Transportation Cost Modeling of Containerized Soybean Exports in the United States

Yun Bai, Xiang Liu, Christian Higgins, YuPo Chiu, and Jihong Chen

Intermodal container transportation is a growing market for soybean exports in the United States. In an effort to understand the optimal strategies for improving the United States' economic competitiveness in this emerging market, this research developed a detailed, multimodal transportation cost analysis model focusing on U.S. soybean container shipments. By using mode-specific transportation network and cost information, the model estimated and compared the "point-to-point" supply chain costs of alternative shipment routes from a domestic production site to a foreign port. For each candidate route, the analysis estimated the transportation time, distance, and cost of each modal segment. This cost analysis model is a building block for a larger research effort that aims to develop strategies to improve freight transportation infrastructure and operations in the context of existing and potential changes in the transportation industry and global market.

The United States is a leading producer and a major exporter of soybeans. A large portion of soybean exports is shipped in bulk, but there is a rising trend toward using intermodal containers to transport soybeans, especially for export. Although container transportation currently has a relatively small share of total U.S. soybean transport, it is a growing niche market that is attracting interest from government and industry sectors (*1*).

Container shipping has several advantages, such as value-added service and traceability (*2, 3*). For U.S. soybean transportation in particular, a significant driver of the recent growing trend toward containerization is the ability to identify a shipment consistently while in transit. Soybeans produced in the United States now have a reputation for both quality and traceability, making them particularly attractive to foreign buyers (*4*).

Although the prospects for U.S. agricultural exports are bright, thanks to relatively high productivity and reputation for quality, there is increasing competition from other producing countries, such as Brazil, in the global market. During the 1990s, the United States accounted for almost 70% of all soybean exports. In 2013, however, Brazil surpassed the United States as the leading global exporter, with a market share of almost 50% (*5*). U.S. exporters are keenly interested in finding the optimal pathway for U.S. agricultural exports and in assessing 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 costs is a stepping-stone toward making optimal decisions to improve the United States' economic competitiveness in exporting soybeans. This is a challenging undertaking; containerized soybeans move internationally by multiple modes of transport (truck, rail, barge, container ship), each of which has its own cost structure and estimation method. In addition, there are many possible routes from a point of origin in the United States to a destination in a foreign nation.

To keep the United States on the competitive frontier for containerized soybean exports, the U.S. Department of Agriculture (USDA) supported a study at Rutgers University to develop a freight cost model to quantitatively assess the total cost of transportation across multiple modes. Unlike past efforts, which focused largely on soybean bulk transportation, this research targets the emerging, important container transportation market. Built on an integrated analysis of transportation-mode-specific cost structures and up-to-date data, this research provides a step-by-step calculation tool by which analysts may estimate the transportation cost from the origin to the destination port for soybean container exports. This research can also be used to evaluate the transportation costs, performance, and bottlenecks of other agricultural products, aiding in setting priorities for future investment in the economic competitiveness of U.S. agricultural exports.

LITERATURE REVIEW AND RESEARCH OBJECTIVES

Literature

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 production centered primarily in the Americas, transportation plays a crucial role in the decisions associated with importing and exporting soybeans. Many aspects of the soybean and agricultural commodity transportation decision making process have been considered. To make an effective transportation plan for soybeans, as well as for other exported crops, it is important to focus on supply chain logistics. Reis and Leal built deterministic models regarding the planning of the soybean supply chain to aid with temporal and spatial decisions (*6*). DaSilva and D'Agosto developed a model to estimate origin–destination (O-D) matrices

Y. Bai, C. Higgins, and Y. P. Chiu, Center for Advanced Infrastructure and Transportation, and X. Liu, Department of Civil and Environmental Engineering, Rutgers University, Piscataway, NJ 08854. J. Chen, College of Transport and Communications, Shanghai Maritime University, Shanghai 201306, China. Corresponding author: Y. Bai, yunbai.cait@rutgers.edu.

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for soybean export (*7*). The model involves transportation from production fields to the processing warehouse and then to the port of exit. Shen and Wang developed binary logit and regression models to study cereal grain movement by truck and rail transportation throughout the United States (*8*). Danao et al. developed a probe to monitor environmental conditions and logistics information during transportation (*9*). Through this, soybean quality is assured, but transportation costs are increased. Lee et al. provided a method to monitor the occurrence of genetically modified soybeans in cultivated fields and along transportation routes (*10*). They used a statistical method to monitor and detect outliers during the process. These models analyze commodity transportation within the United States. This paper proposes a model that also includes international shipping costs, which is a significant part of container movement along different routes.

Clott et al. are among the very few who studied containerized soybean supply chain network optimization modeling with a focus on container repositioning (*1*). However, they did not focus on intermodal cost structure. The U.S. Grain Council and U.S. Wheat Associates investigated the quality and condition of soybeans originating in Illinois and bound for Southern and Eastern Asia (*11*). They concluded that shipping in containers, as opposed to shipping in bulk, was better for maintaining higher levels of quality. Vachal provides more timely insights into market trends and opportunities for marketing grain and oil seeds internationally via containers through analysis of rail and port container traffic activities (*4*). Such research is particularly concerned with the quality of transportation rather than its costs.

HighQuest Partners LLC and Soyatech LLC analyzed key opportunities and challenges facing U.S. exports, particularly with regard to ingredients used in the animal feed industry (*12*). Providing an individual analysis for each of many agricultural commodities, including grains and soybeans, the authors focus on topics such as trade issues, demand, and transportation. Salin and Somwaru quantitatively examined the decline in demand for U.S. soybeans, citing the need for improved farm-to-port transportation infrastructure (*5*). This proposed model builds on this research by assessing the transportation costs associated with such links, expanding to include links to international markets, and recommending how to reduce the costs of such links.

Keith provided an assessment of the U.S. freight railroad system and its ability to handle current and future commodities demand (*13*). Wetzstein et al. investigated the supply-and-demand dynamics of agricultural commodity barge transportation and also produced spatial forecasts of barge rates along the Mississippi River, a major corridor for agricultural commodity transport (*14*). Such work attempts to look at the U.S. agricultural commodity export economy by focusing on the key form of transportation in the supply chain. Friend and Lima focused on the national policy aspect, analyzing the strength and competitiveness of U.S. and Brazilian soybean production according to the countries' different transportation policies (*15*).

Knowledge Gaps

Although soybean transportation research has received growing attention in recent years, several fundamental questions are yet to be addressed. First, a large majority of studies have focused on estimating transportation cost on a single transportation mode, either nationally or on an the international leg. To the researchers' knowledge, no published study has concentrated on total cost analysis across multiple modes, especially for containers, from any production site in the United States to the destination port in a foreign country. A lack of this "point-to-point" cost analysis impedes the evaluation of possible policy and operational changes to the logistics of transporting soybeans originating from the United States. Second, although past research efforts concentrated on bulk transport, this research addresses the growing container shipment market for agricultural transportation on an international scale.

Research Objective and Scope

Building on an understanding of the literature and knowledge gaps, the researchers developed a modeling framework specific to containerized agricultural commodities, with a focus on soybeans. Specifically, this work sought to accomplish the following research objectives:

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

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

OVERVIEW OF SOYBEAN TRANSPORTATION IN THE UNITED STATES

The United States is the world's largest producer, and a major global exporter, of soybeans (*16*). According to the USDA, the largest soybean-producing states include Illinois, Iowa, Indiana, Minnesota, and Nebraska, accounting for 49% of soybean production (2015 data) in the United States (*17*). For total soybean traffic (domestic and export combined) within the United States, barge and rail transport similar amounts of soybean tonnage; trucks transport between two and three times more (Figure 1*a*). For exported soybeans, long-haul barge and rail are preferred (Figure 1*b*).

