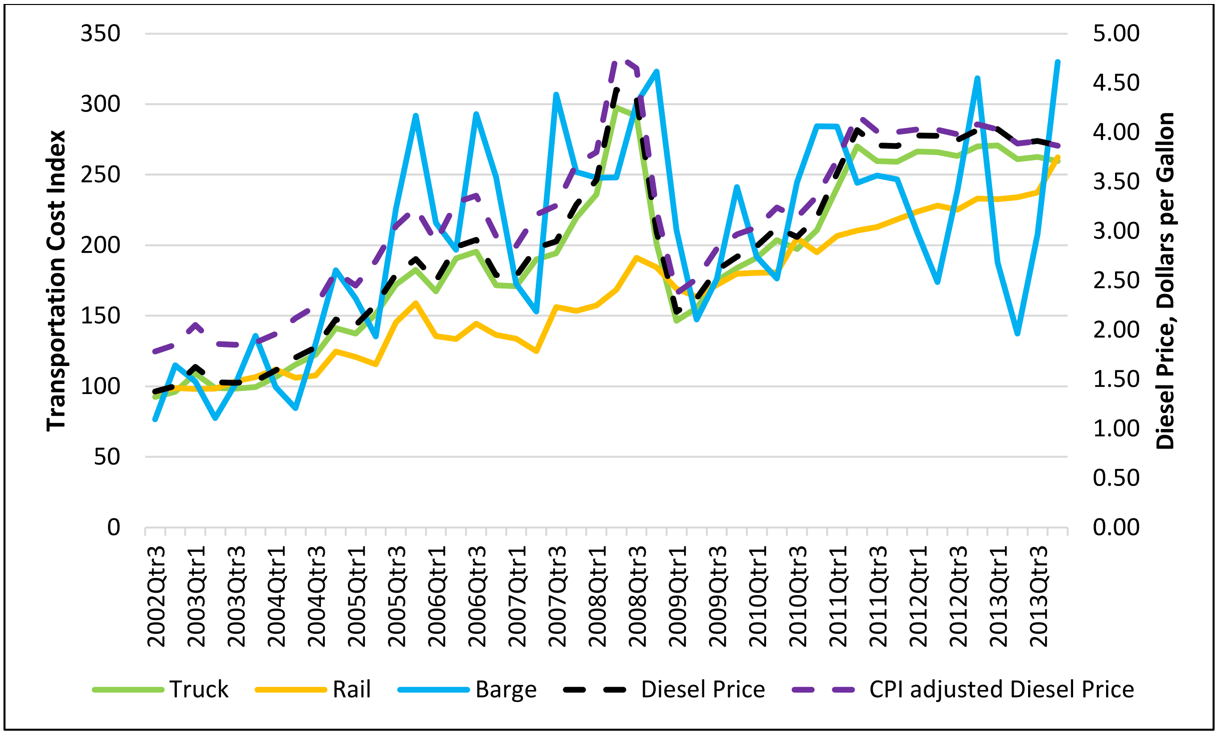


Figure 6 Transportation Cost Index by Quarter, 2002-2013

As indicated by Figure 6, truck and, to a slightly lesser extent, rail transport, are most influenced by diesel costs. Barge costs, however, appear to fluctuate more significantly, especially beginning in 2005. This trend is characterized by noticeable spikes in costs during the second and fourth quarters of the year, likely owing to seasonal adjustments.

Barge transportation cost figures are further examined through Price Spread. Soybean export via barge can be divided based on different export locations. When we use Japan as an example, the two ports of exit from the United States would be along the Gulf of Mexico and the Northwest Coast along the Pacific Ocean. However, as Figure 7 shows below, even though Gulf of Mexico ports of exit are further from Japan than are those in the Pacific Northwest, shipping rates between the entry and exit points are still relatively similar. While the Ocean Freight Rate Index appeared to somewhat follow diesel cost fluctuations before the 2008 global recession, this trend appears to taper off in the post-recession years, given slightly decreasing values for the cost index.

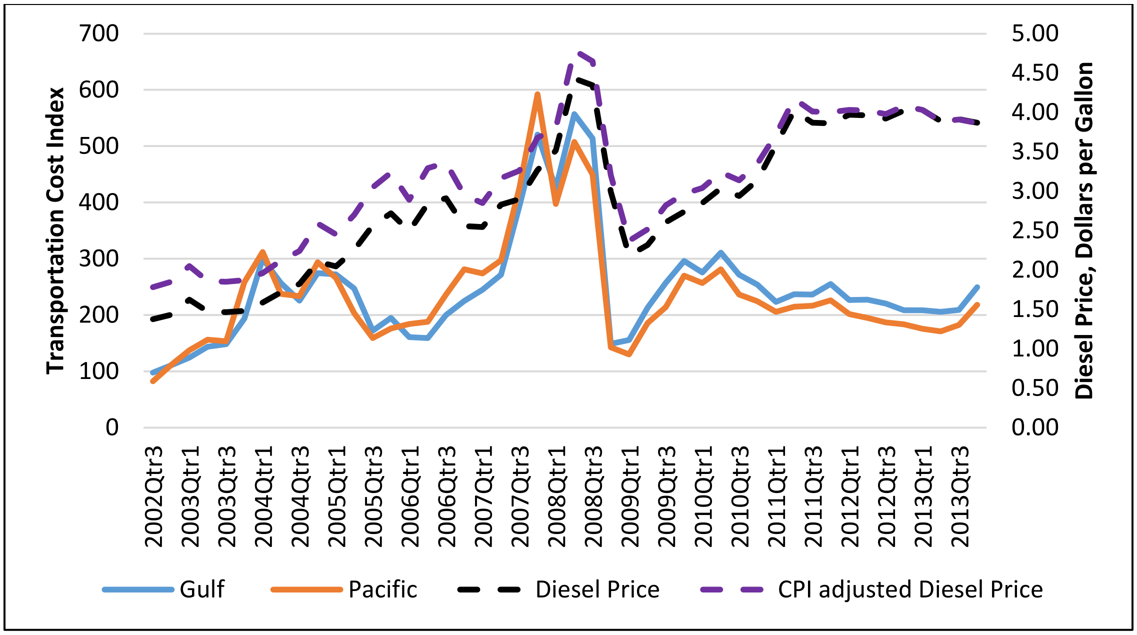


Figure 7 Ocean Freight Rate Index by Quarter, 2002-2013

3.4 Port of Exit and Destination Patterns

Production locations, modal shares, and market costs are all taken into consideration when determining ports of exit. Figure 8 provides an overview of the U.S. soybean production and major U.S. port regions for soybean bulk and container export. The figures are based on data from the USDA, U.S. Army Corps of Engineers and the PIERS database.

Bulk exports occur predominantly via the New Orleans Region and Pacific Northwest, with shares of 69% and 27% respectively. Container exports, however, occur predominantly via California and North Atlantic ports, with shares of 47% and 40% respectively. Five U.S. ports—Los Angeles, Long Beach, Tacoma, Norfolk, and New York—account for 90% of the total export volume (PIERS, 2015). Bulk and containerized soybean shipments vary noticeably across the different United States ports. For bulk shipments, the Gulf of Mexico ports-of-exit comprised over 60% of market share, followed by the North Pacific at 24%. For containerized shipments, however, the South Pacific had the highest share at 47%, followed by the North Atlantic at 40%.

The Port of New Orleans provides a unique situation. Given its location at the head of the Mississippi River Delta, a major soy production location, the port represents 69% of bulk exports, but only 0.1% of containerized exports. Unlike most other major ports in the United States, barge (as opposed to rail) is the primary means of transport of agricultural products to New Orleans. As a result, the port's infrastructure requirements, especially for container transport, are unique in the need to serve incoming barge cargo. Some recent port infrastructure investments at the Port, however, have focused on transferring agricultural products from barge to vessel. These investments include a Vac-U-Vator, which is utilized to vacuum grains from a barge into a hopper and onto a container-bound conveyor belt (Gresham, 2010). Considering the capacity of rail-to-vessel container operation, New Orleans containerized export shares will likely continue to be lower than other portions of the United States. With the recent expansion of the Panama Canal, however, the Port of New Orleans may be poised to provide a larger share of containerized soybean exports, given continued and necessary infrastructure investments.

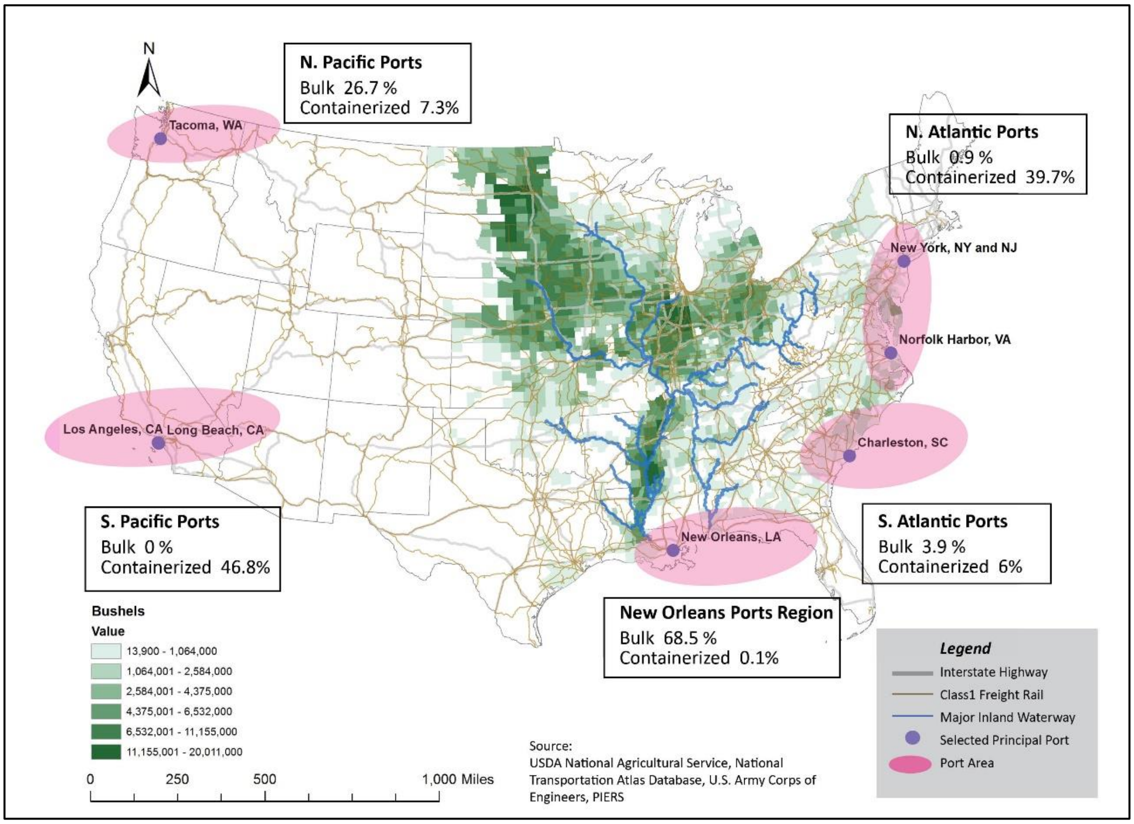


Figure 8 Soybean Production and Major Port Regions for Soybean Exports

Figure 9 lists the top destinations of U.S. soybean exports. China receives 57% of U.S. exported bulk soybeans, followed by Mexico, Japan, Germany, and Indonesia, while the major destination countries for containerized soybeans are Indonesia, Taiwan, Thailand, Vietnam, Japan, China, and Malaysia (PIERS, 2015).

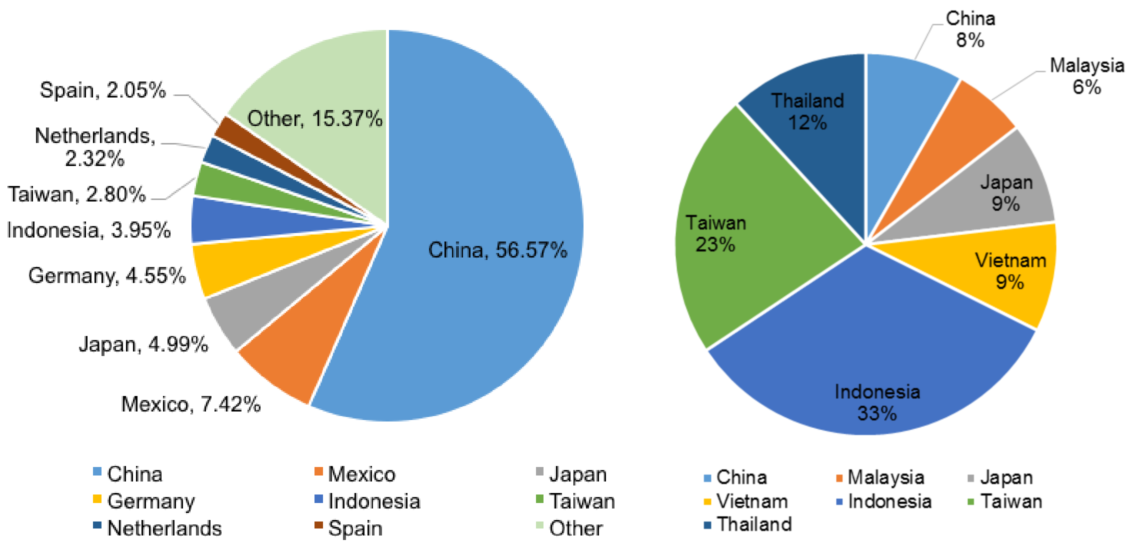


Figure 9 Composition of 2015 United States (a) Bulk, and (b) Containerized Soybean Export Destination

This section explored soybean production and transportation trends for the United States. The information reveals that soybean supply chains and transportation patterns are influenced by a wide variety of endogenous and exogenous factors, ranging from global demand to fuel costs. In the sections to follow, LCMA and GIFT modeling are conducted to analyze costs and optimize the soybean supply chain given these various factors.

4 Methodology Overview and Data Sources

To evaluate soybean freight performance and to optimize the supply chain operations for United States containerized exports, this study proposes two modeling frameworks: a Least Cost Market Analysis (LCMA) model and a Geospatial Intermodal Freight Transportation (GIFT) model.

4.1 Methodology Overview

LCMA Model

Spatial economic analysis frameworks have been developed to determine the geographical boundaries of the competitiveness of imports and exports to and from global origins and destinations. These frameworks were used in previous research for agricultural companies as well as in the analysis of the economic viability of new container terminals to support the United States Army Corps of Engineers' decision-making process. Such models are essentially algorithms designed to determine the lowest cost path from an origin to a destination, taking into account truck and/or rail freight costs, handling charges at ports, and ocean carrier costs. In some analyses, inventory-carrying costs are also included. These costs are impacted by the length of the freight's journey.

