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# An intermodal transportation geospatial network modeling for containerized soybean shipping

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**Abstract**

Containerized shipping is a growing market for agricultural exports, particularly soybeans. In order to understand the optimal strategies for improving the United States' economic competitiveness in this emerging market, this research develops an intermodal transportation network modeling framework, focusing on U.S. soybean container shipments. Built upon detailed modal cost analyses, a Geospatial Intermodal Freight Transportation (GIFT) model has been developed to understand the optimal network design for U.S. soybean exports. Based on market demand and domestic supply figures, the model is able to determine which domestically produced soybeans should go to which foreign markets, and by which transport modes. This research and its continual studies, will provide insights into future policies and practices that can improve the transportation efficiency of soybean logistics.


*Keywords:* International shipping; Rail; Truck; Barge; Agricultural logistics; Intermodal.

## 1. Introduction

The supply chain of soybeans is complex, encompassing multiple production sites and multiple modes of transportation [2]. The United States has a leading producer and a major exporter of soybean, with 54.1 million tons in volume, and 20.4 billion dollars in value in 2016, while the total US agricultural export is about 142 million tons in volume, and 129.7 billion dollars in value for the same year. The total US export of goods in 2016 is about 1454.6 billion dollars [26].

U.S. exporters ship most soybean in bulk, while shipment by means of intermodal containers is starting to increase in popularity due to the operating efficiency, security, and value-added service [2,18]. This is particularly important for transporting non-GMO products to meet the standard on segregated during handling and shipping [15]. Keeping the competitiveness of U.S. soybean exporters in the competitive global market highlights the need for reducing cost of transportation and enhancing quality of service. Containerized soybean is a promising business considering its advantages in shipping time, identity preservation, shipment tracking, etc. It is important to plan the development strategically so that the optimal pathways are utilized and system-wide transportation cost is minimized.

Distinguishing from past efforts largely focusing on soybean bulk transportation, this research uniquely targets an emerging, important container transportation market. Built upon an integrated analysis of transportation-mode-specific cost structures and up-to-date data, this paper develops a network logistics modeling framework that will be useful for strategically minimizing the total transportation cost of soybean export nation-wide. With the methodology in hand, decision makers can evaluate freight performance, identify infrastructure bottlenecks, and compare investment strategies, thereby will provide insights into the optimal investment portfolio for enhancing the cost-effectiveness of U.S. producers and shippers.

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## 2. Literature review and knowledge gaps

Multiple aspects of the soybean and agricultural commodity transportation decision making process have been considered in existing literature. DaSilva and Agosto [24] developed a model to estimate O–D matrices for soybean export. The model involves transportation from production fields to the processing warehouse and finally to the port of exit. Shen and Wang [23] developed binary logit and regression models to study cereal grain movement by truck and rail transportation throughout the United States. Danao and Zandonandi [3] developed a method to monitor environmental conditions and logistics information during transportation. Through this methodology, soybean quality is assured, but transportation costs are increased. Lee et al. [11] provided a method to monitor 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 [8] comprehensively evaluated United States soybean supply chains, tracing the routes from farm to market. Salin and Somwaru [22] 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 commodity transportation within the U.S., they rarely consider international shipping cost which is a significant part of container movement using different routes.

In the case of containerized soybean transportation, Informa Economics and the Illinois Crop Improvement Association [9] investigated the quality and condition of soybeans originating in Illinois and bound for Southern and Eastern Asia. They concluded that shipping containers, as opposed to shipping bulks were better for maintaining higher levels of quality. These results were also found by the U.S. Grain Council and U.S. Wheat Associates [27]. Such pieces of research are particularly concerned with the quality aspect of transportation, rather than with transportation costs. Clott et al. [2] developed a network optimization model for container repositioning in soybean supply chain. However, they did not explicitly address intermodal cost structure. In a related research that is published recently [1], a detailed, multi-modal transportation cost analysis framework is developed to estimate and compare the "point-to-point" supply chain costs of alternative shipment routes from any domestic production site to any foreign port, focusing on soybean container shipments.

Other studies focused more on specific aspects of agricultural transportation. For example, Keith [10] provided an assessment of the U.S. freight railroad system and its ability to handle current and future commodities demand. Wetzstein [28] 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 the key individual transportation making up the supply chain. Friend and Lima [5] focused on the national policy aspect, analyzing the strength and competitiveness of U.S. and Brazilian soybean production according to their different transportation policies.