Figure 2 lists the top destinations of U.S. soybean exports. China receives 57% of exported bulk soybeans, followed by Mexico, Japan, Germany, and Indonesia. The major destination countries for containerized soybeans are Indonesia, Taiwan, Thailand, Vietnam, Japan, China, and Malaysia.

Figure 3 shows an overview of the U.S. soybean production areas and major U.S. port regions for soybean export [data are from the USDA, the U.S. Army Corps of Engineers, and the Port Import–Export Reporting Service (PIERS) database]. Five U.S. ports—Los Angeles and Long Beach, California; Tacoma, Washington; Norfolk, Virginia; and New York—account for 90% of the total export vol-

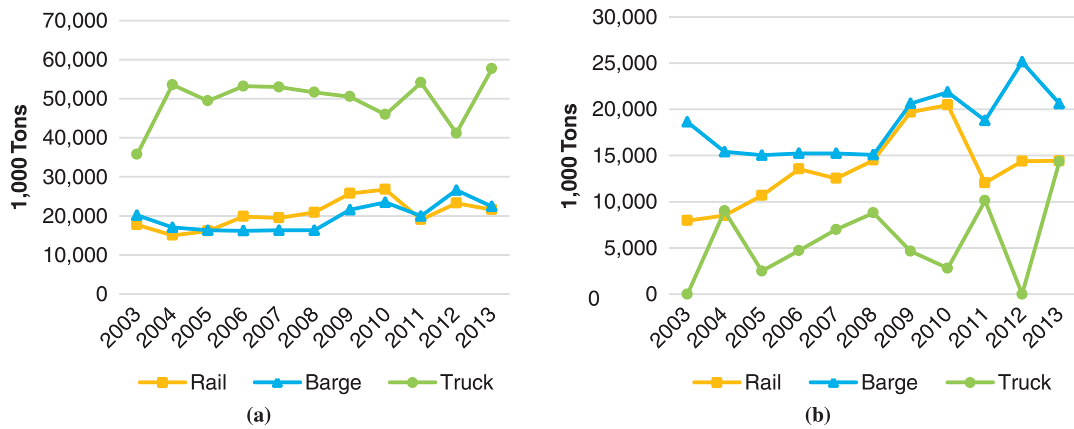


FIGURE 1 Tonnage of soybeans transported in the United States, 2003–2013: (*a*) total and (*b*) export only. (Source: USDA National Agricultural Service, National Transportation Atlas Database, U.S. Army Corps of Engineers, PIERS.)

ume (*18*). Bulk and containerized soybean shipment patterns vary noticeably across the different U.S. ports. For bulk shipments, the Gulf of Mexico ports of exit had more than 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 presents an unusual pattern, shipping 69% of bulk exports but only 0.1% of containerized exports. This is primarily because of a lack of the infrastructure needed to transfer grains and other similar commodities into export-bound containers (*19*). Given the recent expansion of the Panama Canal, however, if the needed investments are realized, New Orleans may see a significant shift in market share of containerized exports. The trends in soybean import and export transportation are significantly influenced by the costs that are analyzed in the section on multimodal transportation cost analysis, which follows.

MULTIMODAL TRANSPORTATION COST ANALYSIS

The global transportation of containerized soybeans requires the integration of multiple modes of transportation from the origin to the destination. Each transportation sector (rail, barge, and truck) has its own operational structure and cost estimation method. Most earlier research focused on a single-mode-specific cost analysis; the supply chain cost analysis for international soybean transportation, especially through containers, has not been adequately studied. From a soybean producer's or shipper's perspective, there are multiple routing and modal options for shipping a container of soybeans abroad. These decisions on route and mode rely on transportation network data and cost data from various data sources. To evaluate the transportation cost competitiveness of U.S. containerized soybean exports, researchers developed a modeling framework to

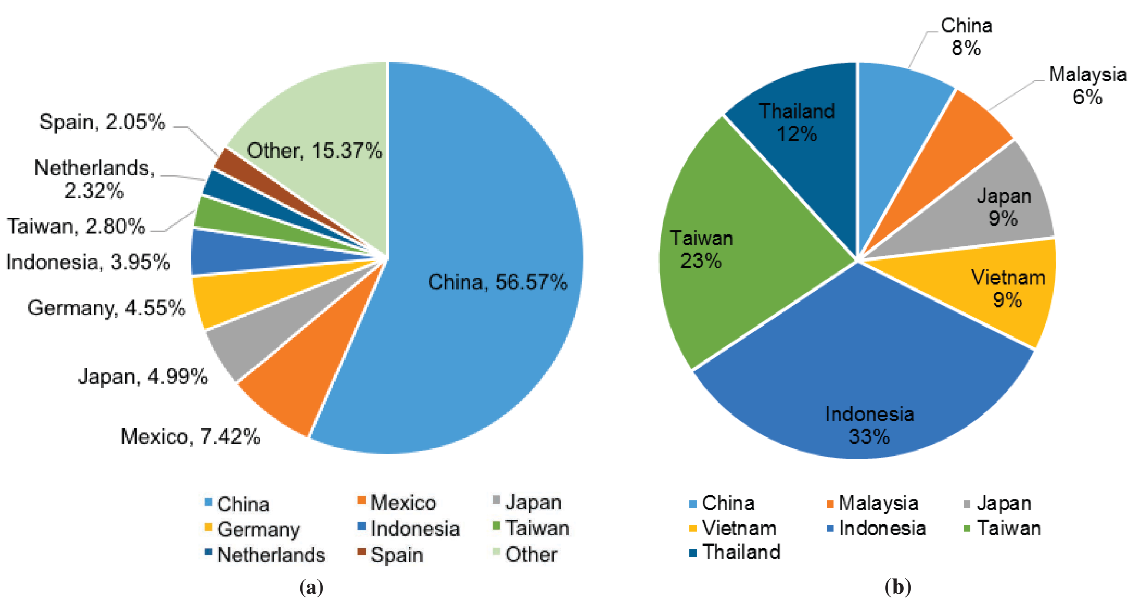


FIGURE 2 Composition of 2015 United States (a) bulk and (b) containerized soybean export destination.