The LCMA modeling was originally used in the Moffatt & Nichol (2011) study to identify the least cost port and mode of transportation to serve an inland hinterland market designated by zip code. In that model, each destination location (e.g., represented by ZIP code) could be served by competing ports (e.g., the West Coast ports against the Mid and South Atlantic ports) and could be reached from the ports via truck or rail using an intermodal container transfer facility (ICTF). Each of the different transportation routes outlined has an associated cost to ship a container from the foreign country of origin to the final ZIP code destination. The cost comprises ocean cost, terminal handling cost, and inland costs. When the process is repeated, a color-coded map showing ZIP codes attributed to the port can be drawn to represent the lowest-cost option. Once all of the ZIP codes have been grouped together, a block of color for each port is then provided for easier visual interpretation of the division of the region across different port LCMAs.

To date, this framework has been used to determine the geographic region best served by any particular port as the lowest cost entry or egress gateway for containerized U.S. international trade. This framework is similar to the reverse site logistics models (also known as location-allocation models in academic research literature, e.g., Azarmand & Neishabouri, 2009). The location allocation models are widely used in supply chain management (e.g., to determine the best locations for warehouses needed to serve retail outlets in a given market area) as well as in GIS-based transportation planning analysis. Spatial equilibrium models differ from reverse site logistics models in that the former determines the geographical area best served by infrastructure in a given location while the latter determines the location best suited to serve a given geographical area.

In this study, the LCMA framework is adapted and extended to assess transportation competitiveness from the perspective of U.S. soybean shippers/exporters. They are likely to be interested in finding out which ports and routes are the best options in terms of minimizing/managing transportation cost for shipping containers. The model first evaluates multiple practical routes from a soybean-distributing origin (e.g., county elevators) to a destination port or export region via different U.S. ports and transportation modes, and ranks them based on cost. A similar framework can be used to determine market areas of domestic ports (i.e., from the port's perspective) which more closely resemble the original form of the LCMA model. This framework is not included in this study, given limitations of scope, but it is discussed as a future research topic in Section 8.

GIFT Model

Like LCMA modeling, GIFT modeling uses algorithms to determine the best origin-to-destination route, although there are some notable differences between these two models. Whereas LCMA is useful in determining the point-to-point route costs and in identifying the least expensive routes from origin to destination, GIFT modeling expands this concept to determine the optimal path based on optimization theory and supply chain network modeling techniques. In addition to geospatial-referenced transportation cost data, GIFT modeling also takes into account demand figures and flow volume to determine the optimal system of freight moves. GIFT is a linear program system that combines transportation network and commodity flow optimization models. The system can be extended to a nonlinear system when considering more complex issues such as traffic congestion, container availability operation logistics, and other constraints. Additionally, some analyses include societal costs of environmental and energy emissions such as carbon and particulate matter. In this study, environmental emissions are assumed to be factored into fuel and transportation costs. The societal costs that are not already factored into general fuel and transportation costs are not considered, as this study is meant to evaluate those costs directly incurred throughout the supply chain.

The GIFT analysis can be applied to multiple levels of analysis, including regional, national, and international scales. The technique has been applied to assess both the strength of the overall freight transportation network and its applications to specific goods and commodities. In this study, the GIFT model methodology is applied to determine the optimal flow of soybeans from major production counties in the United States to multiple Asian markets.

4.2 Data Sources

The USDA National Agriculture Service Database provides soybean production and distribution data. Soybean traffic data by mode derives from the USDA Agricultural Marketing Service database (AMS). Three databases, including AMS, the International Trade Center, and PIERS, allowed us to characterize the soybean market landscape and trace soybeans from field to market. The National Transportation Atlas Database (NTAD), the United States Army Corps of Engineers, and the Bureau of Transportation Statistics (BTS) provided transportation network and intermodal facility data. For truck and barge transportation rates, the USDA AMS datasets, Grain Transportation Report, and Grain Truck and Ocean Rate Advisory (GTOR) were utilized. To analyze rail moves, we used the Public Use Waybill (PUWB) of the Department of Transportation Surface Transportation Board (STB). First-hand data for ocean moves is difficult to obtain, as it is proprietary contract data. As a result, we cross-checked multiple online data resources to estimate the cost values within reasonable ranges. Table 1 provides a full description of the data sources as shown below:

Table 1 Data Sources

Data Type	Description	Database/Source
Network and Modal Data		
Highway and railway network	Roadway and railway GIS network data	NTAD, BTS
Intermodal facility		
Domestic waterway network	Waterway and maritime port GIS data	Navigation Data Center (NDC), U.S. Army Corps of Engineers
Ocean network	Port-to-port distance and route	NETPAS software
Highway performance	Truck operating speed	Freight Facts and Figures 2015, BTS
Railway performance	Weekly rail performance measure - cars on line, train speed, and terminal dwell	Railroad Performance Measure (RPM) Reports
Rail routes	U.S. railway routes and mileages	PC*Miler|Rail software
Commodity Flow		
Commodity flow	Freight analysis framework (FAF)	BTS and Federal Highway Administration (FHWA)
	Commodity flow survey (CFS)	BTS/DOT/Census
	Regional or state level commodity movement	U.S. Army Corps of Engineers, NDC
Rail freight flow	Rail freight waybill by commodity type	PUWB, STB
Grain transportation	Modal share analysis	Modal Share Analysis Report, USDA AMS
	Grain shipment data	Grain Transportation Report Datasets, USDA AMS
	Soybean export origin and destination	PIERS Database
Soybean Production and International Trade		
Soybean production	Soybean production by county level 2015	USDA NASS Quick Stats
Trade, import and export	Soybean export volume (bulk and container)	PIERS Database
	International trade statistics 2001–2015	International Trade Center
	Grain inspections for export by port region	USDA AMS
	U.S. import and export tariff and trade data by commodity	U.S. International Trade Commission (USITS)
Cost		
Oil price	Oil price	Oil Price.com
Highway cost	Truck rate	Grain Transportation Report, GTOR, USDA-AMS
Barge cost	Barge rate	
Railway cost	Tariff rail rate	
	Rail revenue sample by commodity and region	Public Waybill Sample, STB
	Class I railroads variable cost (route and volume specific)	URCS Phase 3 Railroad Cost Program, STB
Ocean shipping cost	Port to port container rate	SeaRates.com, WorldFreightRates.com, iContainers.com
	Coastal container rate	Drewry container reports

5 LCMA Multimodal Transportation Cost Analysis

The global transportation of containerized soybean requires the integration of multiple modes of transportation from the point of origin to the destination. Each transportation sector (rail, barge, truck, and vessel) has its unique operational structure and cost estimation method. While the majority of the prior research focused on a single-mode-specific cost analysis, the supply chain cost analysis for international soybean transportation, especially via containers, remains understudied. Soybean producers and shippers have multiple routing and modal options for shipping a container of soybeans abroad. Their route-selection decisions primarily rely on network availability and cost. Calculating the total cost requires transportation network data and cost data from various data sources. Therefore, to evaluate the transportation cost-competitiveness of U.S. containerized soybean exports, a modeling framework based on LCMA is developed to identify the least-cost transportation options (i.e., route, port, and mode of transportation) to serve the inland market.

5.1 Methodology, Model Input, and Assumptions

The goal of our Least Cost Market Analysis (LCMA) framework is to determine the lowest-cost route for soybean exports by evaluating the different possible transportation modes, intermodal facilities, and ports of exit. Different soybean shipping routes are created in this model based on current shipping routes and prediction of future routes. For each route, either unit cost or route-specific cost by modes, travel distance, and travel time are utilized to develop total route costs that facilitate cost-effectiveness comparisons. A general approach from the shipper's perspective is as follows:

1. Identify the supply chain for containerized soybean exports: route options, transloading locations (ports and intermodal terminals), and transportation modes.
2. Collect transportation time, distance, and cost for each modal segment (including both short haul and long haul domestic transportation links), and ocean segments.
3. Calculate the total shipping time and cost for each specific route.

Earlier in this report, soybean production in the United States was reported based on state and county level figures. For modeling purposes, however, either level of analysis proves difficult. Aggregation at the state level provides too broad an analysis and is not conducive to critical decision making. By contrast, it would take a significant amount of time and effort to compile an origin-destination matrix for a county level production network. To reasonably approximate the soybean traffic flow pattern, a hub-and-spoke type of distribution network is used to consider the origin segment of the soybean supply chain. According to the Informa Economics Study in 2012, the majority of U.S soybean exports are shipped out from farm or country elevator by truck to container yard or transloader, rail shuttles, or barge terminals. Such practice conforms to a hub-and-spoke type of network. The spokes in the network are roadway transportation links between county elevators/intermodal facilities and the hubs, which are terminals in railway or barge systems. County level traffic is aggregated to one of the nearby intermodal freight facilities as the point of origin (i.e., end-of-line terminals) that collects the local soybean supply. Then soybean products are shipped by truck to the next major "hub" facility (e.g., rail or barge terminal, inland port) along the route for containerization and transloading.[1] As such, soybean container movements are divided into three legs, which include short haul by truck from aggregated intermodal facilities to larger transloading facilities, long haul from the transloading facility to exit ports via rail or barge, and ocean shipping to destination ports. Since strategic soybean transportation on a global level is being examined, local transportation to the final destination point is omitted for simplicity.

Intermodal facilities, also known as intermodal freight terminals or dry ports, play an important role in the supply chain of soybeans and other United States commodities. Inland terminals and ports are the activity nexus for soybean exports where they are consolidated, containerized, or transshipped. Currently, about 6% of all United States-based soybean exports are shipped via containers, though a rate of 15% is achievable with government and business support (Clott et al., 2014). However, the distance from soybean production areas to inland intermodal facilities makes increasing container market share a challenge (Vachal, 2014). Additionally, there is a need to have an adequate supply of available containers on hand, which must be able to address fluctuations in supply and demand. Increased infrastructure investment and the construction of additional inland intermodal facilities could increase the flexibility and reliability of the system, which enhances the appeal of United States soybeans in the export market.

Figure 10 is a decomposed diagram for the model framework and calculation process. Note that in practice, the actual freight rate is likely to be a contract-based intermodal rate combining domestic rail and international ocean shipping. Many carriers have also begun to offer integrated rail and road services, and even door-to-door services for a single lump-sum rate. The model can easily incorporate these practices by considering the route- and volume-specific rates instead of using the unit distance cost. In addition, this study assumes shippers bear the following general assumptions and criteria when determining domestic routes: 1) the cost of waterway transportation is always the most competitive; therefore, waterways have higher priority when determining a shipping route; 2) within 100 miles, highway transport is cost competitive; 3) for shipments from the Midwest to the Western U.S., rail is cost competitive once the shipping distance exceeds 210 miles (Gonzales et al., 2013).

1 In practice, the actual container loading location may vary depending on the availability of empty containers in local facilities. Though container match-backs are gaining interest, as they are believed to cut costs and improve efficiency, their coordination is a complex issue and is beyond the scope of this study.

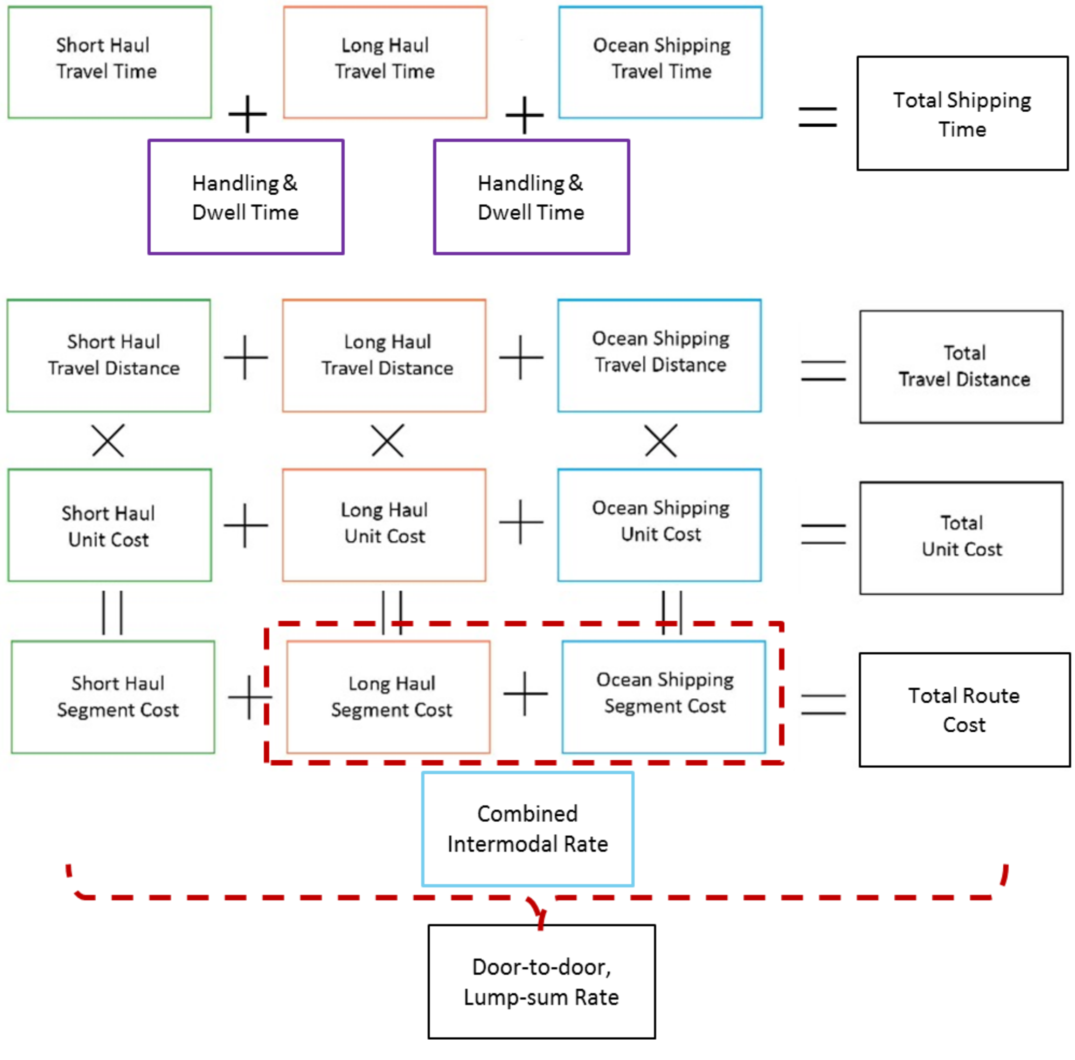


Figure 10 LCMA Based Cost Modeling Framework

Figure 11 shows the United States transportation network and intermodal facilities based on the data collected from NTAD and the U.S. Army Corps of Engineers. Excluding air-based intermodal facilities (not relevant to the transportation of soybeans), Figure 11 summarizes major truck-rail, truck-port, rail-port and truck-rail-port facilities, with points in the figure representing principal ports and major transshipment and/or intermodal transloading facilities.