Freight network optimization has been an active research area for modeling soybean and agricultural transportation decision-making processes. Besides the Clott et al. [2] study that optimizes containerized soybean supply chain, Reis and Leal [21] built deterministic models regarding the tactical planning of the soybean supply chain to aid with temporal and spatial decisions. Nourbakhsh et al. [17] developed an optimization model to optimize supply chain network design for reducing grain post-harvest loss. Similarly, Fan et al. [4] 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. [14], Macharis and Pekin [13], Thill and Lim [25], and Lim and Lee [12]. Winebrake et al. [29] provided 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. [19] modeled various factors that influencing the cost structure, such as value of time, in the intermodal supply chain. However, 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.

While past research has developed relevant network models, efforts were primarily concentrated on bulk transport or transportation cost on a single transportation mode either nationally or in certain international leg. This research addresses an emerging, growing container shipment market for intermodal agricultural transportation on an international scale. This paper builds off our recent research, Bai et al. [1] that estimates the 'point-to-point' intermodal transportation costs associated with intermodal links from farm to port and international markets. We extend to develop a geospatial network model to provide recommendations on how to reduce the system-wide costs by optimizing supply-demand allocation, routing and intermodal transloading. We try to make the model developed in this research generic and applicable to various similar problems.

## 3. Overview of soybean export in port regions

This section presents an overview of the major U.S. port regions for soybean bulk and container export. The statistics is based on data from USDA, U.S. Army Corps of Engineers and the PIERS database. Tables 1 and 2 list the top ports handling soybean traffic in bulk and container format in the US, respectively.

Bulk exports occur predominantly via the New Orleans Region and Pacific Northwest, with shares of 69% and 27% respectively. Container exports, however, occur predominantly

Table 1
U.S. top ports for bulk soybean export, 2015 (PIERS, 2015).

| Export port | Metric ton | % Share of US total bulk soybean export |
|---|---|---|
| New Orleans | 22,168,670 | 63 |
| Los Angeles | 1,109,107 | 3 |
| New York | 257,610 | 1 |
| Houston | 268,035 | 1 |
| Seattle | 2,108,454 | 6 |
| Tacoma | 1,418,850 | 4 |
| Long Beach | 743,781 | 2 |
| Virginia | 1,434,311 | 4 |
| Total | 29,508,818 | 84 |

Table 2
U.S. top ports for containerized soybean export, 2015 (PIERS, 2015).

| Export port | TEU | % Share of US total containerized soybean export |
|---|---|---|
| Norfolk | 39,977.13 | 23.79 |
| Long Beach | 39,308.59 | 23.39 |
| Los Angeles | 32,684.71 | 19.45 |
| New York | 27,771.50 | 16.52 |
| Tacoma | 10,287.84 | 6.12 |
| Charleston | 6463.84 | 3.85 |
| Savannah | 4076.66 | 2.43 |
| Seattle | 2006.49 | 1.19 |
| Baltimore | 1876.30 | 1.12 |
| Others | 3610.37 | 2.15 |
| Total | 168,063.40 | 100.00 |

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 [20]. For bulk shipments, the Gulf of Mexico and North Pacific comprised over 60% and 24% of market share, respectively. 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 is at the head of the Mississippi River Delta, a major soy production location. It shows that this 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 [6]. Given the relative ease of rail-to-vessel agricultural containerized shipping, 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.

## 4. Model formulation

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 soybean. It outputs 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.

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 onto the nearest, discretely located farm origin node. So each farm node $o \in O$ holds a quantity $Q_o$ of soybean (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 $\Sigma_{o \in O} Q_o$ should be greater than or equal to the total demand in all overseas ports $\Sigma_{d \in D} Q_d$ 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 soybean: 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 soybean 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 $\lambda_a$ is used to convert the containerized soybean flow (e.g., MT per year) into traffic capacity measure for each type of modal link. For example, with regard to highways, passenger car (pc) equivalent (e.g., pc per hour) is used to maintain unit consistency between traffic flow and traffic capacity [7]. 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 dis-

