OPTIMIZATION OF REGIONAL EMPTY CONTAINER SUPPLY CHAINS TO SUPPORT FUTURE INVESTMENT DECISIONS FOR DEVELOPING INLAND CONTAINER TERMINALS

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

DOCTOR OF PHILOSOPHY

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ABSTRACT

Containerized grain shipping has been increasingly used as a shipment option by U.S. exporters. Continued evolution and investment decisions in optimizing multimodal operations is a key in continued growth for the container transportation alternative. Agriculture is a leading sector in the Midwest economy. Grain production is particularly important to the natural resource-based economy of the upper Midwest. These increasing volumes of grain are being shipped in containers because containers offer opportunities to lower logistics costs and to broaden marketing options. Exporters are put at a competitive disadvantage when they are unable to obtain containers at a reasonable cost. Consequently exporters incur large costs to acquire these empty containers which are repositioned empty, from ports and intermodal hubs. When the import and export customers are located inland, empty repositioning generates excessive unproductive empty miles.

To mitigate this shortage of empty containers and avoid excessive empty vehicle miles, this research proposes to strategically establish inland depots in regions with sufficiently high agriculture trade volumes. Mathematical models are formulated to evaluate the proposed system to determine the optimal number and location of inland depots in region under varying demand conditions.

An agent-based model simulates the complex regional empty container supply chain based on rational individual decisions. The model provides insight into the role of establishing new depot facilities, have on reducing the empty repositioning miles while increasing the grain exports in the region. Model parameters are used to simulate the impact of train frequency and velocity, truck and rail drayage, demand changes at elevators and depot capacity. For the proposed system, stakeholders will be able to quantify the economic impacts of discrete factors like adjustments of the rail and truck rates and impacts of elevator storage capacity. The initial model is limited to a

single state (MN) and export market. It could be enhanced to present a flexible logistical scenario assessment tool which is of great help to make investment decisions for improving the efficiency of multimodal transportation. The model can be applied similarly to other commodities and/or be used to analyze the potential for new intermodal points.

ACKNOWLEDGMENTS

Time has always been a great teacher. I am grateful to all of those with whom I have had the pleasure to irritate with my intriguing mode of personality during my doctoral tenure.

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This journey would not have been possible without the support of my family. To my family, thank you for encouraging me in all of my pursuits and inspiring me to follow my dreams. I am especially grateful to my parents, who supported me emotionally and financially. I always knew that you believed in me and wanted the best for me. My wife Gurmeet and my son Ranbeer were by my side during this long journey and always supported me with great encouragement.

DEDICATION

I dedicate my dissertation work to my mother and father, Rajinder Kour and Mr. Kulwant S. Wadhwa, who first taught me the value of education and critical thought.

"Thanks for encouraging me to do my best and believing in me, even when I didn't believe in myself. Thanks for always being there for me during the good and the bad. You are the number one reason I am where I am today. I am so lucky to have you."

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1. INTRODUCTION

1.1. Shipping Container

One of the most commonplace items in the world, shipping containers come in a several internationally standardized sizes. With a unique serial number for each container, tracking each box as it makes its way across the world becomes much easier. These unique crates link many different modes of transportation together in a smooth, streamlined process. Because there is no need to load/unload cargo, the process is vastly more economical than other shipping methods. The ability to move the entire shipping container, whether that be by ship, crane, or truck, allows many different transportation infrastructures to interact at a central point in the supply chain process. With such a practical, yet simple object, it is no wonder why it is so popular in intermodal shipping processes. *Intermodalism* is a strategy whereby the overall journey (of cargo) is viewed in its entirety across multiple transport modes, and so improving the links between modes can be as important as the modes themselves. In today's global market, the shipping container is becoming an icon for the industry. With the rising costs of transportation and labor, it is no wonder that the intermodal shipping container is becoming increasingly important to companies across the world.

1.2. The Commerce of Containers

The primary function of these shipping containers is to help generate revenue for the carriers. Traditionally, the ocean carrier built the cost of backhaul into the head haul or come back completely empty, carriers will often take reduced rates for the backhaul journey. These reduced rates are often subsidized by the larger head haul pricing. In the mid 2000's, ocean carriers began to rationalize the costs of inland market locations primarily served by rail. The increased rail costs required them to achieve economies of scale in order to use rail transportation efficiently.

In order to meet market requirements, international shipping containers have evolved to meet a number of different needs – all while maintaining ISO standards of construction. Domestic containers are typically 48’ or 53’ long. ISO containers, by industry convention, are either a Twenty-foot Equivalent Unit (TEU) or Forty-foot Equivalent Unit (FEU) with lengths of 20’ and 40’, respectively. Containers are often available at depots that may be a part of a rail or marine intermodal yard. Occasionally, marine carriers use or lease each other’s containers for a fee, and the understanding that each carrier maintains their own market share.

Minimizing operational expenses while maximizing capital is key, which means companies need to optimize their asset allocation across their business. The number of necessary containers is dependent on the frequency the ship calls at a port, and the average turnaround time for the containers “in the wild”. Turnaround time consists of port time, load/unload time, and transit time to their final destinations. The following expression describes the total TEUs needed for service. For example, a vessel calling every 10 days with a 15-day average turnaround time and loading capacity of 15,000 (TEUs) per vessel would require 22,500 twenty-foot containers on hand to service their customers.

$$\frac{15000\ \{\text{Vessel Capacity (TEUs)}\}\ \times 15\ \{\text{Average Turnaround time (days)}\}}{10\ \{\text{Port Call Schedule (days)}\}}$$

For every day that the average container turnaround time is increased for this vessel, another 1500 TEUs are needed. Interestingly, lowering the number of days between port calls by accelerating vessel transit time increases both the overall system capacity, and the need for containers – unless container turnaround time is also reduced.

In a study, it was determined that if a container moved inland from the Port of Vancouver, that the average annual transpacific roundtrips decreased from eight to six *(1).* All parties are interested in maximizing earning potential per container, and since the container turnaround time in the study was increased, with all other variables held constant, the net cost and the total number of necessary containers increased.

1.3. Empty Container Flows

After being unloaded at the port terminal, trucks or rails haul the containers to inland destinations. Once unloaded at the customer's site, the empty containers are stored in warehouses either to be shipped back empty overseas, or loaded with products for export. Empty container repositioning is a non-value-added process, and is avoided as much as possible. Still, ocean carriers reposition empty containers to fill demand in regions where containers are scarce. Unfortunately, there is a deficit at export locations, while there is typically a surplus at import locations.

In Figure 1, the relationship between the regional, inter-regional, and global repositioning systems can be seen. At a regional level, empties are repositioned primarily by trucks. At the inter-regional level, they are primarily repositioned by rail, and on a global scale, by ocean carrier. This is an extremely costly process, averaging around $9 billion annually, and up to $11.5 billion including inland haulage costs.

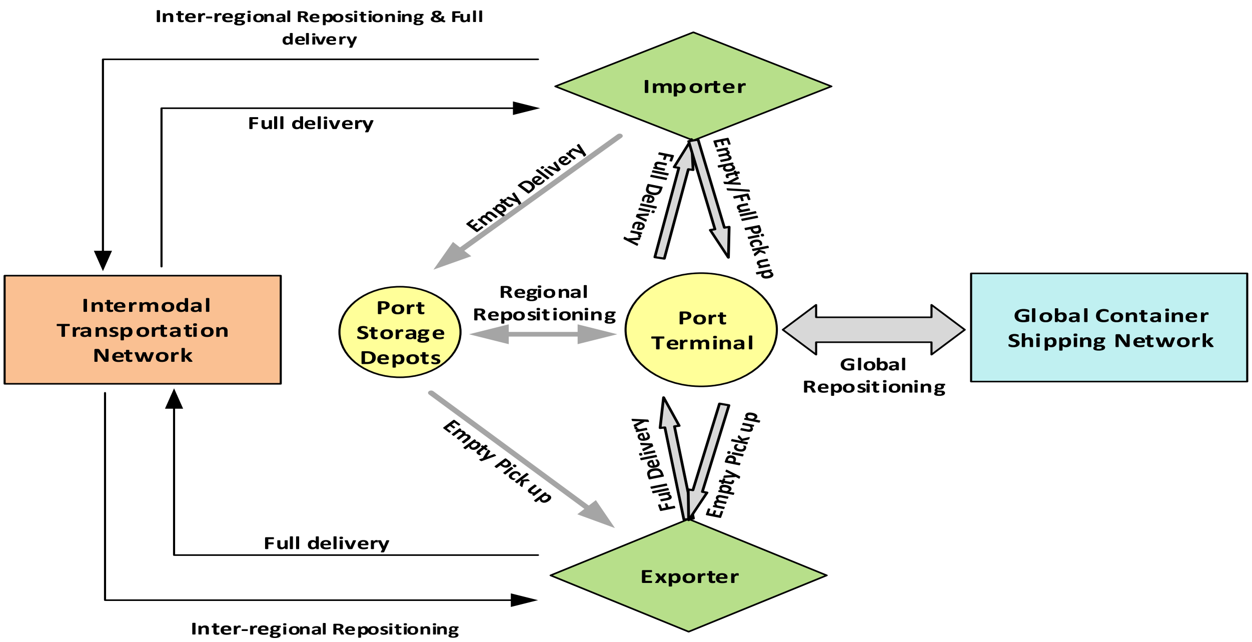


Figure 1. Empty container repositioning
Source: Adapted from Boile, M., S. Theofanis, A. Baveja and N. Mittal (2008): Transportation Research Record: Journal of the Transportation Research Board

1.3.1. Factors Contributing to the Empty Repositioning of Shipping Containers

Importers often take their abundance of shipping crates for granted. Unfortunately for U.S. based exporters, acquiring a container is a more lucrative process. Of an estimated 30 million shipping containers in active use at any time, around 3 million are empty and idle. Turnaround times for containers are still being optimized to asymptotically approach the shortest time (and cost) possible. Large system costs are incurred to make the turnaround time for empty shipping containers as short as possible. To the carriers, as it stands, it is still economically viable to reposition the empty containers, so long as it is immediately after they become available. At a high level, the major factors contributing to empty container repositioning are trade imbalances, changing trade patterns with Asian countries, backhaul cargo opportunities, revenue generation, manufacturing and leasing costs, and usage preferences.

1. Containerization and Trade Imbalances

Trade imbalance in containerized cargo creates logistical issues in both marine containers, domestic trailers, their chassis', and added costs for ocean carriers repositioning empty containers. In addition to the imbalance, the storage of empty containers necessitates increased labor costs, all the while congesting the marine yards.

In 2001, the surge of container production in East Asia led to the double digit annual growth of containerized trade. Total throughput handled by container ports worldwide grew at an average annual rate of 4.7% between 2012 and 2014 (UNCTAD 2105)[1]. Container trade imbalances have been steadily growing from 2008-2015 as depicted by Figure 2, the volume of containers imported to the United States exceeds the number of exported containers shipped to foreign locations. In 2008 about 17.8 million TEU were imported, while about 11.3 million TEU were exported. As is shown by Figure 2 imports reached approximately 20 million TEUs, with the exports increasing at a smaller rate to reach 11.5 million TEUs. Despite the anticipated lower annual growth rate, the volume of containerized trade doubled in 2014 (UNCTAD Secretariat, 2014)[2]. As a result, significantly more empty containers were leaving the United States than coming in. Contributing to the imbalance was the complex logistical task of managing and optimizing head haul and backhaul routes *(2)*. From an economic standpoint, it is a disadvantage to ship backhaul loads, as the rates are as low as 40-50% of head haul rates. For example, in 2007, the average head haul freight rate per TEU was $1,707, while the backhaul rate was as low as $794 (46.5%).

[1, 2] UNCTAD handbook of statistics 2014. (2015). *United Nations Conference on Trade and Development (UNCTAD) Handbook of Statistics*. doi:10.18356/b9457943-en-fr

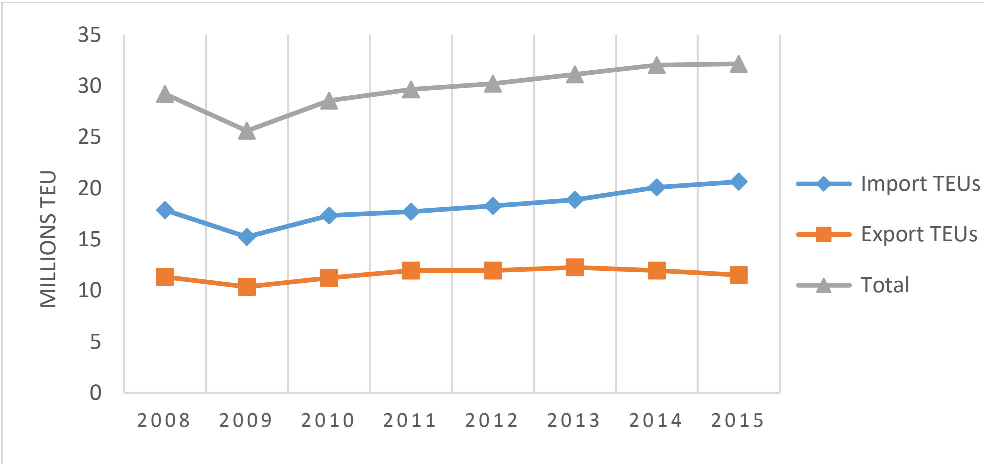


Figure 2. U.S. waterborne foreign container trade (all trading partners)
Source: Authors' Analysis of the U.S. Waterborne Foreign Container Trade by Trading Partners, MARAD

2. Changing Trade Pattern with Asian Countries

A large portion (around 2/3) of United States imported goods' demand is located along the East Coast. Focused on consumer culture, there is a massive influx of loaded containers into ports of New York, New Jersey, and Chicago (serving as an intermodal connector to containers from Asia through Los Angeles and Seattle). In the 1990s, a significant number of empty containers were sent from the East Coast to locations in the Midwest and the South, from where they departed loaded with low priority goods (such as cotton waste, recycled paper, metal scrap and other discards of post-industrial society) towards the West Coast and Asia *(3)*. More recently, however, Asian markets desired less of our exported waste materials, leading to some trans-Pacific carriers rejecting low-value cargo. Interestingly, they preferred to send empty containers to Asia more quickly, rather than loading with low value products. The quick turnaround time, with better-paying shipments, was enough to offset the empty container repositioning cost.

3. Backhaul Cargo Opportunities

Reflecting market trends, the ebb and flow of empty container repositioning is dependent on supply and demand. During low demand periods, carriers favor all available backhaul opportunities. Conversely, during high demand periods, they favor immediate repositioning for higher-value shipments.

Determining the viability of backhauling cargo is dependent upon the cost of empty container transportation, return freight rate, and whether the destination is a direct source of cargo *(4)*. As a result, during the early 2000's, accumulation of empty containers became a serious problem. Beginning around 2005, low export demand combined with the low cost of manufacturing new containers overseas, resulted in carriers preferring to store empty containers in depots near ports for extended periods.

4. Revenue Generation

Ship-owners allocate their containers to maximize their revenue, not necessarily to benefit their customers. Considering trade imbalances and the higher container rates imposed on the inbound trip for trans-Pacific routes, ship owners often prefer to reposition empty containers back to Asia, rather than wait for export loads. Containers can take three to four weeks to get loaded and brought back for export ports, yielding approximately $800 in revenue each. The same amount of time can be used to make around $3,000, greatly offsetting the costs of wait times for export loads.

5. Manufacturing and Leasing Costs

While these conditions are often temporary, accumulation can happen when manufacturing new containers is cheaper than repositioning them. Conversely, repositioning costs may be more efficient when manufacturing and leasing costs are high.

6. Usage Preferences

Shipping and leasing companies are hesitant to share market information on container positions and quantities available. Often times, companies use their containers as a way to advertise their presence. These two factors have made it very difficult to implement a *grey box* concept, where companies would theoretically pool their resources, sharing the containers to optimize their allocation. Not wanting to give up control of their containers, carriers were reluctant to participate, claiming that it was not a large enough advantage over their existing methodologies *(5)*. The North American rail system (TTX Rail Equipment Pool) has proved this untrue. It is indeed possible for transport companies to distinctly separate container assets from modal assets to optimize efficiency.

1.4. Key Partners in Empty Container Repositioning

Container movement contains a vast array of stakeholders at every level, each with their own varied interests, objectives, and methodologies. Some of them include shippers, carriers, lessors, depot owners, port terminal operators, port authorities, truckers, railroads, brokers, freight forwarders, warehouse operators, private entities, and regulatory agencies at both the state and federal levels. With such a wide range of interconnected pieces, the shipping container system is one that is extraordinarily difficult to manage.

Ocean carriers and leasing companies have traditionally had an approximately equal share of the world container fleet, but in recent years, the share has shifted in favor of the carriers. The difference between leasing companies and carriers is that containers are viewed as assets and cargo-carrying equipment, respectively. This leads to a different methodology for handling the containers for both types of companies. Ocean carriers do most of the empty repositioning in/for the industry. Conversely, leasing companies tend to sign agreements that enable them to balance their container inventory, while minimizing empty container repositioning. To combat the added costs of idle containers, they allow a specific quota for off-hired assets at specific locations, and apply additional costs to those that choose to do so.

1.5. Drawbacks of Ineffective Repositioning of Empty Containers

Container shipping has been the fastest growing sector of the maritime industry in the past two decades *(6)*. To remain competitive in the shipping market, companies must effectively develop ways to reposition their empty containers in a manner that is both cost effective, maintains customer happiness, and accounts for trade imbalances, randomness of demands, and other factors in the stochastic and dynamic shipping environment. Eliminating empty loads entirely, unfortunately, is not possible as real-world container networks usually require empty containers to account for the imbalances in loaded flows.

Reducing the repositioning and container equipment management costs by 10% could increase the industry's profitability by as much as 30-50% (ROI 2002). The number of empty containers has been on the rise, with as many as 500,000 in 2010 primarily being stored in areas surrounding major U.S. ports *(7, 8)*. To help ease congestion caused by the excess of empty containers, some ports have implemented restrictions on the number of empties that are permitted and how long they are allowed to stay. Unfortunately, to avoid the fees and inconvenience, carriers overloaded other ports without such regulations, leading said ports to implement them as well. Although this was less of a problem during the 2008-2013 economic recession, it is becoming a problem again as the global economy recovers.

1.6. Tightening of Container Availability for U.S. Exporters

U.S. exporters, recently, have been having an increasingly difficult time finding empty containers for their goods. While the quantity of containers is not diminishing, the locational availability of said containers makes it appear that way. For coastal exporters, it is not a pressing issue, as typically those regions have a surplus. For inland exporters, the increasing costs of container idle time and transportation are driving carriers away from sending their containers far inland. Discrepancies in perception of how much it should cost to ship “unwanted” materials, such as the waste materials the United States used to export to Asia, are causing problems for shipping companies. If the waste material owner views it as a service to the carrier, because to them, shipping something is better than shipping nothing, then they are far less willing to pay the appropriate market value for the container shipment.

Agricultural sectors have increased their output as well, resulting in a greater inland need of containers to regions like the Midwest, to handle the higher volume of exported meat and grain products.

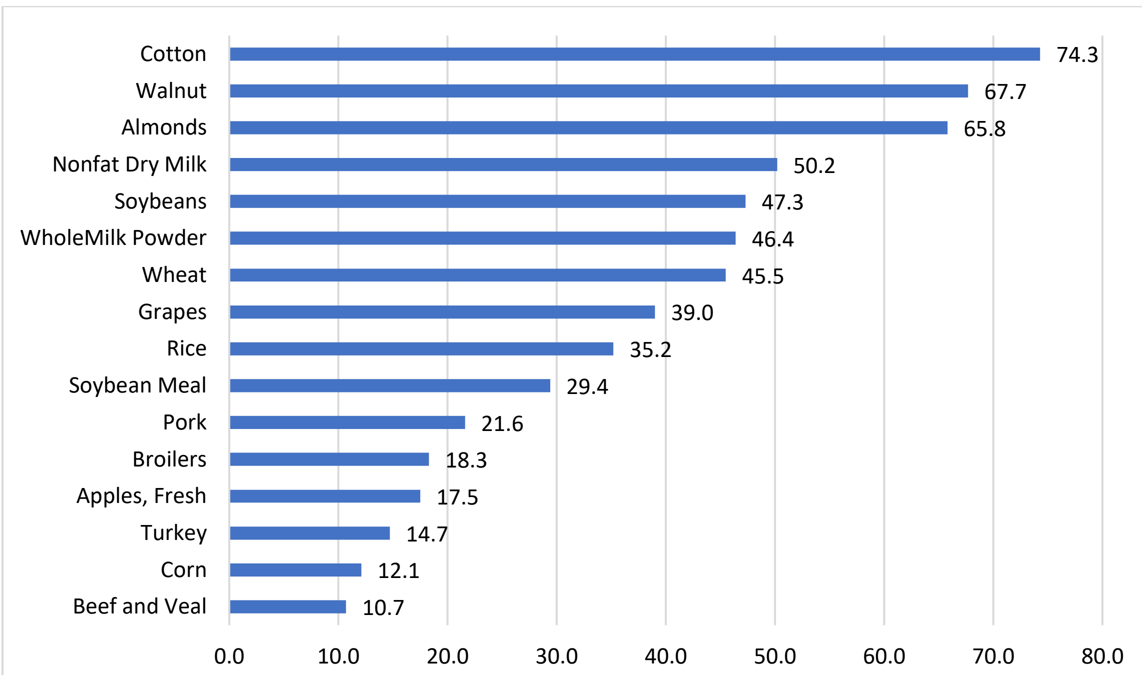


Figure 3. US agricultural exports: percentage share of production 2012-2016

Agricultural exports are a significant percentage share of production in the United States (Figure 3). Already suffering from a shortage of inland container availability, any increase in production is detrimental to efficiently moving product to coastal regions. While the production and export of goods is generally considered good, the rising competition for empty containers is not.

There is speculation that in addition to shifting from a “bulk shipping” method to more container based strategies, that larger ships with significantly increased TEU capability will be used more often. Increasing the number of vessels is not always as economically viable as using one of the mega vessels. Having fewer ports of call will force equipment concentration to key ports. This will further drive the container shortage crisis inland because it will become costlier to ship from a few main locations, rather than having a dispersed quantity of containers in varying locations all along the coasts.

Unfortunately, this leaves U.S. exporters in a tight spot; they will likely end up paying the higher repositioning fees to secure containers for export. Intermodal transport will help alleviate the use of only one method of transport, but exporters will likely see a rise in fees nonetheless.

1.6.1. Factors Contributing to Container Shortages

Container turnaround time, free time, gateway port transloading, inland depots, container location tracking and as previously detailed repositioning costs are all contributing factors to container shortages. These topics will briefly be discussed.

Container turnaround time, the imbalance of loads, and repositioning are important parameters in deciding operating costs of ocean carriers *(9)*. Many carriers are restricting the movement of containers to within 100 miles of the port of discharge, in an effort to ensure the container returns to the vessel in a timely manner. This restriction also helps reduce asset cycle time, inland equipment management, workforce requirements, and intermodal transportation costs. But, reducing the turnaround time increases the container shortage, which in turn increases the shipping cost of trucking the grains to the nearby intermodal hub, for the unloading it in a shipping container to travel overseas.

Container free time is the amount of time the importer and exporter has to load and unload a container. This can become a compounding issue for containers that travel a significant distance. Chicago, unlike other cities, is less concerned about quick turnaround times because many of their intermodal rail hubs ship reasonably locally.

Gateway port transloading plays a critical role in US international merchandise trade. American households depend on the nation's container seaports for everyday items, and American businesses depend on these seaports for facilitating the exchange of merchandise with trading partners around the world. Transloading international equipment near ocean terminals is a recent trend to minimize equipment repositioning from inland locations, and to reduce container cycle time. Because cargo is handled at the port, importers can more accurately predict shipment processing, and optimize ahead of time by using the most appropriate container for the job. Using crates like the 53’ stackable intermodal container in North America has allowed shipments to more quickly reach inland destinations.

Inland depots are helpful when drayage distances between rail terminals and import/export locations are short. Additionally, this reduces inland delivery cycle time by as much as one week for a container if it spends two days on the train to and from destinations in the Midwest and is given four days to unload at the customer’s facility.

Container tracking is extremely important for any shipping company. During its journey, the cargo must stop at a number of locations and these stops should be monitored and the information should be passed on to the clients. To move container equipment, it must move through the transport system with equipment interchange agreements, passing the liability and responsibility between parties. The interchange holder of the equipment should report the container locations; such locations might include on a vessel, truck, train, or in a rail yard or trailer yard facility, or an equipment depot.

Repositioning costs include both the costs of inland and international transportation. Such costs can be lowered by acute imbalances, as carriers could offer discounts for flows in the opposite directions to normal flows. If costs are relatively low, trade imbalance can continue without much of an impact, for the low costs to reposition are of minimal consequence to the shipping industry. In contrast, high repositioning costs may cause shortages of containers in export markets.

1.7. Transportation is Important for the Agricultural Industry

To address the transportation challenges faced by the agricultural industry, we must examine the function of transportation within the industry. In the following sections, a general overview of the key problems agribusiness is facing will be presented and evaluated. In Figure 4 below, the various modes of transportation used within the agricultural sector are detailed. Rail, trucks, and barge shipments are the three primary modes by which agricultural products are transported for export. Without effective, efficient transportation, agriculture could not have become the backbone of our country like it is today. Investment in transportation infrastructure makes shipping easier and faster, which saves money for the farmers, as well as widening the availability while reducing the cost to consumers.

Widely available transportation allows regional farmers to allocate their farms to the most suitable crops, maximizing both quality and quantity. It also allowed workers to migrate to the city to pursue careers in manufacturing and other industrial sectors. Agricultural products are exported all over the world, and as such, must be transported efficiently. Fortunately for American farmers, the United States has an expansive transportation infrastructure which support agriculture export.

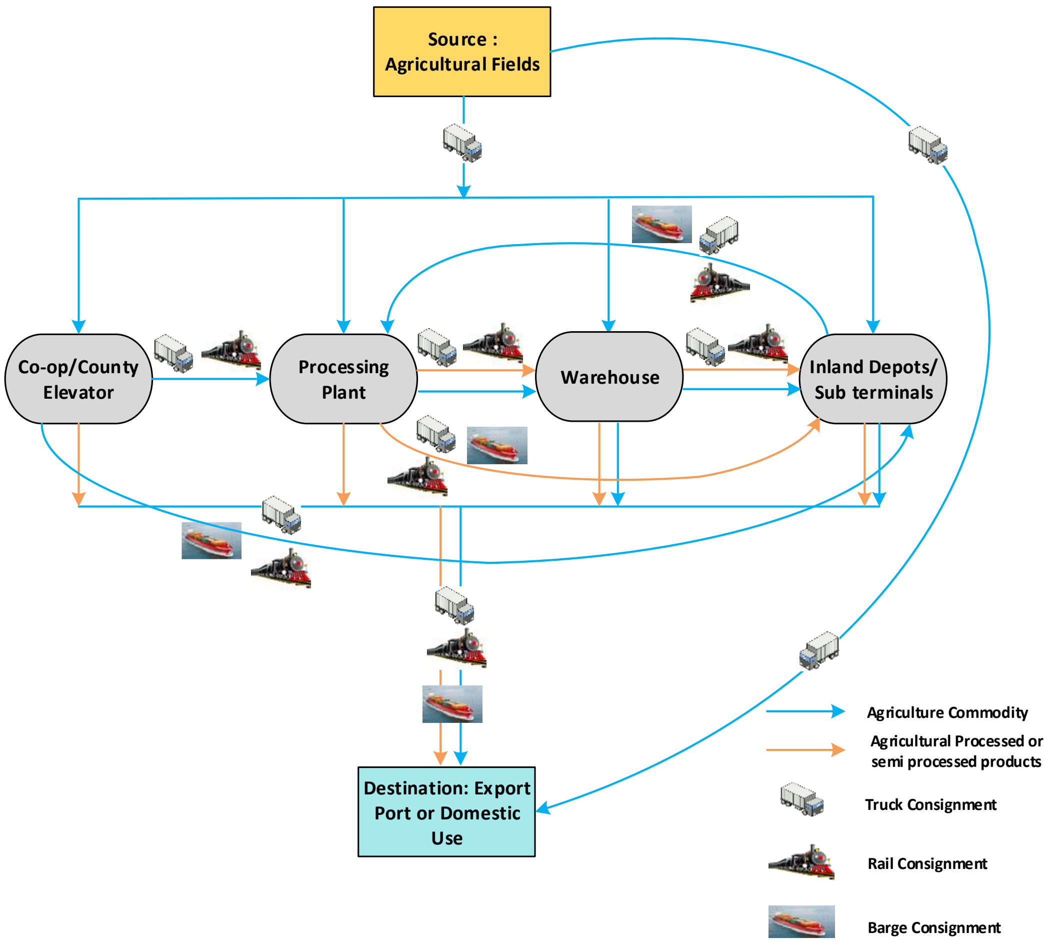


Figure 4. Agriculture supply chain

Innovations in cargo transportation have allowed previously untapped markets and regions to be producers in the agricultural business. For example, refrigerated trucks allowed remote, hot climates like California and Florida to produce meat and other refrigerated products for the nation. Centralizing grain silos in areas near train and hopper car depots allowed for more expansive areas to contribute to a local distribution point. Likewise, ethanol can be produced close to the corn it is made from, and still reach distant markets.