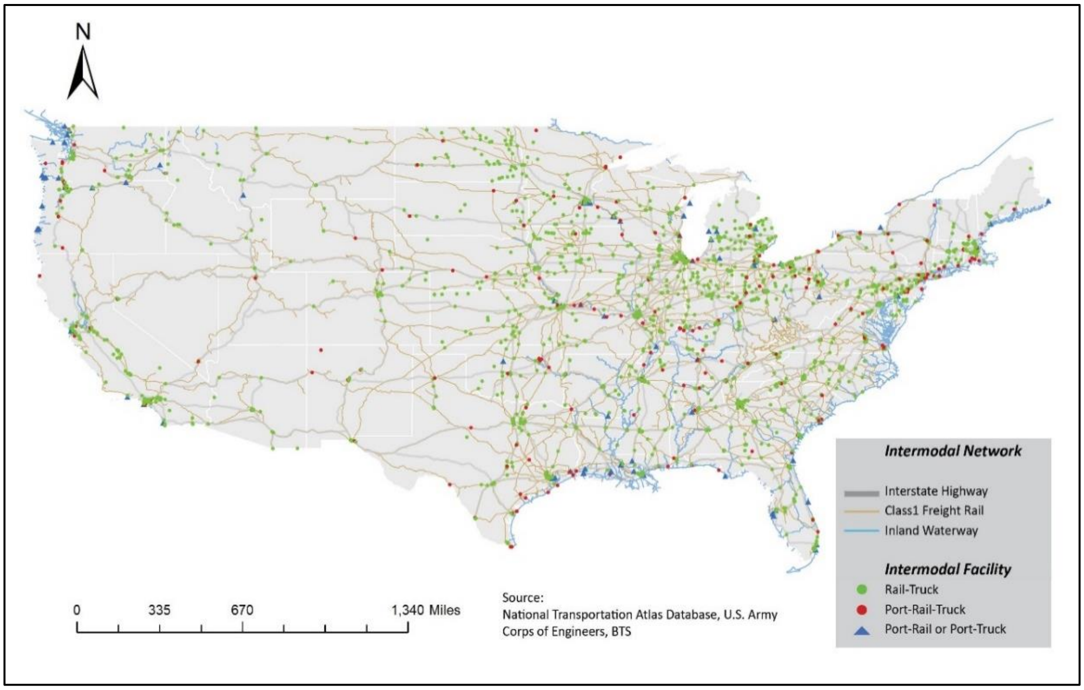


Figure 11 The United States Freight Transportation Network

When compared to barge, rail is a more flexible mode of transportation for containerized soybean exports. The United States rail network can move freight wherever rails are active, which is particularly effective for agricultural commodities like soybeans through sparsely populated areas. Figure 12 provides a glimpse of the national railroad network and intermodal freight volumes for trailer-on-flatcar (TOFC) and container-on-flatcar (COFC) that travel across the United States in 2011 according to USDOT/FHWA special tabulation (2013).

Figure 12 2011 U.S. Intermodal Freight Rail Network and Volume for TOFC and COFC (USDOT/FHWA, 2013)

5.2 Numerical Case Studies

In this section, the proposed methodology is applied to a numerical example in order to estimate the container shipping cost for soybean shippers in the State of Iowa. The purpose of the numerical example is to provide a step-by-step analytical procedure for comparing route-specific costs. In terms of location, Iowa is relatively equidistant to the Atlantic, Gulf, and Pacific coasts, making it an effective location to run LCMA. Given the high demand in China, the Shanghai port is selected for the purposes of this research, as it is a representative route between the U.S. and China. Additionally, Rotterdam in the Netherlands is selected as an additional destination location representing east-coast route options to Europe. As such, soybeans are produced, processed, packed, and transported from Iowa to, for example, either Shanghai in East Asia or Rotterdam in Europe through a well-developed transportation network. The same process can be applied to any other production region and export destination.

In the example, Davenport and Des Moines are used to represent aggregated soybean containerization locations. In order to minimize the complexity of the O-D matrix without sacrificing model utility, soybeans produced in Iowa are assumed to travel through these locations before being shipped to ports of exit throughout the United States. Thus, soybean movements are divided into three segments: short haul by truck from aggregated intermodal facilities to Davenport or Des Moines; long haul from Davenport or Des Moines to selected principal ports via rail or barge, depending on the cost effectiveness of the modal; and ocean shipping from the selected principal port to Shanghai, China or Rotterdam in the Netherlands.

Other factors could also be considered such as travel time and equipment availability. Soybean producers and shippers have multiple routing and modal options for shipping a container of soybeans abroad. For example, some shippers choose to export soybeans via Pacific Northwest Ports, while others choose Gulf Ports to export to China. For this model, six principal ports—Tacoma, WA; Los Angeles/Long Beach, CA; New Orleans, LA; New York, NY and NJ (Port of New York and New Jersey); Charleston, SC; and Norfolk, VA—were sorted out from a list of principal ports compiled from the U.S. Army Corps of Engineers. Such ports were selected based on the cross-matching of soybean exportation data from the USDA and PIERS.

Example 1: Iowa to Shanghai, China (US-Asia Route):

In the first example, shipping routes paired with corresponding origins and destinations are delineated from the State of Iowa to the port of Shanghai, China. Travel distances are compiled and calculated, along with travel time and travel cost for each segment and are then aggregated for each possible shipping route (Figure 13 and Figure 14).

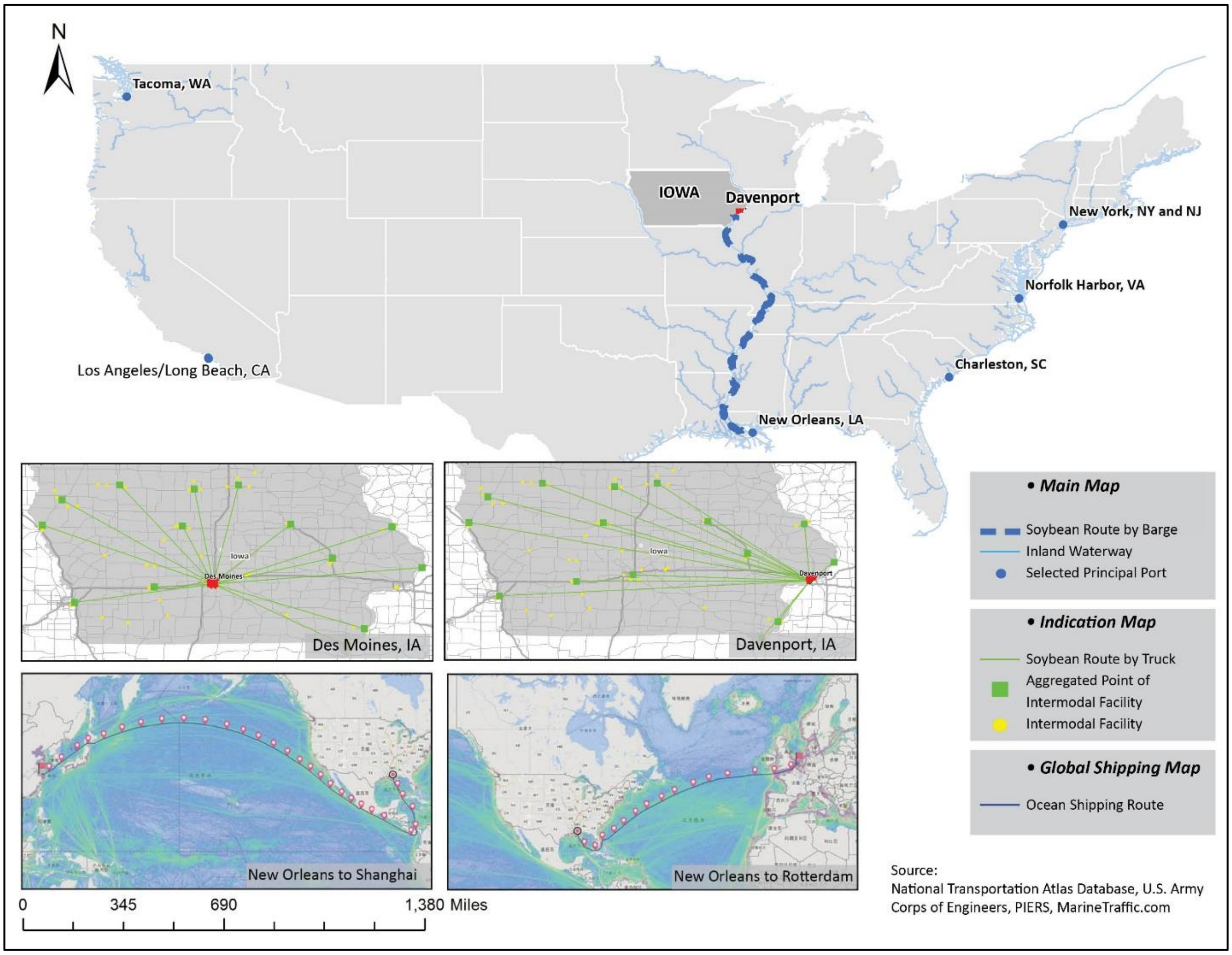


Figure 13 Soybean Transportation Routes from Iowa to Shanghai, Long Haul by Barge

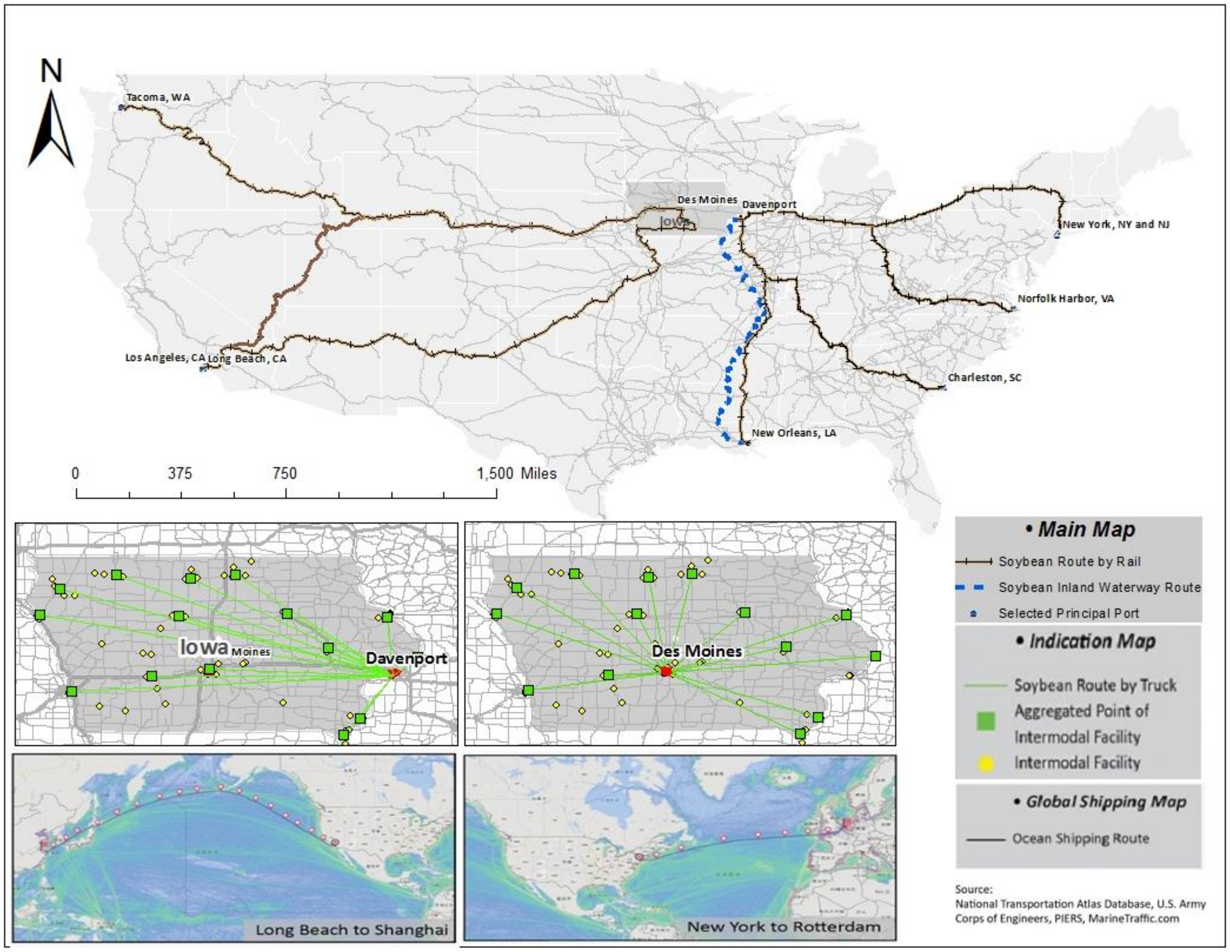


Figure 14 Soybean Transportation Routes from Iowa to Shanghai, Long Haul by Rail

The following five route options between Iowa and Shanghai are selected for cost comparison:

Route 1: Davenport, IA to Shanghai via New Orleans Port, Long Haul by Barge.

Route 2: Davenport, IA to Shanghai via New Orleans Port, Long Haul by Rail.

Route 3: Des Moines, IA to Shanghai via Tacoma Port, Long Haul by Rail.

Route 4: Des Moines, IA to Shanghai via Los Angeles/Long Beach (LA/LB) Port, Long Haul by Rail (UP).[2].

Route 5: Des Moines, IA to Shanghai via LA/LB Port, Long Haul by Rail (BNSF).

[2] Multiple rail routes are available from Des Moines to LA/LB Port, mainly a north route via Union Pacific (UP) railway through Salt Lake City and a south route via BNSF railway through Kansas City. The latter has a slightly longer distance, but it has higher freight volume according to USDOT/FHWA data (see Figure 12).

Route 1 and Route 2 indicate the itinerary from Davenport through New Orleans to Shanghai or Rotterdam via barge or rail, respectively. Route 3 to 5 indicate the itinerary from Des Moines to Shanghai through Tacoma or LA/LB Port specifically via rail. The unit costs by transportation mode and the calculations are shown in Table 2, followed by detailed explanations of individual calculation procedures and assumed parameters.