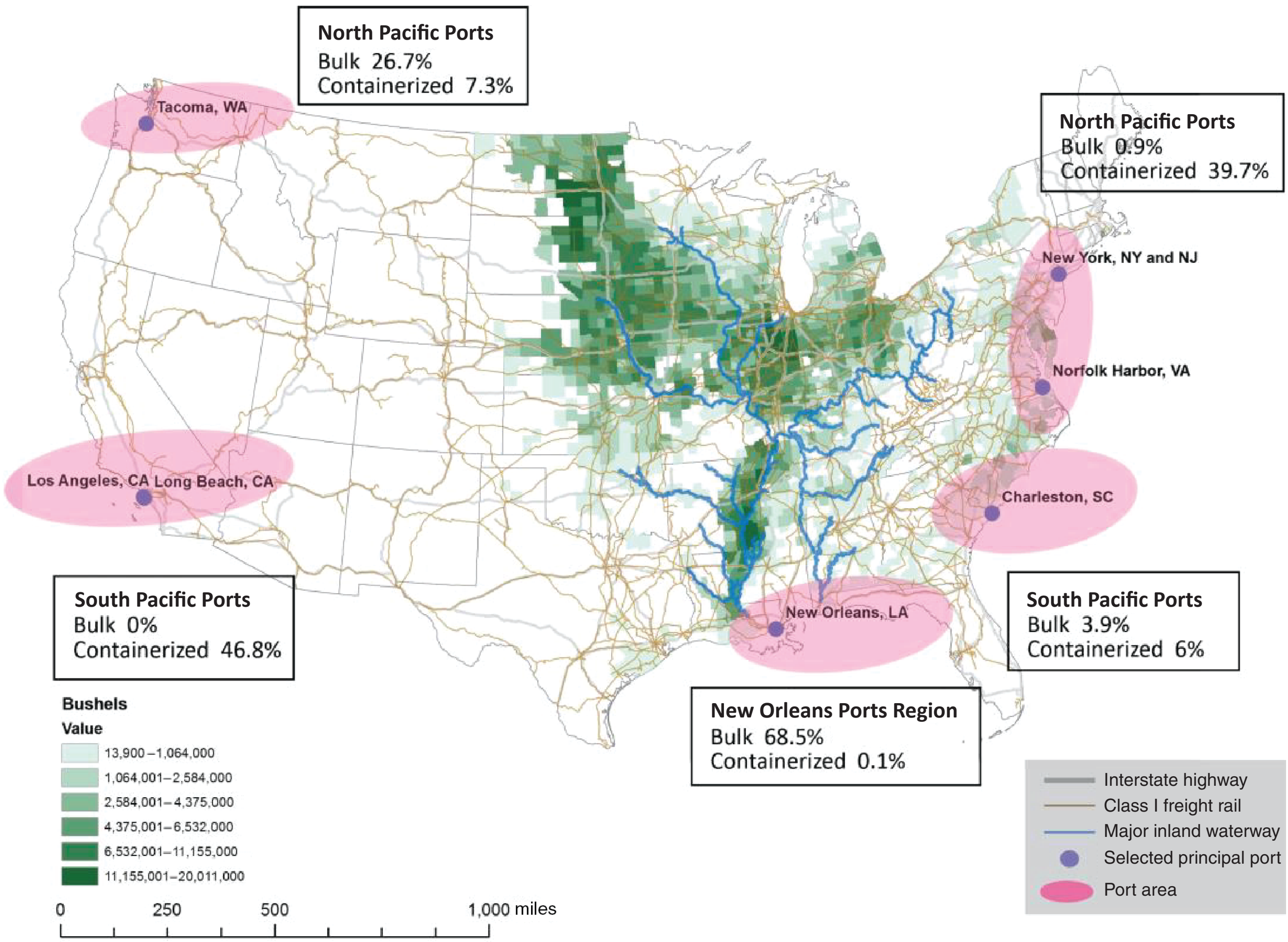


FIGURE 3 Soybean production and major port regions for soybean exports. (Source: USDA National Agricultural Service, National Transportation Atlas Database, U.S. Army Corps of Engineers, PIERS.)

identify the least-cost transportation options (route, port, and mode of transportation) to serve the hinterland market.

Methodology

To estimate the intermodal cost of containerized soybean shipment, a general approach from the producer's perspective was followed and is described below:

1. Identify the supply chain for containerized soybean export: 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.

There are numerous soybean production sites at the county level. It is extremely laborious and impractical, however, to enumerate all O-D pairs from each county-level production point to the destination point. To reasonably approximate the soybean traffic flow pattern, researchers assumed a hub-and-spoke type of distribution network to consider the origin segment of the soybean supply chain. The county-level traffic was aggregated to one of the nearby intermodal freight facilities (i.e., end-of-line terminals) that collect the local soybean supply as the point of origin. Then soybean products are shipped by truck to one of the next major "hub" facilities (e.g., rail or barge terminals, inland ports) along the routes for containerization and transloading. (In practice, the actual container-loading location may vary depending on the availability of empty containers in local facilities. Although container matchbacks—putting cargo into containers that would otherwise travel back to a destination empty—are attracting interest in the belief that they save cost and improve efficiency, matchback coordination is complex and beyond the scope of this study.) As such, soybean container movements are divided into three legs, including a short haul by truck from aggregated intermodal facilities to larger transloading facilities, a long haul from the transloading facility to exit ports via rail or barge, and ocean shipping to destination ports. Because the intent is to look at global soybean transportation on a strategic level, local transportation to the final destination points is omitted for simplicity.

Figure 4 is a decomposed diagram for the model framework and calculation process. In practice, the actual freight rate is likely to be a contract-based intermodal rate combining domestic rail and

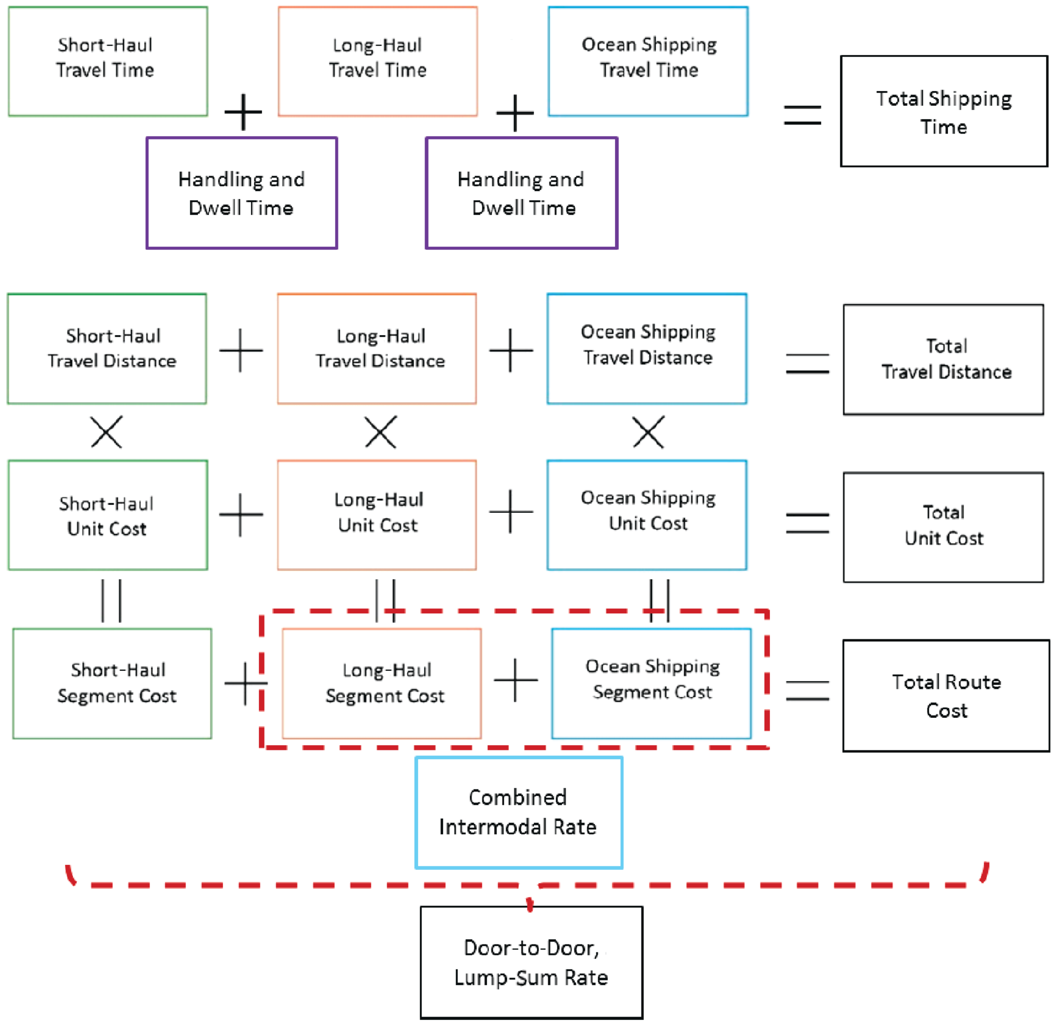


FIGURE 4 Cost modeling framework.