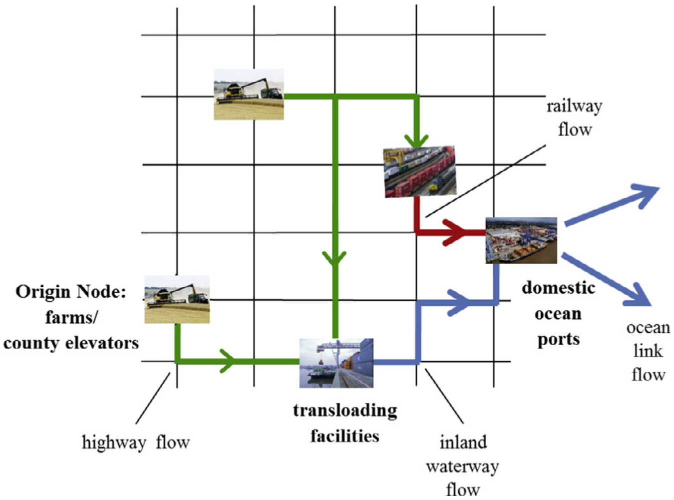


Fig. 1. Conceptual network representation.

tance, so it should be obtained link-specifically when detailed data is available.

Transloading is another important component in the intermodal logistics of containerized soybean. 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. [17] 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. Fig. 1 illustrates the conceptual representation of the containerized soybean shipping network.

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.

$$\min_{\mathbf{x}} \underbrace{C^h \sum_{a\in A_h} x_a t_a + C^r \sum_{a\in A_r} x_a t_a + C^w \sum_{a\in A_w} x_a t_a + C^{oc} \sum_{a\in A_{oc}} x_a t_a}_{\text{Transportation cost for highway, railway, inland waterway, and ocean links}}$$
$$+ \underbrace{\sum_{a\in A_{hr}} x_a C_a^{hr} + \sum_{a\in A_{hw}} x_a C_a^{hw} + \sum_{a\in A_{ho}} x_a C_a^{ho} + \sum_{a\in A_{rw}} x_a C_a^{rw} + \sum_{a\in A_{ro}} x_a C_a^{ro} + \sum_{a\in A_{wo}} x_a C_a^{wo}}_{\text{Transloading cost}} \quad (1)$$

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

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

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

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

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

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.

## 5. Case study

The mathematical model is applied to a case study that encompasses the best available data we obtained. The essential inputs for the GIFT model builds off a relevant recent study [1], in which a cost analysis provides a good overview of the transportation network and intermodal cost structure of containerized soybean exports. The GIFT model expands to incorporate freight tonnage and flows.

### 5.1. Model inputs

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

Table 3
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 | 10,005.5 |
| 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 | 8303,000 | 4151.5 |
| WOOD | OH | 8040,000 | 4020 |
| VAN WERT | OH | 7462,000 | 3731 |
| SUSSEX | DE | 4397,000 | 2198.5 |
| KENT | DE | 3090,000 | 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 |

than in other modes. Note that a limited number of soybean production counties are included in the case study, mainly for the illustrative purpose of our model application. More choice of production counties and finer resolution of shipment origins (e.g., farm level) may yield different model results, but 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 is 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 Table 3 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 4. For these destination countries, nine major destination ports are picked, 3 of which are in China (one each in northern, eastern, and southern China).

Furthermore, 10 intermodal facility locations (major hub cities and inland ports) are considered in the case study. Fig. 2 shows geographically the soybean originating 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. 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.

### 5.2. 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 them requires significant research efforts. Considering that the ocean rates are highly volatile and surcharges vary across ports, two scenarios of ocean shipping rates were used in the case study. The first scenario considers relatively low scenario rates and does not assume any additional surcharges (such as duty, tax, and other origin, destination port charges), while the second scenario considers high scenario rates and assumes surcharges. These results are visualized using GIS mapping software. Note that since the total demand for containerized soybean is much lower than the total supply, only a subset of the production counties are selected by the model 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.

#### 5.2.1. Scenario 1: Low ocean rates without surcharges

Scenario 1 extracts port-to-port ocean rate data from WorldFreightRates.com. These figures appear to be relatively low and do not include surcharges such as duty, tax and other origin, destination port charges. As Fig. 3 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 travelled by ocean is longer from New Orleans to Asia, lower 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.