Table 2 Soybean Transportation Cost Work Table, Iowa to Shanghai

Route 1: Davenport, IA to Shanghai via New Orleans Port, Long Haul by Barge							
Intermodal Facility to Davenport by Truck		Davenport to New Orleans Port by Barge		New Orleans Port to Destination Port by Ocean Shipping		Total	
Distance (mile) (1)	192	Distance	1,330	Distance (2)	11,364	Distance	12,887
Time (hour) (3)	6.4	Time (4)	279.4	Time (5)	705.4	Time	991.2
Unit Cost ($/MT-mile) (6)	0.081600	Unit Cost (7)	0.018204	Unit Cost (8)	0.003110	Unit Cost	0.005801
Route 2: Davenport, IA to Shanghai via New Orleans Port, Long Haul by Rail							
Intermodal Facility to Davenport by Truck		Davenport to New Orleans Port by Rail (CN)		New Orleans Port to Destination Port by Ocean Shipping		Total	
Distance	192	Distance	1,056	Distance	11,364	Distance	12,613
Time	6.4	Time (9)	34.3	Time	705.4	Time	746.1
Unit Cost	0.081600	Unit Cost (10)	0.054323	Unit Cost	0.003110	Unit Cost	0.008556
Route 3: Des Moines, IA to Shanghai via Tacoma Port, Long Haul by Rail							
Intermodal Facility to Des Moines by Truck		Des Moines to Tacoma Port by Rail (UP)		Tacoma Port to Destination Port by Ocean Shipping		Total	
Distance (11)	146	Distance (12)	2,014	Distance	5,603	Distance	7,763
Time	5.6	Time (13)	63.9	Time	347.8	Time	417.3
Unit Cost	0.081600	Unit Cost (14)	0.042033	Unit Cost (15)	0.003321	Unit Cost	0.014792
Route 4: Des Moines, IA to Shanghai via Los Angeles/Long Beach Port, Long Haul by Rail							
Intermodal Facility to Des Moines by Truck		Davenport to LA/LB Port by Rail (UP)		LA/LB Port to Destination Port by Ocean Shipping		Total	
Distance	146	Distance (16)	1,964	Distance	6,509	Distance	8,619
Time	5.6	Time	62.3	Time	404.0	Time	471.9
Unit Cost	0.081600	Unit Cost (17)	0.042328	Unit Cost (18)	0.003062	Unit Cost	0.013299
Route 5: Des Moines, IA to Shanghai via Los Angeles/Long Beach Port, Long Haul by Rail							
Intermodal Facility to Des Moines by Truck		Davenport to LA/LB Port by Rail (BNSF)		LA/LB Port to Destination Port by Ocean Shipping		Total	
Distance	146	Distance (19)	2,162	Distance	6,509	Distance	8,817
Time	5.6	Time (20)	63.6	Time	404.0	Time	473.2
Unit Cost	0.081600	Unit Cost (21)	0.045062	Unit Cost	0.003062	Unit Cost	0.014621

(1): Average distance from multiple aggregated points of intermodal facilities to Davenport by truck.

(2): Distance from export ports in U.S. to destination ports (e.g., Shanghai or Rotterdam) based on NETPAS software.

(3): Travel distance divided by 57.2 mph plus 3 hours delay assumed for truck loading time (Informa Economics, 2012). 57.2 mph is assumed as the average truck speed (FHWA, 2010).

(4): Travel distance divided by 5 knots (5.75 mph) plus 48 hours delay assumed for barge loading time (Informa Economics, 2012). 5 knots average speed is assumed for barge movement (Browning and Genovesi, 1999).

(5): Travel distance divided by 14 knots, the average speed for ocean shipping (Informa Economics, 2012). Port handing and delay time are not considered here due to the large variations in reality. Furthermore, it does not affect our relative comparison among different routes since all routes go through a port.

(6): Data extracted from USDA Grain Truck and Ocean Rate Advisory: Quarterly Updates. 2016 1st quarter truck rate for short haul between 100 and 200 miles in the North Central region is applied assuming 25 metric ton (MT) per truck (i.e., \$2.04 per mile/25 MT = \$0.081600 per MT-mile).

(7): Data extracted from USDA Grain Transportation Report. 2015 2nd quarter barge rate for transporting soybeans from Davenport, IA to Shanghai is applied, i.e., \$24.22 per MT/1,330 miles = \$ 0.018204 per MT-mile.

(8): Data extracted from WorldFreightRates.com on June 30, 2016. Container rate \$609.30 per 20-foot container from New Orleans Port to Shanghai Port is applied, i.e., \$609.30 per TEU/17.24/11,364 miles = \$0.003110 per MT-mile assuming a capacity of 17.24 MT per 20-foot container. Additional fees such as taxes and duties are not included in this rate. Each port tariff is unique with its own rules and rates. Long-term contracts are negotiable and so the actual rates could differ from the tariff market rate. Furthermore, the actual ocean rates fluctuate year by year depending on the market. Therefore, this information is used mainly for illustration of our methodology framework. Multiple other sources can be used to update the ocean rates (see Table 1).

(9): Travel distance divided by 30.8 mph, the average speed for Canadian National (CN) intermodal freight rail in Aug, 2016 (Railroad Performance Measures, 2016).

(10): Data generated from URCS Phase III Railroad Cost Program from Davenport heading to New Orleans by CN railway assuming a carload of 75 and 4 containers (20-foot) per car as a typical trainload. Unit cost is calculated using the total variable cost \$292,564 hauling 5,100 MT (assuming 17.24 MT per container) for 1,056 miles.

(11): Average distance from multiple aggregated points of intermodal facilities to Des Moines by truck.

(12): Distance from Des Moines to Tacoma Port by rail based on the PC*Miler|Rail software.

(13): Travel distance divided by 31.5 mph, the average speed for UP intermodal freight rail in August, 2016 (Railroad Performance Measures, 2016).

(14): Data generated from URCS Phase III Railroad Cost Program from Des Moines heading to Tacoma Port by Union Pacific (UP) railway assuming a carload of 75 and 4 containers (20-foot) per car as a typical trainload. Unit cost is calculated using the total variable cost $431,740 hauling 5,100 MT for 2,014 miles.

(15): Data extracted from WorldFreightRates.com on June 30, 2016. Rate $320.89 per 20-foot container from Tacoma Port to Shanghai Port is applied, i.e., $320.89 per TEU/17.24 MT per TEU/5,603 miles = $0.003322 per MT-mile assuming a capacity of 17.24 MT per 20-foot container.

(16): The north route from Des Moines to LA/LB Port via UP railway through Salt Lake City. The total distances is 1,964 miles based on the PC*Miler|Rail software.

(17): Data generated from URCS Phase III Railroad Cost Program. Unit cost is calculated using the total variable cost $423,975 hauling 5,100 MT for 1,964 miles.

(18): Data extracted from WorldFreightRates.com on June 30, 2016. Rate $343.60 per 20-foot container from LA/LB Port to Shanghai Port is applied, i.e., $343.60 per TEU/17.24 MT per TEU/6,509 miles = $0.003062 per MT-mile assuming a capacity of 17.24 MT per 20-foot container.

(19): The south route from Des Moines to LA/LB Port via BNSF railway through Kansas City. The total distances is 2,162 miles based on the PC*Miler|Rail software.

(20): Travel distance divided by 34 mph, the average speed for BNSF intermodal freight rail in August, 2016 (Railroad Performance Measures, 2016).

(21): Data generated from URCS Phase III Railroad Cost Program. Unit cost is calculated using the total variable cost $496,864 hauling 5,100 MT for 2,162 miles.

Table 3, Figure 15, and Figure 16 summarize the route comparison results for all modes combined, in terms of total distance, time, and cost. For simplicity, a 20-foot container (TEU) is considered to hold about 17.24 MT (633 bushels) of soybeans (Clott et al., 2015), with the total route costs per TEU listed below. From Iowa to Shanghai, the least-cost route will be from Davenport via New Orleans Port by Barge, then from New Orleans Port to Shanghai via international ocean transport. The point-to-point travel distance is 12,887 miles with a total time of transportation of around 41 days. The cost would be around $75 per metric ton, or $1,289 per TEU (in 2015 U.S. dollar value). In Figure 16, ocean transportation overseas accounts for the majority of total travel time in all five routes, and barge transport contributes to a much larger portion of shipping time in route 1 than rail transport in the other four routes. Although this modeling does not account for any particular time constraints, such restrictions could be applied which may affect the outputted optimal route.

Table 3 Total Distance, Time, and Cost of Soybean Shipment from Iowa to Shanghai

Rank by Cost	Iowa To Shanghai	Total Distance (mile)	Total Time (hour)	Total Route Cost	
				$ per MT	$ per TEU
1	Route 1: From Davenport via New Orleans Port by Barge	12,887	991.2	74.76	1,289
2	Route 2: From Davenport via New Orleans Port by Rail	12,613	746.1	107.91	1,760
3	Route 4: From Des Moines via LA/LB Port by Rail (UP)	8,619	471.9	114.63	1,976
4	Route 3: From Des Moines via Tacoma Port by Rail	7,763	417.3	114.83	1,980
5	Route 5: From Des Moines via LA/LB Port by Rail (BNSF)	8,817	473.2	128.92	2,223

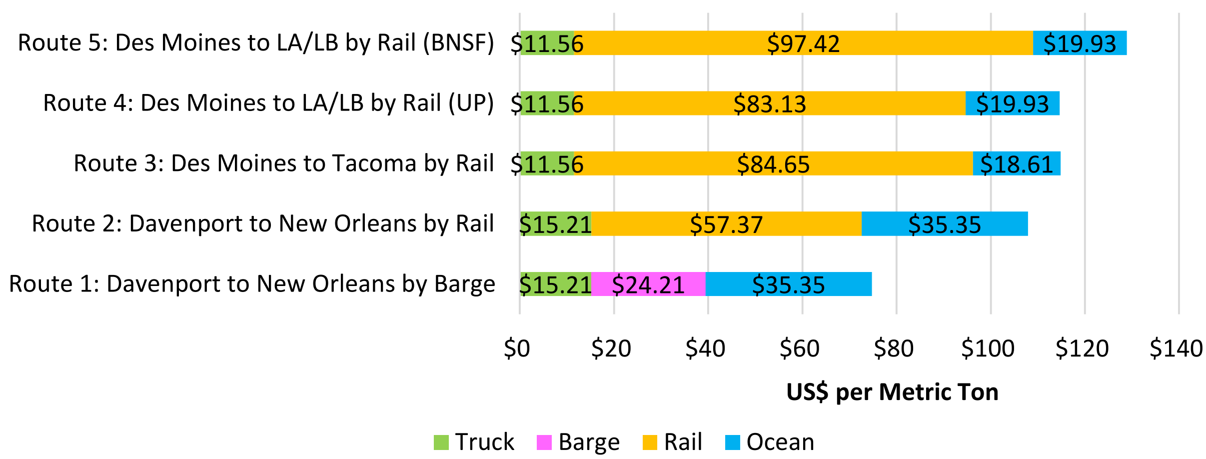


Figure 15 Breakdown of Total Route Cost by Mode from Iowa to Shanghai

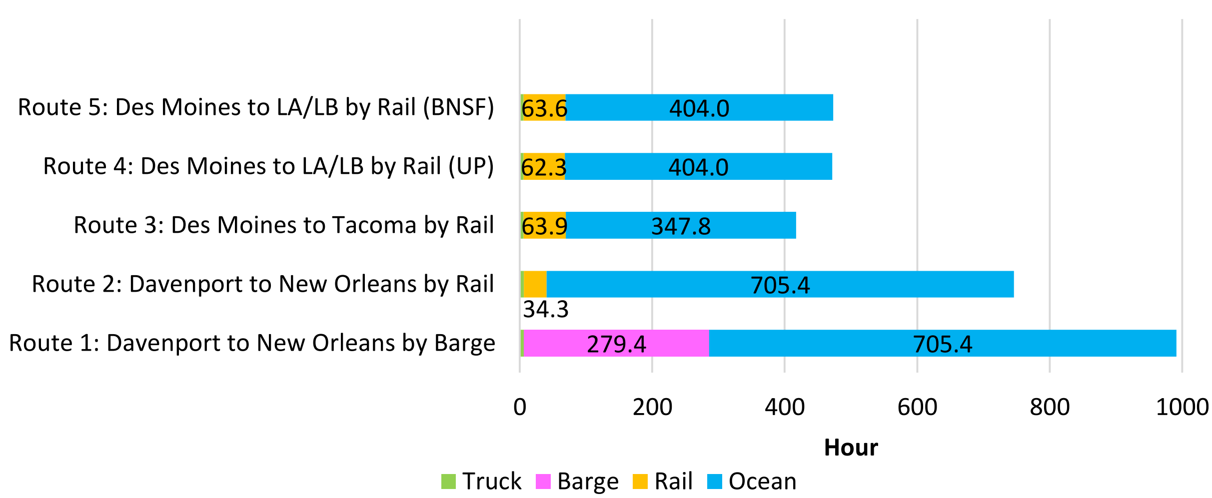


Figure 16 Breakdown of Total Route Time by Mode from Iowa to Shanghai

Example 2: Iowa to Rotterdam, Netherlands (US-Europe)

In the second example, the same methodology is applied to estimate five different routes from Iowa to Rotterdam (Table 4). The purpose is also to compare the transportation cost competitiveness in different markets, i.e., on US-Asia and US-Europe routes.

Route 6: Davenport, IA to Rotterdam via New Orleans, Long Haul by Barge.

Route 7: Davenport, IA to Rotterdam via New Orleans, Long Haul by Rail.

Route 8: Davenport, IA to Rotterdam via New York, Long Haul by Rail.

Route 9: Davenport, IA to Rotterdam via Norfolk, Long Haul by Rail.

Route 10: Davenport, IA to Rotterdam via Charleston, Long Haul by Rail.

Table 4 Soybean Transportation Cost Work Table, Iowa to Rotterdam

Route 6: Davenport, IA to Rotterdam, Netherland via New Orleans Port, Long Haul by Barge							
Intermodal Facility to Davenport by Truck		Davenport to New Orleans Port by Barge		New Orleans Port to Destination Port by Ocean Shipping		Total	
Distance	192	Distance	1,330	Distance	5,368	Distance	6,891
Time	6.4	Time	279.4	Time	333.3	Time	619.0
Unit Cost	0.081600	Unit Cost	0.018204	Unit Cost	0.013608	Unit Cost	0.016320
Route 7: Davenport, IA to Rotterdam, Netherland via New Orleans Port, Long Haul by Rail							
Intermodal Facility to Davenport by Truck		Davenport to New Orleans Port by Rail		New Orleans Port to Destination Port by Ocean Shipping		Total	
Distance	192	Distance	1,056	Distance	5,368	Distance	6,617
Time	6.4	Time	34.3	Time	333.3	Time	373.9
Unit Cost	0.081600	Unit Cost	0.054323	Unit Cost	0.013608	Unit Cost	0.022007
Route 8: Davenport, IA to Rotterdam, Netherland via New York Port, Long Haul by Rail							
Intermodal Facility to Davenport by Truck		Davenport to New York Port by Rail		New York Port to Destination Port by Ocean Shipping		Total	
Distance	192	Distance	1,090	Distance	3,709	Distance	4,991
Time	6.4	Time	38.4	Time	230.2	Time	275.0
Unit Cost	0.081600	Unit Cost	0.056012	Unit Cost	0.015243	Unit Cost	0.026607
Route 9: Davenport, IA to Rotterdam, Netherland via Norfolk Port, Long Haul by Rail							
Intermodal Facility to Davenport by Truck		Davenport to Norfolk Port by Rail		Norfolk Port to Destination Port by Ocean Shipping		Total	
Distance	192	Distance	1,137	Distance	3,952	Distance	5,281
Time	6.4	Time	40.0	Time	245.3	Time	291.7
Unit Cost	0.081600	Cost	0.055107	Unit Cost	0.014551	Unit Cost	0.025633
Route 10: Davenport, IA to Rotterdam, Netherland via Charleston Port, Long Haul by Rail							
Intermodal Facility to Davenport by Truck		Davenport to Charleston Port by Rail		Charleston Port to Destination Port by Ocean Shipping		Total	
Distance	192	Distance	1,151	Distance	4,343	Distance	5,687
Time	6.4	Time	40.5	Time	269.6	Time	316.5
Unit Cost	0.081600	Unit Cost	0.054852	Unit Cost	0.015365	Unit Cost	0.025510

For Rotterdam-bound soybean exports, the final results are shown in Table 5. Similar to the conclusion for Iowa to Asia routes, the itinerary consisting of barge travel from Davenport to New Orleans Port is shown to be the most cost effective, with an approximate cost of $112 per MT, compared to over $130/MT for the remaining routes. In this case, however, the most cost efficient route via barge transport is also the longest in terms of distance and travel time.