international ocean shipping. Many carriers also began 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 the unit distance cost. In addition, some other general assumptions and criteria were followed when determining domestic routes: (*a*) the cost of waterway transportation is always the most competitive, so a waterway has higher priority when determining a route; (*b*) within 150 miles, highway transport is cost competitive; (*c*) once the shipping distance exceeds 300 miles, rail is cost competitive.

Data Sources

The USDA National Agriculture Service Database provides soybean production and distribution data. Soybean traffic data by mode were taken from the USDA Agricultural Marketing Service database (AMS). Three databases, including AMS, the International Trade Center, and PIERS, were used to depict the soybean market landscape and the tracing of soybeans from field to market. The National Transportation Atlas Database, the U.S. Army Corps of Engineers, and the Bureau of Transportation Statistics provided transportation network and intermodal facility data. For truck and barge transportation, the USDA AMS data sets, Grain Transportation Report and Grain Truck and Ocean Rate Advisory, were used. To analyze rail moves, the Public Use Waybill of the U.S. Department of Transportation (U.S. DOT) Surface Transportation Board (STB) was used. Firsthand data for ocean moves are difficult to obtain because they are proprietary contract data. As a result, this research relies on data from multiple online resources for a cross-check so that the cost values are within reasonable ranges. A full description of the data sources is provided in Table 1.

Transportation Network and Intermodal Facilities

On the basis of the data described in Table 1, Figure 5 shows the U.S. transportation network and intermodal facilities. The points represent the major transshipment and intermodal transloading facilities and principal ports. Excluding air-based intermodal facilities (which are not relevant to the transportation of soybeans), truck–rail, truck–port, rail–port and truck–rail–port facilities are shown.

TABLE 1 Data Sources

Data Type	Description	Database or Source
Network and Modal Data		
Highway and railway network Intermodal facility	Roadway and railway GIS network data	NTAD, BTS
Domestic waterway network	Waterway and maritime port GIS data	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 Reports
Rail routes	U.S. railway routes and mileages	PC * MILER–Rail software
Commodity Flow		
Commodity flow	Freight analysis framework (FAF) Commodity flow survey (CFS) Regional or state-level commodity movement	BTS and FHWA BTS U.S. Army Corps of Engineers, NDC
Rail freight flow	Rail freight waybill by commodity type	PUWB, STB
Grain transportation	Modal share analysis Grain shipment data Soybean export origin and destination	Modal Share Analysis Report, USDA AMS Grain Transportation Report data sets, USDA AMS PIERS database
Soybean Production and International Trade		
Soybean production	Soybean production by county level 2015	USDA Quick Stats
Trade, import and export	Soybean export volume (bulk and container) International trade statistics 2001–2015 Grain inspections for export by port region U.S. import and export tariff and trade data by commodity	PIERS Database International Trade Center USDA AMS U.S. International Trade Commission
Cost		
Oil price	Oil price	OilPrice.com
Highway cost	Truck rate	Gain Transportation Report, GTOR, USDA AMS
Barge cost	Barge rate	
Railway cost	Tariff rail rate Rail revenue sample by commodity and region Class I railroads variable cost (route- and volume-specific)	 Public Waybill Sample, STB URCS Phase 3 Railroad Cost Program, STB
Ocean shipping cost	Port-to-port container rate Coastal container rate	SeaRates.com WorldFreightRates.com iContainers.com Drewry container reports

NOTE: GIS = geographic information system, NTAD = National Transportation Atlas Database, BTS = Bureau of Transportation Statistics, NDC = Navigation Data Center, GTOR = Grain Truck and Ocean Rate Advisory, PUWB = public use waybill, STB = Surface Transportation Board, AMS = Agricultural Marketing Service, PIERS = Port Import–Export Reporting Service, URCS = Uniform Rail Costing System.

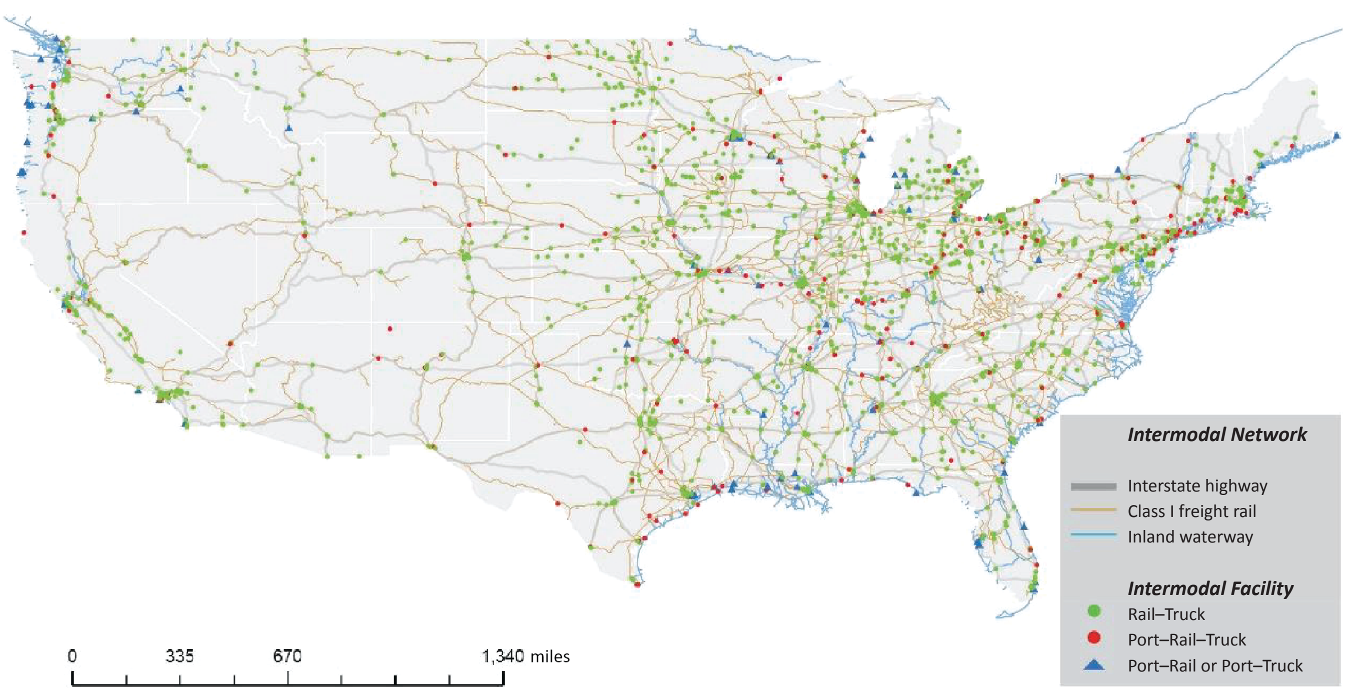


FIGURE 5 U.S. freight transportation network. (Source: National Transportation Atlas database, U.S. Army Corps of Engineers, Bureau of Transportation Statistics.)