Table 4
GIFT model input: total demand at 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 | 1087,240 |
| New York | 214,772 | 2759 | 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 | 2652 | 32,213 | 1852 | 3966 | 83,833 | 3826 | 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 | 2074,962 |

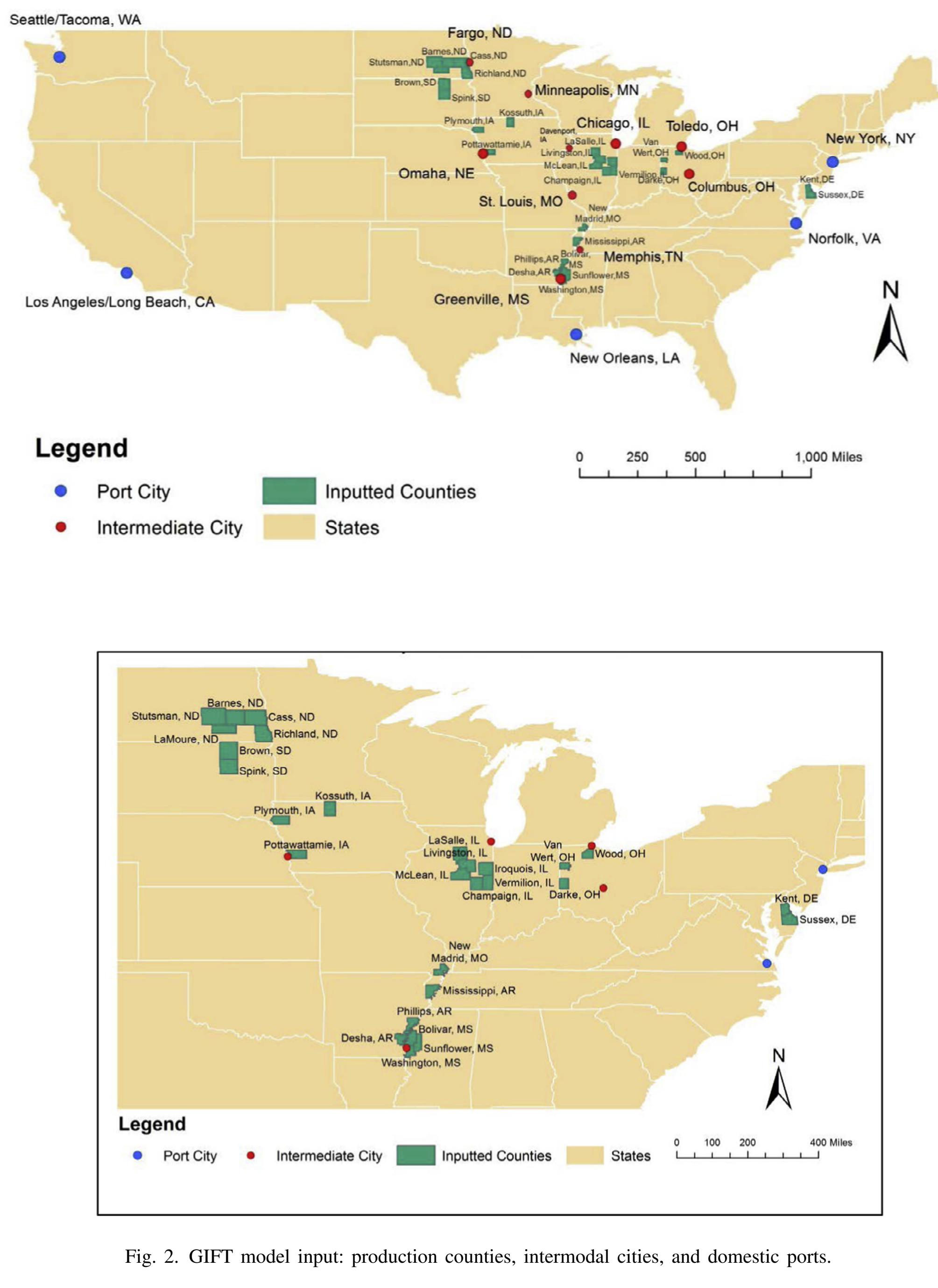


Fig. 2. GIFT model input: production counties, intermodal cities, and domestic ports.