1.7.1. Agriculture Trade and Economy

In recent years, the U.S. GDP has been around \$18-\$19 trillion, with \$225 billion (1.17%) coming directly from agriculture, and \$540 billion (6.5%) coming from agriculturally related industries. Total average agricultural exports were approximately $139.4 billion between 2014-2016, with the net balance of $26.1 billion. Forecasts for 2018 predict that agricultural exports will exceed imports by $24 billion. According to the USDA's Economic Research Service (ERS), every dollar of exports generates an additional $1.50 in related economic activity.

For 2018, wheat exports were projected to account for 46.5% of production, soybeans will be 43.5%, and corn will account for 16.5%. For more perishable items like meat, 17% of poultry will be shipped internationally, and red meat will ship around 10%. With so much at stake, any hiccups in the supply chain or transportation can have detrimental effects on famers and the agricultural industry as a whole.

1.8. Grains and Oilseeds Profile

The largest users of freight transportation in agriculture are the grains and oilseeds. In 2013, grains and oilseeds comprised 28 percent of all agricultural tons and 31 percent of ton-miles moved by all modes of transportation.

1.8.1. Production, Export and Projections Outlook of Grains and Oilseeds

The United States leads the world in grain production, with annual production averaging 561 million tons from 2010-2016. Determining what crops are grown, where, how much, and where/how they are transported is a complicated network. To make these determinations, one must take into account weather and soil conditions, farmers, transportation modes available to the region, and consumer location, as well as government regulations at the state, national, and international level. The majority of the grain produced is intended for consumption by either humans or livestock. Additionally, grain is processed into flour, soybeans turn into soybean oil, and corn is turned into starch, corn syrup, and more. Grain availability varies wildly from year to year, depending on how much farmers can grow and ship. (U.S. grain production ranged from 483 million tons to 653 million tons from 2012-2016.) Grain needs tend to stay fairly constant, with a large portion dedicated to livestock feed that stays at a reasonably consistent demand level. Figure 5 highlights the amount of grain production (in millions of tons) for the previous 6 years. U.S. grain exports declined steadily from 2010 to 2013 due to slower world economic growth, a stronger U.S. dollar and falling prices of bulk commodities. However, after 2013 the grain export trend seems to be slightly upward (Figure 6).

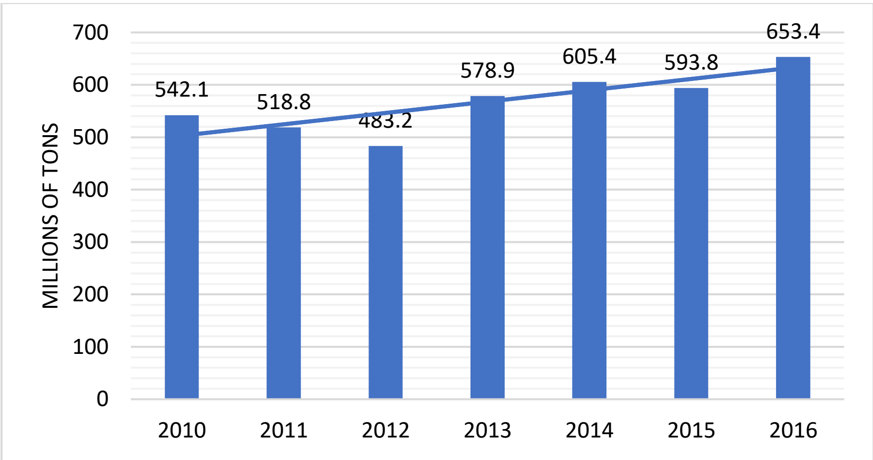


Figure 5. U.S. grain production
Source: USDA

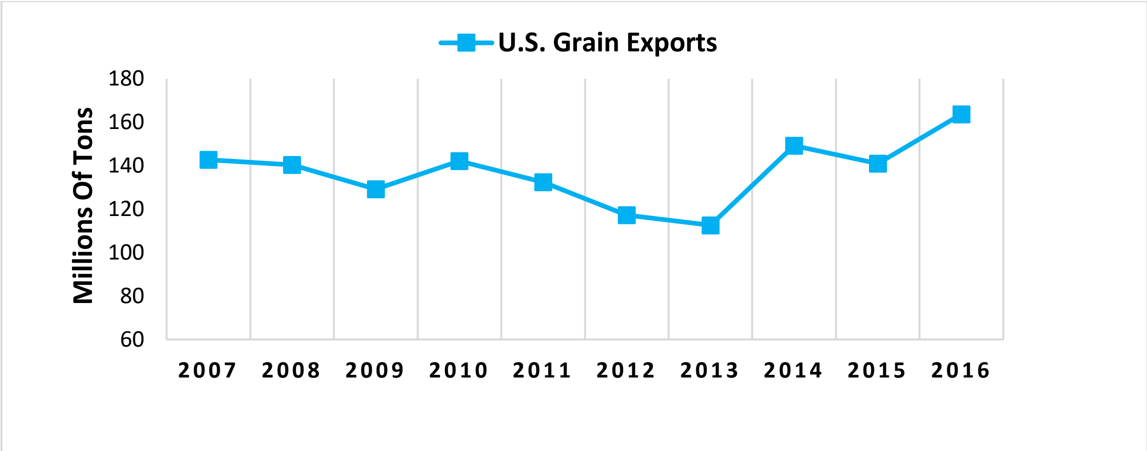


Figure 6. Total U.S. grain exports
Source: USDA

U.S. exports have expanded across bulk and high value product categories, with particularly strong growth among consumer-oriented products commodities. The primary source of growth in in U.S. agricultural exports, are the middle-income countries like China and Mexico. These countries now account for the largest share of U.S. agricultural exports for the bulk products like wheat, soybeans, barley and rice etc.

The five-year projections of grain productions and exports show a sustainable trend (Figure 7). But even this is subjected to improve as world per capita GDP is expected to grow at 1.6% in 2017, compared with 1.2% in 2016 (USDA). This increase reflects a broad-based upswing in the world economy across both developed and developing countries and further will boost the world trade volume. Also, the weakening of dollar indicates the enhancement in the viewpoint of the U.S. trading partners.

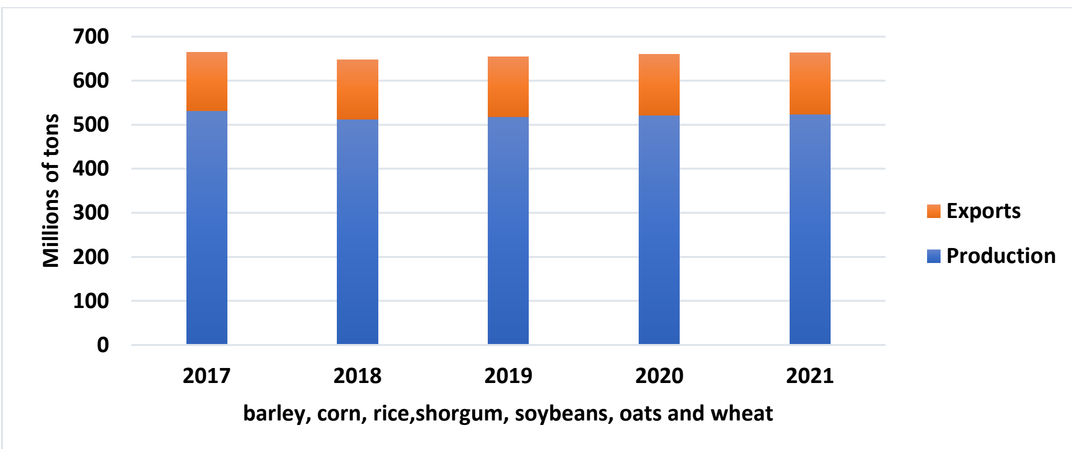


Figure 7. Total U.S. grain projections (productions and exports)
Source: USDA

1.9. U.S. Grain Supply Chain and Transportation

Modal sharing, or portion of total tonnages of grain moved by each mode of transport, is an integral part of the analysis of the grain supply chain. Grain may use multiple forms of transportation to reach the end consumer – starting from farm to truck, truck to rail depot, and ending with either a barge or another truck. While there is competition between the modes of transportation, having multiple methods allows the industry to balance the allocation across those modes. It also enables farmers to use the efficient, relatively inexpensive system to transport the grain produced. From a study done by the USDA, trucks accounted for 64% of total U.S. grain transport in 2013, with 24% for railroads, and 12% for barges. Figure 8 explains further the modal sharing trends for recent years. As seen in the chart, railroads are facing an increasing competition for grain traffic, as trucks are continuing to rise in popularity.

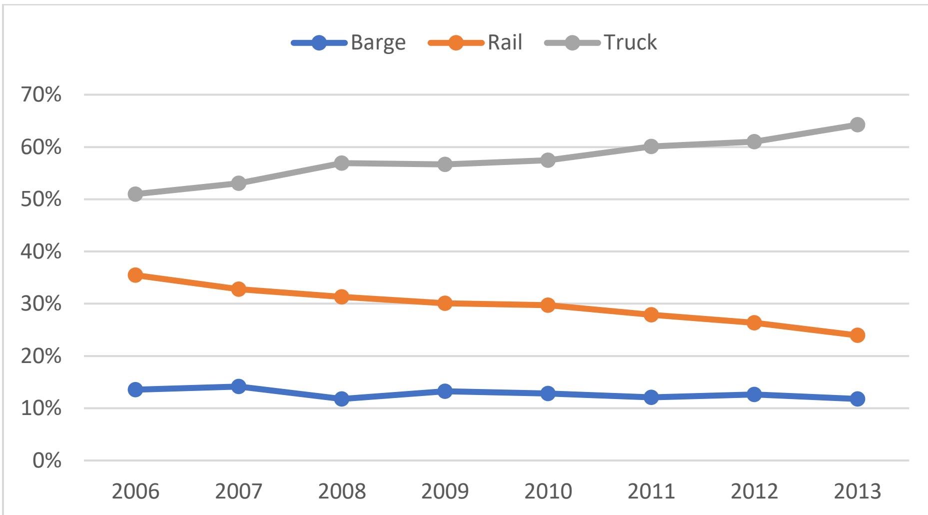


Figure 8. Modal share for total U.S. grain movements (domestic and export)
Source: USDA Agricultural Marketing Services

The logistics chain of grain is as follows (Figure 9): grain is produced and stored at centrally located storage sites, using grain elevators to accumulate for large shipments, then the grain is moved to either domestic or export markets using various modes of transportation. Elevators are more frequently acting as temporary holding areas before grain can be relocated to a mainline subterminal.

The USDA found that the tonnage of grains transported increased by 63% from 1978-2010 and this trend continued. The bulk of this grain consisted of wheat, soybeans, and corn. As of 2010, 61% of grains shipped were corn, followed by soybeans at 18%, and wheat at 16%. Truck use increased by 157% from 1978 to 2004, while barge use increased by 31%, and train by 16%.

The different modes of transportation have practical distance uses. For trucks, shorter distances ranging from 250 to 500 miles, is the most cost effective. Railroads are more often used for distances greater than 500 miles, and barges make an excellent method over water – having the equivalency of 15 rail cars or 60 trucks with significantly less cost.

Class I railroad consolidation is influencing the overall management of the grain handling industry, affecting the barge industry too. Short line railroads which lead inland to the smaller capacity elevators are progressively being bypassed in the grain supply chain. By exploiting operating efficiencies, primarily in the form of consolidating trackage and rolling stock around larger grain elevators, trains are able to be more competitive. By optimizing to fill entire trains with one load of grain, trains can operate much more efficiently.

The flipside to this is that trucks are picking up the slack between the small and large grain elevators. Limitations on roadways due to weather, the intended capacity for the roads, and other infrastructure considerations has raised questions about the increasing dependency on trucks to transport grain to the centrally located grain elevators. For example, the average trip distance in North Dakota was 12 miles in the 1980s and, by 2000 had increased to 32 miles for wheat and 44 miles for barley.

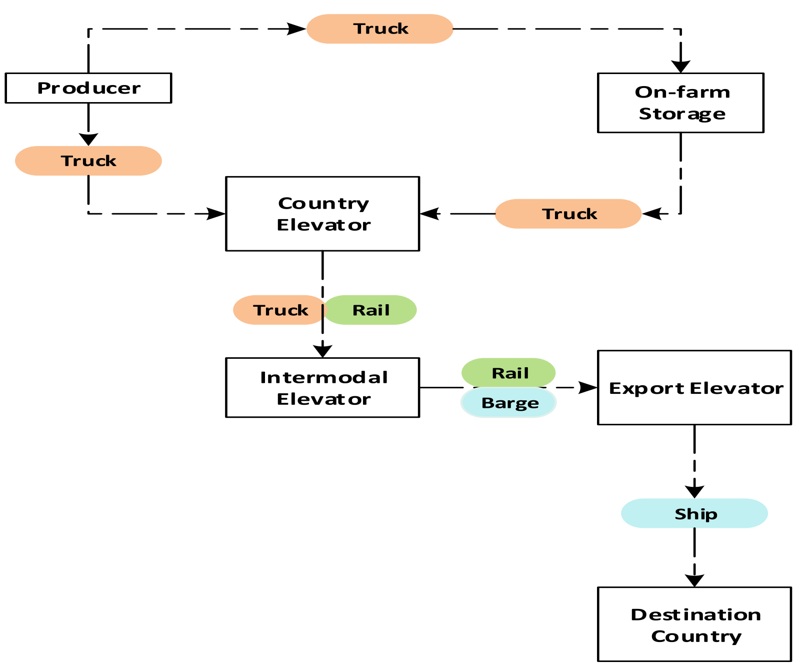


Figure 9. Modal flow of grain exports

In Figure 9, an overview of the flow for grain exports is shown. Ships play a critical part in the facilitation of agricultural exports, especially along the Mississippi River. Significant portions of the corn and soybeans exported from the United States is sent through the river. Interestingly, 40% of the barge fleet is owned by Agribusinesses like ADM, ConAgra, Cargill, and Bunge.

1.10. Grain Containerization

1.10.1. The Connection between Grain Container Logistics and Economic Theory

There is considerable debate about whether changes in supply chain organization lead to improved efficiency. With grain transportation, the traditional bulk handling systems are being challenged by emerging containerized systems.

Mixed systems, as opposed to pure systems, are better at handling volume fluctuations. With grain volumes rising dramatically at the beginning of the harvest season, peaking at the end of fall, and tapering off into winter, the mixed systems are more easily able to accommodate the fluctuations. This pattern is reasonably predictable, but still is dependent on prices and weather conditions.

Pure systems, like bulk handling, have a more difficult time serving peak demands profitably. Since they require more overhead, the peak capacity remains idle during non-harvest seasons. Figure 10 presents two cases, of (a) a normal peak and (b) an exceptionally larger crop year. The economic model illustrates the allocation of railcars under a free market pricing scenario. The bulk system for grain is a high fixed-costs that is subject to a greatly varying peak load, and has a difficult time adjusting to accommodate changes in demand. In Figure 10 (a), the peak load demand is accommodated by the price rise to allocate the available supply, while the off-peak season prices fall to cover short run marginal costs. Still, this leaves railcars empty as there may not be enough demand to use them. Figure 10 (b) illustrates the case of a large crop year that creates a demand surge. The demand cannot be satisfied because the existing fixed infrastructure cannot accommodate it. In this scenario, peak demand can be shifted to off-peak demand for the availability of the empty railcars but the market opportunity is lost by the time.

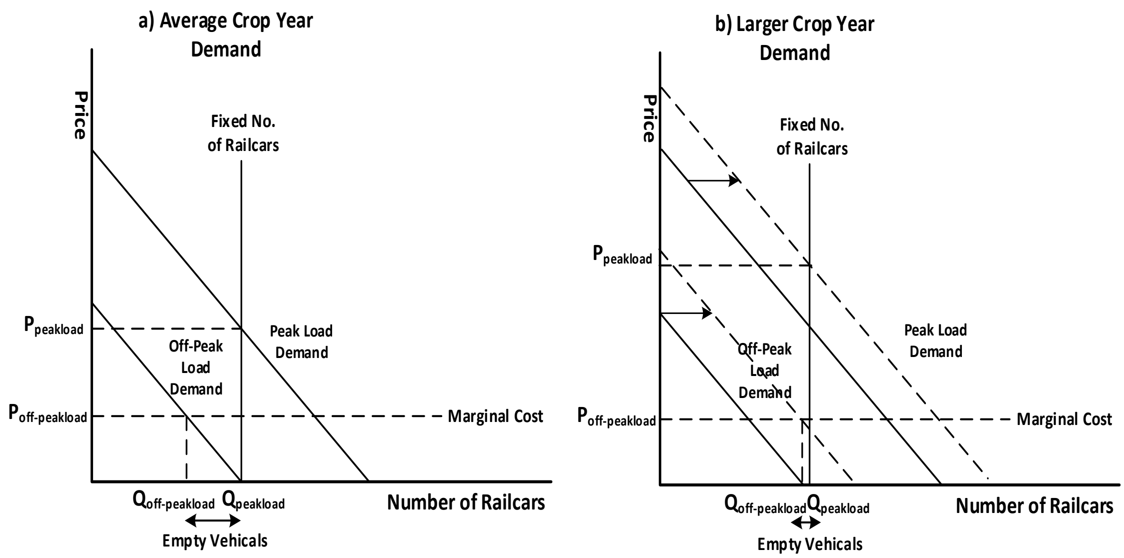


Figure 10. Peak load demand for covered grain hopper cars

The main takeaway is that pure systems suffer due to instability in grain supply and demand. Having a containerized system to shift and accommodate demand could potentially reduce costs during peak demand periods. Because containers are not limited to just one purpose, during off-peak seasons they could be used for other shipments. Additionally, they could be used to assist with bulk handling during peak demand by removing small separations and segregations from the supply chain system. Furthermore, the containers enable small-lot buyers to source at the origin, reducing the overall transit and handling costs, as well as overheads and profits from other entities.

Bulk handling systems are not expected to be replaced by containerization. For lower value or generic products, like oilseeds and feed grains, they do not require segregation for they are going to be processed further in other systems. Bulk handling systems have the advantage of using economies of scale, and thus can drive the prices down, making them a strong candidate for lower quality goods – specifically ones that do not require segregation.

The variety of products required to be handled by the grain system has increased with buyer sophistication. Specialty crops like peas, lentils, quinoa, and others have emerged. Because of their handling requirements, and generally smaller shipments, containers are perfect for these crops.

Containers over bulk handling can have its advantages, as quality can be preserved easier in container quantities. Crops like peas and lentils can get damaged with continuous handling, thus exposing the product to insect damage or other quality deterioration. Using containers significantly reduces damage and maintains the value of the product. It can also reduce inadvertent blending of grains, as the containers can be tracked individually from the farm to their destination.

1.10.2. U.S. Container Industry and Grain Activity

U.S. agricultural exports are adapting to fit the world food market and face global problems such as food security, rising energy costs, dissolution of foreign government grain agencies, and increasing contract sophistication (specifications, expectations of product integrity and quality, etc.) with international buyers. Over the course of this development, containerization of grains has become a relatively small but sustainable supply chain method. In the early 1990s, grain was not often traded in containers. Recently, however, major competitors like Canada and Australia have shipped 3.4 million tons and 2.7 million tons of grains and oilseeds, respectively *(10, 11).*

International dry good trade has two market types: tramp and liner. Tramps are bulk vessel cargo shipments in charter service, and liners are general cargo vessels that follow predetermined trade routes *(12)*. Introduced in the 1950's, the container vessel conforms to the ISO configurations of the 20' and 40' Twenty-foot-equivalent-unit (TEU) and forty-foot-equivalent-unit (FEU) containers, with payloads of 40,000 and 50,000 pounds, respectively. The largest container vessels today have a capacity of 18,000 containers (13). The growth of containerized shipping, both on the global and national scales, is illustrated below by Figure 11. Despite the economic crisis in 2008-2009, there is a clearly defined positive trend in containerized shipping. In 2014, United states accounted for the share of 46.5 million TEUs of the world-wide container traffic which was estimated to be 589 million TEUs. This traffic estimate includes loaded and empty TEUs. Let us now try to understand the relation between grain industry and the utilization adaption of container market.

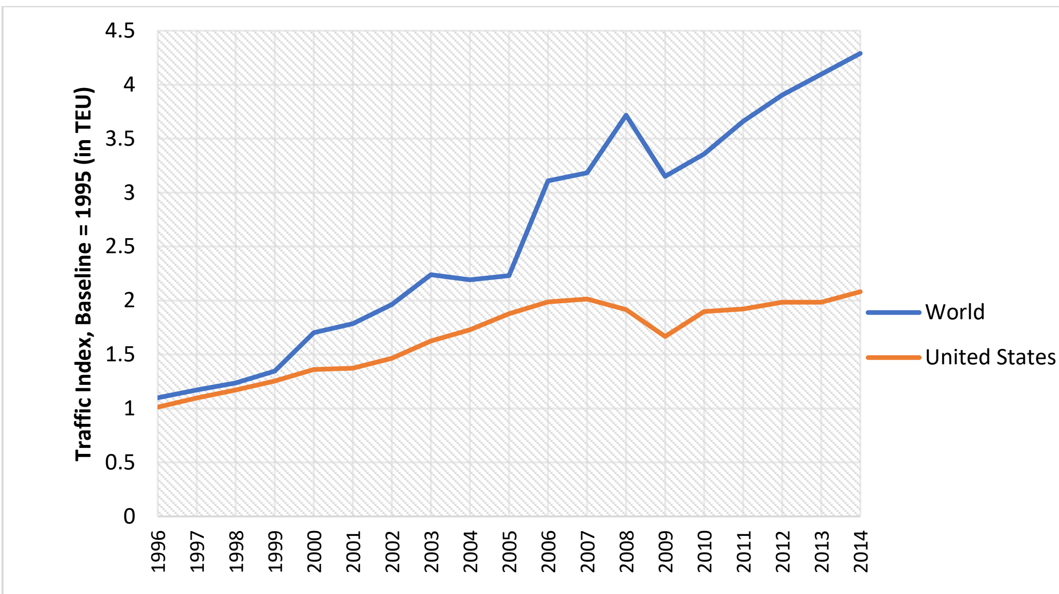


Figure 11. Containerized traffic index (loaded and empty)
Source: U.S.DOT; Worldbank

Containers have been used for decades to fulfill food-grade orders of soybeans to Japan. Recent trends show grains that were traditionally shipped in bulk methods, like feed-grade corn, have started to use more containers. This increase is due to market changes as well as industry investments that have increased availability and visibility of containers as a viable shipping option. Chicago, America's largest inland intermodal hub, has converted several local grain facilities from bulk to containers, taking advantage of the available nearby empty containers.

Union Pacific has invested in a transload facility, coupling the benefits of economies of scale for rail shipping, with minimal drayage costs due to the close proximity to the enormous supply of empty containers at the port of Los Angeles. Currently, the facility located in Yermo, CA, is focusing on distiller dried grain (DDG) feedstock shipments to Asia, but could potentially be used for oilseed products in the future.

1.10.3. Intermodal Network for Agriculture and Grain Products

Understanding the connectivity between major nodes is crucial to understanding how to access domestic and international containerized product markets. The volume concentration and equipment velocity is the key to economic viability for container markets.

1. Leading Container Ports

Container volumes in and out of East Coast ports are growing appreciably. While Los Angeles and Long Beach remain the bell cows of United States container throughput, New York (NY and NJ), Savannah, and Virginia ports are the fastest growing hubs (Table 1). Notably, they're all in the Southeast. Shifting demographics necessarily trigger an up swell in demand. The Port Authority of New York & New Jersey is busy raising the Bayonne Bridge at a cost of $1.3 billion to accommodate larger container ships. After more than one decade of legal wrangling, the Georgia Ports Authority has finally commenced a $706-million dredging project to deepen the Savannah harbor.

Table 1. Top U.S. container ports in TEUs (2009-2015)

Ports	2009	2010	2011	2012	2013	2014	2015	Change 2009-2015
Los Angeles	4,919,167	5,479,351	5,901,905	5,672,564	5,556,230	5,912,415	5,526,289	10.99%
Long Beach	4,063,760	4,736,900	4,687,728	4,713,965	5,297,562	5,349,776	5,172,498	21.44%
New York (NY and NJ)	3,761,330	4,216,136	4,431,053	4,406,913	4,208,723	4,041,831	4,613,058	18.46%
Savannah	1,898,745	2,147,792	2,269,213	2,289,094	2,349,151	2,605,288	2,824,529	32.78%
Port of Virginia	1,413,184	1,472,851	1,527,426	1,727,195	1,872,462	1,999,229	2,003,703	29.47%
Houston	1,262,816	1,341,897	1,430,907	1,491,920	1,563,060	1,664,448	1,753,047	27.96%
Oakland	1,542,881	1,673,857	1,693,993	1,690,612	1,762,202	1,769,048	1,656,440	6.86%
Tacoma	1,150,675	1,086,347	1,156,017	1,387,552	1,573,954	1,714,089	1,646,508	30.11%
Charleston	941,091	1,061,326	1,122,392	1,209,812	1,289,066	1,433,720	1,551,578	39.35%
Seattle	1,219,345	1,601,842	1,573,558	1,435,402	1,236,727	1,008,263	1,072,946	-13.64%
Honolulu	686,180	749,375	745,985	787,281	867,108	891,934	797,906	14.00%
Miami	622,637	678,916	701,815	735,893	709,504	682,386	765,980	18.71%
Jacksonville	631,384	725,472	771,203	715,887	752,402	800,630	755,452	16.42%
Port Everglades	531,546	578,950	608,355	638,546	698,673	748,501	716,182	25.78%
San Juan	809,483	824,964	806,102	720,307	752,254	773,900	715,449	-13.14%
Baltimore	453,125	495,158	505,636	544,018	555,407	574,375	609,186	25.62%
New Orleans	231,554	274,692	306,735	292,301	301,704	329,768	365,699	36.68%
Anchorage	253,977	267,624	266,598	282,268	259,935	334,846	320,530	20.76%
Philadelphia	153,579	166,335	184,414	202,294	264,174	317,789	305,673	49.76%
Wilmington	184,268	199,727	222,240	190,100	222,898	229,565	232,731	20.82%
Wilmington	184,268	199,727	222,240	190,100	222,898	229,565	193,464	4.75%
Boston	158,764	130,206	142,965	146,421	161,080	179,705	191,198	16.96%
Portland	162,051	135,885	156,837	155,396	148,425	130,213	191,198	15.24%
Top 20 U.S. Ports-Total	27,235,810	30,245,330	31,435,317	31,625,841	32,625,599	33,721,284	33,981,244	19.85%
All U.S.Ports - Total	28,467,280	31,507,445	32,745,592	33,236,967	34,484,687	35,867,974	35,665,402	20.18%

Source: U.S. Army Corps of Engineers, Intermodal Association of America (IANA)

2. Inland Container Transportation

Inland truck and rail demand between consolidation points along the coast has increased due to the growth of U.S. container traffic. Shipping lines, traditionally, have combined drayage and ocean shipments into one service contract. Recently, however, shipping companies have separated the ocean services and the drayage portion of the contracts. Unfortunately, this has created challenges in procuring chassis and container supplies, especially for small companies not near the supply pool. While drayage is not the primary focus of this analysis, it still impacts the economics and fluidity of container movements *(14)*. Both trucks and rail are vital to the transportation of containers, focusing on individual and trainload shipments, respectively. Double stack loads have been invaluable to the economic viability of lower-value commodities.