Table 5 Total Distance, Time, and Cost of Soybean Shipment from Iowa to Rotterdam

Rank by Cost	Iowa To Rotterdam	Total Distance (mile)	Total Time (hour)	Total Route Cost	
				$ per MT	$ per TEU
1	Route 6: From Davenport via New Orleans Port by Barge	6,891	619.0	112.46	1,939
2	Route 8: From Davenport via New York Port by Rail	4,991	373.9	132.80	2,289
3	Route 9: From Davenport via Norfolk Port by Rail	5,281	291.7	135.37	2,334
4	Route 10: From Davenport via Charleston Port by Rail	5,687	316.5	145.07	2,501
5	Route 7: From Davenport via New Orleans Port by Rail	6,617	275.0	145.62	2,510

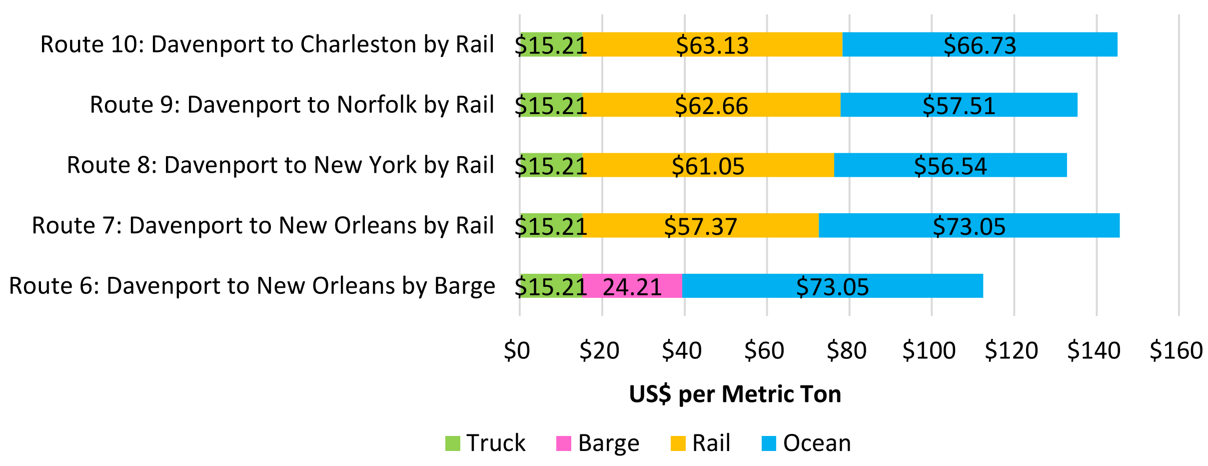


Figure 17 Breakdown of Total Route Cost by Mode from Iowa to Rotterdam

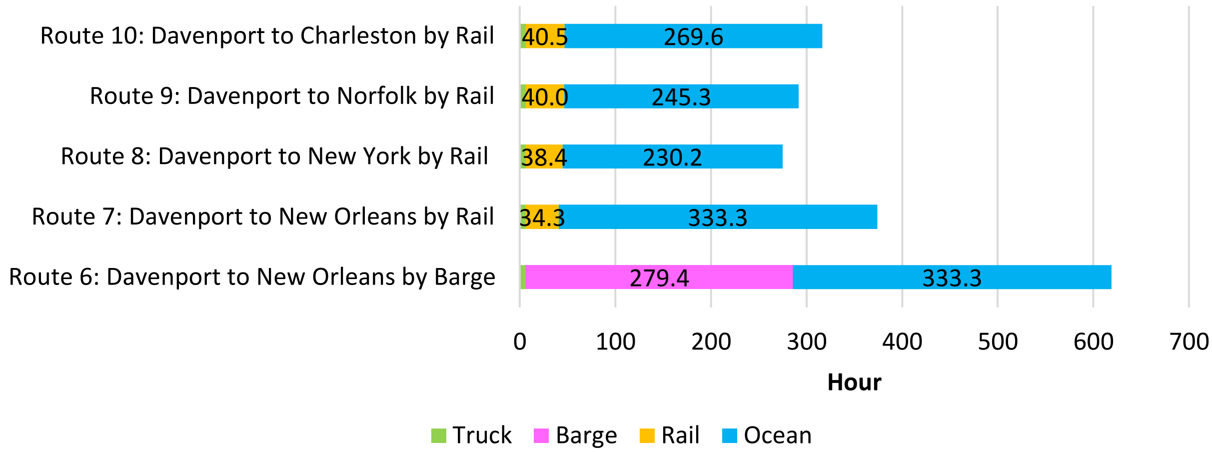


Figure 18 Breakdown of Total Route Time by Mode from Iowa to Rotterdam

Visualized for both destinations (Shanghai and Rotterdam), the geographical output of route selection is provided in Figure 19. As these results show, the most cost efficient route for the transport of soybeans from Iowa to Shanghai is through the Port of New Orleans via barge, given a total route cost of just under $75/MT. Although New Orleans is not currently a major port for containerized soybean export, the cost incentive may lead it to a more competitive position in the future relative to moving Asia-bound soybeans by rail via the Pacific Northwest (Informa Economics, 2012). To ship soybeans from Iowa to Rotterdam, using barge on the Mississippi River via New Orleans Port also represents the optimal route in terms of cost efficiency. The alternatives, via rail through New York, Norfolk, Charleston, and New Orleans prove to be more expensive, largely due to the higher costs of the rail segments. The results shed light on the cost-effective corridors for long haul and international shipping for future soybean-based agricultural development.

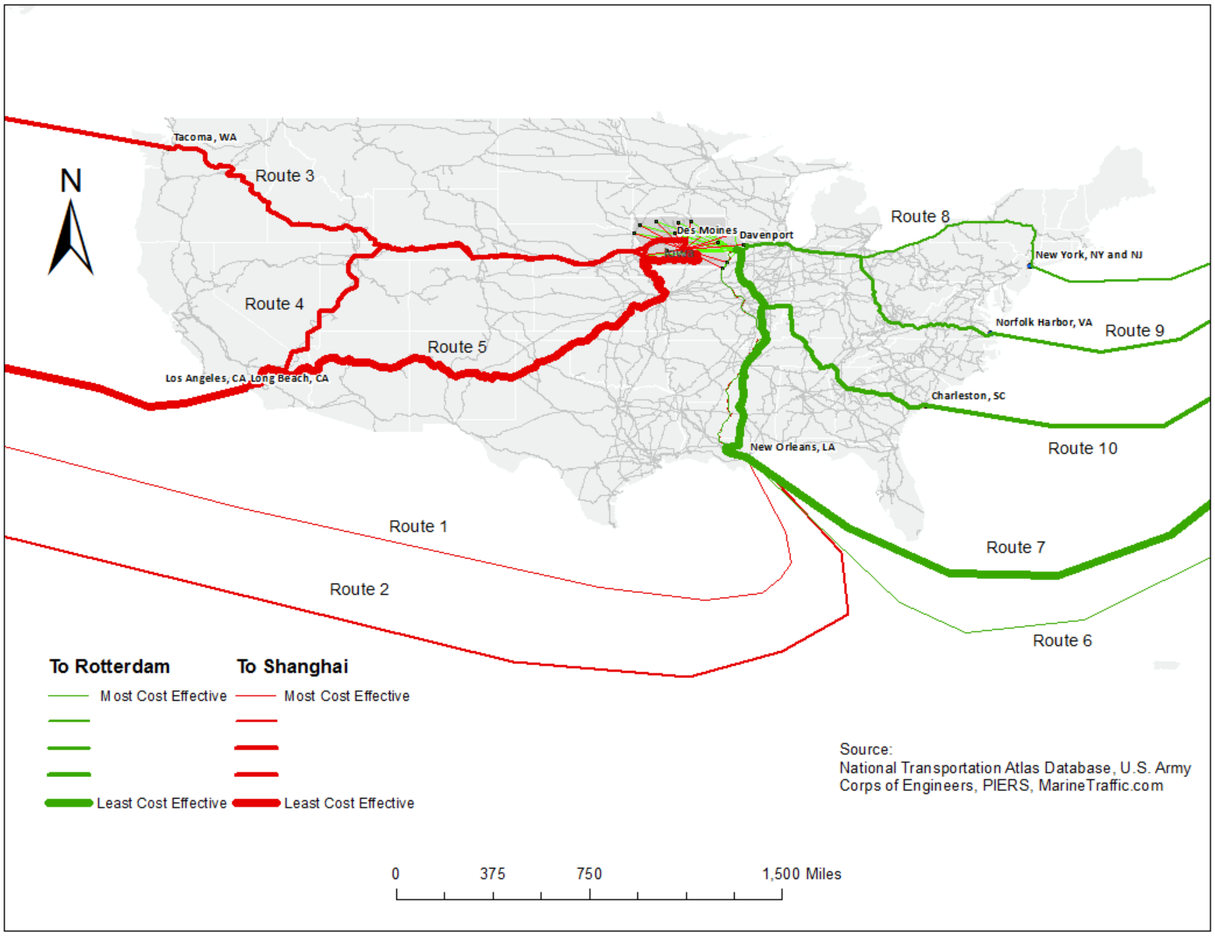


Figure 19 Visual Comparison of Route Transportation Cost of Selected Routes

5.3 Model Validation and Sensitivity Analysis

As we mentioned earlier, the actual freight rate that a carrier can offer is likely to be a contract-based intermodal rate with the domestic truck and/or rail legs included, and is contingent on route, volume, and time of year. Furthermore, the profit margins for transporting soybean on multiple modes of transportation are proprietary data, and it is difficult to obtain the exact total cost incurred by carriers between every origin-destination pair. The volatile modal rates are subject to multiple factors such as fuel price. Although fair comparison of our estimated transportation cost versus the actual rate that farmers/shippers pay is difficult, it is still possible to validate the cost analysis on mode level using the "best" available information to us. For example, we consulted New Jersey Shortline Railroad Association for the "sanity check" of our estimate on unit intermodal rail cost. The Public Waybill Sample from STB can be used to verify rail cost. Besides, we used Drewry coastal container rate data to verify the ocean shipping and intermodal costs. Table 6 shows the 2015 rates versus our estimated route cost for the Iowa to Shanghai example.

Table 6 Comparison between the LCMA Model Estimates and Drewry Data

	Min	Max	Year Average
Our Model Estimate: Iowa To Shanghai (excluding truck cost)	1,027 (Route 1)	2,023 (Route 5)	-
2015 Drewry Coastal Rate (20-foot container): U.S. Mid-West (Chicago) to Shanghai	1,360	1,640	1,460

Note: All number units are $/TEU

The U.S. Mid-West Chicago to Shanghai monthly rate is the closet data we obtained for validating our results. Min, max, and year average rates are listed. As there is no detailed information about the Drewry rates, we are not able to compare the route specific costs. Yet, the data from the U.S. Mid-West (Chicago) to Shanghai is used for a rough comparison with our intermodal costs (excluding local truck cost). The actual rates appear to fall within the range of our lowest and highest estimates.

Sensitivity Analysis on Train Speed

Operational train speeds could vary widely on different lines. We further conduct a sensitivity analysis on train speed to illustrate how this factor affects the total shipping time. This information helps shippers evaluate transportation time and cost when choosing transportation modes and ports of entry. In addition to using the average intermodal speed, we consider an extreme scenario in which the train speed is 60 mph on all track segments from Iowa to Shanghai (the first example). The results are shown in Figure 20. The ranking of multimodal routes based on total route time does not change even when train speed doubles. This is because ocean shipping time dominates the majority of the total shipping time on all the selected routes.

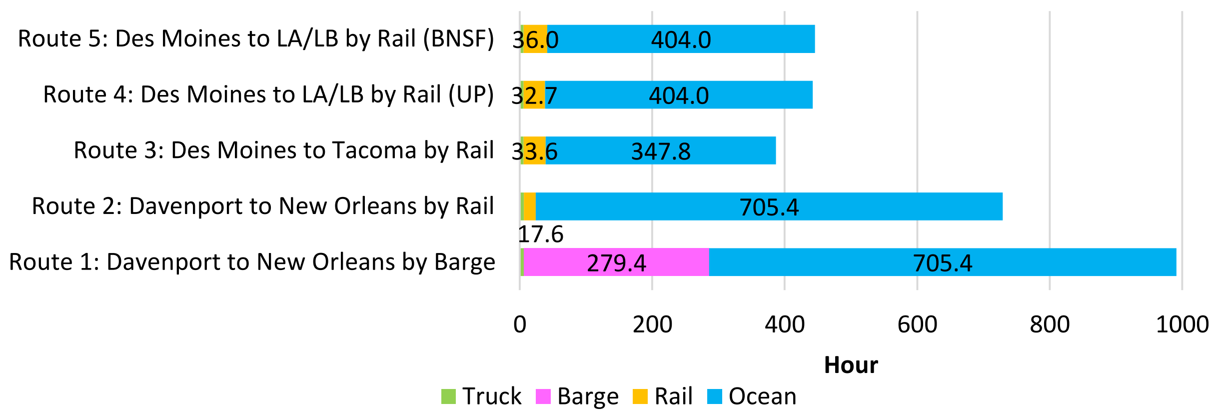


Figure 20 Breakdown of Total Route Time by Mode from Iowa to Shanghai (at Train Speed 60 mph)

5.4 Insights from the Analysis

The results of the LCMA allow for an effective visual and analytical comparison of the multiple routes available for shipping soybeans and other goods. In the particular case of Iowa-produced soybeans bound for Shanghai or Rotterdam, mode choice appears to play a significant role in costs, particularly in transportation from the intermediate intermodal facility to the port of exit.

