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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