3. Rail Container Terminals

Intermodal means of transporting containers are primarily dependent on rail and truck involvement, and are closely tied to the grain container exports analyzed here. Drayage is the service of transferring a container between loading and shipping sites. Truck involvement is primarily in dray for the transportation between Midwest grain production and export locations. Drayage distance is an extremely important consideration to account for, when assessing the economic viability of transport cost for containers illustrated in Figure 12. Cost increases with distance, and as such, rail becomes vastly more cost effective over long distances. Chicago has transformed bulk-grain facilities into container loading ones with relative ease, for there is a large inland container pool available to pull from.

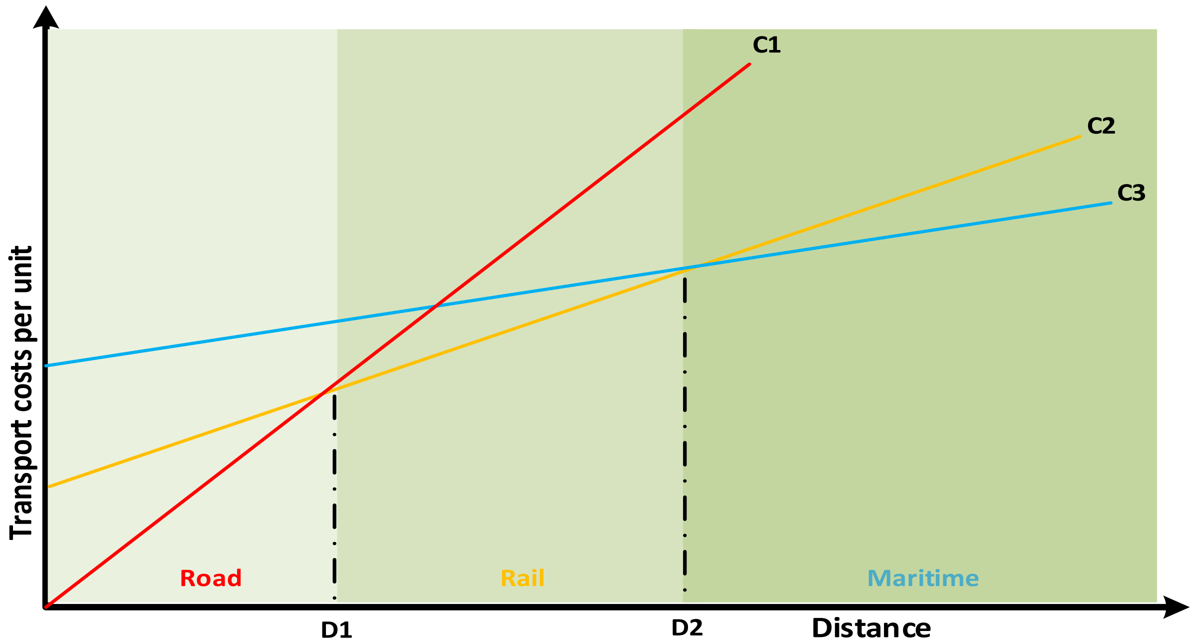


Figure 12. Modal cost analysis
Source: Rodrique, J-P et al. 2012

Grain shipments currently depend on backhaul or match-back opportunities created by high-value inbound products because it is a lower-value containerized good. Portland was one of the top origins for containers in 1998, but is no longer even in the top 20 *(15)*. This is likely due to changes in shipping schedules, and as a result, rail patterns for empty containers. These patterns change over time because of international vessel operator decisions. Being able to recognize and adapt to the transient conditions is critical to the success of the long-term growth and sustainability of the grain industry.

1.10.4. Grain Product Shipment Activity Through Rail

The Public Waybill sample provides a good understanding of the inland origins and port region destination network for container traffic. Rail shipments can disaggregate much of the inland traffic. While activity has increased over the past years, agricultural shipments are still a minority of the total rail traffic, as is seen in Figure 13. Farm products, Standard Transportation

Commodity Code (STCC) group 01, accounted for 0.3% in 2006, and 2.873% in 2014, peaking in 2009 with 3.635%. This peak was during the economic crisis, when total rail traffic had plummeted.

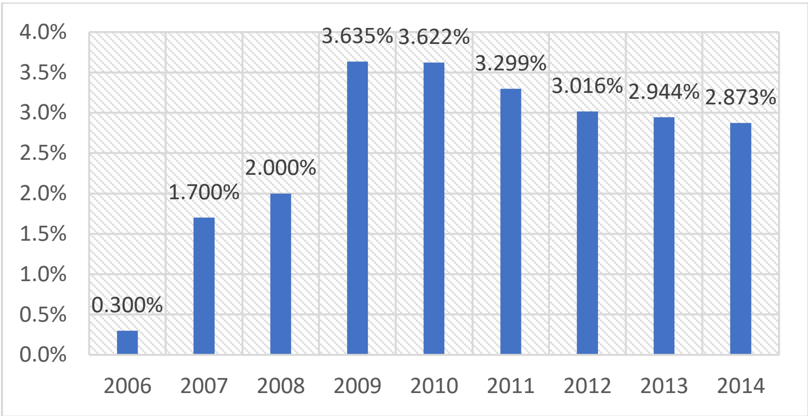


Figure 13. Farm product STCC group share in all rail container traffic
Source: Bureau of Transportation Statistics

2. PROBLEM STATEMENT

There has been a significant growth in container shipments over recent decades. Averaging around 10-11% growth per year, the United States is one of the largest and fastest growing markets for containerized trade *(16).* The high volume of containers passing through U.S. ports shows the opportunities available within ports and inland transportation networks. Because of the rapidly growing container trade, freight and rail companies are having to adapt to the increased throughput. International container trade is causing congestion in the United States' transportation network, as well as ports and other gateways. With such an increase in container traffic, rail capacity is going to become even more critical as demand continues to increase.

Empty container repositioning remains the largest and most longstanding issue for containerized maritime trade. Despite its abysmal cost-benefit ratio, it remains a staple in international shipping practices. Balancing empty loads between the different transportation methods, as well as accounting for costs involved with empty container repositioning is an extremely complex logistical endeavor. Typically, empty vehicle miles only become a significant problem when import and export customers are further inland, leading to significant overhead costs for all stakeholders involved.

Among agricultural businesses, there has been a substantial increase in the demand for containerization of grains and other commodities. Traditionally shipped in bulk-transportation methods, often holding upwards of 60,000 tons of a single-cargo type, grains exported from the United States are now seeing an uptick in the use of containers. According to the Seabury Group, citing that 17% of agricultural products were shipped from the United States via containers in 2016 – this figure includes high-value perishables as well as the grains. Since 2006, containerized grain shipments from the United States to Asia have more than doubled, and this trend is expected to continue. Reasons for this include:

- Increased demand for Identity Preserved and specialized grains, used in tofu, miso, and soy milk. It must be loaded locally to preserve the grain's food safety.
- Containerized imports allow smaller quantities, which enables smaller Asian importers who otherwise cannot commit the required capital to import agricultural products.
- Dietary shifts from rice to grain, meats, and dairy in China require significant increases in the amount of these goods to be imported. Containers make the logistics much simpler.

Because of the growing demand of exports from the United States, and economic downturns slowing growth of imports, there is an increasing imbalance of available empty containers. Since there are no containers available, particularly for inland exporters, it is becoming extremely difficult to ship goods overseas. The disparity in distance between places where imports are being unloaded, and exports loaded, coupled with rising energy and transportation costs, means an even greater challenge for U.S. based exporters. It is becoming unfavorable and costly to provide empty containers to rural Midwest and Plains grain exporters, since inland rail and truck transportation rates have increased manifold.

No single solution will resolve the imbalanced dynamics between inland exporters and coastal importers. Large scale, long term coordinated efforts between railways, trucks, and shipping lines will be essential in solving the logistical problems currently faced by the industry. With the growth of agricultural exports, the newfound economic viability may be the catalyst required to shift the imbalance.

Minnesota is the fourth largest agricultural exporting state in the United States. Grain has to travel relatively long distances to reach to intermodal terminals or ports in order to be shipped to its domestic or international destination. Therefore, containers are seen as the preferable choice of shippers to transport grains because it offers possibility to decrease transportation cost and widen marketing options. Unfortunately, current exporters are put at a competitive disadvantage when they are unable to obtain containers at a reasonable cost and new market entrants face a barrier in serving new markets. This situation has increased the desire with inland, small-market shippers for additional and closer inland container terminals with shorter truck hauls and increased access to empty containers.

Centering on Minnesota, through literature reviews, the shortage of available export containers is largely due to the following reasons:

1. There is a reduction in number of available empty containers due to the limited container depots.
2. Due to the volume concentration and equipment velocity goals there is huge dependence of ocean carriers on large intermodal terminals (Inland Ports) in Chicago, which is the cause of expensive drays for the shippers in the region.
3. In order to improve asset utilization and turnaround time many carriers have uncoupled or terminated their chassis business. This affected inland market customers with restricted container dray service, forcing them to transload near the coasts, where import loads are unloaded. This transloading in proximity to the ocean ports has lessened the inland flow of containers.

2.1. Proposed Solution

To mitigate excessive empty vehicle miles, and shortage of containers, it is proposed to strategically establish Inland Depots in regions with sufficiently high trade volumes. Inland depots aim to minimize total system costs for empty container repositioning, while providing customers with their desired level of service. Inland depots will fill a gap in the transportation market, and optimize empty container movements within a region, while simultaneously providing a region with a buffer storage for empty containers. Additionally, import containers will be able to wait locally (reducing the congestion at the ports) until a corresponding export load is found.

2.2. Characteristics of Ideal Location for Inland Depots

To be a good candidate for an Inland Depot, there must be at least one class I railroad servicing the area, as well as a developed logistics base to complement the rail – including trucks, third party logistics providers, forwarders, warehousing, and other logistical operations. In order for this logistical base to operate smoothly, adequate interstate and marine access are necessary. If available, space should be allocated for expansion, and the throughput volume must be sufficient enough that full intermodal trains can arrive and depart, with enough room to move containers and cargo around easily. To manage this complex array of entities, a real-time information system for tracking containers would be critical to coordinate with all members of the supply chain. High capacity highways would also be crucial to the inland depot's success, as the links between rail and marine intermodal terminals facilitate efficient transportation between locations in the transportation process.

2.3. Research Objective

In order to address the two main concerns of excessive empty vehicle miles and shortage of empty containers in the study region, this research recommends opening new empty container depots inland in the region, in addition to the depots currently being located near the ports. The specific objectives of this research are as follows:

Phase 1. Use GIS approach coupled with weighted linear combination to classify and evaluate the current status of brownfield sites and find the acceptable locations for new container depots. The comprehensive GIS database was used to analyze the data collected for brownfields in the study area.

Phase 2. In order to find the optimal location for the new empty container storage depots a quantitative model that solves a depot location-allocation (LA) problem taking into consideration the existence of inventory and capacity constraints of the depots, under deterministic demand patterns, was developed.

Phase 3. To develop an agent based model for empty container movement in the region to investigate the feasibility, viability, and effectiveness of the proposed system. We use a model to simulate the movement of empty containers in the proposed system, subject to the real configuration and behavior of the network. The framework will be used to analyze the response of system performance measures to changes in model parameters.

2.4. Significance

Earlier models in the literature addressing optimal depot locations mostly proposed operational tools to be run every few hours, to determine the best set of 'hiring' depots from a set of existing depots. This was done to minimize the cost of transporting empty containers in the network. In contrast, the amalgamation of research presented here details a strategic model, focused on public benefit. New depot locations are determined from a pre-specified set of potential sites. Additionally, the introduction of new depots closer to elevators, farms, or other production clusters, not only reduces vehicle miles (and cost), but also adds capacity to store empty containers in the region with higher import activity. Previous studies recommend that inland depots be located in the upper Midwest, but have not touched on (either exploratory or empirically) a solution for the shortage of empty container problems in the area. One of the goals of this research is to outline and provide a practical approach to container shortages for grain farmers at the regional level. It is a first attempt of a realistic solution to help boost farmers' exports, as well as increasing the profit margins because of the reduced empty container drayage costs. Mathematical models are developed and presented to evaluate the proposed system, while also analyzing the benefits from the inland depot concept. All of this is analyzed within the context of deterministic and stochastic demand patterns.

This research is meant to provide an outline of the significance and scope of the empty container allocation problem. It is intended to be speculative, in that it describes the benefits that will be experienced as a result of this undertaking. Such benefits are primarily the reduction in empty miles, and the availability of empty containers for farmers and producers to export grains to the international market. To evaluate the effectiveness of the proposed solution, the models developed will be applied to specific regions within the overall study region, accounting for the nuances and particular conditions therein. To reinforce its credibility, stress testing of the proposed model will be done under a number of different scenarios to create the best and most accurate deterministic and stochastic models.

3. STUDY AREA

The State of Minnesota is the most appropriate area to evaluate the sites for new inland depot locations. The Minnesota economy is mainly made up of the transportation system. Consequently, the system within the state has diverse freight movements that range from home deliveries to venture supplies, consumer goods to business parts and equipment and from crops to iron ore. Competent and timely freight movement, in Minnesota matters to the largest companies in the state, small, and medium sized ventures, consumers, workers, and farmers. The freight not only affects Duluth and Twin Cities as the main transport hubs but also has an influence on the communities within the larger Minnesota. By the year 2035, it is expected that the freight loads to Minnesota will have doubled from the 2002 size. Current Volume

A good freight transportation system is imperative for the steady economic growth of a state. Some of the challenges that hinder the smooth operations in Minnesota include; huge freight vehicles, an increase in freight quantities, and a wearing out transportation infrastructure. The necessary changes on the freight infrastructure need the participation of both the private and public sectors. The two should be part of the development because the private ventures often move their freight on improved transportation infrastructure done by the government. Moreover, the private sector also operates and owns major parts of the road and rail network.

3.1. Minnesota's Freight

1. The main forms of cargo in Minnesota include farm products, metallic ores, coal, food products, and nonmetallic minerals. Some of the freight that has monetary value to the state includes food products, farm products, electrical materials, and transportation equipment. Taconite, in Northeast Minnesota, is the most shipped commodity, which is done via water

and rail but in the Western Minnesota, food and farm products are common commodities. (Minnesota Department of Transportation, Minnesota Statewide Freight Plan)

2. According to the estimates obtained in early 2012 by Mn/DOT, the freight shipments leaving Minnesota to other locations account for 30%, while 24% accounts for those arriving from different destinations. Approximately one-third of Minnesota's freights travel from one destination to another within the state, while about a fifth only passes through the state to other parts of the nation. (Minnesota Department of Transportation, Minnesota Statewide Freight Plan). Minnesota exports to 200 countries and more but some of the close trading partners such as Canada have a mutual trade efficiency that surpasses $14 billion every year as per 2016 (http://can-am.gc.ca/business-affaires/fact_sheets-fiches_documentaires/)

3.2. Intermodal Freight Transportation in Minnesota

Cargo moves into and out of Minnesota utilizing various modes of transport such as rail, road, plane, and trucks. On most occasions, shippers load similar goods and commodities onto various forms of transportation for diverse parts of the journey. The movement of cargo involves various means of transport; consequently, the conveying of freight between locations is an imperative opportunity and challenge for haulers and producers. For effective transfer of commodities and goods it is important to have intermodal facilities such as elevators, freight container operations, vehicle ramps, and terminals.

As a producer of heavy commodities, such as iron ore, grain among other crops: Minnesota heavily depends on water and rail for cargo movement. When transporting heavy loads, railroads and ships are the best mode of transportation. In Minnesota, freight movement is imperative;

therefore, the state ought to have proper infrastructure in rail and water. The condition of the state's infrastructure has a direct influence on its economy.

The railways transport in Minnesota accounts for one-seventh by value in dollars and one-third measured by weight. Since 2013, railroad carloads worth approximately 3.8 million and about 245 million in tons travelled through the Minnesota rail for over 4,500 miles (Minnesota Regional Railroads Association). Goods and commodities that travel by truck are often loaded onto rail at private intermodal facilities. The private intermodal facilities are also used in the unloading process from rail to truck; therefore, rail is imperative in Minnesota for the freight transfer. More than forty locations are available within the state for truck and rail intermodal transfers.

Travelling across the Great Lakes, Minnesota has made it possible for other states to share the freight by transporting grain, iron ore, and other agricultural products, down through the Mississippi river. In 2015, the transportation of about 35 million tons of cargo was done through Twin Ports within Superior WI and Duluth MN, Two Harbors, Silver Bay, as well as Taconite Harbor on Lake Superior. Additionally, 12 million more tons were transported through Minneapolis' river ports, St. Paul, Savege, Red Wing, and Winona. Similar to rail transport, goods and commodities ferried through water ought to be followed in and out of ports; therefore, intermodal transfers are imperative.

Different from other forms of transport, airfreight carries items that are light in weight, but of high value. Minnesota has more than 12 airports scheduled to carry goods and commodities and approximately 20 more that offer freight flights on demand. Minnesota does not have a freight carrier that specifies cargo transportation to specific destinations of the world, despite having Minneapolis-St. Paul airport for freight services within the country. Therefore, the state depends highly on trucks that transport goods to Chicago where they are air shipped globally. On most occasions, the goods and commodities have to be ferried in passenger planes from Twin Cities. Twin Cities often experience truck congestion as they try to carry cargo to St. Paul airport Minnesota for air shipment.

3.3. Exports of Minnesota

The agriculture sector is very important within Minnesota. The state is the fourth largest exporter of agricultural products within the country (Figure 14). In 2014, the state exported agricultural products worth $ 7.3 billion an improvement since 2000, as the sector had grown by 236%.

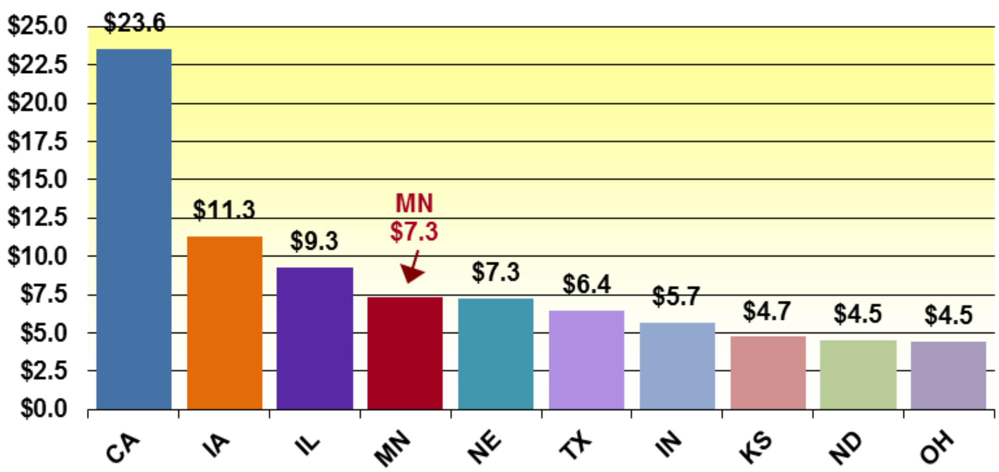


Figure 14. Agricultural exports in Minnesota (billion $)
Source: U.S. Bureau of Census, USDA; MDA-AMD.

Agriculture is the highest exporting industry of Minnesota (Figure 15). The total growth of the agricultural sector within Minnesota from 2000 to 2014 was 193% higher than the national growth. Some of the top exported commodities from Minnesota include pork, soybean products, soybeans, dairy, corn, and feed that make up about 70% of the exports. Consequently, the state's economy is highly dependent on agriculture as it has created more than 60,000 jobs directly or indirectly. The largest markets for agricultural products from Minnesota are China, Canada, Mexico, Japan, South Korea, and Taiwan sequentially. The first six markets are also America's top markets in agricultural products. For about fourteen years, the accumulated growth from these six markets was more than 200%. China was leading with a growth of 850%, then Mexico at 202% and Canada at 187%.

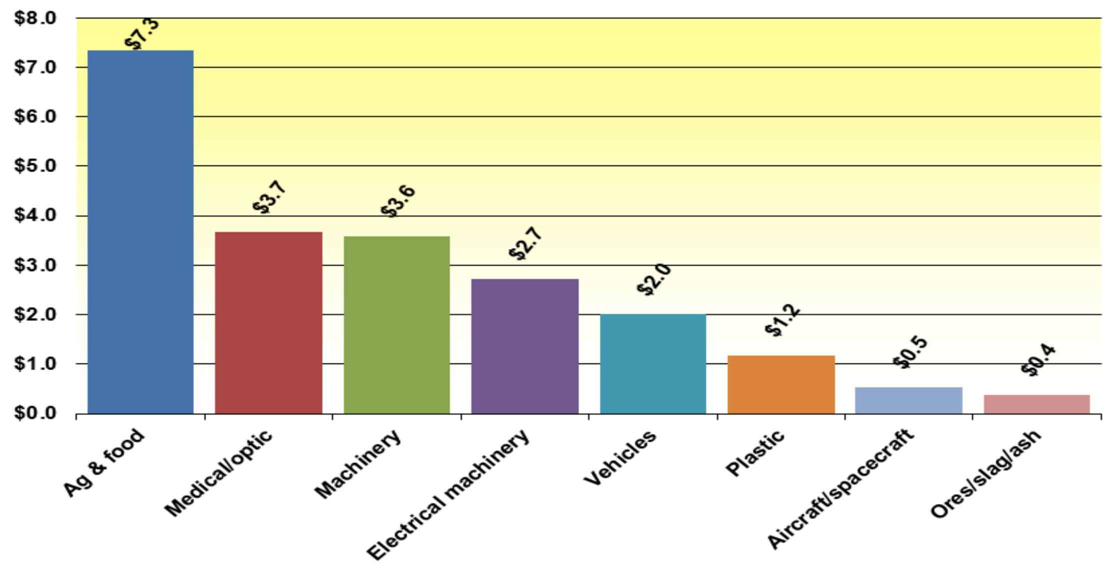


Figure 15. Exporting industries in Minnesota (billion $)
Source: U.S. Bureau of Census, USDA; MDA-AMD.

3.4. Problems with Current Practice in the Study Region

1. Limited Intermodal Services

The Midwest is a very important transportation gateway as it connects the importers and exporters in MN, WI, and the upper MI that are contiguous to Pacific Northwest (PNW) gateways. These gateways take part in significant exports of containerized agriculture commodities. The current port of choice for most Midwest exporters are the Pacific Southwest ports of Los Angeles and Long Beach due to the limited or circuitous intermodal services to other regions outside the northern Minnesota. For Example, due to the east-west orientation of the rail network, the intermodal service linking Minneapolis to Los Angeles moves via Chicago, which makes the shippers to dray containers to Kansas City rail terminals making it an economical choice for small subset of shippers.

2. Constrained Expansion of Existing Terminals

The exponential growth of the trade has constrained the capacity of the present rail intermodal services in Minnesota. Moreover, the increasing intermodal traffic presents a challenge for rail terminals in urban settings. The decision to expand an intermodal terminal is influenced by the limitations of land and locality that is impacted by noise, congestion, and other perceived sources of pollution. The BNSF Intermodal terminal in St. Paul is an example of a terminal that has limited ability to expand.

3. Higher Repositioning Cost

Minnesota is experiencing a lack of empty container pool due to which the shippers must arrange them from other sources, drastically increasing the cost of repositioning empty containers. For the exporters at St. Paul Minnesota, the cost trucking empty containers from Chicago is almost equal to trucking the load to Chicago. But, if the shipper in St. Paul already had a container available locally it would cost him almost half the price than those of Dilworth shipper.

4. Higher Investment Cost for a Class I Terminal

The cost of developing a Class I intermodal terminal is much higher, that the return on the investment made cannot be justified for the inland locations. However, the private entities could be encouraged to invest for a short line intermodal terminal or an inland depot, if the location already has some infrastructure in place. The cost of trucking containers from Montevideo to St. Paul MN, is estimated to be $21 per ton. This compares to the cost of using rail to move containers which is only between $10 to $13.69 per ton.

5. Intermodal Terminal Growth in Chicago

There is significant intermodal growth in the Chicago area. Even at the time of recession the lift counts increased by about 7.18% (Chicago Metropolitan Agency for Planning, (CMAP)), a big portion of it is agriculture commodities contributed from upper Midwest. Increase in intermodal port volumes may result in better intermodal rail efficiencies, but today the intermodal terminals with the current facilities in Chicago are not prepared to handle the projected volumes.

Trucks have been regarded as the economical mode of transportation for the roundtrip movements of less than 500 miles. But due to the rising fuel prices, increasing congestion and driver shortages the trucking distance of 500 miles is challenged. To overcome the problem more intermodal rail terminals are developed on the same rail road, thereby decreasing the space between them. Chicago and big intermodal hubs are already exhausted and congested to have more terminals.

So, there should be an intermodal facility or an Inland depot at the production clusters to stop this movement to Chicago and will also help to mitigate the problem of congestion in these metro cities.

6. Many Exports Need Containers

Minnesota is the fourth largest agricultural exporting state in the U.S. The grain has to travel long distances to reach to the U.S. ports. In some cases, the identity preserved grain is loaded into a container directly from the field. While in some other cases the soybeans and Dried Distillers Grains (DDG) are trucked to an intermodal facility and then the containers are loaded for their journey by rail to a nearby port gateway. In this way, utilizing the grain containers the producer can control the purity of the grain till it reaches its final destination.

3.5. Need of Inland Ports in Minnesota

Input from various manufacturing and food processing firms in the South-East Minnesota region noted a consistent desire for better access to railroad container transportation. The issues revolved around congestion and a poor rate structure for import and export container shipments through the Twin Cities, no direct or expedited service to the Pacific southwest ports of Los Angeles/Long Beach, increasing trucking costs to reach Chicago or Kansas City, and poor equipment availability in terms of empty containers. Several food shippers faced a further complication with the need to access refrigerated equipment. In spite of all these issues, virtually every interested shipper saw a great potential for better market access, especially foreign exports, if additional container terminal capacity or the start-up of a nearby facility could be arranged.

The Class I railroads, in particular BNSF and Union Pacific west of Chicago (including their predecessors), at first came to the intermodal revolution reluctantly. Eventually, the container services became major profitable business centers for the railroads, they in turn consolidated their investments into the major long-distance end-point terminals. This maximized their return on a high capital-intensive operation and reduced total labor costs. They and shippers relied on truckers to do the final distribution and deliveries, and to collect cargo back into the major terminals.

Ocean carriers also sought to decrease their expenditures, by offering incentives as motivation to consumers who did not move their containers inland. The ocean carrier always experienced repositioning problems due to empty containers imbalance. The ocean carriers knew it was cost ineffective to transport an empty container without obtaining any revenue. With decreased containers in the internal terminals, there were higher savings and improvement of container use by not having them idle in corridors.

The railroads did their part to cooperate in this increasing inland service dislocation. Always conservative in capital investment, the rail carriers protected their major terminal investments and maximized their profits by pricing smaller and intermediate terminals above the competitive rates they maintained on containers moving through the major urban terminals. A prime example is the Twin Cities, where the basic container rate to ship a container from the West

Coast to Minneapolis or St. Paul is as much as $700 higher than for a container moving on to Chicago, making it a break-even cost proposition to truck the container back to the Twin Cities after it has passed its ultimate destination. This reflects both the extreme congestion in the Twin Cities terminals that would require investments to fix, and the desire by ocean and rail carriers to maintain economies of scale while minimizing empty equipment positions outside the major hubs.