Importance of Rail Transportation

Its world-class freight railroad system offers the U.S. a unique economic advantage over other countries when transporting large volumes of cargo over long distances. In our case studies, containers are moved on the rail leg over distances that can often exceed 2,000 miles. The transportation cost per TEU per mile on rail is generally lower than truck; hence, rail provides an economically competitive long haul of agricultural products to the port of exit. The railroad industry has a diverse pricing strategy to attract traffic demands from a variety of shippers. While the actual rate information is not available to us, we used the published cost calculation tool from STB to infer the variable cost of moving containers by rail. The actual rate is likely to be higher than our estimate. Despite this discrepancy, it is evident that on routes from Iowa to Shanghai or Rotterdam involving rail links, intermodal rail transportation accounts for a large portion of the total transportation cost. This result indicates that the use of rail may profoundly affect the total transportation cost. According to the Association of American Railroads, the American freight rail network capacity will reach its limit by 2035 with an 88 percent projected tonnage growth (Cambridge Systematics, 2007). In this case, both the future transportation cost and travel time would increase, resulting in shippers' switching to other cheaper transportation options such as barge. The close tie between the agricultural and railroad industries has long been recognized. The cost analysis model developed in this study further highlights the cost impacts of intermodal rail movement of soybeans within the United States.

Potential All-Waterway Shipment through New Orleans Port

When containers are shipped overseas through New Orleans Port via barge transportation along the Mississippi River, the total cost per TEU is the lowest. Currently, New Orleans Port primarily takes bulk traffic, though it has the potential to ship more containers due to its cost advantage. The premise is that its longer shipment time would be acceptable given the cost advantage. This might be reasonable under certain circumstances when the shippers/customers are less sensitive to the in-transit time of agriculture products like soybeans. Looking forward, the widening of the Panama Canal is expected to bring the volume through the Gulf Coast from 1.5 million TEUs to 3 million TEUs by 2028 (Port of New Orleans, 2016). The Port's 2020 Master Plan outlines a blueprint for growth with some permits already in place that can more than double the Port's current capacity up to 1.6 million TEUs with future phases. With these improvements, all-waterway containerized soybean transportation through New Orleans Port and the widened Panama Canal may emerge as a competitive alternative to the currently popular land-bridge services (sea-land intermodal) supported by the nationwide freight rail system. The future step of this cost analysis framework could be to account for anticipated future changes to inland and international waterway systems and future soybean traffic flows through different ports.

6 Freight Network Optimization

In this section, a freight network logistics optimization model, referred to as a Geospatial Intermodal Freight Transportation (GIFT) model, is developed to strategically optimize the national freight flow of containerized soybeans. The LCMA model described in the previous section provides a good overview of the transportation network and costs of containerized soybean exports. It entails essential inputs for the GIFT model which expands to incorporate freight tonnage and flows. The primary purpose of the GIFT model is to help determine the best possible scenario that the industry can possibly achieve with minimum system-wide transportation costs. It also provides useful insights into strategic planning and infrastructure investment so as to enhance the cost competitiveness of United States soybean exporters.

6.1 Model Formulation

The soybean transportation network is represented graphically $G=(V,A)$ with a set of nodes $v \in V$ and a set of directed links $a \in A$. The network contains three types of nodes: origin nodes $o \in O \subset V$ (farms/county elevators), intermediate nodes $i \in I \subset V$ (intermodal facilities and domestic ports), and destination nodes $d \in D \subset V$ (overseas ports). Soybean supplies in farms within a certain range (e.g., county level) are assumed to aggregate at the nearest, discretely located farm origin node. So each farm node $o \in O$ holds a quantity Q_o of soybeans (e.g., MT per year) that needs to be shipped to one or multiple overseas ports for exportation. Each overseas port $d \in D$ demands a minimum amount of soybean Q_d (e.g., MT per year). To ensure problem feasibility, the total supply in all farms $\sum_{o \in O} Q_o$ should be greater than or equal to the total demand in all overseas ports $\sum_{d \in D} Q_d$ so that demands can be met. Since not all soybeans produced are bound for export, this condition is not difficult to meet.

The network also consists of four types of links for the intermodal shipment of containerized soybeans: highway $a \in A_h \subset A$, railway $a \in A_r \subset A$, inland waterway $a \in A_w \subset A$, and ocean waterway $a \in A_{oc} \subset A$. In this problem, highway links primarily connect farms to the nearby railway or waterway intermodal facilities, where soybeans are containerized. These containers of soybeans are then transported to major United States ports via railway or inland waterway. Finally, ocean links (vessels) will be used to transport soybean containers from the United States domestic ports to destination countries (overseas ports). As the nodes are connected by the links, for each node $v \in V$, outbound and inbound links are defined by A_v^+ and A_v^-, respectively.

Decision variables $x_a, a \in A$ are used to denote the flow of containerized soybeans on each link. Each link $a \in A$ (of any mode type) has a known transportation distance t_a, $a \in A$, and a capacity c_a to accommodate soybean flow and background traffic b_a (i.e., non-soybean traffic). The background traffic is defined as the traffic flow of other passenger or freight users that share the same transportation link facility. A conversion factor λ_a is used to convert the containerized soybean flow (e.g., MT per year) into a measure of traffic capacity for each type of modal link. For example, with regard to highways, passenger car (pc) equivalent (e.g., pc per hour) is used to unify truck and pc traffic measures and maintain unit consistency between traffic flow and traffic capacity (HCM, 2010). The unit transportation costs (e.g., \$ per mile per MT) on highway, railway, inland waterway, and ocean links are denoted by C^h, C^r, C^w and C^{oc}, respectively. In practice, link cost, especially for railway, is not simply proportional to distance, so it should be obtained link-specifically when detailed data is available.

Transloading is another important component in the intermodal logistics of containerized soybeans. Defined as the switch of transport mode, transloading is assumed to occur at intermediate facilities and port nodes. The technique described in Nourbakhsh et al. (2016) was followed to model the associated handling cost between modes, which adds a set of transloading nodes ($V_{tr} \subset V$) with each connecting to a railway or waterway intermodal facility node by a virtual transshipment link. We consider six types of possible transloading virtual links: highway to rail (e.g., at rail terminals) $a \in A_{hr} \subset A$, highway to inland water (e.g., at inland ports) $a \in A_{hw} \subset A$, highway to ocean (e.g., at ocean ports) $a \in A_{ho} \subset A$, rail to inland water $a \in A_{rw} \subset A$, rail to ocean at ports $a \in A_{ro} \subset A$, and inland waterway to ocean $a \in A_{wo} \subset A$. Transloading through these virtual links incurs a specific handling cost C_a^{hr}, C_a^{hw}, C_a^{ho}, C_a^{rw}, C_a^{ro}, C_a^{wo}. The transloading cost is facility-specific and dependent on several factors, such as total throughput, capacity, congestion, and queuing delay, and could be already included in the intermodal rate in practice. In that case, the transloading cost can be modeled by adding it directly to the associated rail or water link cost without using the virtual link. Furthermore, since we look at a strategic level problem involving long-haul international ocean links, the impact of local highway congestion on total transportation cost is likely to be negligible. This factor could be incorporated in future research when further data about infrastructure capacity is available. Figure 21 illustrates the conceptual representation of the containerized soybean shipping network.

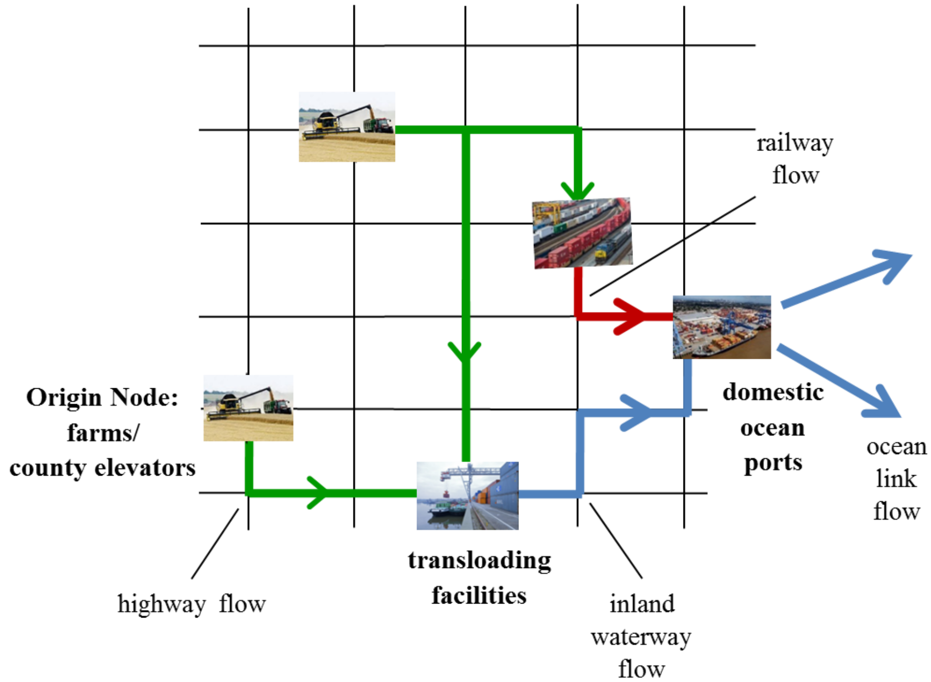


Figure 21 Conceptual Network Representation

The strategic flow optimization model is formulated as a linear program. The objective is to minimize the total system cost of transportation and transloading from all origin nodes to all destination ports, subject to a number of constraints. Constraints (2)-(4) ensure that soybean supply and demand are met, as well as flow conservation in all intermediate nodes. Constraint (5) stipulates that the amount of flow on each link (including the virtual links) does not exceed the remaining infrastructure (transportation link and intermodal facility) capacity. Constraint (6) is the non-negativity constraint required by the linear programming system.

$$\min_{\mathbf{x}} \underbrace{C^h \sum_{a \in A_h} x_a t_a + C^r \sum_{a \in A_r} x_a t_a + C^w \sum_{a \in A_w} x_a t_a + C^{oc} \sum_{a \in A_{oc}} x_a t_a}_{\text{Transportation cost for highway, railway, inland waterway, and ocean links}}$$

$$+ \underbrace{\sum_{a \in A_{hr}} x_a C_a^{hr} + \sum_{a \in A_{hw}} x_a C_a^{hw} + \sum_{a \in A_{ho}} x_a C_a^{ho} + \sum_{a \in A_{rw}} x_a C_a^{rw} + \sum_{a \in A_{ro}} x_a C_a^{ro} + \sum_{a \in A_{wo}} x_a C_a^{wo}}_{\text{Transloading cost}} \quad (1)$$

Subject to $\sum_{a \in A_v^+} x_a - \sum_{a \in A_v^-} x_a \le Q_o, \forall v = o \in O$ (2)

$$\sum_{a \in A_v^+} x_a - \sum_{a \in A_v^-} x_a = -Q_d, \forall v = d \in D \quad (3)$$

$$\sum_{a \in A_v^+} x_a - \sum_{a \in A_v^-} x_a = 0, \forall v \in V \setminus \{O \cup D\} \quad (4)$$

$$\lambda x_a + b_a \le c_a, \forall a \in A \quad (5)$$

$$x_a \ge 0, \forall a \in A \quad (6)$$

In summary, the model optimizes the containerized soybean supply chain to achieve the least system cost, by strategically (i) selecting the supply regions for containerized soybean export, (ii) matching the destination ports, and (iii) determining the intermodal routes and container flow on these routes in between each origin-destination pair.

6.2 Model Inputs

The mathematical model is applied to a case study that encompasses the best data available to us. The top 28 soybean production counties were selected as county level soybean origin nodes from four regions of the United States. These include 10 counties from the Upper Midwest states of Iowa, North Dakota, and South Dakota; 9 counties from the Central Midwest states of Illinois and Ohio; 7 counties from the Mississippi River Delta states of Arkansas, Mississippi and Missouri; and lastly 2 counties from the Mid-Atlantic state of Delaware. Besides those counties with very high production rates, most notably in the Upper Midwest and Illinois, the remaining counties were chosen to balance the model geographically. Ohio and Delaware are much closer to major ports (specifically New York and Norfolk) than the other counties, so these locations may potentially have higher economic efficiency. Those counties along the Mississippi River may be competitive since soybeans can be shipped to New Orleans via inland waterway, where unit costs are lower than in other modes. Note that a limited number of soybean production counties are included in the case study, mainly for the purpose of illustrating our model application. A larger selection of production counties and finer resolution of shipment origins (e.g., farm level) may yield different model results, but a similar flow pattern or conclusion may still hold. When adding production counties, the model can be adapted to generate additional routes for consideration.

Production and demand input data for each origin node and destination node was obtained from several databases, mainly the USDA county level soybean production data and 2015 PIERS soybean export data. Production data for the top 28 counties in the form of annual county level soybean production is listed in Table 7 below. From 2015 PIERS data, 5 billion pounds of United States soybeans are exported in containers from four major ports: Los Angeles/Long Beach, Tacoma, Norfolk, and New York. These four ports account for 90% of the total export volume. The major destination countries are Indonesia, Taiwan, Thailand, Vietnam, Japan, China, and Malaysia. The annual total demand data forms the base demand input for the GIFT model, as shown in Table 8. For these destination countries, nine major destination ports are chosen, 3 of which are in China (one each in northern, eastern, and southern China).

Table 7 GIFT Model Input: County Level Production

County	State	Production (BU)	Production (Metric Ton)
BROWN	SD	14,256,000	7128
SPINK	SD	12,900,000	6450
CASS	ND	20,011,000	10005.5
STUTSMAN	ND	15,782,000	7891
BARNES	ND	13,846,000	6923
RICHLAND	ND	12,300,000	6150
LA MOURE	ND	11,900,000	5950
PLYMOUTH	IA	11,155,000	5577.5
POTTAWATTAMIE	IA	10,216,000	5108
KOSSUTH	IA	10,081,000	5040.5
MCLEAN	IL	18,603,000	9301.5
CHAMPAIGN	IL	16,284,000	8142
LIVINGSTON	IL	16,249,000	8124.5
IROQUOIS	IL	15,563,000	7781.5
LA SALLE	IL	14,545,000	7272.5
VERMILION	IL	13,280,000	6640
DARKE	OH	8,303,000	4151.5
WOOD	OH	8,040,000	4020
VAN WERT	OH	7,462,000	3731
SUSSEX	DE	4,397,000	2198.5
KENT	DE	3,090,000	1545
MISSISSIPPI	AR	15,430,000	7715
DESHA	AR	10,000,000	5000
PHILLIPS	AR	12,748,000	6374
WASHINGTON	MS	15,110,000	7555
BOLIVAR	MS	15,000,000	7500
SUNFLOWER	MS	12,820,000	6410
NEW MADRID	MO	10,249,000	5124.5

Table 8 GIFT Model Input: Total Demand in Destination Countries/Regions in MT

	Indonesia	**Japan**	**Malaysia**	**China**	**Taiwan**	**Thailand**	**Vietnam**	**Total**
LA/LB	343,638	111,435	25,617	112,379	318,213	36,906	139,051	1,087,240
New York	214,772	2,759	44,976	15,763	17,924	64,932	17,791	378,917
Norfolk	128,103	17,946	62,762	44,558	57,985	126,528	30,061	467,942
Tacoma	2,652	32,213	1,852	3,966	83,833	3,826	12,520	140,862
Total Demand	689,165	164,352	135,208	176,667 North 34,783 East 57,217 South 75,218	477,955	232,192	199,423	2,074,962

Furthermore, 10 intermodal facility locations (major hub cities and inland ports) are considered in the case study. Figure 22 shows geographically the soybean origin counties, domestic ports, and intermodal facility locations in the case study network. Note that the port of New Orleans is also included in the analysis, even though it is not currently a major port for soybean container shipping. Considering its advantageous location and significant role in soybean export logistics, it could be a promising port for containerized soybean export in future.