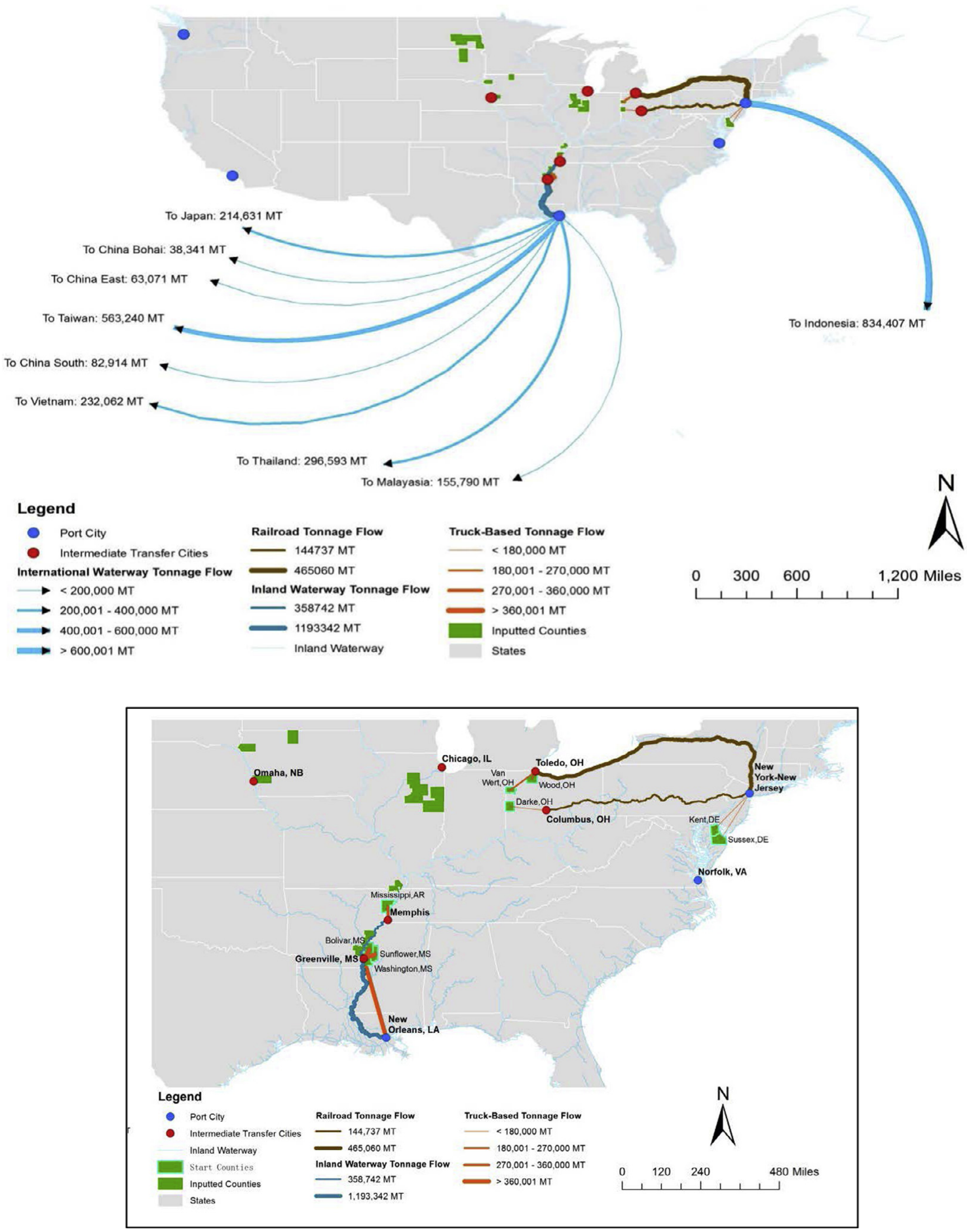


Fig. 3. Scenario 1 model results with low ocean rates.

#### 5.2.2. Scenario 2: High ocean rates with surcharges

Scenario 2 considers port-to-port ocean rate data from SeaRates.com. These figures appear be more expensive given the inclusion of origin and destination port fees and terminal handling charges. Unlike in Scenario 1, the results in Scenario 2 show soybean flow as being more dispersed throughout the United States production counties and ports-of-exit (Fig. 4). Production is optimal from 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 by the Pacific Northwest ports, compared to the charges by 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 export, which also depends on the fluctuation of rail rates and how the Canal widening affects ocean rates. However, the GIFT model could easily include the new rates to generate revised optimal results. The resulting conclusion of optimization is sensitive to the inputted cost data, especially when the differences of route costs are not significant.