These changes added to the confusion of inland shippers' especially the exporters of unique products such as identity-preserved grain and feed supplements, were increasing their overseas markets, the supply of containers began to dry up. The closest alternative was to obtain an empty container and truck it from Chicago, for loading and taking it back. The second option would be trucking the load to Kansas City or Chicago and pay for the loading expenses, time, penalty in cost, paper work, and the possibility of having the freight damaged or lost. These changes in the market have increased the desire for the inland, shippers and farmers in small markets, to have small container terminals that are closer to bring back their short truck tows as well as the access to empty containers.

4. PHASE 1

4.1. Abstract

Minnesota is the fourth largest agricultural exporting state in the U.S. For Class I railroads grain and grain related food products accounted for 7.9% of carloads, 11.3% of tons hauled and 12.2% of revenues. Much of the grain exported, has to travel long distances (more than 1,000 miles) to reach U.S. ports. These increasing volumes of grain are being shipped in containers because containers offer opportunities to lower logistics costs and to broaden marketing options. Consequently, exporters are put at a competitive disadvantage when they are unable to obtain containers at a reasonable cost for their exports and new market entrants experienced threat to their new markets. This situation has increased the desire with inland, small market shippers for more and closer container terminals, for shorter truck hauls, and increased access to empty containers.

The objective of this phase is to prepare a comprehensive database of Brownfield sites and find the suitable locations amongst them in order to establish new container depots in the state of Minnesota. Geographic Information Systems (GIS) with multi attribute Weighted Linear Combination (WLC) that is based on weighted average, are the tools used to conduct the analysis. The criteria that were used to select suitable sites are Grain elevators, highways, railroads terminals, port terminals, social and economic factors. The result of the study showed that there are 90 locations that are potentially feasible for the development of new container depots in the state of Minnesota.

Keywords: GIS (geographical information systems), multicriteria analysis, exploratory spatial data analysis (ESDA), location-allocation analysis, decision support

4.2. Brownfields

The increased costs in the redevelopment of a site due to unknown or actual environmental pollution of land that is redundant, unexploited, or neglected within viable and industrial locations are known as Brownfield *(17).* Brownfields are commonly linked to metropolitan locations that were once industrialized and evacuated. A Brownfield can range from a small deserted filling station to a large steel mechanized operation. The definition of Brownfield on certain instances may be the opposite of "Greenfields" which is a location reputed to be free from contagion, and had not been previously utilized for industrial or commercial reasons. The pollution levels at Brownfield locations can vary from soil fragments to widespread contagion of ground water. The counteractive costs of a Brownfield can be as little as a few thousand to millions of dollars depending on the project's level of cleanup and pollution levels *(18).*

Brownfields have been in existence for many years. This has led to a Superfund program that was first launched in 1980 by the United States Congress to offer monetary aid for the overhaul of perilous locations. Additionally, the remediation sought to improve sites that had been established to pose risks in safety and public health as well as degrade the quality of an environment. The United States Environmental Protection Agency (U.S. EPA) took charge over the Superfund program. A National Priority List (NPL) was created which is a catalog of hazardous locations that qualify for the Superfund program and need a widespread remediation. This list made it easier to rank locations entitled to the Superfund program. The reformation of Brownfields was one of President Bush's main agenda which was reflected by allocating to the EPA a budget of $38 million in April 2001 to enable ninety communities to clean up the land *(17).* Furthermore, the President also sanctioned a program that would help in decreasing the liabilities in the Superfund as well as increase funds on cleanup and appraisal called S 350. Despite these efforts, there are about 500,000 polluted industrial and commercial sites as stated by the office of U.S. Government Accounting. It would be very beneficial for the country to have computer-based tools to help in the effective location, monitoring and updating of records on Brownfield locations.

4.2.1. Minnesota Brownfields

The characteristics of brownfield properties exist in most parts of Minnesota, presenting an opportune time to improve the state's economy, reduce carbon emissions, better the environmental health, and free communities from their distress. There are about 425,000 brownfields in the United States (https://portal.hud.gov/). The metropolitan and industrial locations in Minnesota are where brownfields are mostly found and few are found in the rural areas. From 1995-2014, the Minnesota Pollution Control Agency (MPCA) listed more than 8000 brownfields in the state that required clean up. By September 2014, more than 63,828 acres had been registered. Additionally, more than 13,674 acres were registered via the Petroleum Brownfields program. The locations total up to 77,502 acres, space that is larger than St. Paul and Minneapolis combined.

4.2.2. Benefits of Brownfield Cleanup and Redevelopment

The revitalization of the sites will bring about social, fiscal, and environmental benefits to the people living in the area.

1. Job Retention and Creation

The revitalization of brownfield enables people in a community to obtain and retain jobs. For every $10,000- $13,000 invested in brownfield recovery one permanent job is created, showed a national study in 2008 *(19).*

2. Tax Base Expansion and Revitalization

In more than 50 states, taxes worth $ 309 million was collected from 1993 to 2010 for the brownfield redevelopment *(20)*. The same research found that cities would collect more than $872 million to $1.3 billion every year in tax revenue if brownfields were revitalized in total of 58 cities. Numerous Brownfield sites can be found within metropolitan locations; therefore, the magnitude of tax collectable provides fiscal stimulus above what a single state or national grant could achieve.

3. Public Health Improvements

Places that have numerous brownfields are faced with increasingly high threats to public health due to the exposure to low quality air, harmful chemicals, high asthma occurrences, increased lead levels in blood, and a lack of recreation centers. Negative effects on health include death due to cancer and respiratory diseases. Therefore, the revitalization of brownfields ensure improved health for neighboring communities.

4. Meeting Increasing Demand for Land Availability

The recovery of brownfields is a way of saving land especially Greenfield land, which is often habitable and suitable for agriculture. Brownfields also present a chance for the creation of a sustainable environment, as they are located close to canals, railways, and old roads which makes them assessable and thus offers a locational advantage. The changes help in the reduction of emissions and saving energy.

4.3. Data Collection

Based on the previous work published in the literature and the main objectives of this research the following factors were considered in developing a model to determine the optimal location to open new depots. Each factor was represented in a geographic information system (GIS) data layer (Table 2):

- Physical Factor: Abandoned, idled or underused industrial and commercial sites (Brownfields)
- Convenience Factor: Grain elevators
- Proximity Factor: Highways, Railroads and Waterways
- Social and Economic Factor (distance for the residential areas, parks and schools etc.)

Each of these factors are briefly explained below:

- Convenience Factor: Grain elevators

The use of storage and transport capacity offered by grain elevators requires purposely designed container depots in the proximity, from where the freight can be transferred. The depots should be designed to be commodity specific, like in case of grains these should be designed as bulk terminals used to transport grains to the desired destinations.

- Proximity Factor: Highways, Railroads and Waterways

The complexity of modern freight distribution, the increased focus on intermodal and co-modal transport solutions appears to be main causes of the container capacity issues and thus needs a renewed focus on hinterland logistics. Congestion, energy consumption and empty movements become the driving forces to consider the setting of container depots near the railroad terminals, as the next step in freight planning. Also, due to the massification of flows in networks, through a concentration of cargo on a limited set of ports, there is an intense need for these depot nodes to appear along.

- Social, Economic and Noise Factor (distance for the residential areas, parks and schools etc.)

Trucks, trains and ships help moving cargo and surge economic growth but at the same time they also burn fossil fuels that creates air pollution.

The warehouses, distribution centers, intermodal and other logistic facilities operate 24 hours a day, seven days a week, creating constant noise. Noise pollution, when encountered continuously and at high levels (of over 85 decibels) contributes to permanent hearing loss from trauma to the structures of the inner ear. So, to address this problem, the site for setting up of new depots should be at a safe distance from the population of the city.

Table 2. Data collection from regulatory sources

Data Layer	Format	Source
Brownfields	Recorded in Excel spreadsheets which are readable by ArcMap as .csv files and shapefiles	Minnesota Pollution control Agency (MPCA) https://www.pca.state.mn.us/
Grain Elevators	Recorded in Excel spreadsheets which are readable by ArcMap as .csv files and shapefiles	http://www.bnsf.com/
Port Terminals	Shapefiles	https://www.rita.dot.gov/
Railroad Terminals	Shapefiles	https://www.rita.dot.gov/
Highways	Shapefiles	
Property Statistics	Recorded in Excel spreadsheets which are readable by ArcMap as .csv files and shapefiles	https://beacon.schneidercorp.com/

The intent of this section is to signify the step by step procedure adopted to collect the data for all the factors involved. The structure of the data collection is presented below (Figure 16):

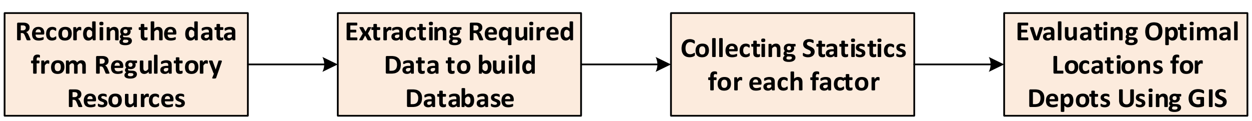


Figure 16. Flow chart for data collection

4.3.1. Property Statistics

The online EPA database and Beacon and qPublic.net are interactive public access portals that provides statistics on each property like tax parcel ID, area of the parcel, land use type, previous land use, business name, vacancy of the property etc. The data obtained is stored in excel files and later converted to the ArcMap shapefile. Moreover, the land use type is further divided on the basis of an area, Acreage $\geq$ 15. Now, the vacancy status of the property can be searched using property tax information and can be added as another new field in ArcMap. Table 3, below show the different fields of the data that were added for each potential site.

Table 3. Fields for each potential site

Site Number	Field
1	Business Name
2	Street Address
3	Area in Acreage
4	Land use Type
5	Status

4.3.2. Geographical Information Systems (GIS) - Multicriteria Decision Making

GIS - Multicriteria Decision Making can be defined as a process that transforms and combines geographical data (criterion maps) and value judgement to obtain overall assessment of the decision alternatives *(21, 22, 23, 24, and 25).* The rationale behind the integrating GIS and Multicriteria Decision Making (MCDM) is that these two distinct areas of research can benefit from each other. GIS plays an important role in storing, manipulating, analyzing and visualizing spatial data for decision-making. MCDM provides systematic evaluation procedures and algorithms for structuring decision problems, and designing, evaluating and prioritizing alternatives *(26, 27, 28, 29 and 30).*

Geographic Information System based MCDM has been used for evaluating accessibility to public parks in Calgary, Alberta *(31).* The approach involves the weighted linear combination with the entropy weighting method for obtaining the criterion (attribute) weights. The results of this research can help the park planning authorities in identifying the needs for improving the accessibility to public parks, monitoring the changes of accessibility patterns over time, and locating new public parks. GIS-based multicriteria analysis is used to identify the significant opportunities and risks associated with the use of biochar *(32).* They identified the areas where biochar application could deliver greatest benefit.

The GIS was effectively used to design a model for electing an appropriate landfill site in municipalities *(33)*. The Analytical Hierarchy Process (AHP) is used for calculating the weights for each criterion, such as residential area, road network, Geology, Geomorphology and soil. By using this modelling approach, GIS once again proved to be a valuable tool for evaluating multiple criteria in decision making. The research was to provide a preliminary wind power suitability analysis for installing medium (100 -1000 kW) and large (1000 - 3000 kW) size wind turbines in urban areas, such as the City of Chicago. Fyodorova *(34)* performed a research to provide a preliminary wind power suitability analysis for installing medium (100 -1000 kW) and large (1000 - 3000 kW) size wind turbines on abandoned and contaminated urban lands (Brownfields), such as the City of Chicago. Geographic Information Systems (GIS) and a multi attribute Weighted Linear Combination (WLC) method were the primary tools utilized to conduct the analysis. The criteria used to select suitable sites such as wind speeds, historic landmarks, avian and wildlife habitat, conservation lands, proximity to airports, roads, and transmission lines.

4.4. Analysis Methods

The most common methods used for locational analysis are Boolean Overlay and Weighted Linear Combination (WLC). Both methods "are often made up of combined approaches as none of the individual approaches provide a comprehensive method *(35)*. The Boolean method uses Boolean operation such as intersection, difference, union and other operations for the input layers. However, "Boolean searches are limiting because they provide only "yes" or "no" answers" *(35).* On the contrary, the WLC method allows assigning weights according to the relative importance of each layer to the overall suitability measurement, and then combining the map layers to obtain an overall suitability score *(36).* According to Rodman and *(37)*, this method is flexible and allows different inputs to be used to evaluate a variety of scenarios.

4.4.1. Weighted Linear Combination Analysis

To identify the appropriate sites for the development of container depots in the study area the Weighted Linear Combination (WLC) approach was used in this research. The factors such as proximity to elevator clusters, proximity to railroad and port terminals and social and economic factors were identified that were used for WLC analysis. ArcGIS Spatial Analyst 10.4 was the primary tool used for data conversion and the WLC and overlay analysis. The complete process is expressed in the flowchart in Figure 17.

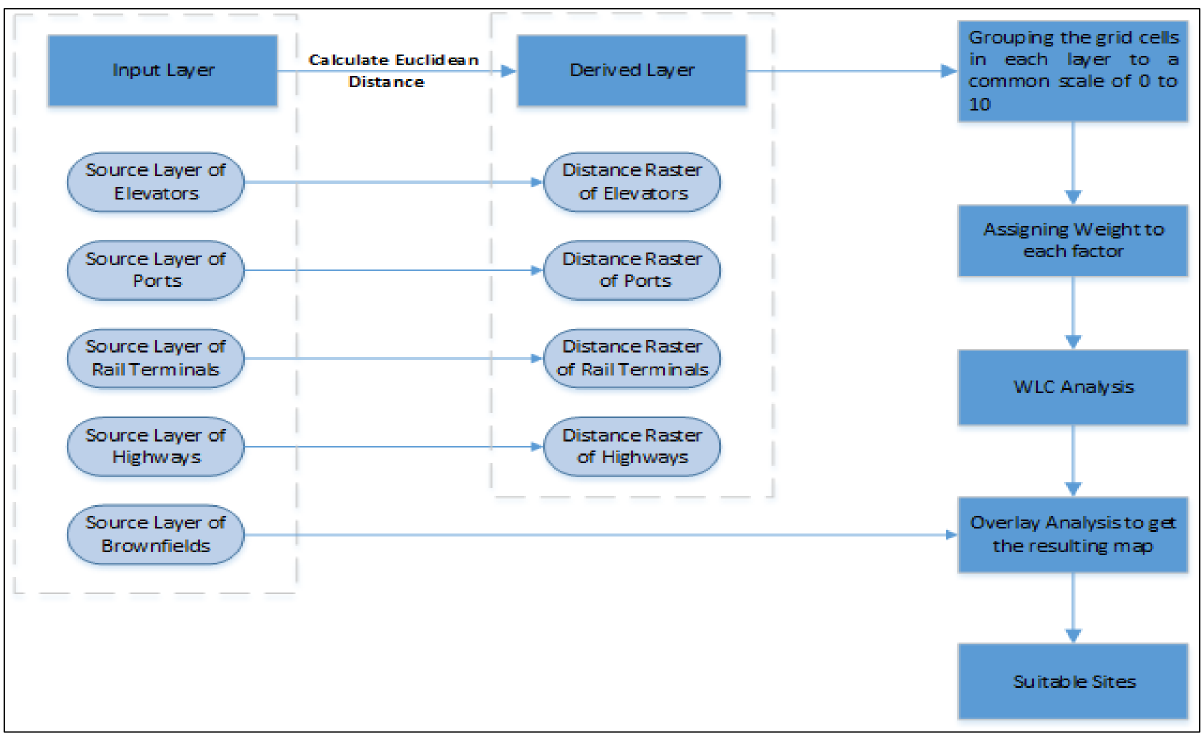


Figure 17. Flow chart for WLC analysis

1. To begin the analysis, all the data were converted to the same projection. All the data were stored in NAD27 Minnesota Project Zones in Central State Plane. The data acquired from other sources were stored in different projections and were reprojected to NAD27 Minnesota Project Zones in Central State Plane using the Arc Toolbox's Data

Management Tools >Projections and Transformations >Project, to keep the projection format consistent.

2. The next step was to prepare data for the WLC analysis by converting them to raster format and then reclassifying the grid cells in each raster layer into ten classes and assigning scores to classes.

First, all map layers (Brownfield sites, elevator clusters, Highway, Railroad terminals, Port terminals) were converted from vector to rasterbased data since all calculations were based on cell values. The Euclidean distance (Spatial Analyst Tools >Distance) was used for conversion because it creates the range of distances (buffer zones) that are calculated from the center of the objects of interest (layer features such as roads, landmark features) while converting vector layers to raster format. The distances are calculated using Euclidean algorithm. The maximum_distance was set to 25,000 meters to consider only grid cells within 25,000 meters from objects of interest as candidates. Grid cells outside of the threshold distance of 25,000 meters were therefore assigned to 'NoData' category in the output. After road data was converted to grid format, all other layers were set to the same extent as the road raster layer before being converted to raster format because it had the largest extent. The extent options were specified via Geoprocessing > Environments > Raster Analysis. Euclidean distance calculations were done in feet by default and Raster calculator (Spatial Analyst Tools >Map Algebra) was used to convert feet to meters.

Next step is to Reclassify (Spatial Analyst Tools >Reclass) grid cells in each layer to set them to a common scale. The Reclass tool allowed grouping the grid cells on each layer into ten classes and assigning score to each class on a scale of 0 to 10, 0 being the least suitable and 10 being the most suitable (Figure 18). The classes and score categories for all the variables under consideration are shown in Table 4. It should be noted that 'NoData' cells were assigned zero values, because the process of overlaying ‘no value’ cells with cells containing numerical values would result in a ‘no value’ grid cells in the output layer.

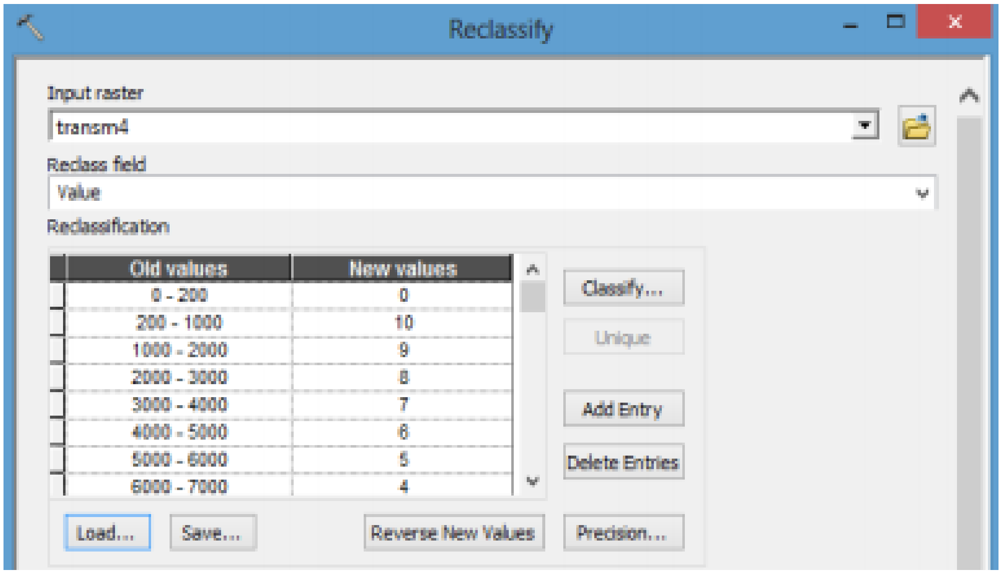


Figure 18. Reclassify tool showing grid layers reclassification

Table 4. Classes and suitability score of factors for WLC analysis

Layer	Class	Score	Layer	Class	Score
Grain Elevators	0-200m	1	Ports Terminals	0-3000m	1
	200-400m	2		3000-4000m	2
	400-1000m	3		4000-5000m	3
	1000-2000m	4		5000-6000m	4
	2000-3000m	5		6000-7000m	5
	3000-4000m	6		7000-8000m	6
	4000-5000m	7		8000-9000m	7
	5000-6000m	8		9000-10000m	8
	6000-7000m	9		10000-11000m	9
	7000-10000m	10		11000-12000m	10
	>10000	0		>12000	0
	No Data	0		No Data	0
Rail Road Terminals	0-3000m	1	Highways	0-200m	1
	3000-4000m	2		200-400m	2
	4000-5000m	3		400-1000m	3
	5000-6000m	4		1000-2000m	4
	6000-7000m	5		2000-3000m	5
	7000-8000m	6		3000-4000m	6
	8000-9000m	7		4000-5000m	7
	9000-10000m	8		5000-6000m	8
	10000-11000m	9		6000-7000m	9
	11000-12000m	10		7000-10000m	10
	>12000	0		>10000	0
	No Data	0		No Data	0
Social and Economic Factor	0-200m	10			
	200-400m	9			
	400-1000m	8			
	1000-2000m	7			
	2000-3000m	6			
	3000-4000m	5			
	4000-5000m	4			
	5000-6000m	3			
	6000-7000m	2			
	7000-10000m	1			
	>10000	0			
	No Data	0			

3. Finally, Weighted Overlay tool (Spatial Analyst Tools >Overlay>Weighted Overlay) was used to conduct WLC analysis. During this analysis, each reclassified dataset was

multiplied with its associated weight and then all weighted raster layers were combined to produce a composite raster map showing a final suitability score for each grid cell; see Figure 19, for a screenshot of the composite map which is the result of the weighted overlay operation.

Table 5, shows an example of what weight percentage was assigned to each criterion. The weight represents the relative importance of each layer and can be modified when the criteria importance changes. The importance of each layer was based on personal judgment.

Table 5. Weight assigned to each layer

Factors	Weights
Elevator clusters	32
Port terminals	21
Railroad terminals	21
Highways	11
Social and economic factor	15

The grain elevator cluster is the most important factor in the analysis. The use of storage and transport capacity offered by grain elevators requires purposely designed container depots in the proximity, from where the freight can be transferred. They are the only demand nodes for empty containers in the system. So, they will play a vital role in decreasing the empty miles travelled. Thus, the factor is ranked as most important with the highest weightage.

In the freight distribution planning, factors such as congestion, energy consumption and empty movements become the driving forces to consider the setting of container depots near the railroad and port terminals. Here, port and railroads terminals are given intermediate weightage because they are not dispersed throughout the city. Most of them are already located at a safe distance for the city population. Moreover, accessibility and proximity to railroad terminals and port terminals is very crucial because it affects the cost effectiveness of the project.

Social, Economic and Noise Factor like distance for the residential areas, parks and schools etc. review the less weightage but still are very important for the locational analysis. The goods movement industry is heavily reliant upon diesel fuels from ships, trucks, locomotive, forklifts, cranes and more but at the same time Trucks, trains and ships help moving cargo and surge economic growth but at the same time they burn fossil fuels that creates air pollution. The warehouses, distribution centers, intermodal and other logistic facilities operate 24 hours a day, seven days a week, creating a significant noise pollution. So, the site for setting up of new depots should be at a safe distance from the population of the city.

The function of the road, from a freight perspective, is manifold. Road freight is most often necessary in the beginning and in the end of the multimodal transport chain. Minnesota has a good connectivity of highways, Minnesota Department of Transportation has designated 2,960 miles of roadway outside the Twin Cities area as interregional corridors, that link together the Twin Cities, Rochester, Fargo-Moorhead, Duluth and about 50 other communities. High priority IRCs include Interstates 35, 90 and 94, as well as all or parts of Highways 10, 52, 61, 169 and 212. Medium priority IRCs include all or parts of Highways 2, 8, 10, 14, 23, 34, 53,60, 63, 95, 169, 210 and 371. That being so, the factor highways is given the least weightage in the analysis.

The suitable site classes are ranging from 1 to 10. One (red) being the least suitable and 10 (green) being the most suitable sites (Figure 19). The least suitable sites are the sites that are less preferred for the development on new depots.

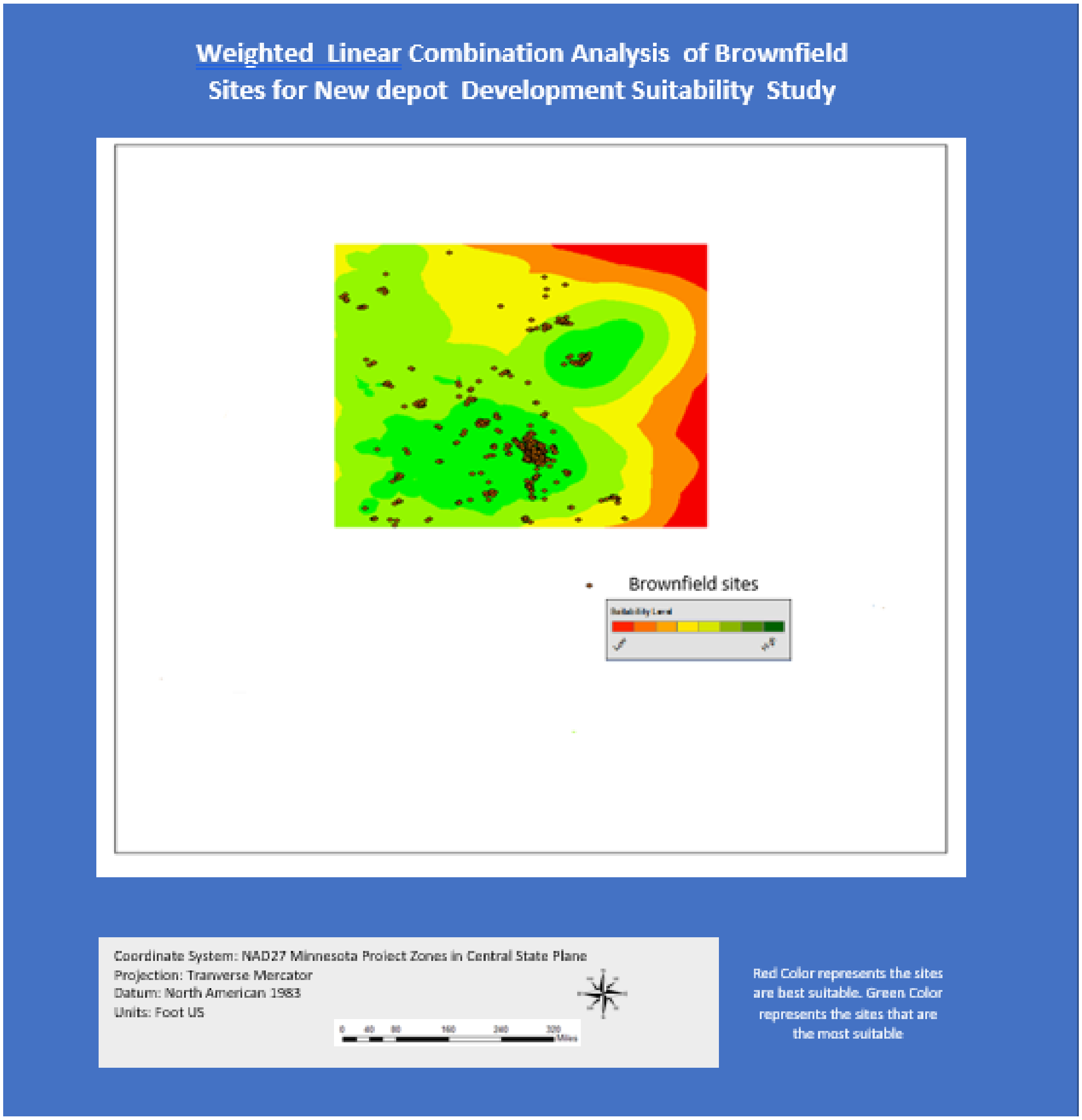


Figure 19. Weighted linear combination analysis result

4.4.2. Overlay Analysis

Further overlay analysis is done to identify the specific suitable sites and to clean final map. First, the suitability map represented in Figure 19, which is a raster layer, was converted to vector format using Raster to Polygon tool (*Conversion Tools>From Raster*), then the sites with suitability scores ranging from 7 to 10 (the most suitable sites) were selected to be overlaid with brownfields layer. Figure 20, shows the brownfields that meet all the 5 criteria considered in this research for selecting suitable sites for opening new depots in the study region.