With regard to the transportation network, 66 highway links, 50 rail links, 4 inland waterway links, and 35 ocean links (port pairs) are extracted from the national freight network, based on NTAD, BTS, NDC databases, PC*Miler|Rail, and NETPAS software, as well as multiple online sources for verifying ocean link distances. The data used for unit or link specific transportation cost is the same as that used in the LCMA model.

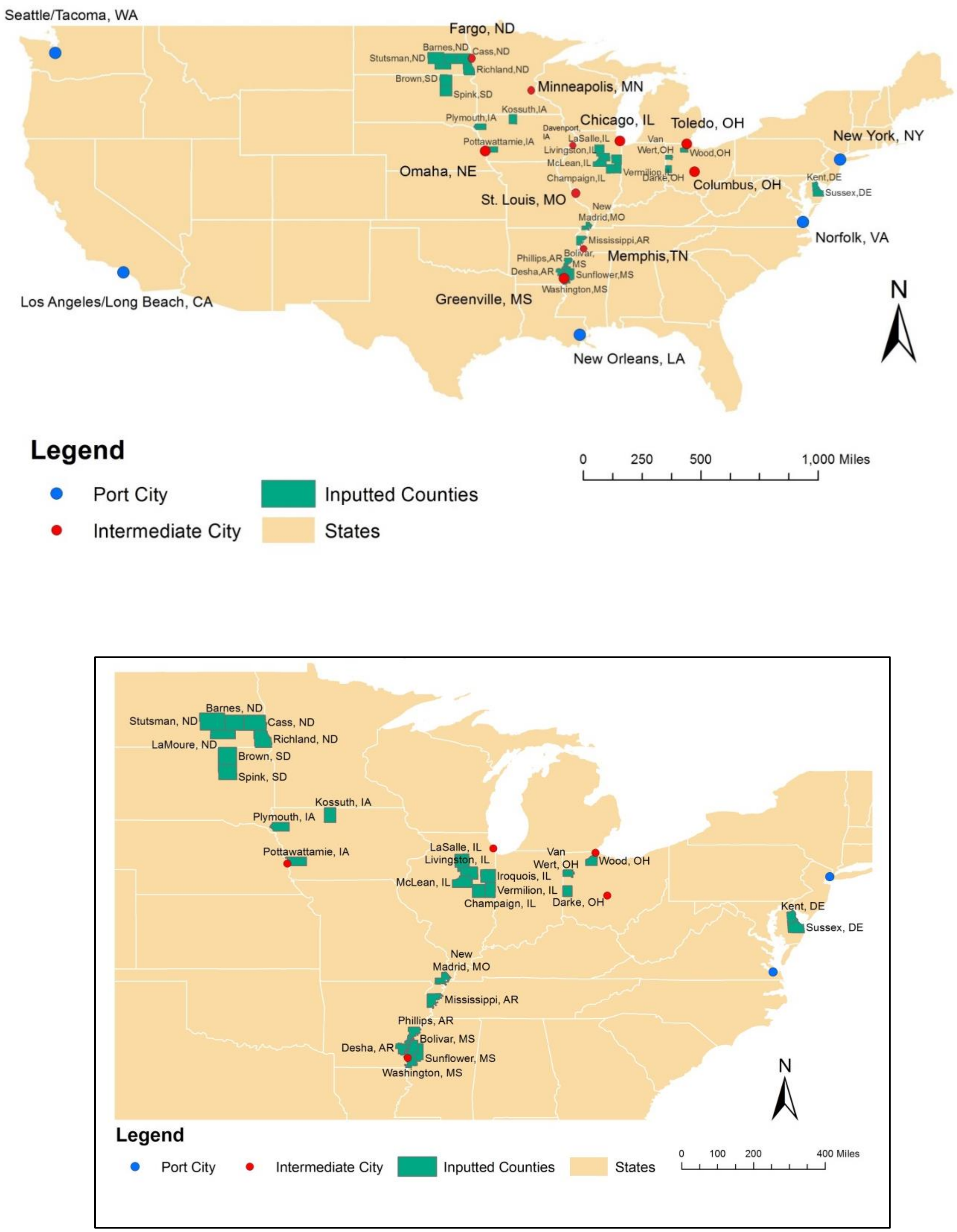


Figure 22 GIFT Model Input: Production Counties, Intermodal Cities, and Domestic Ports

6.3 Model Implementation and Output

The modeling system for mathematical programming and optimization, GAMS software, is utilized to implement the proposed GIFT model formulation and solve for optimal results given the inputted network and parameters. Thus, we apply the model to a numerical case study at national scale. In the case study, Constraint (5) is not enforced, as the infrastructure capacity and background freight flow data on all links and intermodal facilities is not readily available, and collecting the data requires significant research efforts. Considering that the ocean rates fluctuate and surcharges vary across ports, two ocean shipping rate scenarios were used in the case study. The first scenario considers relatively low rates and does not assume any additional surcharges (such as duty, tax, and other origin or destination port charges), while the second scenario considers high rates and assumes surcharges. These results are visualized using GIS mapping software. Note that since the total demand for containerized soybeans is much lower than the total supply, the model selects only a subset of the production counties for export in these results. Also, as our case study includes only 28 production counties nation-wide for simplicity, the results only show the optimal soybean flow for these (potential) leading exporters, and do not reflect the entire picture of national soybean export flow.

Scenario 1: Low Ocean Rates without Surcharges

Scenario 1 extracts port-to-port ocean rate data from WorldFreightRates.com. These figures represent relatively low rates and do not include surcharges such as duty, tax and other origin or destination port charges. As Figure 23 shows, when ocean shipping rates are low, it becomes optimal to export via the Port of New Orleans. In this scenario, soybean supply is centered around the Mississippi River Delta counties and transported via barge to New Orleans. Although the distance of ocean travel is longer from New Orleans to Asia relative to western ports, lower ocean rates make it cheaper than transporting the soybeans from the Midwest and Upper Midwest by rail to the West Coast. The results additionally generated export flow from production counties in Delaware and Ohio via truck and rail to the Ports of New York and Norfolk. Given the low ocean rates, the model minimizes rail transport because it is significantly more expensive under this scenario.

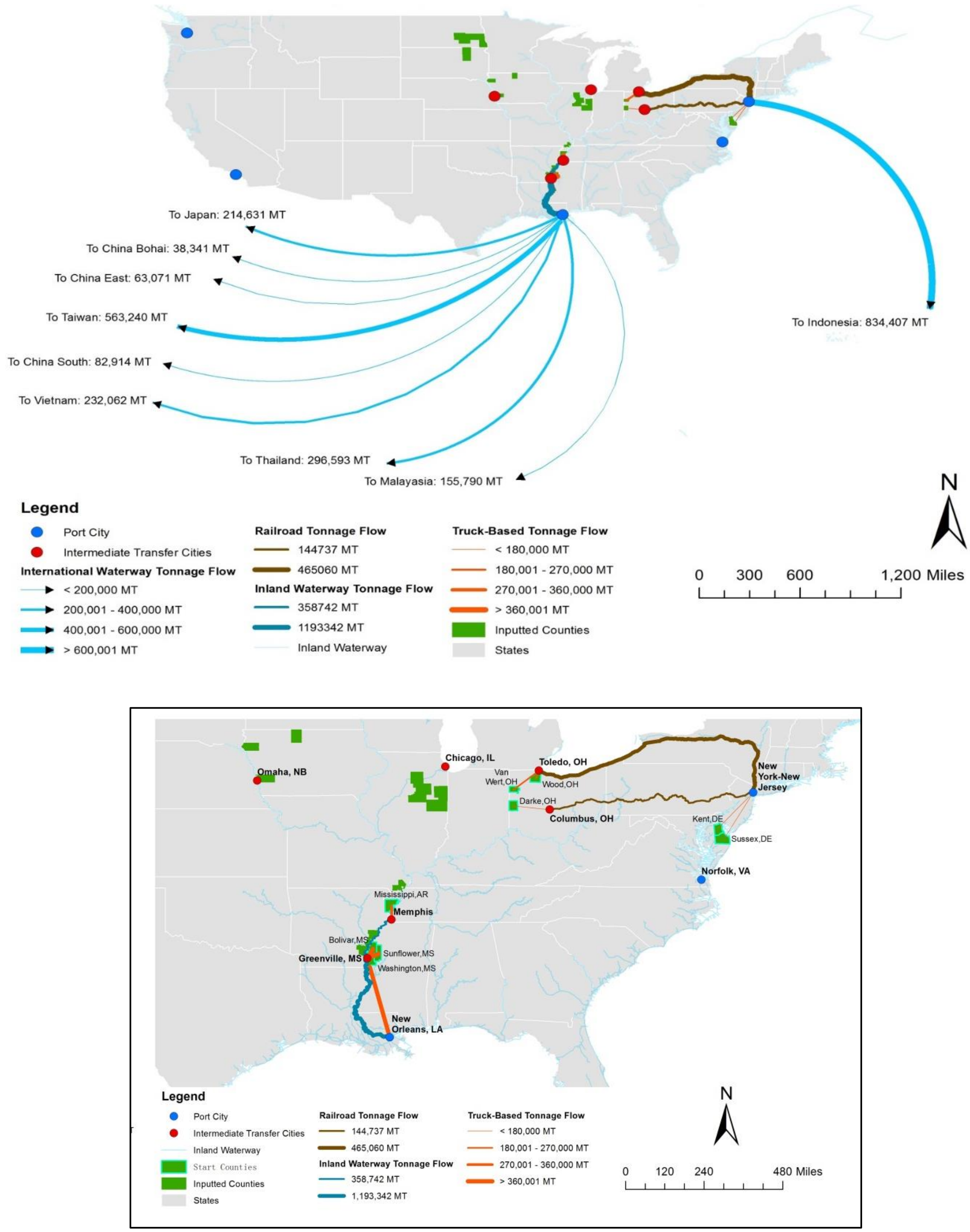
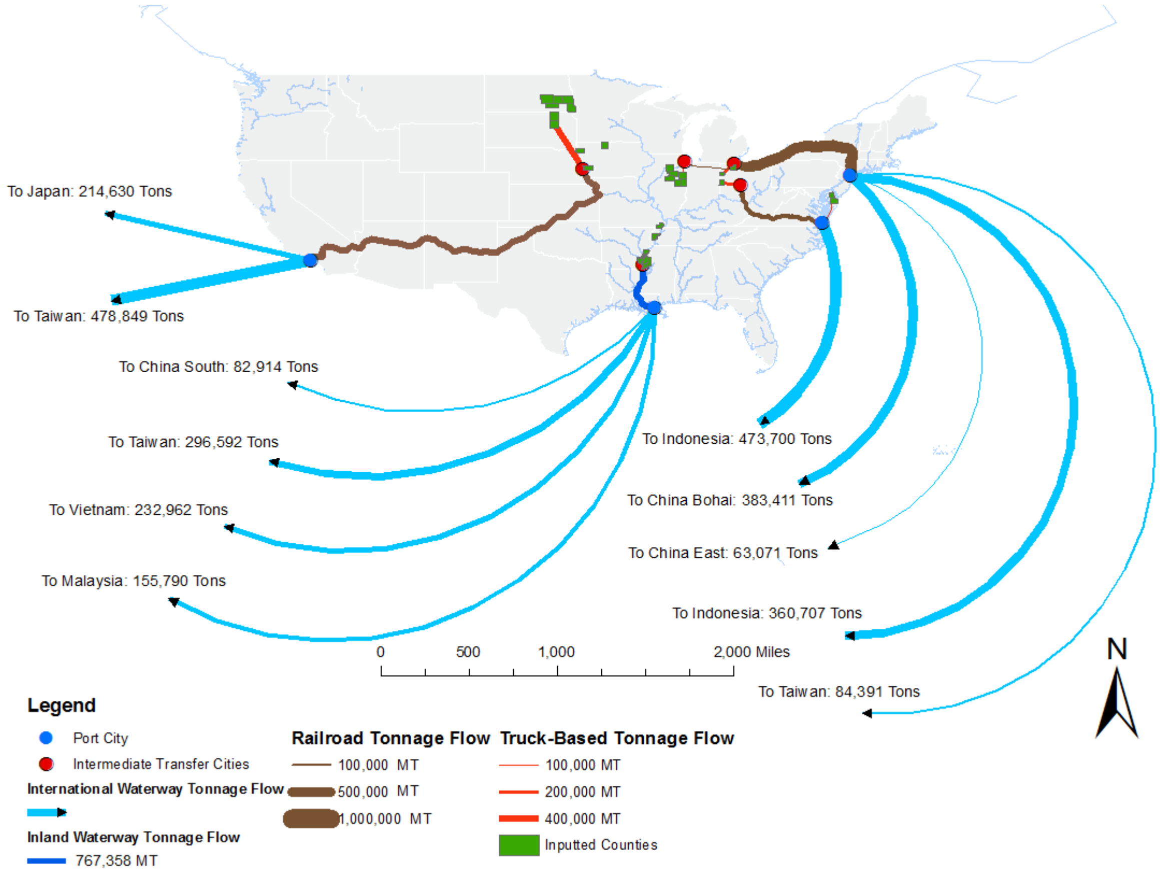


Figure 23 Scenario 1 Model Results with Low Ocean Rates

Scenario 2: High Ocean Rates with Surcharges

Scenario 2 considers port-to-port ocean rate data from SeaRates.com. These figures represent relatively high rates given the inclusion of origin and destination port fees and terminal handling charges. Unlike in Scenario 1, the results in Scenario 2 show optimal soybean flow to be more dispersed across the United States production counties and ports-of-exit (Figure 24). As previously stated, soybean production is optimal in the Mid-Atlantic, Midwest, Upper Midwest, and Mississippi River Delta regions. Those soybeans produced in the Upper Midwest are transported by rail to the Port of Los Angeles/Long Beach. The model does not, however, generate any exports bound for the Pacific Northwest. This discrepancy is likely attributed to higher port charges/tariffs at the Pacific Northwest ports, compared to the charges at the Port of Los Angeles/Long Beach. However, given the widening of the Panama Canal, it may become even more optimal to further utilize the Gulf and East Coast ports for soybean exportation, which also depends on the fluctuation of rail rates and how the widening of the Canal affects ocean rates. However, the GIFT model could easily include the new rates to generate revised optimal results. The results of the optimization are thus sensitive to the inputted cost data, especially when the differences of route costs are not significant.