NUMERICAL CASE STUDIES

The proposed methodology was applied to a numerical example to estimate the container shipping cost for soybean producers in Iowa. The purpose of the numerical example was to provide a step-by-step analytical procedure for comparing route-specific costs. Different soybean shipping routes were generated on the basis of current shipping routes and the general assumptions on possible future routes stated above. For each route, the unit transportation cost per ton-mile, travel distance, and travel time were used to develop total route costs. The approach can be applied to any route. Given the high demand from China, the Shanghai port was selected for this research, as Iowa to Shanghai is a representative route between the United States and China. Rotterdam, in the Netherlands, was chosen as an additional destination to represent East Coast route options to Europe.

Example 1. Iowa to Shanghai, China

In this section, shipping routes paired with corresponding origins and destinations were delineated from the cities of Davenport and Des Moines, Iowa, to the port of Shanghai, China. Travel distances were compiled and calculated, along with travel time and travel cost for each segment, and then aggregated for each possible shipping route (Figure 6).

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

Route 1. Davenport to Shanghai via New Orleans, Louisiana—long haul by barge;

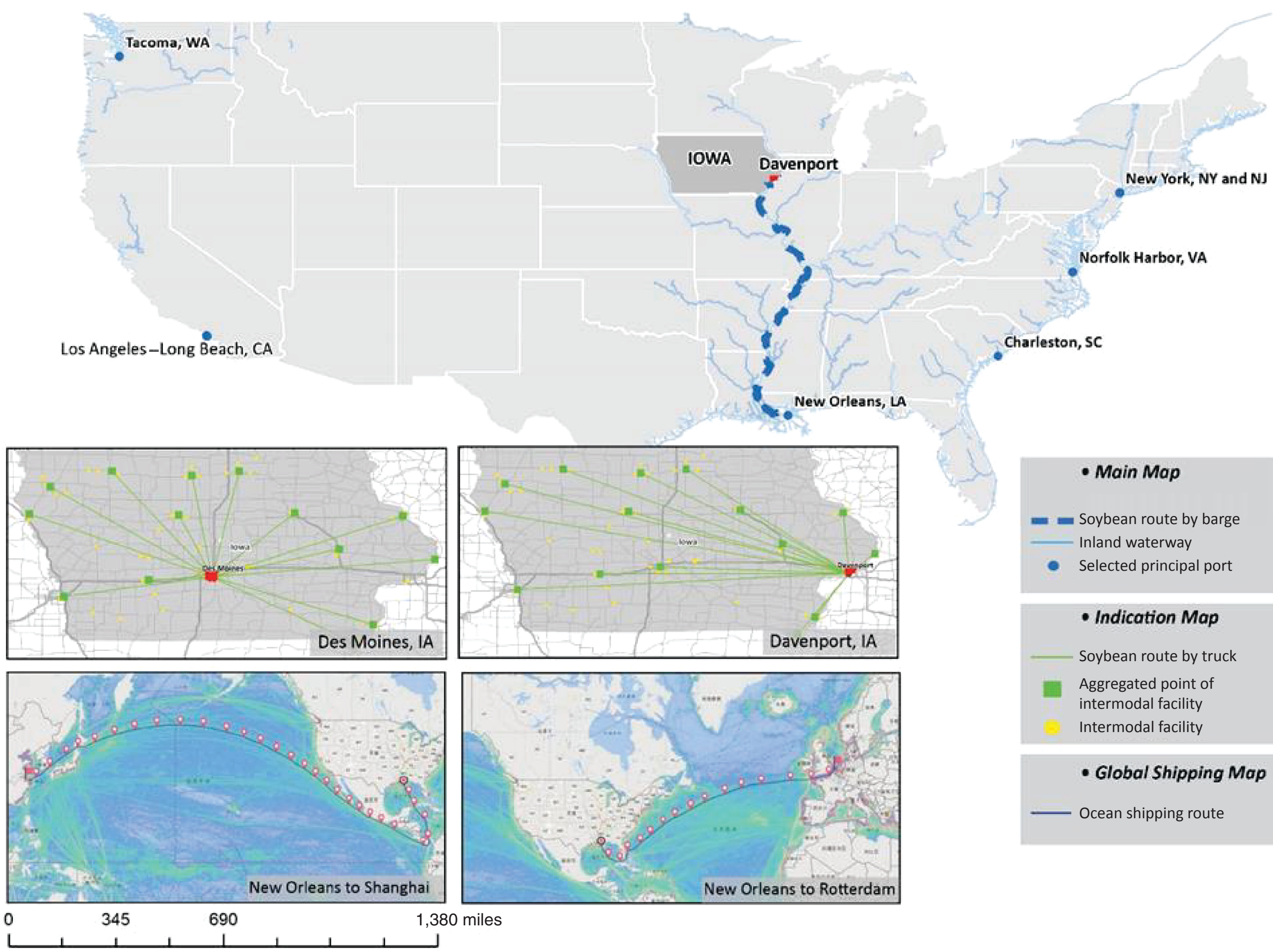
Route 2. Davenport to Shanghai via New Orleans—long haul by rail;

Route 3. Des Moines to Shanghai via Tacoma, Washington—long haul by rail;

Route 4. Des Moines to Shanghai via the ports of Los Angeles and Long Beach—long haul by rail [Union Pacific Railroad (UP)]; and

Route 5. Des Moines to Shanghai via the ports of Los Angeles and Long Beach—long haul by rail (BNSF Railway).

Route 1 and Route 2 indicate the itinerary from Davenport through New Orleans to Shanghai or Rotterdam via barge or rail,



(a)

FIGURE 6 Soybean transportation routes from Iowa to Shanghai, long haul: (*a*) by barge. (Source: National Transportation Atlas database, U.S. Army Corps of Engineers, PIERS, MarineTraffic.com.)