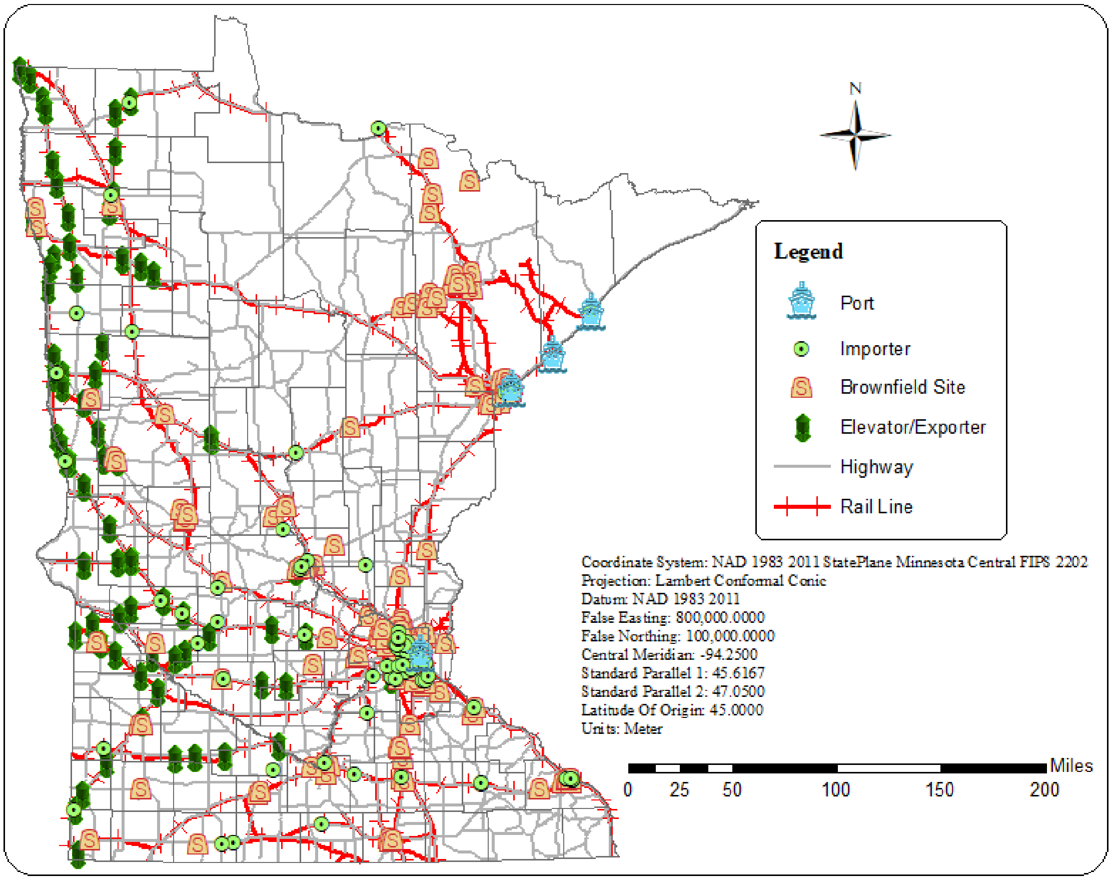


Figure 20. Locations of the identified inland depot sites (brownfield sites)

4.5. Results

The final results of the WLC analysis show that there are 90 potentially suitable sites for the empty container depot development. 31 of the suitable sites have a score 6 and 7, i.e., they are the most suitable sites and the other 59 are classified as 5 which are as less suitable sites. The total acreage of suitable sites composes 2050 acres. As can be seen in Figure 20, majority of the suitable sites appeared in the south and the north-east region of the study area. Most of these sites in the south are closer to elevators and the ports, which happens to be the high weightage factors. The sites in the north-east region are in proximity to the ports and railway terminals, while keeping a distance from the grain elevator clusters. To identify the sites that are ideally suitable for depot development would require additional and detailed examination.

4.5.1. Discussions

The development of new depots on the brownfield sites will solve the container availability problem in the portions of the study area, where the exporters are put in competitive disadvantage when they are unable to obtain containers at a reasonable cost for their exports. Moreover, the opening of new inland depots will also reduce the empty container movements between regional importers, marine terminals, empty container depots, and export customers, which is a non-revenue generating exercise.

The recovery of brownfields is a way of saving land especially Greenfield land, which is often habitable and suitable for agriculture. Brownfields' redevelopment also presents a chance for the creation of a sustainable environment which could be a vital factor for improved health of neighboring communities. The revitalization of brownfields will also enable people in a community to obtain and retain jobs.

The locational decision-making analysis was evaluated using AcrGIS 10.4. Integrating the Weighted Linear Combination into geographic information system (GIS) modeling, this research provides a practical and easy way to select optimal locations. Comparing to conventional methods, it greatly improves the efficiency of selection and saves time and costs for people. By adding/removing related factors, and adjusting evaluation criteria, the method can be applied in other fields involving spatial decision making and land value evaluating, such as locating commercial and public facilities, city planning, and optimal public transportation routes selection.

This research used a simplified Euclidean distance instead of traveling distance of road networks. Because road networks are extensive in the state of Minnesota, it is assumed distances are not significantly different using this method. If this method is applied to other areas with sparse road networks, the results may be less appropriate. The network analysis in geographic information system (GIS) can calculate the shortest routes and shortest travel time for any location to specified facilities. Therefore, in future studies, based on their preference, users can choose to use either the shortest routes or the shortest travel time to evaluate such factors.

5. PHASE 2

5.1. Abstract

Agriculture is a leading sector in the Midwest economy. Grain production is particularly important to the natural resource-based economy of the upper Midwest. Exporters are at a competitive disadvantage when they are unable to obtain containers at a reasonable cost. To mitigate this shortage of containers and avoid excessive empty vehicle miles, it is proposed to strategically establish inland depots in regions with sufficiently high trade volumes. Inland depots would minimize total system costs for empty container repositioning while providing customers with desired levels of service. Mathematical models are formulated to evaluate the proposed system and implementation is performed as a case study for soybean container shipments in the study region of Minnesota. The proposed system has been demonstrated to significantly reduce empty vehicle miles traveled and total system costs, yielding benefits to regional exporters and individual stakeholders. Findings show that even if soybean trade volumes in the region remain static or decrease, inland depots will still result in noteworthy system cost and empty vehicle mile savings. Finally, the model can be applied similarly to other commodities and/or be used to analyze the potential for new intermodal points.

Keywords: Inland container terminals, Empty container repositioning, Container shortage, Deterministic model, Grain transportation

5.2. Introduction

The United States is a leading producer of many grains and needs to use shipping methods with single-cargo capacities as large as 60,000 tons to meet the needs of export customers. Container transportation currently accounts for only a small percentage of U.S. grain transportation but its use is slowly increasing *(38).* Since 2006, containerized grain shipments between the United

States and Asia have more than doubled, with the upward trend expected to continue. There are several reasons for this trend. First, there is an increased demand for identity-preserved and specialized grains such as food-grade soybeans used in tofu, miso, and soy milk processing. To preserve food safety, the grain must be loaded at its production point. Identity-preserved products are those that can be traced throughout the supply chain and are easily distinguished from GMOs (genetically modified organism). This distinction is critical to global grain purchasers *(39)*. Containerized shipping facilitates easy traceability from the respective seed stock, the field the crop was grown in, and every point in transit from grain silo to final destination. Secondly, containerized imports facilitate shipping of smaller quantities, benefitting countries that otherwise cannot commit the necessary capital to import large quantities of agricultural goods. It is not economical to charter a ship unless it is mostly full, so cargoes are layered in holds separated by plastic tarpaulins. This significantly increases the likelihood of cross-contamination between crops and can pose significant quality and identity problems as well. Containerized cargo remains intact and enclosed, which can be of great benefit to markets in Asia which have little storage capacity. In addition, bulk grain terminals in developed countries are typically less efficient than container terminals, where there has been more restructuring to support growth *(40)*. Containerization allows for significantly expanded transportation alternatives with minimum public-sector investment, if containers can be loaded at the terminal to full capacity *(41).*

An increasing imbalance of available empty containers has developed because of growing demand for U.S. exports and an economic downturn that is slowing the growth of imports. It is becoming increasingly difficult to ship goods overseas because of the lack of available containers, particularly for inland exporters. U.S.-based exporters also face challenges arising from the distances between the loading and unloading of products, and from rising energy and transportation costs. Exporters are at a competitive disadvantage because they are unable to obtain a reasonable supply of containers at a reasonable cost. New market entrants face these barriers as they attempt to serve new markets. The U.S. departments of Commerce, Transportation, Energy, and Agriculture, as well as industry coalitions *(42, 43)* are acting on instructions from the President of the United States and are trying to identify critical issues that hinder an increase in exports *(44).* The general consensus across these agencies and groups is that transportation costs must decrease to sustain and enhance U.S. agricultural export competitiveness.

In the shipping industry, there are headhauls and backhauls. Headhauls are typically movements of higher-value consumer products or product components. These movements are the primary haul, so shippers pay a premium for contracted container transportation with a nominal repositioning fee. Backhauls are necessary to reload and relocate containers back to import markets for recirculation. The velocity and recycle speed between headhauls is a critical factor in a carrier's container supply profitability. Recently, the oversupply of ocean capacity has led carriers to avoid repositioning empty containers.

Inland container depots are dry ports equipped for handling and temporary storage of containerized cargo as well as empty containers. These depots allow customers in remote locations to receive port services more conveniently and closer to their premises. Ocean carriers tended to reduce the number of supported container depots and simplified their inland networks. Service was discontinued in some unbalanced lanes. For example, Wisconsin exporters now must truck containers to intermodal loading centers in Illinois because of the recent closure of the Milwaukee Intermodal Terminal on the Canadian Pacific Railroad *(45).*

The combination of these factors has created a strong need for inland container depots which would result in reduced drayage and increased access to empty containers. To maintain U.S.

competitiveness for containerized grain exports, this research seeks to outline and provide a practical solution to container shortages for grain farmers at the inland regional level. The region of study for this research is the state of Minnesota and the numerical solution will be implemented as a case study for soybean container shipments.

5.3. Problem Statement

Compared to other inland regions, there are wide imbalances in service and costs for shipping from Upper Midwest intermodal terminals to overseas markets. Frequently, there is an inadequate supply of containers for grain exports. The price disparities pose a significant problem for many regions compared to areas such as Chicago and Memphis which are favored by service from Class 1 railroads and ocean carriers. Even though the Pacific Northwest (PNW) rates are much higher than those in Southern California, PNW ports are currently the only viable outlet for Minnesota exporters shipping to Asia.

There are many advantages to putting grains in containers for export, but there will be significant operational challenges if the export supply chain were to grow to nearly double the current flow of containers. To mitigate empty vehicle miles and the shortage of containers, it is proposed to strategically establish inland depots in regions with sufficiently high trade volumes. These depots minimize total system costs for empty container repositioning while providing customers with a more stable level of service. Inland depots will fill a gap in the transportation market and optimize empty container movements within a region while simultaneously providing the region with buffer storage for empty containers.

Grain transportation research has received growing attention in recent years, but several questions remain unanswered. Prior studies recommend that inland depots be located in the upper Midwest, but neglect to provide a solution for the shortage of empty containers in the area. This distinct lack of experimental analysis inhibits the evaluation and implementation of possible policy and operational changes to the logistics of U.S grain transportation. Additionally, most studies have focused on the globally-scaled repositioning problem. At the time of this document's presentation, no published study has focused on minimizing the regional repositioning cost of empty containers across multiple modes from any U.S. production site to its exit gateways. Finally, although past research focused on bulk transport, this research addresses the growing container shipment market for U.S. grain transportation.

5.4. Literature Review

5.4.1. Grain and Agricultural Commodity Supply Chain

A review of existing literature has revealed that while many aspects of the grain and agricultural supply chain have been studied, there is a lack of experimental analysis addressing the shortage of shipping containers and the minimization of regional repositioning costs of empty containers. Keith *(46)* assessed the capacity of the current national freight system to support economic growth in agriculture and other sectors of the economy. The potential impacts of government programs to expand the rail sector's capacity to reduce highway congestion were examined and rail's ability to create a more efficient transportation platform was evaluated. Wetzstein *(47)* conducted a study on the supply-and-demand dynamics of purely barge transportation for agricultural commodities with the aim of predicting barge rates and associated volatilities by river segment. This study also produced spatial forecasts of barge rates along the Mississippi River. For the barge rate forecast, a spatial vector autoregressive model was created with the dependent variables calibrating prices of barge transportation. Using an origin-destination (O-D) matrix, DaSilva and D'Agosto *(48)* developed a constrained gravity model to estimate O-D matrix for the export flow of Brazilian soybeans. If the supply chain configuration is known, and absolute percentage errors are monitored over time, this model would be useful for the strategic planning of transportation for the export of soy products. For U.S.-based soybean supply chains, Informa Economics *(49)* evaluated the routes from farm to market and assessed the impacts of transportation infrastructure. This research made particular note of containerized soybean shipping and highlighted the importance of proximity to container depots for consistent container usage. The challenge that the United States faces as a dominant country in the global soybean market depends on competing countries' ability to reduce their respective transportation costs by improving infrastructure capacity, according to Salin and Somwaru *(50).* Differences in transportation costs could make South American soybean exports more profitable than those from the United States, suggesting that the U.S. world market share could decline by up to 18.5% without developments and improvements to the U.S. transportation infrastructure from farm to port.

5.4.2. Empty Container Repositioning

The empty container repositioning problem aims to reposition empty containers efficiently and effectively to minimize costs while meeting customer demands for empty containers. Literature on this topic may be classified into two groups according to the research context associated with the transport modes.

The first group addresses empty container repositioning in seaborne shipping networks. In the first group, some studies consider a single shipping service route or a service network with a specific route structure. Shi and Xu *(51)* studied the optimal empty container repositioning policies in two-port systems. A Markov Decision Process was used to find the optimal controlling policies for two cases, that is an offline case where demand has a known distribution and an online case where is demand is partially known. Zhang et al. *(52)* developed threshold-type policies to reposition empty containers. With the aim of minimizing total operating cost, the threshold control policy was extended to multiple port systems. Song and Dong *(53)* presented flow balancing-based empty repositioning policies in shipping service routes with typical topological structures. One advantage of focusing on a specific structure of the service route is to provide opportunities to design optimal or near-optimal repositioning policies in uncertain situations. However, a focus on a specific structure or a single service route simplifies the routing decisions and excludes the transshipment operations, which is an important component of container shipping operations. On the other hand, some studies consider more general shipping networks. Epstein et al. *(54)* developed a knowledge-based decision-making model for repositioning and stocking empty containers. An empty container logistics optimization system was developed where the multi-commodity multi-period model manages the repositioning problem and an inventory model determines the safety stock required at each location. Long et al. *(55)* formulated a two-stage stochastic programming model for the empty container repositioning problem in a maritime shipping network with random demand, supply, ship weight capacity, and ship space capacity. The sample average approximation method and the progressive hedging strategy are applied to solve the optimization problem. Di Francesco et al. *(56)* addressed the maritime repositioning of empty containers with port disruptions. The problem is modeled and approximated by a single-scenario model (deterministic) and a multi-scenario model (stochastic) incorporating the non-anticaptivity conditions.

In the second group, the following studies focus on the empty-container repositioning problem in inland or intermodal transportation networks. Yun et al. *(57)* utilized the (s, S)-type inventory control policy to reposition empty containers inland between terminals and customers with random demands for empty containers. The study used a simulation-based optimization tool to find a near optimal (s, S) policy. Dang et al. *(58)* extended the work of Yun et. al to a port area with multiple depots and considered three types of decisions: repositioning empties from overseas ports, inland repositioning between depots, and leasing from lessors. A simulation-based genetic algorithm was developed to optimize threshold parameters, which are adopted as policies for empty container repositioning. Lee et al. *(59)* considered joint empty-container-repositioning and fleet-sizing problems in a multi-port system. For this study, a single-level threshold policy was used to control the inventory and empty container flow between ports. The formula assumes the travel time for each pair of ports is less than one period length, and the shipping routes are not directly considered. As such, the model may be more appropriately regarded as a regional inland network.

While previous work contributed to the supply chain planning with the existing or simplified backhaul market, this study introduces the potential for new intermodal points to facilitate inland loading.

5.4.3. Research Objective and Scope

Built upon an understanding of the literature and knowledge gaps, we develop a modeling framework specific to containerized grains. To find the optimal location for new empty container storage depots in the study region, we develop a quantitative model that solves a depot location-allocation (LA) problem, taking into consideration the existence of inventory and capacity constraints of the depots under deterministic demand patterns.

This is a first attempt at a realistic solution to help boost farmers' exports and profits by increasing the availability of empty containers and thereby reducing empty container drayage costs. To evaluate the effectiveness of the proposed solution, the models developed are applied to specific regions within the overall study region (Minnesota), accounting for the nuances and particular conditions therein. To reinforce its credibility, stress testing of the proposed model will be done under a number of different scenarios.

The output of this research will influence transportation decisions and further help stakeholders set priorities for future investment that will positively impact the inland transportation of containerized grain and enhance the economic competitiveness of U.S grain exports.

5.5. Mathematical Formulation

The model, under deterministic demand conditions, aims to minimize total system costs (fixed cost of opening new depots + empty container repositioning cost) in the time horizon while satisfying the demand-supply volumes at the elevator clusters and port nodes. A directed network graph G = {N, E} is considered, where N is the set of nodes and E is the set of edges. Dummy subscripts *d*, *e*, *m*, *ele*, and *p* represent depot facilities, exporters, importers, elevator clusters and the port terminals, respectively in the region (Figure 21).

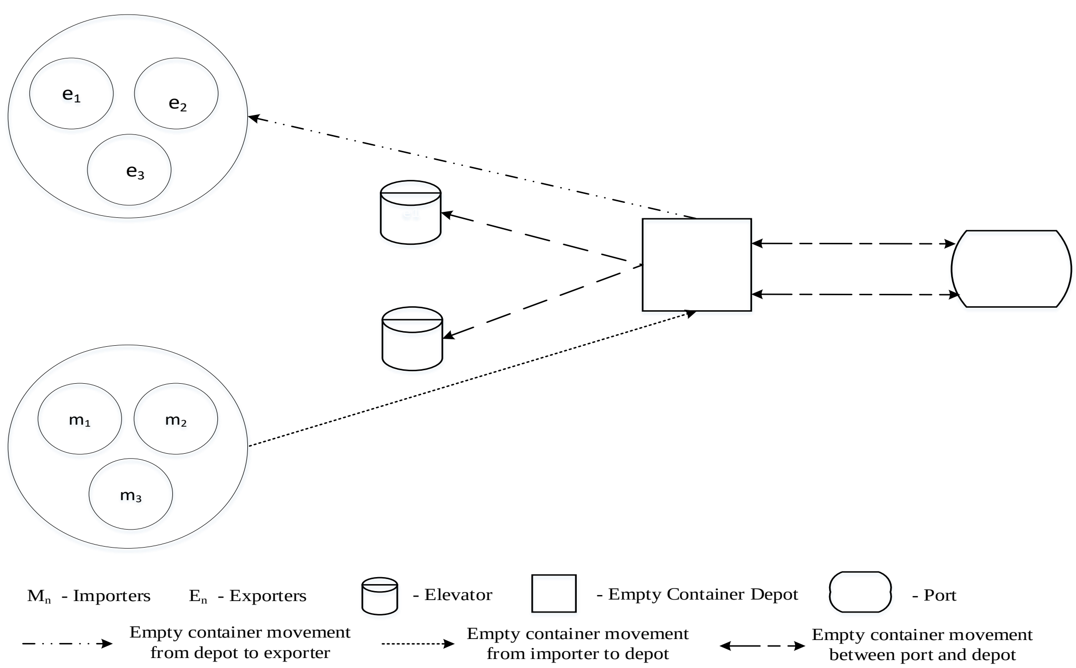


Figure 21. Empty container movements in the grain supply chain (proposed solution)

Edges represent the directed movements: import customer-to-depot(X_{md}), depot-to-exporter (X_{de}), depot-to-elevator (X_{dele}) depot-to-port terminal (Y_{dp}, Z_{dp}), port terminal-to-depot (Y_{pd}, Z_{pd}) (Table 6, Table 7)

Table 6. Model variables, parameters, and calculated quantities

Variable	Description	Category
D_{ele}^{t}	Demand of empty containers by elevator 'e' (*ele* Є Ele, *t* = 1… T)	Parameter
D_{e}^{t}	Demand of empty containers by exporter 'e' (*e* Є E, *t* = 1… T)	Parameter
S_{m}^{t}	Supply of empty containers to depots from importer 'm' at time 't' (*m Є M, t = 1… T*)	Parameter
S_{p}^{t}	Supply of empty containers to depots from port terminals (*p Є P, t = 1… T*)	Parameter
D_{p}^{t}	Demand of empty containers to depots from port terminals (*p Є P, t = 1… T*)	Parameter
S_{p}^{t} - D_{p}^{t} =h_{p}^{t}	(If $h_{p}^{t} > 0$ port '*p*' can supply empty containers, if $h_{p}^{t} < 0$ port '*p*' has demand of empty containers.	Calculated
V_{d}^{0}	Initial inventory at depots (*d Є D, t =0*)	Parameter
X_{dele}^{t}	Number of empty containers, shipped by truck from depot 'd' to elevator '*ele*', in time period '*t*'. *(d Є D, ele Є Ele)*	Variable
X_{md}^{t}	Number of empty containers, shipped by truck from importer '*m*' to depot '*d*', in time period '*t*'. *(d Є D, m Є M)*	Variable
X_{de}^{t}	Number of empty containers, shipped by truck from depot 'd' to exporter '*e*', in time period '*t*'. *(d Є D, e Є E)*	Variable
Y_{dp}^{t}	Number of empty containers, shipped by rail from depot 'd' to port '*p*', in time period '*t*'. *(d Є D, p Є P)*	Variable
Z_{dp}^{t}	Number of empty containers, shipped by barge from depot 'd' to port '*p*', in time period '*t*'. *(d Є D, p Є P)*	
Y_{pd}^{t}	Number of empty containers, shipped by rail from port 'p' to depot 'd', in time period '*t*'. *(d Є D, p Є P)*	Variable
Z_{pd}^{t}	Number of empty containers, shipped by barge from port 'p' to depot 'd', in time period '*t*'. *(d Є D, p Є P)*	
V_{d}^{t}	Inventory at depot *'d'* in the beginning of time period '*t*'. *d Є D, t=1…. T)*	Parameter
V_{p}^{t}	Inventory at port *'p'* in the beginning of time period '*t*'. *d Є D, t=1…. T)*	Parameter
B_{d}^{t}	Binary, '*1*' if depot '*d*' is open at time '*t*'; '*0*' otherwise. *(d Є D, t=1….T)*	Binary
$a_{de}^{t}, a_{md}^{t}, a_{dele}^{t}$	Represents cost incurred in trucking a container (TEU) between the nodes in time period *'t'*	Calculated
b_{pd}^{t},b_{dp}^{t}	Represents cost incurred in shipping a container(TEU) by rail car, between the nodes in time period *'t'*	Calculated
c_{pd}^{t}, c_{dp}^{t}	Represents cost incurred in shipping a container(TEU) by barge, between the nodes in time period *'t'*	
f_{d}^{t}	Fixed cost of opening a depot 'd', in time period *'t' (d Є D, o* Є O, *t = 1… T)*	Parameter
TC	Total supply chain cost	Objective

Model Assumptions:

- Empty containers do not move directly from an import customer to an export customer in the region.
- All empty containers that come into a depot are assumed to arrive in the beginning of a time period *t*, while exiting containers are checked out of the depot at the end of period *t*.
- Empty containers do not move among depots in the region.
- Operational cost structure is linear and does not vary with the depot location given that they are located in the same geographical area.
- Customer clusters will continue to exist in the planning time horizon.
- Variables not in the formulation are implicitly taken to be zero.
- Grain from local elevator is transported to export elevator via shuttle service
- Grain remains in storage until enough grain is consolidated to fill an entire shuttle train (110 railcars).
- The maximum capacity of a depot is to store 200 TEUs (containers) at a time.
- The depot capacity does not vary across locations.

Table 7. Model equations and constraints

Description	Objective and Constraints	ID
Minimize TC	Min($\sum_t \sum_{d\epsilon D} f_d^t * (B_d^t - B_d^{t-1}) + \sum_t \sum_{m\in M} \sum_{d\epsilon D} (X_{md}^t * a_{md}^t) + \sum_t \sum_{e\in E} \sum_{d\epsilon D} (X_{de}^t * a_{de}^t) + \sum_t \sum_{d\epsilon D} \sum_{ele\epsilon Ele} (X_{dele}^t * a_{dele}^t) + \sum_t \sum_{p\in P} \sum_{d\epsilon D} Y_{pd}^t * b_{pd}^t + Z_{pd}^t * c_{pd}^t) + \sum_t \sum_{d\in D} \sum_{p\epsilon P} (Y_{dp}^t * b_{dp}^t + Z_{dp}^t * c_{dp}^t)$	1
Demand and supply		
Importer	$\sum_{d\in D}(X_{md}^t) = S_m^t;\ \forall$ m $\epsilon\, M,\ \forall\, t\, \epsilon\, T$	2
Exporter	$\sum_{d\in D}(X_{ed}^t) = D_e^t;\ \forall$ e $\epsilon\, E,\ \forall\, t\, \epsilon\, T$	3
Elevator	$\sum_{d\in D}(X_{dele}^t) = D_{ele}^t;\ \forall$ ele $\epsilon\, Ele,\ \forall\, t\, \epsilon\, T$	4
Flow Balance		
Depot	$\sum_{ele\in Ele}(X_{dele}^t) + \sum_{p\in P}(Y_{dp}^t) + \sum_{e\in E}(X_{de}^t + Z_{dp}^t) \leq V_d^t;\ \forall$ d $\epsilon\, D, \forall\, t\, \epsilon\, T$	5
Port	$\sum_{d\in D}(Y_{pd}^t + Z_{pd}^t) \leq V_p^t;\ \forall$ p $\epsilon\, P,\ \forall\, t\, \epsilon\, T$	6
Inventory		
Depot	$V_d^{t\text{-}1} + \sum_{m\in M}(X_{md}^t) + \sum_{p\in P}(Y_{pd}^t + Z_{pd}^t) - \sum_{p\in P}(Y_{dp}^t + Z_{dp}^t) - \sum_{ele\in Ele}(X_{dele}^t) + \sum_{e\in E}(X_{de}^t + Y_{de}^t) + \sum_{e\in E}(X_{de}^t + Y_{de}^t) = V_d^t;\ \forall$ d $\epsilon\, D, \forall\, t = 1 \ldots T$	7
Port	$V_p^{t-1} + \sum_{d\in D}(Y_{dp}^t + Z_{dp}^t) - \sum_{d\in D}(Y_{pd}^t + Z_{pd}^t) = V_p^t - h_p^t\,;\ \forall$ p $\epsilon\, P,\ \forall\, t = 1 \ldots T$	8
Capacity		
Depot	$\sum_{m\in M}(X_{md}^t) + \sum_{p\in P}(Y_{pd}^t + Z_{pd}^t) + \sum_{e\in E}(X_{de}^t) \leq K_d * B_0^t; \forall$ d $\epsilon\, D, \forall =$ 2…..T	9
Rail	$Y_{dp}^t, Y_{pd}^t \leq$ Capacity; $\forall$ d $\epsilon\, D, \forall$ m $\epsilon\, M, \forall$ p $\epsilon\, P, \forall$ e $\epsilon\, E, \forall\, t\, \epsilon\, T$	10
Binary		
New Depot	$B_d^t \geq B_d^{t-1};\ \forall$ d $\epsilon\, D, \forall =$ 2…..T	11
Existing depot	$B_d^t = 1;\ \forall$ d $\epsilon\, D, \forall =$ 2…..T	12
Non-Negativity		
Truck	$X_{md}^t \geq 0;\ \forall$ d $\epsilon\, D, \forall$ m $\epsilon\, M,\ \forall\, t\, \epsilon\, T$	13
Rail	$Y_{dp}^t, Y_{pd}^t \geq 0;\ \forall$ d $\epsilon\, D,\ \forall$ p $\epsilon\, P,\ \forall\, t\, \epsilon\, T$	14
Barge	$Z_{dp}^t, Z_{pd}^t \geq 0;\ \forall$ d $\epsilon\, D,\ \forall$ p $\epsilon\, P,\ \forall\, t\, \epsilon\, T$	15
Variable		
Integer	$X_{md}^t,\ X_{dele}^t,\ X_{de}^t, Y_{dp}^t, Y_{pd}^t, Y_{de}^t, Z_{dp}^t,\ Z_{pd}^t$	16
Binary	$B_d^t\ \in \{0,1\};\ \forall$ d $\epsilon\, D, \forall\, t =$ 1…..T	17

The objective function and constraints are summarized in Table 7. Constraints (2) and (3) meet the empty container demand and supply requirements of the regional exporters and importers in time period *t*. Constraint (4) meets the empty container demand volume requirement at elevator *ele* in time period *t*. Constraint (5) assures that the sum of outgoing volume from the depot *d* in time period *t* meets the depot inventory limitation. Constraint (6) assures that the sum of outgoing volume from the port *p* (to the depot o) in time period *t* meets the port inventory limitation. Constraint (7) defines the beginning inventory at every depot in time period *t*. Constraint (8) defines the beginning inventory at every port terminal in time period *t*. Constraint (9) makes sure that the inventory at depot *d* in time period *t* must meet the depot capacity limitation. Constraint (10) ensures the capacity limitation of rail shipments. Constraint (11) ensures that the depot is opened only once, and once it is opened it remains open for all subsequent time periods, if not underutilized. The selected inland facilities are truly in high-demand. Even if demand falls significantly for these locations, they will continue to have enough demand to warrant that they remain open and operational. From a practical point of view, the monetary costs involved in reopening the facilities later offset the benefit of closing the facility when not needed. Constraint (12) keeps the existing depots open in the system; (13) through (15) are non-negativity constraints; (16) is an integrality constraint; and (17) is a binary constraint.