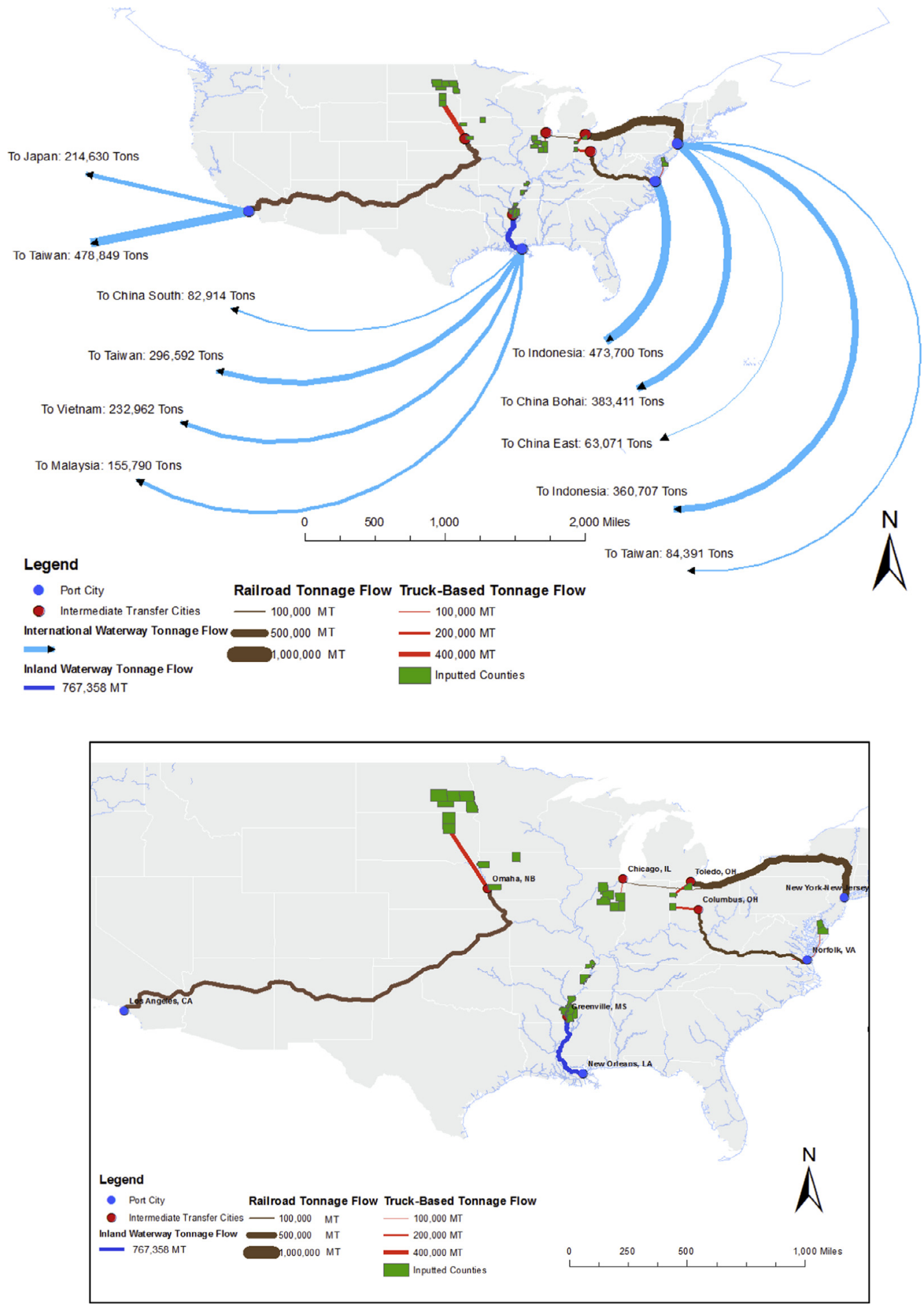


Fig. 4. Scenario 2 model results with high ocean rates.

## 5.3. Result comparison

### 5.3.1. Comparison of model results

The resulting "optimal" traffic flow distribution based on the optimization model from previous sections is compared with the actual flow based on 2015 PIERS data (Table 5). The modeling accounts only for a sample of 28 counties; as a result, the comparison of absolute traffic volume is

Table 5
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 |

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.