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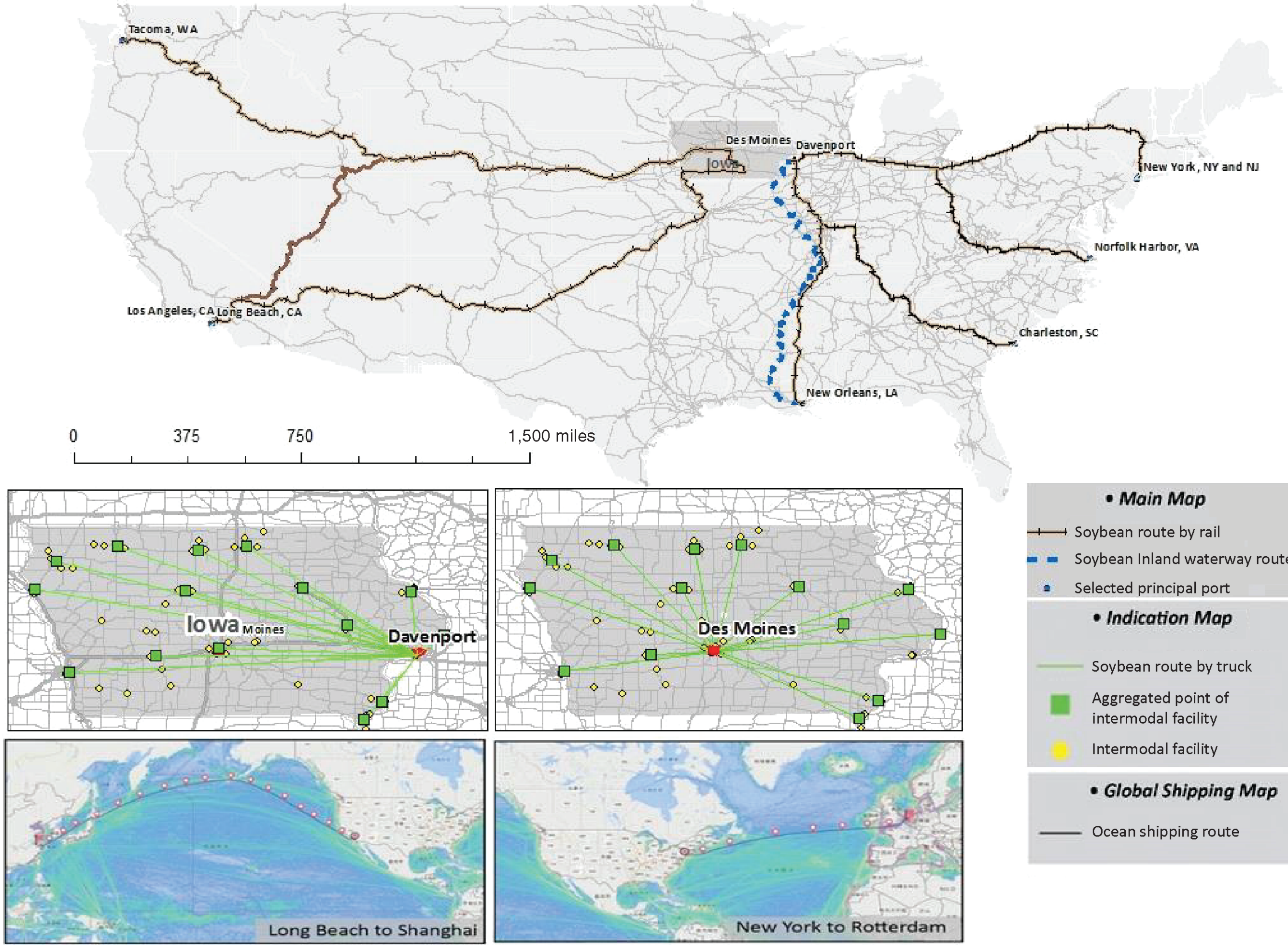

(b)

FIGURE 6 *(continued)* **Soybean transportation routes from Iowa to Shanghai, long haul: (*b*) by rail. (Source: National Transportation Atlas database, U.S. Army Corps of Engineers, PIERS, MarineTraffic.com.)**

respectively. Routes 3, 4, and 5 indicate the itinerary from Des Moines to Shanghai through Tacoma or the ports of Los Angeles and Long Beach, specifically via rail. Routes 4 and 5 were considered because multiple rail routes are available from Des Moines to Los Angeles and Long Beach, mainly a northern route via the Union Pacific Railroad through Salt Lake City, Utah, and a southern route via BNSF Railway through Kansas City, Kansas. The latter route is slightly longer, but it has a higher freight volume according to FHWA data (*20*). The unit costs by transportation mode and a calculation worktable are shown in Tables 2, 3, 4, 5, and 6, followed by detailed explanations of individual calculation procedures and assumed parameters.

Table 7, Figure 7*a*, and Figure 7*b* summarize the route comparison results for all modes combined, in terms of total distance, time, and cost, on the basis of 2015 data. For simplicity, 20-ft containers [20-ft equivalent unit (TEU)] are considered, each of which holds about 17.24 metric tons (633 bushels) of soybeans (*1*); total route costs per TEU are given below. From Iowa to Shanghai, the least-cost route will be from Davenport to New Orleans by barge, then from New Orleans to Shanghai via international ocean transportation. The point-to-point travel distance is 12,887 mi, with total transportation time of around 41 days. The cost would be around $75 per metric ton, or $1,289 per TEU (in 2015 U.S. dollars). 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 on Route 1 than does rail transport on the other four routes. Although this modeling does not account for any particular time constraints, such restrictions may impact the outputted optimal route.

Example 2. Iowa to Rotterdam, the Netherlands

In the second example, the same methodology was applied to estimate five different routes from Iowa to Rotterdam (Figure 6). The purpose is also to compare the transportation cost competitiveness in different markets—that is, between the United States to Asia and the United States to Europe routes. These five routes were

Route 6. Davenport to Rotterdam via New Orleans—long haul by barge;

Route 7. Davenport to Rotterdam via New Orleans—long haul by rail;

TABLE 2 Soybean Transportation Cost Work Table, Iowa to Shanghai: Route 1—Davenport to Shanghai via Port of New Orleans Port, Long Haul by Barge

	Distance (mi)	Time (h)	Unit Cost ($/MT-mi)
Intermodal facility to Davenport by truck	192[a]	6.4[b]	0.081600[c]
Davenport to New Orleans port by barge	1,330	279.4[d]	0.018204[e]
New Orleans port to destination port by ocean shipping	11,364[f]	705.4[g]	0.003110[h]
Total	12,887	991.2	0.005801

[a]Average distance from multiple aggregated points of intermodal facilities to Davenport by truck.
[b]Travel distance divided by 57.2 mph plus 3-h delay assumed for truck loading time; 57.2 mph is assumed as the average speed for truck driving (*21*).
[c]Data extracted from (*22*). Rate per mile in North Central Region is applied and assumed to haul 1 mi (more than 100 mi but less than 200 mi), assuming 25 MT per a truck, i.e., $1.98 per mi/25 MT = $0.079200 per MT-mi.
[d]Travel distance divided by 5 knots (5.75 mph) plus 48-h delay assumed for barge loading time; 5 knots average speed is assumed for barge movement (*23*).
[e]Data extracted from (*24*). Rate $24.22 per MT is applied, i.e., $24.22 per MT/1,330 mi = $ 0.018204 per MT-mi.
[f]Distance from export ports in United States to destination ports (e.g., Shanghai or Rotterdam), from Netpas software.
[g]Travel distance divided by speed (14 knots, the average speed for ocean shipping). Port handing and delay time are not considered here because of the large variation in reality. Furthermore, it does not affect the relative comparison among different routes because all routes go through a port.
[h]Data extracted from WorldFreightRates.com on June 30, 2016. Rate of $35.35 per MT from New Orleans port to Shanghai port is applied, i.e., $35.35 per MT/11,364 mi = $0.003110 per MT-mi. 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 be different from the tariff market rate. Besides, the actual ocean rates fluctuate year by year depending on the market. Therefore, this information is used mainly to illustrate the methodology framework. Multiple other sources can be used to update the ocean rates (see Table 1).