5.6. Case Study Region Overview

The implementation of the model is performed as case study for soybean container shipments. Within the study area of Minnesota, the most concentrated location of soybean production is the southwest portion of the state, with an average yield of 8.5 million tons annually (Figure 22). Five million tons of soybean are exported from the state, and, of those, 5 million tons (94%) are exported to international buyers such as Indonesia, Japan and Taiwan *(60)*.

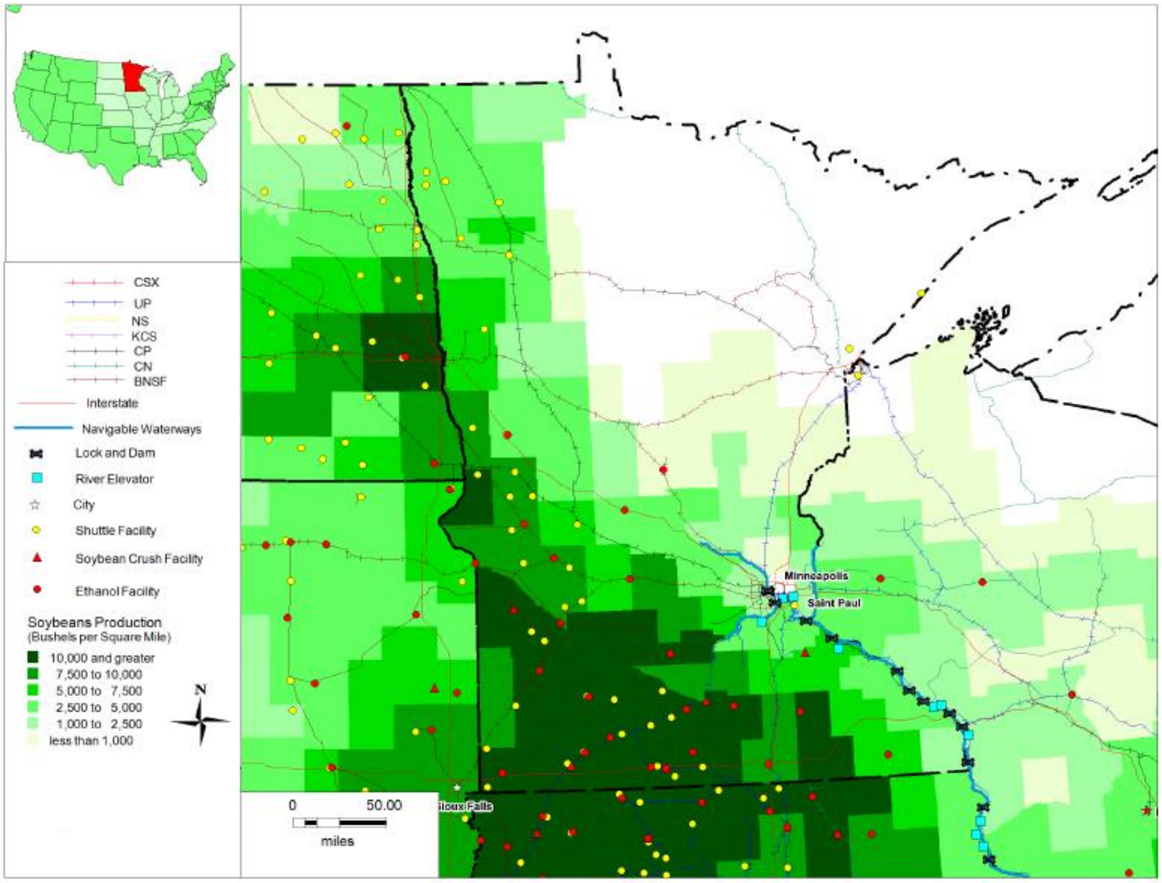


Figure 22. Soybean production and storage facilities in Minnesota

Soybean barge movements from Minnesota (MN) are primarily destined for the Gulf Coast for international export. A relatively small number of barges is used for domestic repositioning of soybeans. Rail transport for MN soybeans is split between the Gulf Coast and the PNW (Table 8).

Table 8. Percentage of soybeans moved to export ports (top 5 states in 2016)

	Barge		Rail				
	Export Moves	Domestic	Export Moves				Domestic
State	**Center Gulf**	Moves	**Center Gulf**	**PNW**	**Texas Gulf**	**Atlantic**	Moves
Iowa	91%	9%	80%	10%	2%	0%	8%
Illinois	93%	7%	53%	14%	4%	0%	29%
Minnesota	91%	9%	2%	91%	0%	0%	7%
Indiana	93%	7%	36%	5%	0%	0%	59%
Nebraska			11%	81%	4%	0%	4%

Source: Public Use Waybill, Army Corps of Engineers and Informa Economics

5.6.1. Advantage of Intermodal Service in Minnesota

Because it is served by four Class I railroads, Minnesota shippers have a competitive advantage in several transportation corridors. Three of those railroads have intermodal terminals that provide shippers with connections to PNW ports, two utilize the Atlantic gateways through Canada, and one has direct service to the Gulf Coast. The BNSF (Burlington Northern Santa Fe) and CP (Canadian Pacific) railroads provide domestic intermodal service to Seattle and Chicago, respectively. CN's (Canadian National) Duluth terminal has the potential to more readily serve the following international gateway ports: New Orleans (Louisiana), Mobile (Alabama), Montreal (Quebec), and Halifax (Nova Scotia). Minnesota is connected to navigable water through the Mississippi River and Duluth ports. Marine transportation is slower but more fuel-efficient than either rail or truck intermodal service.

5.6.2. Current Regional Practice (Base Case Scenario)

Minnesota exports more products than it imports – especially agricultural products. Traffic movements become unbalanced and these imbalances limit access to empty containers for Minnesota exporters. There are significantly fewer empty containers than are necessary for inland grain shippers. Unfortunately, the current solution is to truck empty containers from Chicago or other distant terminals. Drayage costs for repositioning empty containers from Chicago are comparable to trucking the load to Chicago. If a St. Paul exporter has a locally available container, their cost is $436 less than the Dilworth, MN, exporter – including tariffs and fuel surcharges. In Minnesota, BNSF markets the Dilworth Facility as an intermodal hub, but it is no longer rail-served. All containers are trucked to the St. Paul BNSF terminal for train loading. At the Dilworth facility, there was an insufficient container pool and the costs of repositioning empty containers were high (Wilbur Smith Associates).

It is clear from this situation that container shipping price disparities are inhibiting major U.S. grain production regions (MN & Upper Midwest) from serving certain overseas markets that could otherwise yield sustainable export growth. The rail service that links Minneapolis to Los

Angeles is routed through Chicago (increasing the transit time), so to fulfill the contract commitments, some trucking companies dray containers to Kansas City rail terminals or even to southern California ports. Consequently, PNW ports are currently the only viable outlet for MN exporters shipping to Asia. The Upper Midwest needs more competitive options for container availability and shipping. Because of the unavailability of the containers in the region, grain exporters have to bear the drayage cost. Furthermore, because of the increase in transit time, they are penalized for contract violations. So, there is a need to develop a more creative logistical solution for the expansion and improvement of the transportation infrastructure from inland regions to ports. The proposed solution is to establish inland depots in regions with sufficiently high trade volumes to minimize costs for empty container repositioning and provide customers with the level of service they so desperately need.

5.7. Numerical Analysis

To determine the number and location of inland depots to optimally serve the region in terms of managing and handling empty containers, data were gathered or generated based on information found in various sources. To establish new inland container depots a comprehensive database of brownfield sites is prepared, and ArcGIS 10.4 is used to map and evaluate these sites and select the potential locations for inland depots (minimum of 10 acres).

5.7.1. Data Description

A set of potential sites for container depots is identified based on the above-mentioned criteria. Distances between import customers, elevators, ports and depots are calculated. Fixed cost of opening depots is estimated based on the land cost estimates for the identified potential brownfield sites, their cleanup costs, equipment purchase costs, and infrastructure costs. Land cost estimates for brownfield sites ranged from $25,000 to $45,000 per acre *(19)*. Cleanup costs on the brownfield sites varied from $40,000 to $100,000 per acre depending on the site contamination, clean-up procedures required, and agencies involved *(19).* Additional costs for constructing and building initial infrastructure were estimated at about $1 million. Storage capacity at depot sites is estimated based on the square footage area of the depot and a 20 ft. (TEU) dimension, considering containers stacked four high. The cost of all the equipment needed to operate a small container depot is estimated to be around $679,000 *(61)*.

One strategy to identify empty container supply is to identify top importers. The Journal of Commerce identifies top importers by headquarter location, where decisions are generally made. The top import list shows that more than 977,300 import containers are routed to the United States by 14 companies in Minnesota, Wisconsin, and Illinois *(62)*. Export and import customer business locations in the study region were aggregated and customer clusters were formed and mapped. Annual import-export data were obtained for the years 2011-2017 and were projected until the year 2030.

The USDA National Agriculture Service Database provides soybean production and distribution data. For truck and barge transportation, the USDA Agricultural Marketing Service data sets, Grain Transportation Report and Grain Truck 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.

5.7.2. Implementation of Deterministic Model to the Study Region

To perform the case study, two cases are analyzed to determine the effectiveness of inland container depots in reducing empty vehicle miles and increasing the regional capacity for handling future demand of empty containers to transport soybeans from the farm to the PNW gateway. In this analysis, we assume that 98% of soybeans produced are transported to the exit gateways for export. Case 1 (base case) models the current situation and evaluates the present condition when no inland depots exist (Figure 23). In this case we assume that the there is an insufficient container pool in the region, so exporters obtain containers from Chicago and bear this repositioning cost. The model calculates the cost of empty container repositioning.

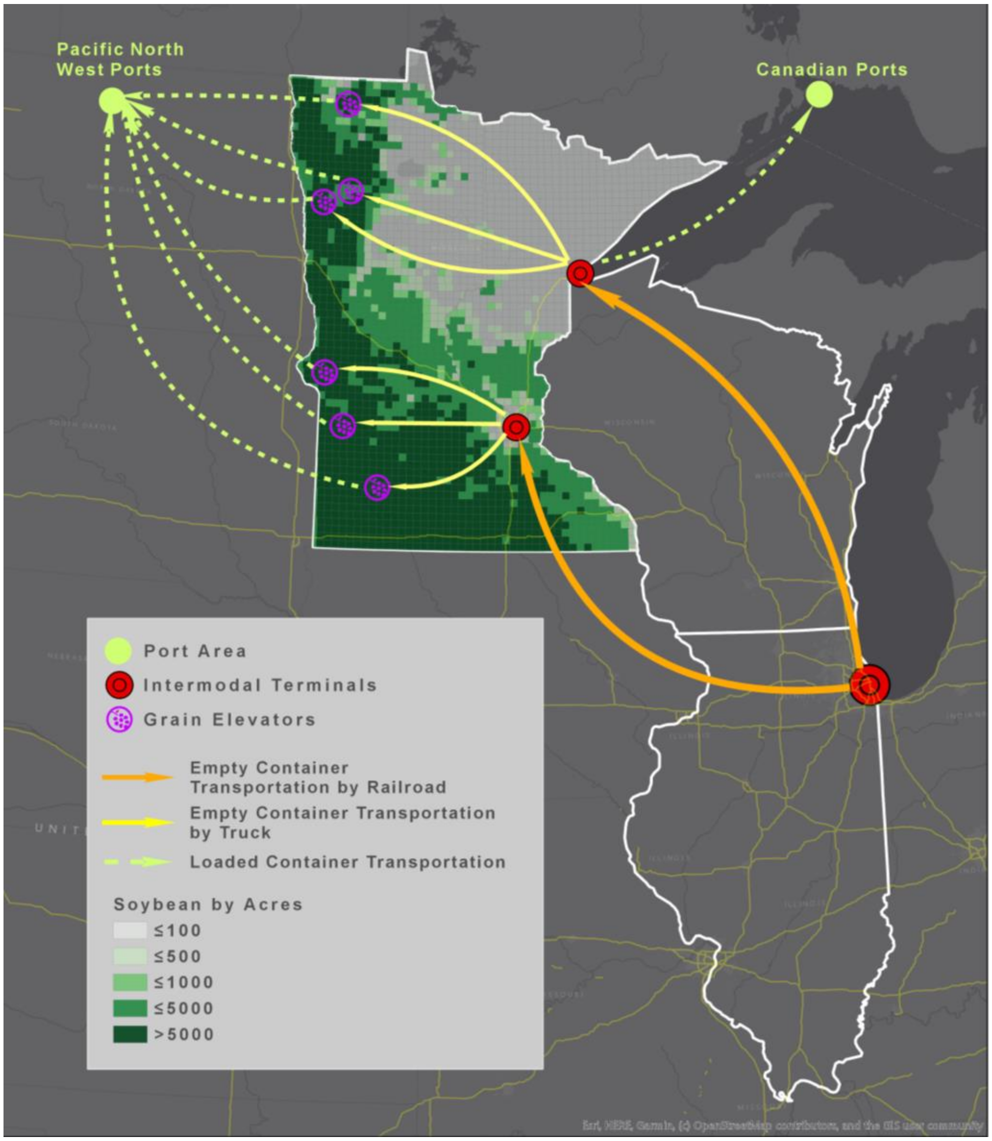


Figure 23. Base case (no inland depots exist)

Case 2 models the proposed system considering the optimal number and location of inland depots which are determined from a set of potential sites (Figure 24). The model assesses the capacity of depots for handling future empty container volumes. The cost of repositioning empty containers is calculated, and the cost savings are compared with the base case, while maintaining the customer service level.

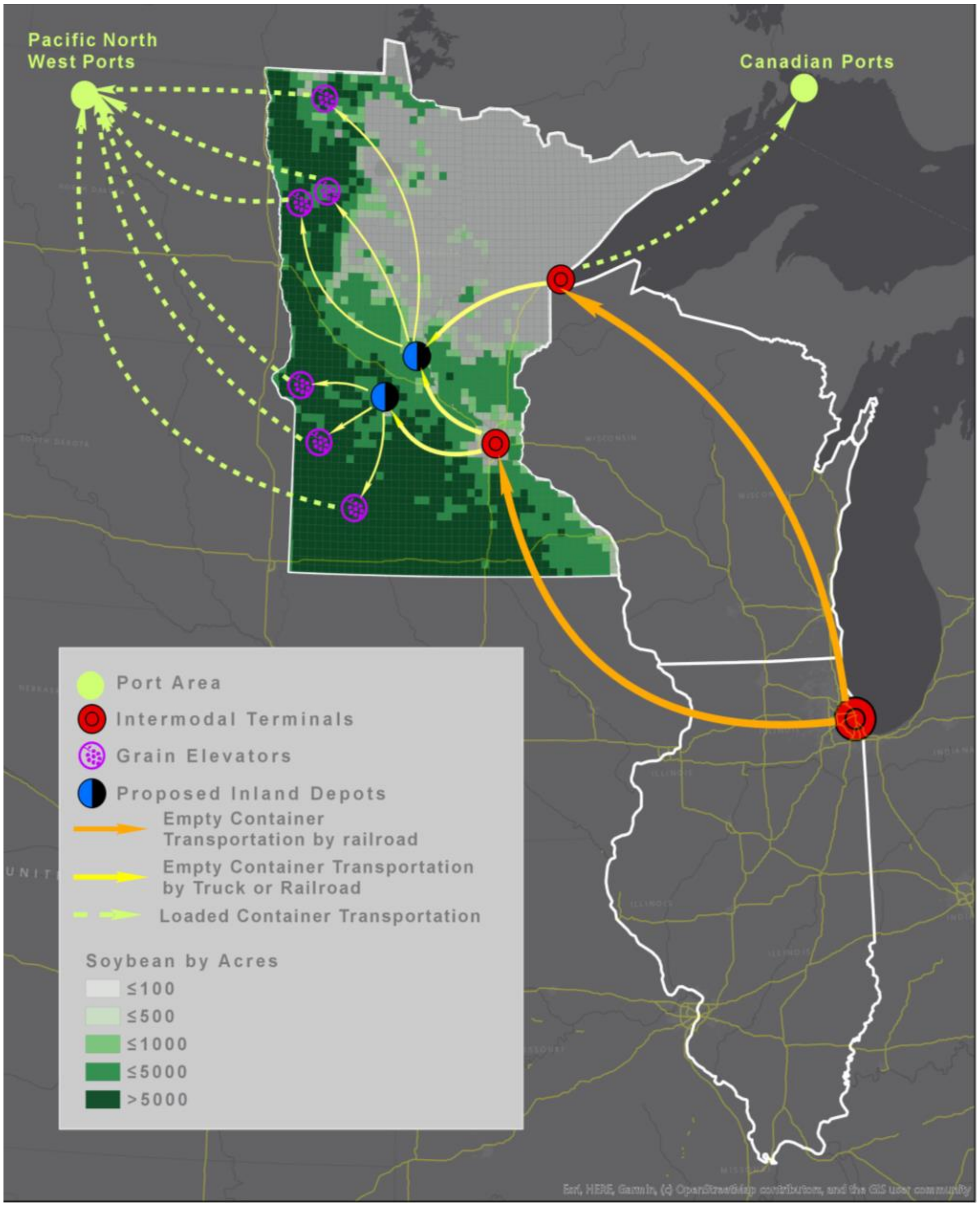


Figure 24. Proposed system (with inland depots)

The models are run on an Intel® Pentium® Processor 4 with Mobile CPU 1.7GHz, 12 GB RAM. We used the NEOS (Dolan, 2001) server in GAMS win32 24.9.1 and mixed integer problems are solved to optimality.

5.8. Results

The results indicate that in Case 1 (Table 9) if the current scenario continues and container volumes increase as predicted, the empty vehicle miles will be 470 million with a total system cost of $660 million by t = 16 (2025). In Case 2, five new depots would open by t = 20 (yr. 2030). The empty vehicle miles will be 280 million miles by t = 16 (2025) with a total system cost of $ 305 million at t = 16 (2025). Compared to Case 1, the total system cost is reduced by 45% (~$355M) by t =16. In terms of empty vehicle miles traveled in the region to satisfy regional demand and supply for empty container volumes, results show that with the proposed system, Case 2 shows a 40% reduction in empty vehicle miles by t=16, as compared to Case 1.

Table 9. Results of the proposed system using deterministic model

	Existing system (Case1)	Proposed system (Case 2)
Number of depots opened	0	5
Empty Miles Travelled	470M by t = 16	280M by t = 16 1010M by t =20
Total System cost (opening new depots + empty repositioning miles)	$660M at t = 16	$305M at t = 16 $1320M at t = 20

5.8.1. Evaluating Robustness of Proposed System

The robustness and effectiveness of the proposed system are evaluated under varying conditions of the model input parameters. Two main input parameters are considered to build different scenarios: variation in demand and supply patterns of empty containers (because of new customer clusters) and demand and supply trade volumes (increase or decrease in soybean production). A base-case considers the following values for these input parameters: existing demand-supply patterns in the region, projected customer demand-supply volumes based on historic trends. Scenarios are built by varying one parameter at a time to estimate the sensitivity of the solution vis-à-vis a base case. Scenarios are built to address the following key questions:

Scenario 1: What if, after new inland depots have already been opened, new customers enter the system, leading to a change in the demand pattern of empty containers in the region? Will the new depots continue to be effective in reducing empty vehicle miles and total system cost? Will their location continue to be optimal?

Scenario 2: What if trade volumes of soybean do not grow as predicted and remain steady? If trade volumes decrease, will there be any significant benefit of putting the proposed system into operation?

a) Scenario Analysis for an Inland Depot (Brownfield Site)

The data-driven decision making helps transportation providers regulate operational functions that can lower operational costs and thus increase efficiency. The information extracted from data could be used to adjust capacities, equipment deployment, infrastructure investment planning, etc. A number of measurements and metrics are used to calibrate the performance of the freight sector. Volumes are the most apparent way to measure an inland depot's freight movement. For our analysis we used total throughput of empty containers in TEU as a unit of measurement. In the current analysis the depot is set to hold a train worth of containers that is 200 TEUs.

The deterministic model has an inbuilt condition to check for overutilization and underutilization of new inland depots. The model records the containers demanded by the depot in a period of time and if these are more than the depot's capacity, it looks for another depot based on the proximity calculated by weighted shortest distance. In this case, if the depot is underutilized for a certain period of time, (which is set to 2 years) them the model closes the depot for further operations.

For each depot and the exporters (grain elevators), the storage capacity of depot and the demand volume (TEU) of the elevator is needed. The distances between each depot and each elevator were calculated using Google maps. The trucking cost of a container (TEU) per mile is based on a study of American Transport Research Institute *(63).* The indicated costs in the study were supplemented by current average price of fuel. To analyze intermodal rail moves, the Public Use Waybill of the U.S. Department of Transportation (U.S. DOT) Surface Transportation Board (STB) was used. The location opening costs for each depot include the land price, costs for the infrastructure, costs of operators, as well as investment costs for the equipment. For finding an exact solution for this problem, a branch-and-bound algorithm was applied. Table 10 shows the volume of empty containers handled at one randomly chosen potential location for an inland depot.

Table 10. Results of the proposed system for an inland depot

Scenario	Input parameters	Empty container throughput(TEU)	Total driven miles by truck	Total driven miles by rail	System Cost
Base Case	All parameters unchanged	226,133 (t=16)	33M	22M	$83M
Scenario 1 (Production Increases)	Change in the distribution of demand patterns	339,199 (t=20)	101M	123M	$263M
Scenario 2 (Change in trade volumes)	Volumes remain static	281,458 (t=20)	157M	181M	$380M
	Decrease in Volumes (Projected vol. drop by 25%)	313,342 (t=20)	254M	136M	$510M

b) Scenario Analysis for the Whole Proposed System

Analysis of Scenario 1: This scenario is analyzed to study the effect of new customer clusters in the region that may develop in the study period between years 2018-2030. Two new customer cluster locations are introduced in the region; the first in 2022 and another in year 2024. The analysis is run for the time horizon (years 2018-2030) with the same set of potential sites for inland depots. Analysis showed that new customer clusters in the region would require three additional inland depot facilities to serve them optimally (Table 11) and save 24% on empty miles travelled and 29% on the total system cost compared to the existing scenario. However, at the same time, the region would still require the inland depots that were opened in 2020. Because existing levels of soybean production continue and, with their demand supply volumes still being valid, none of the earlier inland depot locations would be ineffective or unjustified.

Table 11. Results of the proposed system for different scenarios

Scenario	Input parameters		Existing system	Proposed system	% Change from existing system
Base Case	All parameters unchanged	Empty miles travelled (t=16)	470M	280M	40% decrease
		Total system cost(t=16)	$660M	$305M 5 New Depots	54% decrease
Scenario 1 (Production Increases)	Change in the distribution of demand patterns	Empty miles travelled (t=20)	910M	695M	24% decrease
		Total system cost (t=20)	$1120M	790M 3 New Depots	29% decrease
Scenario 2 (Change in trade volumes)	Volumes remain static	Empty miles travelled (t=20)	880M	620M	30% decrease
		Total system cost (t=20)	$1010M	$765M 2 New Depots	24% decrease
	Decrease in Volumes (Projected vol. drop by 25%)	Empty miles travelled (t=20)	560M	390M	30% decrease
		Total system cost (t=20)	$780M	$685M 1 New Depots	12% decrease

Analysis of Scenario 2: If trade volumes of soybeans in the region remain the same or decrease, analysis shows that even when additional capacity will not be a requirement, opening inland depots will significantly reduce empty vehicle miles traveled and total system costs in the region. From Table 11, when trade volumes remain static, opening inland depots would save 30% (260 million) in empty miles travelled and 24% ($245 million) in costs by t = 20, over the existing system. When trade volumes drop to 25% of the projected volumes, savings from inland depots are still significant at 30% (170 million) in empty miles travelled and 12% ($95 million) in total system costs by t = 20.

5.8.2. Discussions

This phase presented a strategic model for inland empty container depot development in regions of Minnesota with increasing trade volumes and trade imbalances. It examined the issue with a focus on agricultural exporters. Results indicate the potential for inland depots to reduce empty vehicle miles traveled and associated costs and improve the system's efficiency. In the short term, the concept may seem costly to the parties involved. However, when viewed in the long term, congested highways, overcrowded intermodal terminals, and the increasing cost of repositioning empty containers for inland exporters, especially in consideration of associated external costs, would justify the cost of building new inland depots. Considering the anticipated increase in trade volumes and the chronic and evolving imbalance of global trade, the proposed system seems to be a promising solution to the empty container shortage problem in the study region.

The proposed system has been demonstrated to significantly reduce empty vehicle miles traveled and total system costs in the study region, yielding benefits to regional exporters which will further support the growth of U.S. economy. The sensitivity analysis shows that the model and its solution are robust under various input parameter conditions. After scenario testing, the following recommendations and conclusions can be drawn:

- When new customers enter the system in the study period at probable locations, the analysis shows that return on investment from inland depots opened in the beginning of the study period will continue to be realized even when new customer clusters develop later. The analysis showed that, though additional inland depots will be required to service new clusters at minimal system costs, none of the initial inland depot locations will be unproductive.
- Even if soybean trade volumes in the region remain static or decrease, empty container depots will still result in noteworthy system cost and empty vehicle mile savings. These savings would justify the opening of inland depots.