The 2015 actual throughput shown in Table 5 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 through the LA/LB Port under both high and low ocean rate scenarios. By comparison, the model chooses New Orleans Port for a much higher proportion of soybean exports for both scenarios. The results imply that, if cost is the only concern, most containerized soybeans should use inexpensive barge through the Mississippi River system and exit the Gulf Coast via New Orleans Port, despite the fact that it would require longer ocean distance. This finding coincides with our result from the LCMA analysis of cost by shipping from Iowa to Shanghai and Rotterdam. The second scenario is relatively closer to the current status quo, which indicates that ocean shipping rate is a critical factor affecting the optimal flow pattern under the current infrastructure network configuration.

A limiting factor of our case study is the omission of infrastructure condition and capacity bottlenecks, including export elevators, locks, and dams on inland waterway, ports, and connecting highway and their existing utilization for the movement of other goods. Aging infrastructure such as road surface and river locks and dams impede the efficiency of agriculture transportation through Gulf Ports.

The case study can be extended to account for additional factors (e.g., infrastructure capacity, various business requirements) if more data is 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 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 questions based on the available data. The optimization model is advantageous in terms of identifying the optimal practices among numerous alternatives. 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 for improving the economic competitiveness of soybean logistics.

#### *5.3.2. Impact of inland waterway transportation cost*

A sensitivity analysis is also conducted to reveal the impact of inland waterway transportation cost on optimal flow assignment. With all other input parameters same as the benchmark case, we vary the inland waterway cost from 30% increase to 30% decrease of the benchmark case. The total modal flow (in metric tons) and its percentage share in the total flow are shown in Table 6.

The result is more sensitive to increased inland waterway cost than the reduced cost. For example, if we reduce inland waterway cost by 20%, the total flows on inland waterway links increase only from 16% to 18% of the total flow, but if inland waterway cost increases by 20%, the total flows on inland waterway links decrease from 16% to 9% of the total flow. Truck flow is affected only when the cost increases more than 20%, as most truck flow is short-haul transportation from farm to intermodal facilities. The major competitor to inland waterway transportation is rail transportation. Further reduction of inland waterway cost (by even 30%) will not significantly affect the flow pattern. This probably resulted from the relatively small amount of soybean shipping demand utilizing the inland waterway links, as only a portion of all production counties (and shipping demands) are considered in our case study. Except for those counties located along the Mississippi river and near New Orleans port which have cost advantages in utilizing inland waterway transportation, other production counties in the case study are dominantly in favor of rail transportation because of their geographical locations. To reflect the more realistic impact, a full scale case study considering all soybean supply counties and transportation network capacity would be necessary in the future.

## 6. Concluding remarks

In summary, this research develops a network optimization model for soybean container transportation in the United States. The model optimizes supply and demand allocation, routing, intermodal transloading, and flow assignment under infrastructure capacity constraints. 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.

### *6.1. 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 a low cost route for many areas in the Midwest and along the Mississippi River corridor. 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

Table 6
Comparison of actual port throughput to GIFT model results.

| Inland waterway cost change | +30% | +20% | +10% | 0% (benchmark) | −10% | −20% | −30% |
|---|---|---|---|---|---|---|---|
| Total inland waterway flow | 231,144 | 384,600 | 684,444 | 767,358 | 767,358 | 834,600 | 834,600 |
| | 5% | 9% | 14% | 16% | 16% | 18% | 18% |
| Total rail flow | 1571,994 | 1571,994 | 1571,994 | 1489,080 | 1489,080 | 1421,839 | 1421,839 |
| | 37% | 35% | 33% | 31% | 31% | 30% | 30% |
| Total truck flow | 2481,049 | 2481,049 | 2481,049 | 2481,049 | 2481,049 | 2481,049 | 2481,049 |
| | 58% | 56% | 52% | 52% | 52% | 52% | 52% |

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.

### 6.2. 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 [16].

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. 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.

### 6.3. 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.

### 6.4. Future research

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

- The transportation analysis does not yet take into account the value of time applied to the supply chain. The results for both scenarios indicate a strong preference for shipment via barge through New Orleans which, however, requires almost doubled time. The quality of service (and ultimately the monetary value) of the shipment could an impact on optimal flow and should be considered in the model.
- Although the theoretic model can take into account infrastructure capacity, we do not really consider this factor in our analysis due to insufficient data, including port capacity, road congestion, container availability, and match-backs. Congestion and capacity issues on the remaining portions of the transportation network, including rail, are largely disregarded due to its complexity and data limitation.
- 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.

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. In future development, decision makers can use the adapted model to identify the optimal integration of optimal strategies to best improve the economic competitiveness of soybean exports in the United States.

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