TABLE 3 Soybean Transportation Cost Work Table, Iowa to Shanghai: Route 2—Davenport to Shanghai via Port of New Orleans, Long Haul by Rail

	Distance (mi)	Time (h)	Unit Cost ($/MT-mi)
Intermodal facility to Davenport by truck	192	6.4	0.081600
Davenport to New Orleans port by rail (CN)	1,056	34.3[a]	0.054323[b]
New Orleans port to destination port by ocean shipping	11,364	705.4	0.003110
Total	12,613	746.1	0.008556

NOTE: CN = Canadian National Railway.
[a]Travel distance divided by 30.8 mph, the average speed for CN intermodal freight rail in August 2016 (*25*).
[b]Data generated from URCS Phase III Railroad Cost Program from Davenport heading to New Orleans by CN railways, assuming 75 carloads and four containers (20-ft) per car as a typical trainload. Unit cost is calculated by using the total variable cost of $292,564 hauling 5,100 MT (assuming 17.24 MT per container) for 1,056 mi.

TABLE 4 Soybean Transportation Cost Work Table, Iowa to Shanghai: Route 3—Des Moines to Shanghai via Port of Tacoma, Long Haul by Rail

	Distance (mi)	Time (h)	Unit Cost ($/MT-mi)
Intermodal facility to Des Moines by truck	146[a]	5.6	0.081600
Des Moines to Tacoma port by rail (UP)	2,014[b]	63.9[c]	0.042033[d]
Tacoma port to destination port by ocean shipping	5,603	347.8	0.003321[e]
Total	7,763	417.3	0.014792

[a]Average distance from multiple aggregated points of intermodal facilities to Des Moines by truck.
[b]Distance from Des Moines to Tacoma port by rail based on the PC*MILER–Rail software.
[c]Travel distance divided by 31.5 mph, the average speed for UP intermodal freight rail in August 2016 (*25*).
[d]Data generated from URCS Phase III Railroad Cost Program from Des Moines heading to Tacoma Port by UP railway, assuming 75 carload and four containers (20-ft) per car as a typical trainload. Unit cost is calculated by using the total variable cost of $431,740 hauling 5,100 MT for 2,014 mi.
[e]Data extracted from WorldFreightRates.com on June 30, 2016. Rate of $18.61 per MT from Tacoma port to Shanghai port is applied: i.e., $18.61 per MT/5,603 mi = 0.003322 per MT-mi.

TABLE 5 Soybean Transportation Cost Work Table, Iowa to Shanghai: Route 4—Des Moines to Shanghai via Port of Los Angeles and Long Beach, Long Haul by Rail

	Distance (mi)	Time (h)	Unit Cost ($/MT-mi)
Intermodal facility to Des Moines by truck	146	5.6	0.081600
Davenport to Los Angeles–Long Beach port by rail (UP)	1,964[a]	62.3	0.042328[b]
Los Angeles–Long Beach port to destination port by ocean shipping	6,509	404.0	0.003062[c]
Total	8,619	471.9	0.013299

[a]The north route from Des Moines to Los Angeles–Long Beach port via UP railway through Salt Lake City, Utah. The total distance is 1,964 mi based on the PC*MILER–Rail software.
[b]Data generated from URCS Phase III Railroad Cost Program. Unit cost is calculated by using the total variable cost of $423,975 hauling 5,100 MT for 1,964 mi.
[c]Data extracted from WorldFreightRates.com on June 30, 2016. Rate $19.93 per MT from Los Angeles–Long Beach port to Shanghai port is applied, i.e., $19.93 per MT/6,509 mi = 0.003062 per MT-mi.

TABLE 6 Soybean Transportation Cost Work Table, Iowa to Shanghai: Route 5—Des Moines to Shanghai via Port of Los Angeles and Long Beach, Long Haul by Rail

	Distance (mi)	Time (h)	Unit Cost ($/MT-mi)
Intermodal facility to Des Moines by truck	146	5.6	0.081600
Davenport to Los Angeles–Long Beach port by rail (BNSF)	2,162[a]	63.6[b]	0.045062[c]
Los Angeles–Long Beach port to destination port by ocean shipping	6,509	404.0	0.003062
Total	8,819	473.9	0.014621

[a]The south route from Des Moines to Los Angeles–Long Beach port via BNSF Railway through Kansas City, Kansas. The total distance is 2,162 mi based on the PC*MILER–Rail software.
[b]Travel distance divided by 34 mph, the average speed for BNSF intermodal freight rail in August 2016 (*25*).
[c]Data generated from URCS Phase III Railroad Cost Program. Unit cost is calculated by using the total variable cost $496,864 hauling 5,100 MT for 2,162 mi.

TABLE 7 Total Distance, Time, and Cost of Soybean Shipment from Iowa to Shanghai

Rank by Cost	Iowa to Shanghai	Total Distance (mi)	Total Time (h)	Total Route Cost $ per MT	Total Route Cost $ 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 Los Angeles–Long Beach 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 Los Angeles–Long Beach port by rail (BNSF)	8,817	473.2	128.92	2,223

Route 8. Davenport to Rotterdam via New York—long haul by rail;
Route 9. Davenport to Rotterdam via Norfolk, Virginia—long haul by rail; and
Route 10. Davenport to Rotterdam via Charleston, South Carolina—long haul by rail.

The results are shown in Table 8. Similar to the findings for the routes from Iowa to Asia, the itinerary consisting of barge travel from Davenport to New Orleans is shown to be the most cost-effective, but also the most time-consuming, among the five routes.

In summary, 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 per metric ton. 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 with respect to moving Asia-bound soybeans by rail via the Pacific Northwest. To export soybeans from Iowa to Rotterdam, shipment through New Orleans via barge down the Mississippi River also represents the optimal route in terms of cost efficiency. The additional alternatives, via rail through New York, Norfolk, Charleston, or New Orleans, proved to be more expensive, largely because of higher costs for shipping by rail. The results shed light on the most cost-effective corridors for long-haul and international shipping for future soybean-based agricultural development.

Sensitivity Analysis of Train Speed

Operational train speeds could vary widely on different lines. The researchers conducted a sensitivity analysis of train speed to illustrate how this factor affects the total shipping time. This information would help shippers evaluate transportation time and cost when choosing