6. PHASE 3

6.1. Abstract

Containerized grain shipping has been increasingly used as a shipment option by U.S. exporters. Continued evolution and investment decisions in optimizing multimodal operations is a key in continued growth for the container transportation marketing alternative. An agent-based model simulates the complex regional empty container supply chain based on rational individual decisions. The model provides insight into the role of establishing new depot facilities for storing empty containers, have on reducing the empty repositioning miles while increasing the grain exports in the region, considering the randomness in inland domestic market consumption and export demand.

This simplified initial model assumes a shipping volume, based on an historical average, with demand variability attributed to the Pacific Northwest export gateway. Spatial and temporal effects are captured in the dynamic supply chain. It is designed to replicate the real world and improves the accuracy of decision-making in the modeling process. Model parameters are used to simulate the impact of train frequency and velocity, truck and rail drayage, demand changes at elevators and depot capacity. For the proposed system, stakeholders will be able to quantify the economic impacts of discrete factors like shifts of grain transported to the domestic market and export gateways, adjustments of the rail and truck rates and impacts of elevator storage capacity. The initial model is limited to a single state (MN) and export market. It could be enhanced to present a flexible logistical scenario assessment tool which is of great help to make investment decisions for improving the efficiency of multimodal transportation. The ability of stakeholders to quantify effects among agents is especially valuable to local producers seeking to remain competitive in a global grain market.

6.2. Using Agent Based Model for Analyzing Randomness in Demand Patterns

To analyze probable randomness at elevator sites, in the inland empty container repositioning network and their influence on the depot location, an agent based model is used. Because it is possible that change at a node in the empty container supply chain may occur in-combination or have an interdependence, so we considered to study the interactions between the nodes rather than to consider them independent and study their individual effect. For example, it is possible that a surge in international demand from grains may at the same time enable a large scale empty container demand, which further may affect (decrease) the repositioning from the region due to the matching load available for backhaul. So, to deal with this type of system dynamics, agent based models are the right fit.

6.2.1. Agent Based Modelling

Agent based modeling (ABM) is a class of computational model that is primarily used to understand how individual elements influence the system as a whole. Each individually programmed agent can help dynamically determine the convergence or stability within an economic context. ABM is not intended to replace traditional econometric or optimization modeling rather, it allows for the incorporation of spatial and temporal dependence that traditional operations management and system dynamics models ignore.

Agent-based modelling is a useful complement to more traditional model representation using a system of equations like in optimization. Agent-based modelling more easily allows one to do things that are difficult to capture in traditional approaches, such as:

- Systems or networks which are ever changing due to the agent behavior
- System which involves a huge number of agents and agent interactions
- Systems which involves non-linear interactions

- An evolving system where the agent learning is the goal

ABM is critical in finding the solution to complex problems, because it effectively shares information concerning distinct decisions among regional decision makers. The autonomous decision makers solve problems through ubiquitous cooperation and communication interactions. For the context of this research, Soybeans are produced across Minnesota. Transportation decisions being made based upon farm production, elevator grain handling capacity and demand for empty containers, and railroad service capacity and frequency. Perfect information is not needed for all agents in order to make decisions. Therefore, it is a good candidate for ABM. Additionally, key factors may emerge as a result of individual interactions.

Through ABM models, an iterative process is used to discover an equilibrium over time. Multiple iterations generate a distribution of outcomes rather than a specific equilibrium point. ABM uses the intrinsic qualities of agents with multiple decision variables and possible behaviors to simulate activities such as train deliveries to a location. This example does not have a wide range of possible values but offers widely different outcomes with little change in input. Certain scenarios, like a lack of specific information or the possibility of improved information, can also be accounted for by selectively turning on or off the desired behaviors. This micromanagement of details yields simulated data for a wide range of possible scenarios.

Complex systems allow the network of interactions to adapt based on information concerning the overall environment. For this research, this complex behavior refers to different types of agents and their objectives and yields self-organization and emergence. Self-organization is a phenomenon of the collective or individual behavior appearance within a system without external influence to guide the system to a result *(64)*. Emergence is defined as the way patterns begin to form out of a combination of simple behaviors. Ants trying to find food, for example, results in the emergence of an ant expressway to the food.

6.2.2. Complex System Modeling

ABM is a recent and promising direction of research, which allow to develop new computational approaches to the investigation of economic processes modeled as dynamic distributed systems of self-interested agents *(65).* Huge success and explosive growth of ABM in different fields was predicted and indicates shift from equation-based models towards simulation agent-based models *(66)*. Computation capabilities provide researchers with new dimension extending classical methods in the socio-economic sciences. They allow one to explore theories and mechanisms for consistency simulating numerous scenarios and agent behaviors. In situations when analytic solution is problematic because of number of agents and event-driven behavior simulation model can provide powerful tool for analyzing processes from different angles. There are different areas of applications of ABM. Today we can experience variety of ABM tools and platforms *(67, 68, and 69).*

One of the most simple and powerful platforms is a Java based software called NetLogo, which has built-in graphical interface, high-level programming language and number of add-ons for connecting with systems like R or Python. The main purpose of NetLogo is modeling of complex distributed systems evolving with time. NetLogo© is an ABM environment that can be used for simulating social and natural phenomena. . It has several types of agents – turtles, patches, links, and the observer agent. The observer agent has a view of the whole NetLogo system that is being modeled and is used for running the primary parts of the program (linked to buttons on the interface). In addition, it provides a way to interact at the command level on the main interface. Patches represent square and box cells on the main 2D or 3D view of the world, respectively. The turtles are agents that can move around on the world surface and draw. Links are the relationships between turtles.

It is particularly well suited for modeling complex systems over time, and with the use of a GIS extension, landscapes that are spatial can be accurately modeled. Geographic Information Systems (GIS), are an alternative method of modeling – primarily focusing on geographic spaces rather than time and behavior. Agent Based Modeling focuses on the behaviors and timelines within a geographic space. Integrating the two could potentially allow for a highly robust modeling system that most efficiently utilizes the strengths of each type of system. This can be realized in two ways:

- Dynamic coupling – access to geographic data is generated during the model's computations *(70)*. Agents have access to underlying information and are able to read/write spatial data into the database throughout the model generation.
- Static Coupling – geographic data are imported into the simulator prior to running *(70)*. It is less intensive as far as computing capacity is concerned, and also creates a more realistic representation of space when compared to the existing space capabilities of Netlogo©.

Freeman et al. work *(71)* deals with changing in farms distribution over Canadian Prairie. Authors presented ABM tool to analyze the evolution of farmer's financial state and farms size over the period 1960–2000. Lawerence *(72)* Canadian grain transportation system is considered. The main idea was to test availability of rail transport system for grain delivery during all year and to find possible weak links, delays and capacity shortages. Using NetLogo with GIS add-on they developed model and provided findings about grain delays (very high chance for small elevators) and profitability for using entrant railway, developing important insight about future policy recommendations for governing the Canadian elevators and railroad system which is to consolidate elevators into big and medium hubs to increase their flexibility.

This research deals with economic simulation of wheat supply chain, where containers, elevators, depots and port agents interact to utilize empty containers to transport grain to the exit gateways. This problem falls into novel approach of agent-based computational economics (65). It is worth mentioning that currently there not many works on ABM application in this particular area. One example is about land use distribution analysis *(73)*, where ABM is used to estimate different scenarios of wildlife changes in the Mediterranean area because of growing farming activities.

6.3. Model Initialization Information

In the initial phase, all the physical boundaries are loaded into the simulation environment that is Netlogo. The shapefiles that contain the location of the physical characteristics are loaded first, including all elevator locations, potential inland depot locations (brownfield sites), intermodal terminals, ports, the placement of the highways, rail lines and the state boundaries. As part of the shapefile, there is projection information that gives the simulation a reference to the dimensions of each file in physical space. This information is used as a conversion factor so each agent in the simulation can convert the simulated landscape to the real environment, particularly for the use of distance measurements. Agents within the landscape can only measure simulated distances. However, once they are given a conversion factor, they can convert simulated distance to real distances and their decision-making behavior then closely replicates a real process**.**

6.3.1. Facility Development Cost

The facility assumptions for an inland depot is based on 10 acres plot of land. To fence the perimeter of 10 acres on three sides requires 495 feet of fence (Table12). The infrastructure development consider the costs of cleaning the brownfield sites, pavements, an office and work lights. Equipment costs include the cost of one container lifter, two chassis, and one hustler *(61)*.

Table 12. Investment assumptions for developing an inland depot

Category	Number	Unit	Unit cost
		Facility Development	
Land acres	10	Cost per acre	$2500
Fence feet	495	Cost of fence per foot	$15
Pavement acres	10	Cost per acre	$12000
Lightning	3	Cost of lights	$5000
Office building Sq.F	500	Cost per square foot	$80
		Equipment	
Container lifter	1	Cost of lifter	$600,000
Chassis	2	Cost of Chassis	$7000
Hustlers	1	Cost of hustlers	65,000

This model considers only the fixed cost investments for operating an inland depot. The estimated cost of facility development is calculated to be $207,425 and the total calculated equipment investment is $679,000.

6.3.2. ISO Containers

For global trade the standard container dimensions are 40’ or 20’ in length. For the basis of container volume measurement 20’ container size has been adopted, with the abbreviation of “twenty-foot equivalent unit” into the metric “TEU”. The standard container exterior height is 8’6” *(74)*. To meet the state weight restrictions and Federal Bridge Formula maximum cargo weights of 80,000 pounds for truck, tractor, chassis, container, and cargo combined is allowed for imported contents *(75)*. Containers that are moved by rail and vessel only can be loaded to the container’s maximum capacity. For 20’ dry containers, the maximum payloads range from approximately 55,000 to 66,000 pounds *(76, 77)*

6.3.3. Elevator Capacity

There are 98 elevator locations in Minnesota (MN). They are owned by various companies, of which a number are primary facilities, which predominantly take grain for the purpose of exporting it out of the state using railroads (Figure 25). The total capacity of all of the delivery locations in the state is 216 million bushels (Table 13). For this model, the processing facilities will not be included because they do not buy grain for the purpose of exporting the raw commodity. The capacity of the primary delivery facilities is a number for the shipments to various export points, or % of the total elevator storage capacity in Minnesota.

Table 13. Minnesota elevator capacity in bushels

	# Elevators	Storage Capacity
Shuttle Elevators[3]	34	112,848,963
Non-Shuttle Elevators	64	102,667,043
Total	98	215,516,006

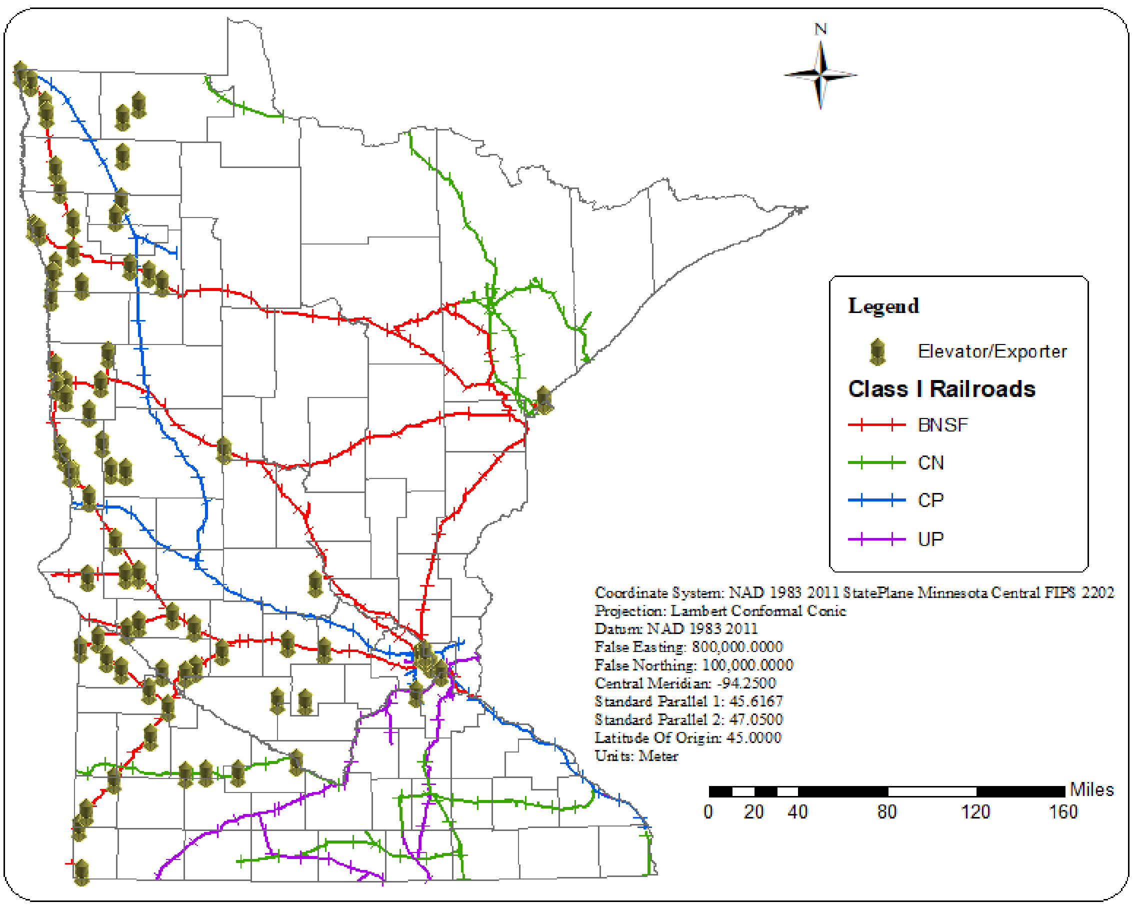


Figure 25. Minnesota elevators and class I railroads

[3]Shuttle elevators have dedicated rail services to ship grains to domestic facilities and exit gateways

Individual elevators are defined based on their elevator shapefiles. The shapefiles provide each elevator's location in the landscape, as well as the capacity of each location, the railway that services it. The rail and trucking distance is measure in Netlogo, when it is coupled with GIS. Once an elevator is created, a rail siding belonging to the respective railway that serves the elevator is added to the elevator location. The rail siding is initialized to meet the requirements of the specific elevator location.

Assumptions:

Only non-shuttle elevators volumes are considered for this empty container supply chain model. There are 98 facilities in MN with shuttle loading capability. They are distributed along rail mainlines and branch lines. Most are located to the south and west of the state, serving areas where shuttle crop production tends to be greatest.

6.3.4. Trucking Drayage

The movement of containers by truck and trailer is called drayage. Intermodal operations depend on the trucking sector for critical first- and last-mile connections between the rail connections at intermodal terminals, the shippers, and the customers. Bulk grain from the elevator is packaged in bags and stacked on pallets or loaded directly into a container that has been sanitized and lined with a plastic bag. Once a container is loaded it can be loaded on to a truck pulling a flatbed semitrailer. Using online Drayage Directory we identified 44 companies in the Twin Cities and two companies in Duluth and all of these companies are based in Minnesota *(78).* Figure 26 shows the rates per mile for trucking empty containers.

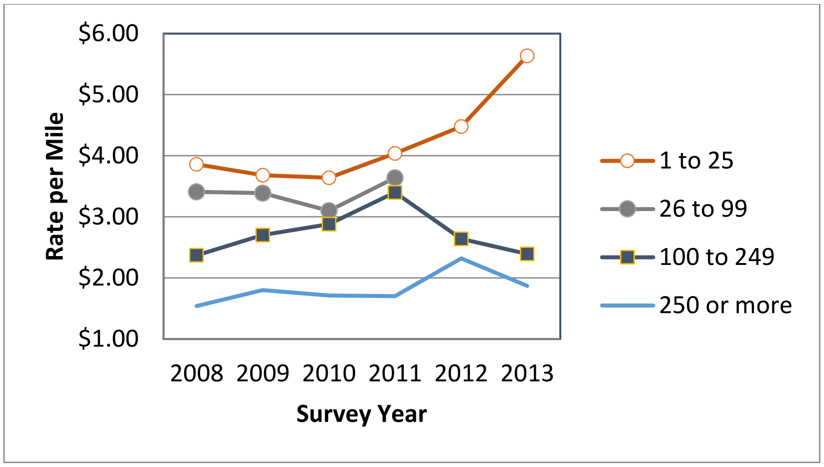


Figure 26. Truck rates per mile as per survey year

In this research empty containers are drayed to and from inland depots, where empty equipment is stored to await future *(79)*. In addition, the driven distance is composed of the sum of travelled distance between elevator locations and inland depots, import customers to inland depots and in addition between inland depots and ports.

6.3.5. Rail Drayage

There are 20 railroad companies operating in Minnesota which claims 4,485 miles of active railroad track in the state which ranks 8th in the nation. A total of 3,586 miles, or 81 percent of the mileage, is owned by the state's Class I railroads. Minnesota has been known as the gateway to Chicago as domestic service destination and the Pacific Northwest (PNW) as the exit gateway destination (Figure 27). In addition to Minnesota the intermodal terminals of the state provide services to the shippers of North Dakota and Wisconsin.

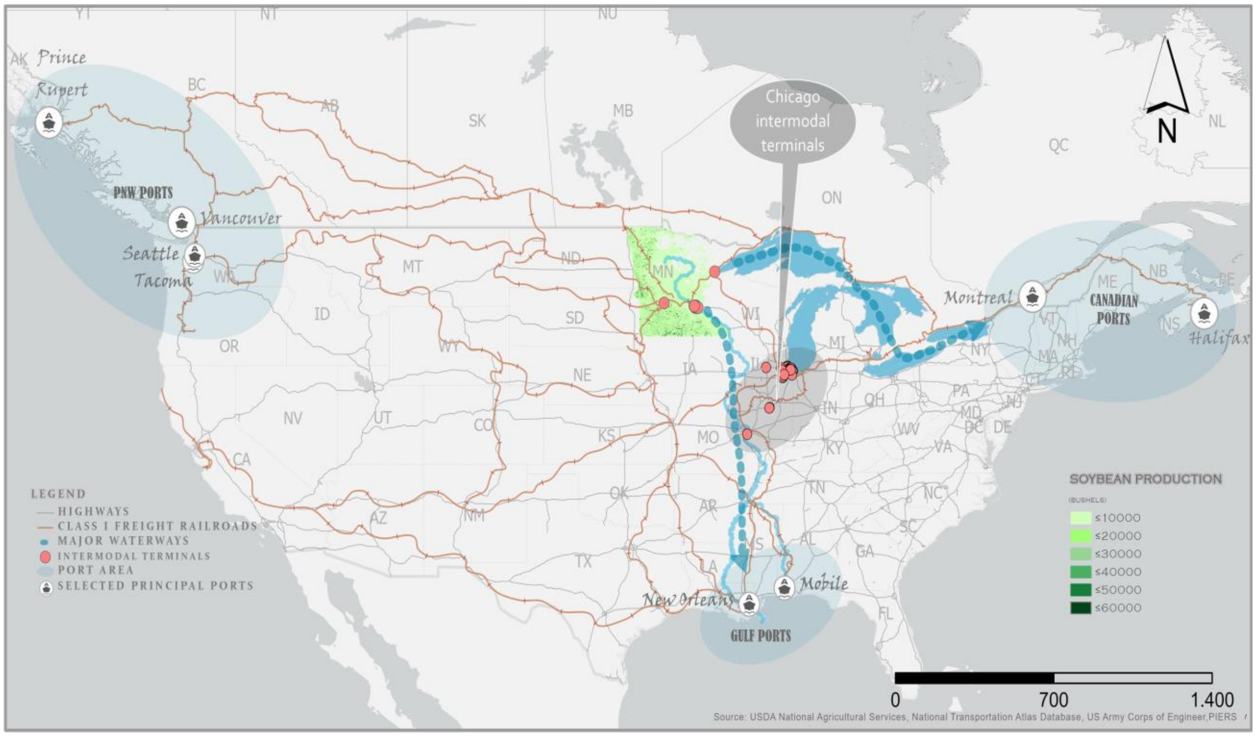


Figure 27. Soybean production and exit gateways for Minnesota

The Federal Railroad Administration (FRA) classifies track into a series of categories based on physical condition (i.e., tie and rail condition, surface, cross-level, etc.). For each category, trains are permitted to travel up to a set speed, with the higher numbered categories allowing higher speeds. Permissible speeds generally differ for freight trains which can travel up to 40 mph on FRA Class III track. Typical short line track is maintained to FRA Class II (24 mph maximum for freight), and Class I (10 mph maximum). The rail velocity input is fed to the model based on the rail class and FRA category.

The containers on rail typically move under contract and not tariff rates and so the price information is very limited. We used the cost that was estimated to dray containers using rail, from Montevideo to the Shoreham *(80)*. The indicated costs in the study were supplemented by current average price of fuel. In the model, the railways obtain rates from text files containing the freight rate in dollars per bushel mile. To analyze intermodal rail moves the Public Use Waybill of the U.S. Department of Transportation (U.S. DOT) Surface Transportation Board (STB) was used.

Assumptions:

- BNSF shuttle trains have 110 cars
- Throughput capacity calculations assume shipment of soybeans.

6.4. Simulation of Empty Container Supply Chain Model

6.4.1. Model Setup

The model setup should be performed before running simulation in order to place all the shapefiles and to define all the variable and their initial values. The supply of empty containers is made through Chicago intermodal terminal. The model accepts the input for trucking and rail drayage cost. The user also has the option of providing input for truck and rail velocity (Table 14a**).** For transportation of empty containers from Chicago, the mixed mode switch can be used to choose the option between only highways (base case) or highways and railways (proposed model) (Table 14b). Once the containers are loaded with grain they vanish from the model. Empty containers travelling from Chicago by rail, partially gets unloaded at intermodal terminal and ports while the remaining lot is sent to the inland depots for storage for future use. The slider option can be used to regulate the number of containers moving either to terminals and ports or depots. In order to eliminate the initial bias, during the simulation warmup period, all the ports and depots are given an initial inventory of empty containers which can be manipulated with the use of sliders (Table 14c). The elevators set demand of empty containers based on the historical data obtained from USDA National Agriculture Service, National Transportation Atlas Database, U.S. Army Corps of Engineers and PIERS. This model uses a heuristic to make sure that approximately 95% of the elevator storage in a given year, is shipped to the exit gateways.

Table 14. Model setup summary (a, b and c)
(a)

Input Window	Short Description
Truck velocity	Average speed of truck on highway
Truck cost	Average cost of truck per mile
Train velocity	Average speed of freight train
Train cost	Average cost of train per mile
Cost per depot	Fixed cost of opening a depot

(b)

Switch Name	On	Off
Depot	Proposed system	Base case
Mixed mode	Railways and highways	Highways
Shortest route by cost	Shortest distance by cost	Shortest distance by time
Chicago by train	Empty containers move by railways	Empty containers move by Highways
Open new depot	Proposed system - Search for new depots	Base case – No depots open
Close underuse depot	Closes underutilized depots	underutilized depots remains open

(c)

Slider Name	Short Description
Number containers at port	Beginning inventory at the port for simulation warm up period
Number containers at depot	Beginning inventory at depot for simulation warm up period
Number containers daily in	Empty containers entering Minnesota per train per day
Average containers daily demand	Demand of empty containers by elevators
New depot threshold	Throughput capacity of new depot

6.4.2. Recording

Netlogo has great visualization and recording tools like plots and monitors. For evaluating the effectiveness of the system some performance metrics are created. Plots are used to record the total system cost, total empty miles travelled by highways and railways and total number of empty containers used in the system (Figure 28). Monitors are used to display number of depots opened and number of empty containers ordered by depots over the period of simulation.

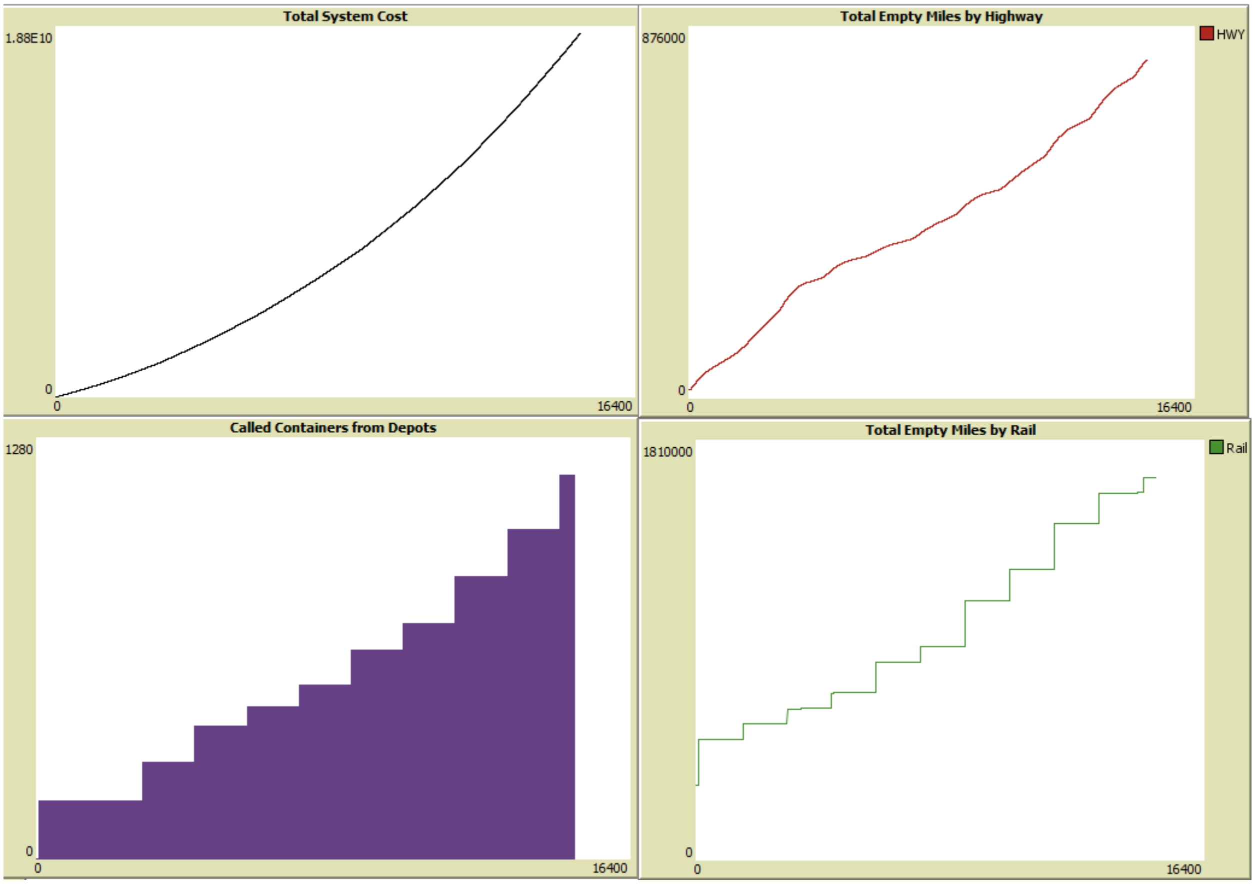


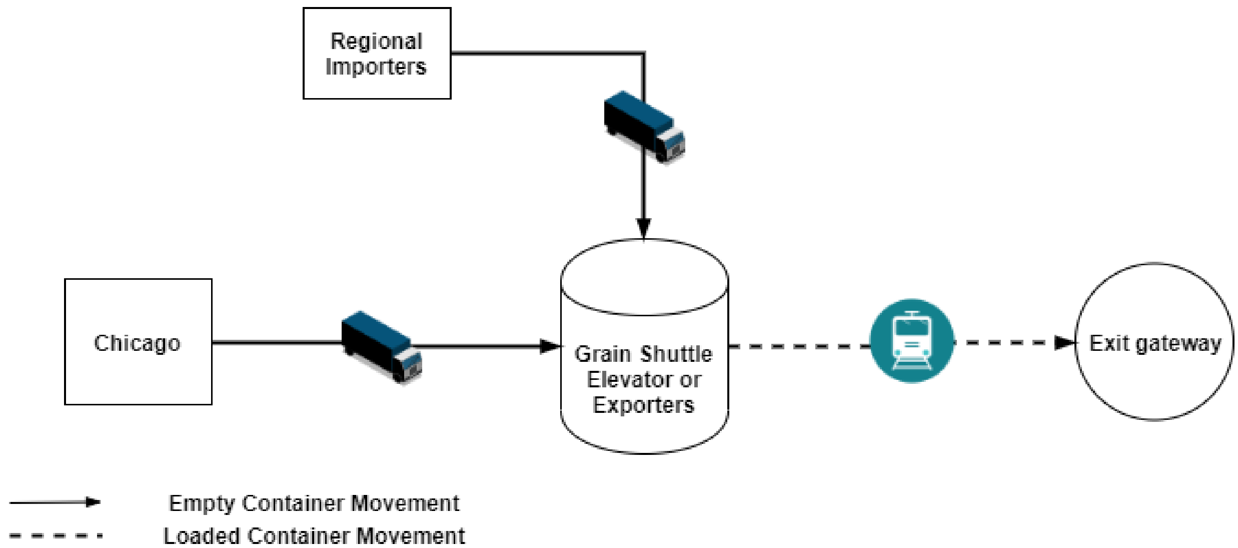
Figure 28. A snapshot of monitors crated in Netlogo

6.4.3. Validation

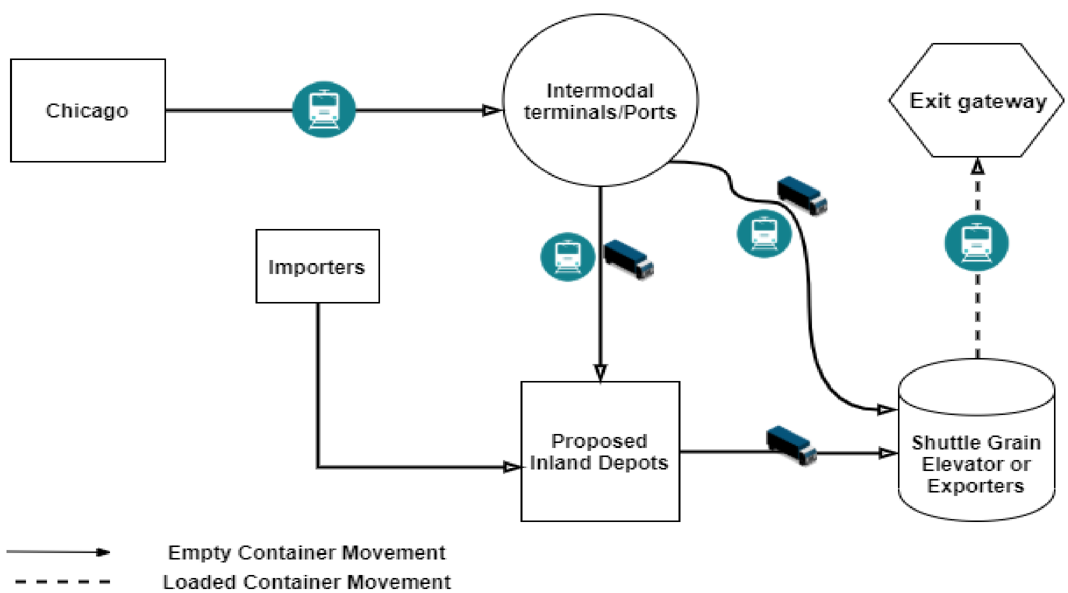
Validation of the model is done by comparison of shipments of soybeans from Minnesota to exit gateways. Shipments were chosen as these are independent of datasets used in the simulation and will provide an accurate indication of the ability of this model to replicate real world behavior. With the importance on the accuracy of shipments, a rule was added to the rail behavior to ensure elevators were able to deliver all of the soybeans they wanted to deliver.