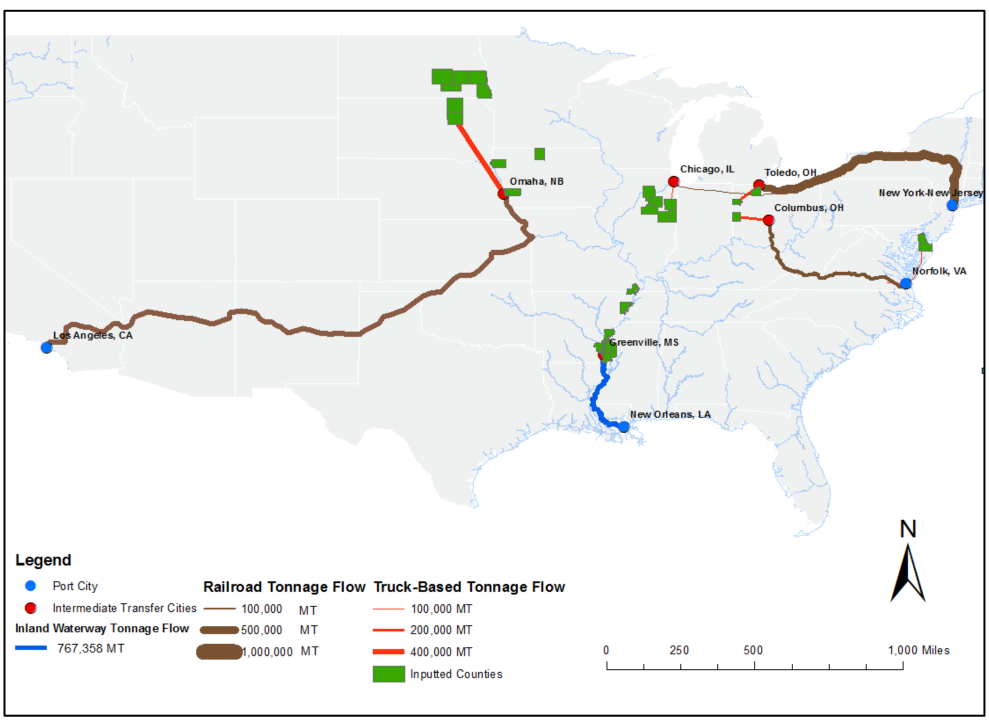


Figure 24 Scenario 2 Model Results with High Ocean Rates

6.4 Insights from the Analysis

In this section, the resultant "optimal" traffic flow distribution based on the optimization model from previous sections is compared with the actual flow based on 2015 PIERS data (Table 9). The modeling accounts for a sample of only 28 counties; as a result, the comparison of absolute traffic volume is infeasible. Instead, we compare the percentage distribution of containerized soybean traffic by the port of exit. The four major ports for containerized soybean export comprise over 90% of all containerized exports in the nation. The model results are sensitive to ocean rates.

Table 9 Comparison of Actual Port Throughput to GIFT Model Results

Port of Exit	2015 Actual Throughput	Scenario 1 (low ocean rates)	Scenario 2 (high ocean rates)
LA/LB	52%	0%	25%
New York	18%	34%	32%
Norfolk	23%	0%	17%
Tacoma	7%	0%	0%
New Orleans	0%	66%	27%

The 2015 actual throughput shown in Table 9 suggests that the LA/LB Port accounted for over half of all containerized soybean exports. However, our model results indicate no more than a quarter of all Asian-bound exports should optimally be routed through the LA/LB Port under both high and low ocean rate scenarios. By comparison, the model selects New Orleans Port for a much higher proportion of soybean exports in both scenarios. The results imply that, if cost is the only concern, most containerized soybeans should use inexpensive barge transport through the Mississippi River system and exit the Gulf Coast via New Orleans Port, despite the fact that it would require longer ocean travel. This finding coincides with our result from the LCMA analysis of the cost of shipping from Iowa to Shanghai and Rotterdam. The second scenario is relatively closer to the current status quo, which indicates that ocean shipping rates are a critical factor affecting the optimal flow pattern under the current infrastructure.

A limiting factor of our analysis is the omission of infrastructure conditions and capacity bottlenecks, including export elevators, locks, and dams on inland waterway, ports, and connecting highways and their existing utilization for the movement of other goods. According to Informa Economics (2011), aging infrastructure such as deteriorating road surfaces, river locks, and dams impede the efficiency of agriculture transportation through Gulf Ports.

The preliminary optimization model can be extended to account for additional factors (e.g., infrastructure capacity, various business requirements) if more data becomes available. For example, in addition to cost, there might be other considerations when determining the optimal traffic flow distribution such as shipping and handling time. Finally, the emerging changes to transportation infrastructure (e.g., the widening of the Panama Canal) or to the economy (e.g., the varying price of fuel) may alter the optimal routing results. The generalized transportation optimization framework can be adapted to address these factors based on the available data. The optimization model is advantageous in terms of identifying the optimal practices among numerous possible combinations of decisions (e.g., routing). In future research, the optimization model can be packaged into a GIS-based decision-support tool that enables an expedited comparison and prioritization of various infrastructure investment strategies to improve the economic competitiveness of soybean logistics.

7 Discussion

This study, and its potential subsequent follow-up studies, can be used to devise informed infrastructure investment strategies or to develop strategic planning and management strategies. This section discusses some important elements related to this study. Some of these discussion points are beyond the scope of this research but could be explored in future efforts.

Transportation Cost and Infrastructure Capacity

Maintaining low transportation costs and high reliability is important for U.S. competitiveness. According to our cost analysis, shipping by barge via New Orleans Port is the lowest cost route for shippers in Iowa, and probably for many other areas in the Midwest and along the Mississippi River corridor as well. However, the utilization of low-cost barge transportation for containerized soybeans is currently limited. New Orleans Port takes most of the bulk soybean exports but has limited capacity for container operations. The expanding Panama Canal allows for larger vessels and is projected to further bring down ocean shipping costs. Infrastructure investment in the Mississippi River and New Orleans Port facilities has a high potential to generate significant reductions in transportation costs, thereby increasing the competitiveness of U.S. soybean transportation with global competitors.

The fluctuations in ocean shipping cost, delay, and additional storage needs caused by transportation infrastructure bottlenecks can undermine service reliability and increase cost, making it challenging for U.S. shippers to make optimal decisions in the highly dynamic global market. Due to data limitations, this research does not account for either infrastructure capacity (e.g., port and land congestion) or the handling capacity of port or intermodal facilities. For container transportation, the delay caused by congestion in one leg may cause cascading delays to its subsequent sectors, thereby increasing transportation cost and time. One future direction of this work is to incorporate infrastructure capacity into the analysis.

Equipment Availability and Coordination

The repositioning and use of empty containers have long been critical issues for intermodal transportation. Presumably, a more efficient use of empty containers can reduce the deadweight movement, therefore reducing cost. For example, BNSF Railway, a major freight railroad company in North America, believes that match-backs are important for driving U.S. exports to overseas markets, especially in Asia. Opportunities for the utilization of match-backs exist at inland rail hubs across the country, and those opportunities will multiply as U.S. exports increase (Mongelluzzo, 2013).

The seasonality and variability of agricultural production creates a transactional need for equipment, marked by slow months when exports are low, followed by a surge in equipment needs in the fall. The importation of many consumer items, by contrast, tends to generate a steady flow of inbound equipment. Business models need to be established that utilize the available advanced information sharing and equipment-tracking technologies among stakeholders electronically. Coordination among multiple logistics entities at different spatial locations is challenging. Advanced modeling research is necessary to optimize the supply chain at the operational level to incorporate the option of container repositioning and to minimize the total cost.

In addition, balancing inbound and outbound demand for different sizes of containers is another challenge. According to Clott et al. (2014), demand for the importation of 20-foot containers is relatively lower than that for 40-foot containers in the interior of the U.S., while the latter faces limitations to move in most U.S. roads due to truck size and weight restrictions. For this reason, 20-foot containers, though do not fully utilize economy of scale, are preferable for shipping soybeans as compared to 40-foot containers. Furthermore, coordinating wheeled chassis repositioning is another critical issue that often impedes the efficiency of container operations.

Strategic Planning and Decision-Making for Supply Chain and Infrastructure Enhancement

Infrastructure conditions and capacity are essential for accommodating the growing demand for container shipments. Improving infrastructure is one of the most promising strategies to keep the United States on the competitive frontier of soybean exportation. Improved infrastructure can reduce transportation cost, especially for moving large volumes of cargo over long-haul distances on rail and inland waterway sectors. The current cost analysis can be adapted to account for potential infrastructure changes.

Besides expanding existing infrastructure or building new infrastructure, the optimal use of existing infrastructure is also an important strategy. This optimal use requires strategic planning to properly balance supply and demand and optimally allocate traffic flows over multiple modes of transport across multiple stakeholders. Instead of making small-scale, localized, and incremental changes, long-term, systematic transportation planning on a regional or national scale may achieve a more significant net benefit given limited resources.

Our preliminary modeling is an initial step toward a larger-scale exploration of system-wide decision making for the optimization of soybean export logistics. While the preliminary results are constrained by data availability, the analytical procedure and methodological framework can be adapted to address a broader set of questions regarding the identification, evaluation, comparison, and prioritization of improvement strategies that can minimize total logistics cost, thereby making U.S. exports more competitive in the face of emerging competition with other nations.

8 Conclusions and Future Research

This research develops a methodological framework and detailed calculation procedure for estimating the total transportation cost for soybean container exports in the United States. The cost estimates can be used to further evaluate the impact of prospective changes in freight industry both nationally and globally. Ultimately, subsequent studies can recommend strategies for prioritizing and optimizing investment in the U.S. transportation infrastructure and logistics system to further improve the country's economic competitiveness in global soybean markets.

For researchers, this research can serve as a long-term reference to aid in the understanding of transportation costs in various transportation sectors (rail, barge, roadway, ocean shipping), and support various other research efforts related to agricultural transportation and logistics. For practitioners, the cost-analysis methodology and GIS-based routing are currently implemented into a computer-aided decision support tool that can automate route selection, cost calculation, route cost comparison, and visualization. The geospatial intermodal freight transportation (GIFT) model can be expanded to optimally distribute containerized soybean traffic through multimodal transportation networks. The model minimizes total transportation cost while meeting demand. In future development, decision makers can use the adapted model to identify the optimal set of strategies to best improve the economic competitiveness of soybean exports in the United States.

Despite the versatility of the LCMA and GIFT models, our analysis does have its limitations. Many details in the transportation and handling processes are omitted to simplify the problem. For example:

- The LCMA analysis does not yet take into account the value of time applied to the supply chain. The results for both Shanghai- and Rotterdam-bound soybeans indicate a strong preference for shipment via barge through New Orleans. However, this doubles the time of the journey, which may affect the quality (and ultimately the monetary value) of the shipment. This possible decrease in quality during the prolonged lead-time is not yet reflected in the model.
- We do not take into consideration factors of port capacity, congestion, container availability, and match-backs, or their related cost. Congestion and capacity issues on the remaining portions of the transportation network, including rail, are largely disregarded due to their complexity and the limitation of available data.
- On the other hand, while such factors may impede the viability of the United States soybean market, the anticipated opening of the newly widened Panama Canal will likely benefit many aspects of the soybean supply chain. How to incorporate these factors and the changing infrastructure environment are interesting topics left for future research.
- Furthermore, the URCS from the STB only calculates variable railroad costs under certain circumstances. Future research can be developed to account for the total cost of the rail sector or actual charges. In addition, future research may account for a lump-sum bundled rate for rail and ocean intermodal transportation, based on specific contract types and market circumstances.

For future research, the cost information can unfold a series of new research opportunities with respect to the optimal design and operation of agricultural transportation and logistics systems in the United States. The current LCMA framework can be further developed and built into an economic model to analyze the cost differential between a specific United States port and the next least-cost alternative to serve the inland locations. For example, the area in dark green in the figure below denotes the region where Oakland is the lowest cost port gateway for North Asia supply chains. The cost differential is zero, meaning it has an outright cost advantage in serving these markets. This is Oakland's Primary Market area for this trade lane. The areas in the lighter green shades denote Oakland's Secondary Market area for this trade lane. The yellow area is where Oakland is even less competitive and the red regions indicate that it is not able to compete on a cost basis (Figure 25). Ultimately, based on the cost analysis between any origin-destination pairs, the LCMA framework can be extended to show the economically advantageous market region for each shipping point in the United States.

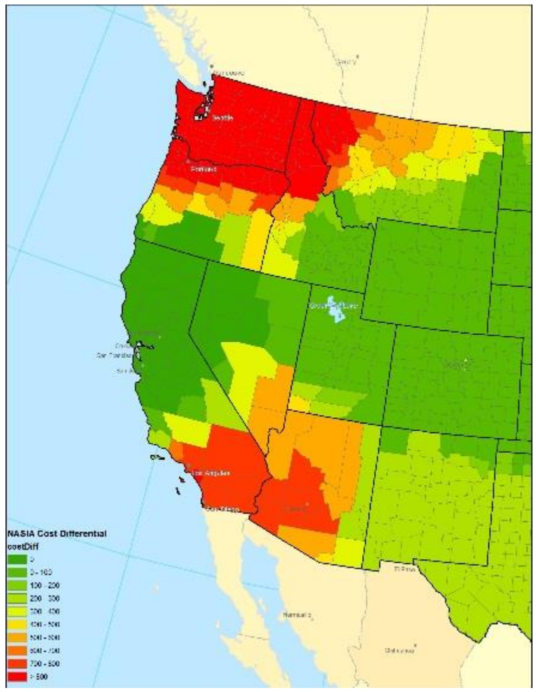


Figure 25 Application Example of an Extended LCMA Framework

In terms of transportation network optimization, the GIFT model can be further developed in several respects. First, the handling and storage costs may be taken into account to better reflect actual operational characteristics. Second, link and nodal congestion can be incorporated. Transportation and handling costs might be a nonlinear function of traffic volume instead of the constant or linear function assumed in the current study. Third, the optimization model can be modified to account for empty container issues, such as where to reposition the empty containers, to further reduce transportation cost.

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