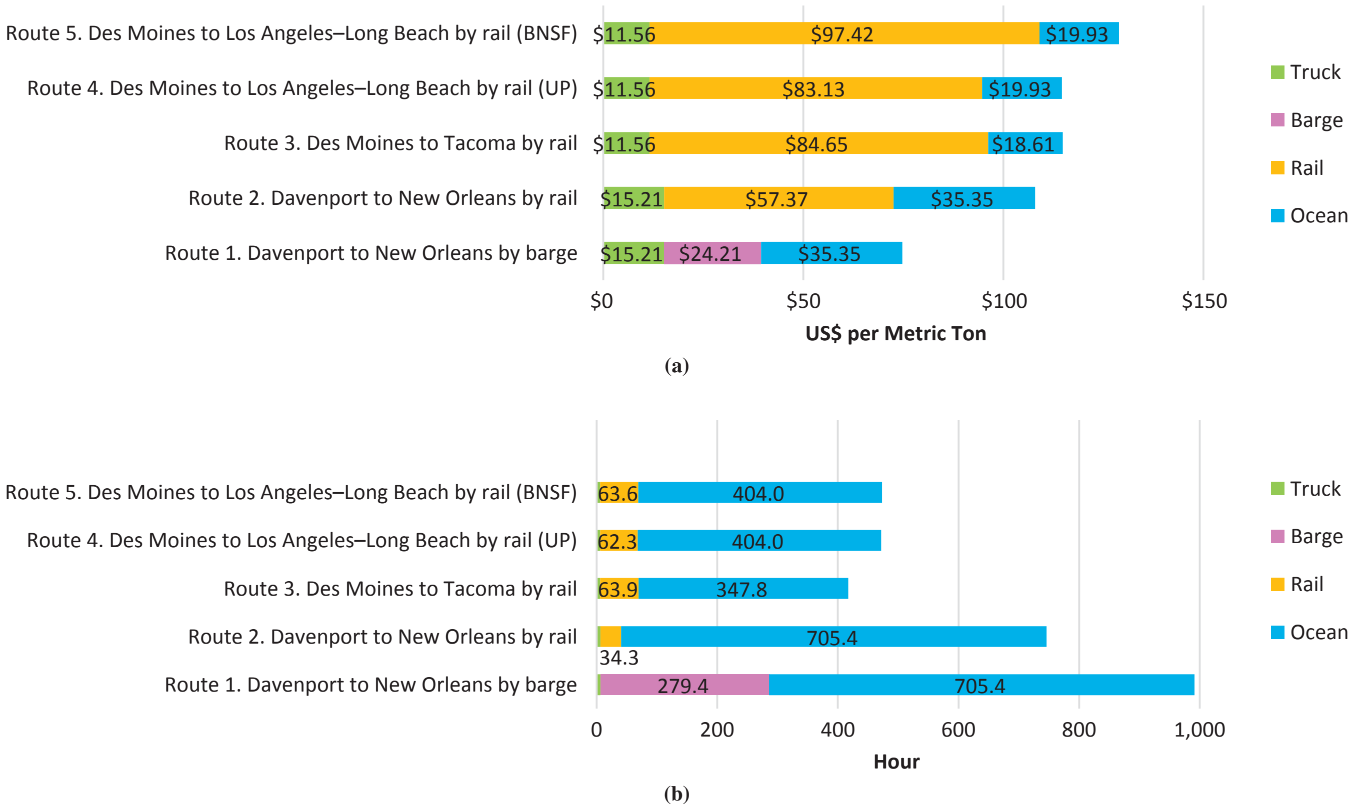

FIGURE 7 Breakdown of (*a*) total route cost and (*b*) total route time by mode from Iowa to Shanghai.

transportation modes and ports of entry. In addition to using the average intermodal speed, the researchers considered an extreme scenario in which the train speed is 60 mph on each track segment from Iowa to Shanghai (the first example). The results are shown in Figure 8. It shows that 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.

RESEARCH CONTRIBUTION AND ONGOING RESEARCH

This research developed a methodological framework and detailed calculation procedure for estimating the total transportation cost for soybean container exports in the United States. Largely absent from present-day transportation investment decision making is a national-scale entity that examines multimodal investment needs and trade-offs.

This research aimed to address this issue by identifying and aggregating multimodal transportation network data into one methodology. The cost estimates can be used to evaluate further the impact of prospective changes in the freight industry, both nationally and globally. Ultimately, sequent 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 the global soybean markets.

This research contributes to the prior literature by developing a multimodal transportation cost analysis model for containerized soybean exports in the United States. The methodology, information, and calculation tool can be adapted to other agricultural products. For researchers, this research can serve as a long-term reference to

TABLE 8 Total Distance, Time, and Cost of Soybean Shipment from Iowa to Rotterdam

Rank by Cost	Iowa to Rotterdam	Total Distance (mi)	Total Time (h)	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

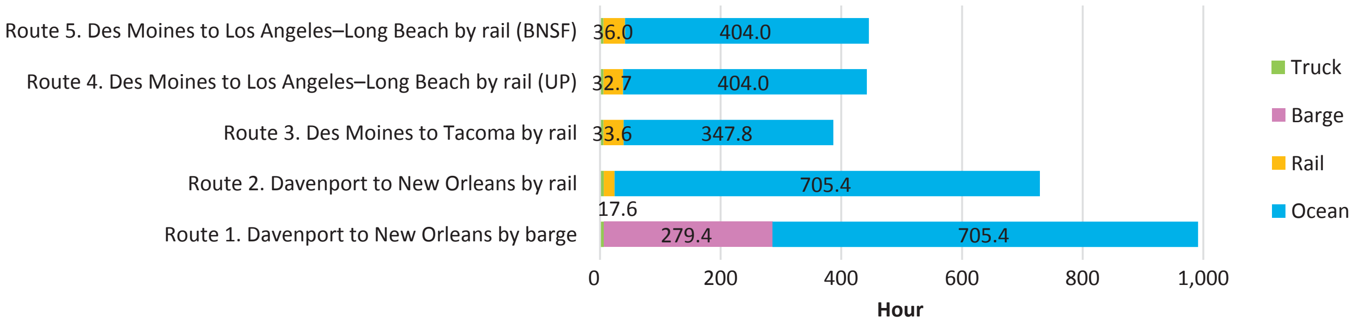

FIGURE 8 Breakdown of total route time by mode from Iowa to Shanghai (at train speed 60 mph).

understand the 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 geographic information system–based routing are currently implemented into a computer-aided decision support tool that can automate route selection, cost calculation, route cost comparison, and visualization.

One immediate next step for this research is to develop a least cost market analysis framework to show the spatial economically advantageous market region for each shipping point across the United States. This paper was developed from a strategic point of view and considers only the major elements in the supply chain by aggregating the transportation costs of the individual transportation cost links (truck, rail–barge, and ocean shipping). Many details in the transportation and handling processes are omitted to simplify the problem. For example, factors such as port capacity, congestion, container availability, and matchbacks and their related costs were not taken into account. The illustration of the methodology in this paper focuses on the scenario in which soybeans have been transloaded in containers in the rail sector. In other scenarios in which soybeans are transported in hopper cars by rail and transloaded to containers in the port, the methodology should be modified accordingly. In general, the point of transloading might be affected by various factors, such as the availability of empty containers, operating cost, and other issues.

The model in this paper relies on data that are publicly available through the sources listed in Table 1. It does not yet incorporate insight from farmers or exporters. An important next step is to refine the model's details and data accuracy with stakeholders in the industry. Next, this model assumes that total transportation costs are equal to the sum of the individual transportation cost links and does not consider margins or the likelihood of varying cost rates for each mode. Additionally, congestion and capacity issues on the remaining portions of the transportation network, including rail, are largely disregarded because of the complexity of these issues and the limitation of the data. On the other hand, although such factors may impede the versatility of the U.S. soybean market, the newly widened Panama Canal will likely benefit many aspects of the soybean supply chain.

Additional consideration should be applied to analyze the effects of transportation costs on international trade. Transportation costs and correspondingly, international trade, are notably influenced by geography, technology, infrastructure, fuel costs, and trade policy (*26*). The ability to determine total landed cost percentages for each network O-D pair could prove significant in determining which portions of the larger trade route network are most susceptible to transportation disruptions and, correspondingly, which particular routes will most influence total trade. How to incorporate these factors and the changing infrastructure environment are interesting topics left for future research.

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