6.4.4. Simulation

Using prior research, relevant literature, and industry knowledge, the goal of the research is to effectively model the complex empty container supply chain for grain transportation. This study proposed a model to capture major transportation corridors in the movement of empty containers within the state fulfilling the demand of exporters and grain elevators to transport grain to the exit gateways. The agents in the model are containers, elevators, inland depots and ports. To help the reader visualize the simulation, figures seeks to explain how empty container supply chain agent-based simulation is structured. Figure 29a shows the base case scenario and figure 29b shows the proposed system.



(a)



(b)

Figure 29. a) Base case b) Proposed system

The simulation is replicated for 60 months, with 12 months equating to one calendar year and each replicate proceeding for 5 years. We collected 560 iteration, yielding 33600 months of data. In order to reduce the computing time and to make the model economical, simulation will be performed on weekly basis instead of daily basis. The dimensions of the simulated area are 400 kilometers east and west, and 350 kilometers north and south. This spatial information was added to the simulation environment such that all agents that populate the simulation operate within the boundaries of the simulated world, and in effect, operate within a landscape similar to the real world. Elevators, ports, intermodal terminals and depot locations were positioned with the aid of a shapefile that located highway as well as the rail network. The number of trains that move on the rail lines were randomized by normal distribution as railway behavior was not explicitly modeled. Most variables are cleared at the start of the week, with the exception of inventories of depots, intermodal terminals and ports.

Base case:

In this model the base case refers to the condition when the exporters have to order empty containers from Chicago. These containers are trucked to the exporters, who pay for this empty run. So, this adds to the container availability challenges for shippers not well positioned. During the peak demand periods ocean carriers are seeking to maximize equipment utilization, both for vessels and containers. This is generally achieved by increasing the number of turns per year, which translates into shorter load/unload times at ports and also places greater demands on shippers adhering to tighter service windows. This also makes it more difficult for regional shippers accessing the containers, particular during heavy regional congestion periods.

Proposed System:

We propose to open inland depots in the regions of high trades volumes to provide availability and to reduce the repositioning of empty containers. For the proposed system the model uses a mixed mode where the containers travel from Chicago to Minnesota intermodal terminals by railroads and then choose either highways or railways to travel to the ports and depots based on the selected option of shortest route by cost or by time. Finally, when empty containers are demanded by exporters or elevators, they are trucked from the depots.

6.5. Agent Behavior

This section will describe in some detail the agent behavior of empty container supply chain agent based simulation model. Due to the relative lack of prior research on this topic, to that end much of what is detailed here comprises a set of rules, whereby I use relevant literature, expert views and industry knowledge to try to realistically re-create the complex empty container transportation system supply chain. To help the reader visualize the simulation, Figure 30 provides an overview of the Netlogo interface screen .The runtime procedure in the simulation is where all of the individual agent’s behaviors are realized. The runtime procedures in NetLogo© is the smallest time gap for each simulation run within the span of one tick, which in this model is one week.

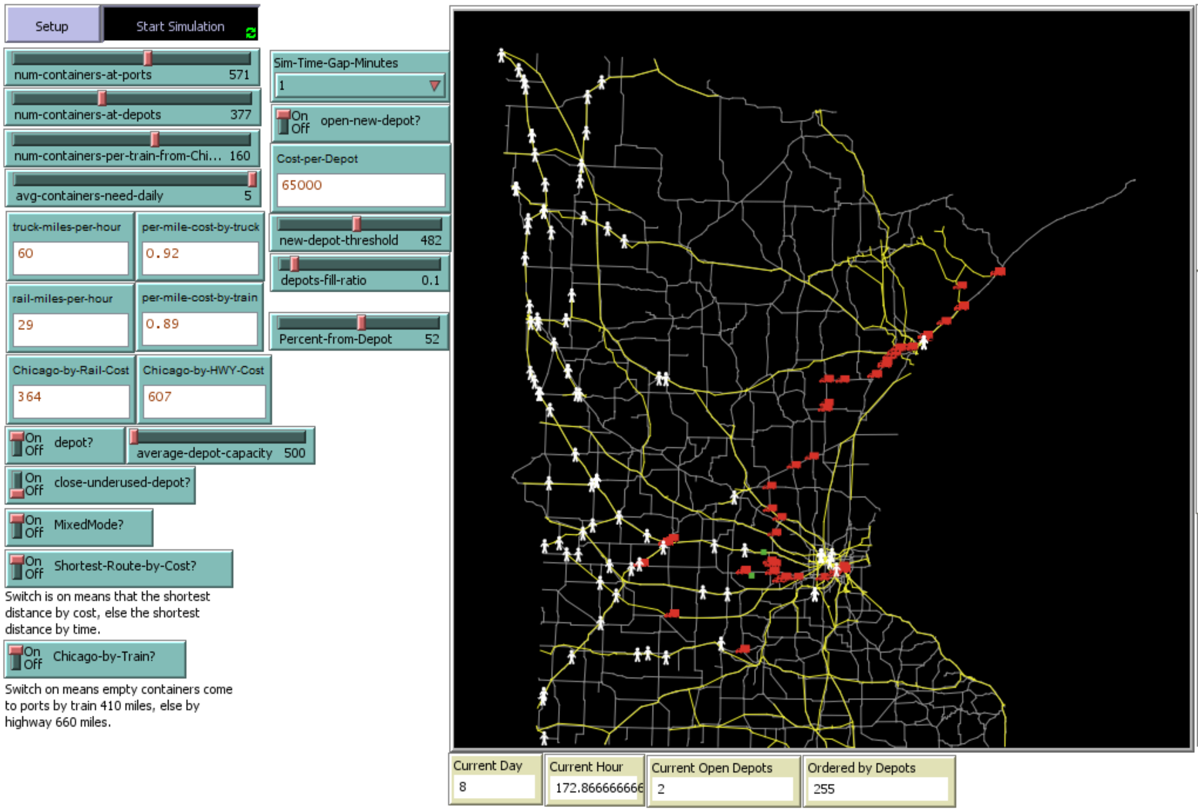


Figure 30. Screen shot of Netlogo interface

6.5.1. Elevators

The elevator acts as a gathering site for rail wheat shipments. The evolution of increasingly larger container ships places more importance on rail in order to move larger volumes of containers away from and back to the port quickly. The economies of scale achieving in moving the trainload volumes is essential to competitively delivering grain to export and domestic customers located long distances from the production region. In this model, the elevators do not store grain as a market function or as speculators in the market. It is assumed elevators seek to maximize profit through velocity in turning over wheat inventory based on outbound rail capacity. Elevator capacity, which becomes some multiple of the storage capacity, changes each month based on the number of trains allocated to each elevator. This creates fluctuations in rail service. The storage capacity is directly proportional to the number of trains received – as the railway is the primary supply chain mode for the elevator. This simplification is well-justified based on monthly shipment information reported by elevators as well as national public data sources regarding grain production and rail transportation volumes.

6.5.1.1. Potential Demand for Empty Containers

Demand decisions by the elevators are fixed for all the months of the year, and are the same in each year of the simulation. The demand of empty containers in the model is linked with the harvest information. In every period each elevator set a certain percentage of empty containers needed, of their total demand in a year (Table 15). These demand patterns are assumed to remain the same for each year of the baseline simulation. To maintain a fairly constant output, the elevators must adjust the percentages of their potential demand in a period of time. For example, the highest inventory amounts are in August, so the relative percentage will be high. In September, the percentage demand of empty containers will decrease as they will have comparatively less grain to ship.

Table 15. Demand volume of empty containers by month

Month	Demand Volume (%)
January	50%
February	45%
March	35%
April	25%
May	15%
June	10%
July	10%
August	100%
September	90%
October	80%
November	70%
December	60%

6.5.1.2. Ordering Empty Containers from Depots

Prior to elevators determining the depots they would like to place an order, a subset of depots derived from all the depots according to the proximity and ability of depot to deliver empty containers. A depot may be in proximity, but if it cannot deliver to the elevator, because the depot has no available containers, then the depot is not accessible. In this case the order shifts to another depot in proximity. In the model, the most needed exporters will get containers first. The need of containers is measured based on the accumulation of needed container gap. For instance, if today an elevator require five containers and get none, then the need level will be 5. If next day the same elevator require five containers and get two, then the total need level will be eight. Next period, the elevators get supply of containers based on need priority. This will help avoid some of the remote exporters have less chance to getting containers. In order to render the delivery problem tractable, I had to divide the full set of depot subsets that approximately correspond to the demand and catchment areas of the different elevators. This implies a large catchment area for large elevators and so on down to the smallest elevators with smallest catchment area.

6.5.2. Rail Service

In this model the empty containers travel through rail, from Chicago to Minnesota intermodal terminals. Thereafter, they get distributed to ports and depots as per their demand. Railroads take delivery of soybean containers from the elevators and transport it to the port destination. The annual number of rail allocated to elevators would be consistent with the average soybean production that would be transported to non-truck markets in the same time-frame. Although about 10% of the wheat is processed within Minnesota, the majority moves long distances to export terminals or domestic mills. In this model, each elevator is allocated trains in 100 car train units – with an allowable calibration (for simplification) within the rail car allocation that allows the elevators to reject train spots if the elevator's facility has less than one train of containers. Although this is not true in the real world scenario the elevators are penalized for canceling trains that they have ordered in a yearly contract.

6.5.3. Intermodal Terminals and Ports

The proximity of Minnesota to the Chicago intermodal terminals present opportunities to shippers in Minnesota. Chicago is the closest location where the six largest North American Class I railroads come together. Further, an estimated 46 percent of all intermodal containers cross through the Chicago area *(81)*.

Two intermodal terminals in the Twin Cities (Table 16) also provide rail intermodal service options via drayage for much of Minnesota, Wisconsin, Iowa, and the Dakotas. The facility is two miles north of I-94, and operates 24/7. The site encompasses 44 acres and the yard's capacity is approximately 338,000 lifts per year. Between five and seven intermodal trains are handled at the yard per day; two of these are high-priority runs between St. Paul and Chicago. Approximately 500 trucks/container units enter the facility per day, with origins in Minnesota, Wisconsin, Iowa, and the Dakotas.

Table 16. Class I railroad intermodal terminals of Minnesota

Railroad	Facility name	Domestic service destination	Exit gateway destination
CP (Canadian Pacific)	Minneapolis Terminal	Chicago, IL	Vancouver, BC Montreal, QC
BNSF(Burlington Northern Santa Fe Railway)	St. Paul Intermodal Facility	Chicago, IL Seattle, WA	Seattle, WA Tacoma,WA Portland, OR
CN (Canadian National)	Duluth Terminal		Vancouver, BC Montreal, QC Prince Rupert, BC New Orleans, LA Halifax, NS Mobile, AL

Duluth is one of the newest additions to intermodal facilities in the Upper Midwest. The facility opened in March 2017 as a cooperative partnership between CN and Duluth Cargo Connect. The terminal dedicates 7.5 acres for ramp operations and has yard storage capacity for 1500 TEU with an annual throughput capacity of 45,000 TEU. The shippers have an advantage of a $500 to $700 over shipping through Chicago was stated. Direct trade through the Port of Prince Rupert was seen as another advantage.

6.5.3.1. Delivery to the depots

Once the intermodal terminals receives the order of empty containers from depots, a log keeping variable records all the orders and when the order is worth a train full of containers, then the order is placed at Chicago intermodal terminals. In the model it is assumed that there is infinite supply of empty containers at Chicago and this simplification is well-justified based on the fact that six class I with 46% of all intermodal containers passes through Chicago. When the Intermodal terminals at Minnesota receive train of empty containers shipped from Chicago, it subtracts it from the order's log. The terminal updates its inventory at the start of delivery sequence of train because the terminal is not able to update its inventory within a train delivery sequence as only one type of agent can perform behaviors at one time. The model takes user input for the frequency and velocity of the train. These containers are unloaded and stored at yard space, waiting for future orders from the depots. The depots with higher throughput will have higher likelihood of getting empty containers.

6.5.4. Inland Depots

In the cases where ISO containers make it to the interior of the country, it has created opportunities for relatively low-cost transportation for agricultural products in some locations. For example, containerized soybean shipments originating within 100 miles of Chicago, have grown over time primarily due to the prevalence, availability and cost of accessing empty containers destined to Asian markets. Inbound container movements to the U.S. from Asia are primarily driven by population density and economic geography, which is why so many containers end up in locations such as Chicago, IL or Memphis, TN. There and many diverse, high-value agriculture products close to these and other ports, mostly within 400-500 miles from the ports, but gaining access to containers to support agricultural exports has historically been a major challenge for shippers.

Inland Ports serve a vital and common function in most regions, connecting agricultural markets, regional manufacturing and economic activity to and from markets abroad. Many of these inland ports are key container terminals where ocean containers are transferred between modes (truck/rail/ocean) and distributed to suppliers and customers inland or exported to markets in Asia or Europe.

6.5.4.1. Delivery to Elevators

Prior to attempting delivery, each depot updates a record keeping variable to hold their current inventory amount. A depot logging variable is used so the depot records the number of containers that are ordered. After each delivery the elevator resets its inventory value from the last delivery made by the depot. This variable is a count of the number of soybean containers shipped by rail to the exit gateways. The elevator then checks to see how much grain and if it has grain worth of a container then an order is place to the depot. After an order is placed, truck distance and the rates are accessed to calculate the cost of draying container to the elevator, which further adds-up to the total system cost. The number of containers delivered is subtracted from the depot's inventory.

6.5.4.2. Open New Depots

In the proposed system the model might open new depots based certain sets of heuristics. The model opens the first depot based on the level of service. It chooses random location where the depot can provide service to most of the exporters in certain radius. The decision to open depots after the first one is based on two variables depot capacity and depot throughput threshold. During the peak load times (that is first four months from the month of harvest) more orders of empty containers are placed which further translates into more orders to the intermodal terminals. There is a possibility that a depots reaches its capacity to store these containers if there is a lag between receiving and fulfilling the orders from elevators. The model records the number of times a depot reaches its capacity during a particular period of time. Each depots provide services with limitations of equipment, operator, availably of truck for drayage and so it is constrained to fulfill the demand of elevators. This behavior is represented in the model by introducing a variable called depot threshold capacity. Each depot is given a throughput threshold which is capacity of the depot to fulfill demand of elevators.

The model also records the number of times a depot reaches its throughput threshold. The user can set frequency limits of these variables at which the model can decide to open a new depot. Once the model decides to open new depot from the set of potential depot locations, it calculates the existing depot proximity to all these depot locations and at the same time the model also has a record of number the containers ordered by each elevator. With both these information available the model calculates the optimal location from the set of available potential locations to open a new depot. In future if there is a change in farm population distribution or the international and domestic demand of soybean changes the model decides to close the underutilized depots or open new depots based on the heuristic defined above.

6.5.5. Elevator Delivery Behavior

Once deliveries of empty containers have been made, an elevator then compares its inventory against the amount the railway serving it is scheduled to pick up in that particular period. If the elevator has sufficient inventory to fill what the railway will transport in that particular period, then the elevator allocates the amount the railway will need and subtracts that allocation from its inventory.

6.5.6. Railways Take Delivery

The railway accepts delivery of loaded containers from the elevators. Once the railway has taken delivery, the railway updates this delivery which is recorded in a variable called number of containers of grain shipped.

6.5.7. Port Delivery

The final action is for containers to be delivered to port. Deliveries at port are assumed to have been called in. Ship tonnage is allocated as a function of inland capacity. The number of ships is determined after the total port deliveries are calculated. Randomness is introduced such that only a discrete number of ships can dock in a given month, while deliveries from each of the companies is continuous, allowing for demurrage to occur at port.

6.6. Results

6.6.1. Model Validation

An approximate validation of results is performed if the model is broadly consistent with the real world results. For validation the study uses shipments of soybeans from Minnesota to exit gateways. While the simulation consistently overestimates shipments, we note that shipments generated with the simulation track actual shipments quite closely (Figure 31). In fact, the simulation consistently overestimates shipments because the rail service is available frequently, generated out of random normal distribution, with an average of three per day. Furthermore, the soybean shipments in the model are calculated as a fixed percentage of the total shipments from Minnesota to PNW ports by railways, so in a year with higher production the simulated wheat shipments will be higher as well. Another reason for this overestimation of the simulated data is due to the adjustment in the model, where we applied a heuristic which makes sure that the elevators can demand certain percentage of containers every month (this is linked to the percentage of grain supplied by the farmers to the elevators). This heuristic is included to make sure that elevators have grain available through the year and to maintain consistent flow of empty containers in the simulation model.

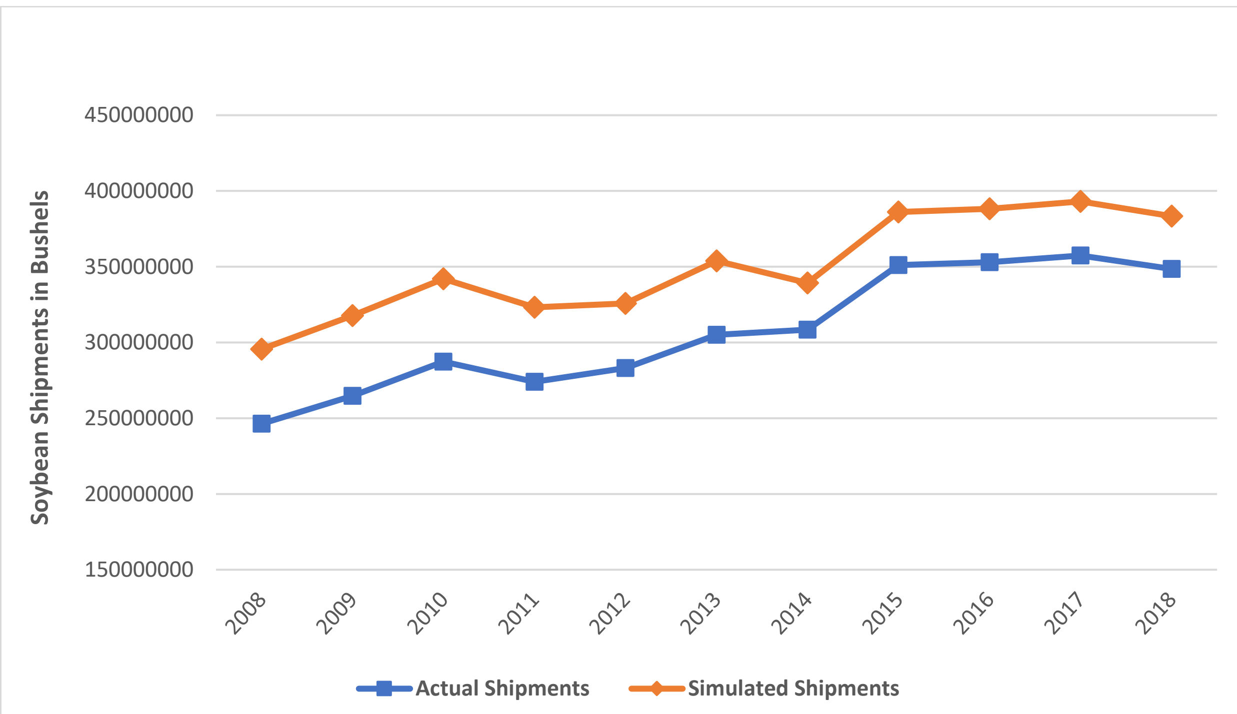


Figure 31. Soybean shipments from Minnesota

As a pragmatic simulation framework, several simplifications were needed. While some may not mirror system behavior for the full duration of the simulation, the simulation closely tracks real soybeans shipment data. Therefore, it is indicative that the model is a reasonable representation of the empty container supply chain for Minnesota. While certain assumptions and heuristics have affected the long-term accuracy of the simulation, the model generates realistic output for many other measures of system performance.

6.6.2. Statistical Testing

In order to test, if there is significant difference between the means of actual shipments and simulated shipments, we want to confirm the assumption that the variance of two groups are equal. Bonett and Levene's method to test the estimated ratio of two variances is used. In our null hypothesis we assume that two variances are equal.

Null hypothesis	$H_0: \sigma_1 / \sigma_2 = 1$
Alternative hypothesis	$H_1: \sigma_1 / \sigma_2 \neq 1$
Significance level	$\alpha = 0.05$

Method	Statistic	DF1	DF2	P-Value
Bonett	0.21	1		0.644
Levene	0.15	1	20	0.700

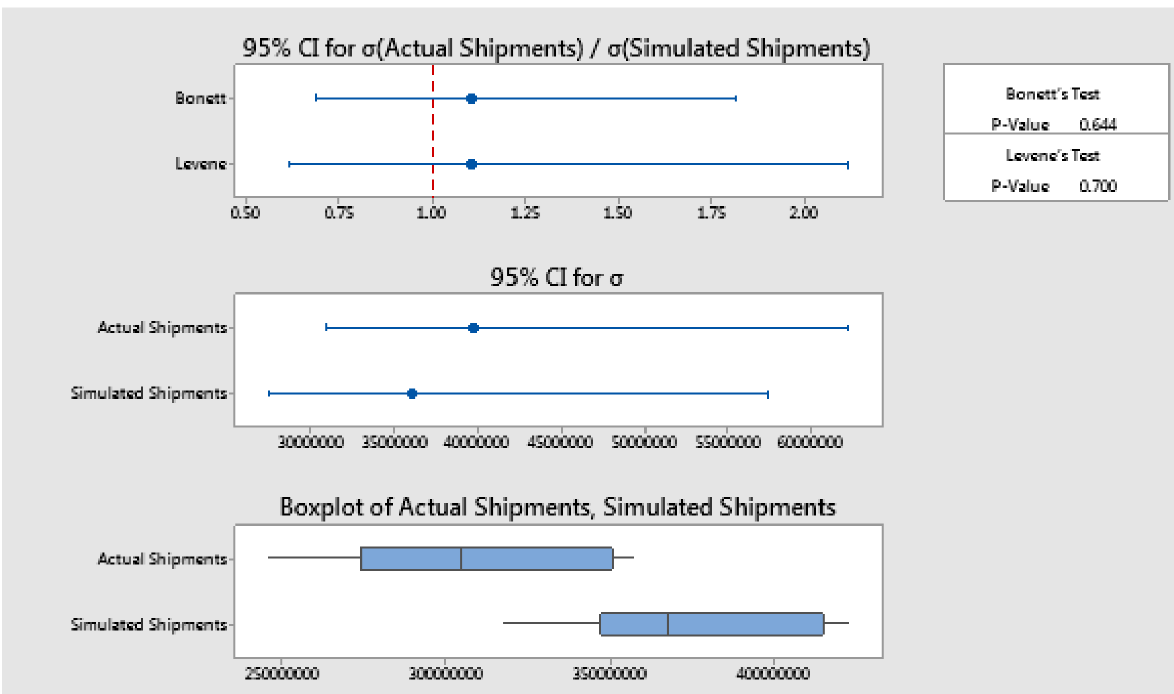


Figure 32. Test for two variances: actual shipments and simulated shipments

The p-values from both Bonett's and Levene's tests are greater than 0.05 which concluded that the null hypothesis cannot be rejected. This confirms that the variances of two groups are similar.

Now, we can safely use the two sample t-test to check if the means of actual shipments and simulated shipments are significantly different. We considered our null hypothesis (Ho) as: There exists no significant difference between the mean of the actual shipments and the simulated shipments, and Alternate Hypothesis (H1) that: The means of two groups are statistically different from each other.

Sample	N	Mean	StDev	SE Mean
Actual Shipments	11	330320000	42782060	12899276
Simulated Shipments	11	349858873	33534493	10111030

Null hypothesis H_0: $\mu_1 - \mu_2 = 0$

Alternative hypothesis H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
-1.19	18	0.249

The result shows that the t-value is smaller than the t-significance with a p-value of 0.249, which implies that we cannot reject the null hypothesis. The testing concluded that the difference between the means for the two groups is statistically insignificant.

6.6.3. Analyzing Uncertainty in Empty Container Volumes at Elevator Sites

We are assuming that the distribution of farm population remains constant over the period of simulation. But in future if the distribution changes it would further effect the grain production and shipping. We assumed the production volume to represent the demand of empty containers for soybean export in the region, since it is a known fact that in the study region (MN) five million tons of soybean are exported from the state, and, of those, 5 million tons 94% are exported to international buyers such as Indonesia, Japan and Taiwan. A regression model was developed and a trend line is fitted on the historical data (2008 – 2018) of soybean production (Figure 33).

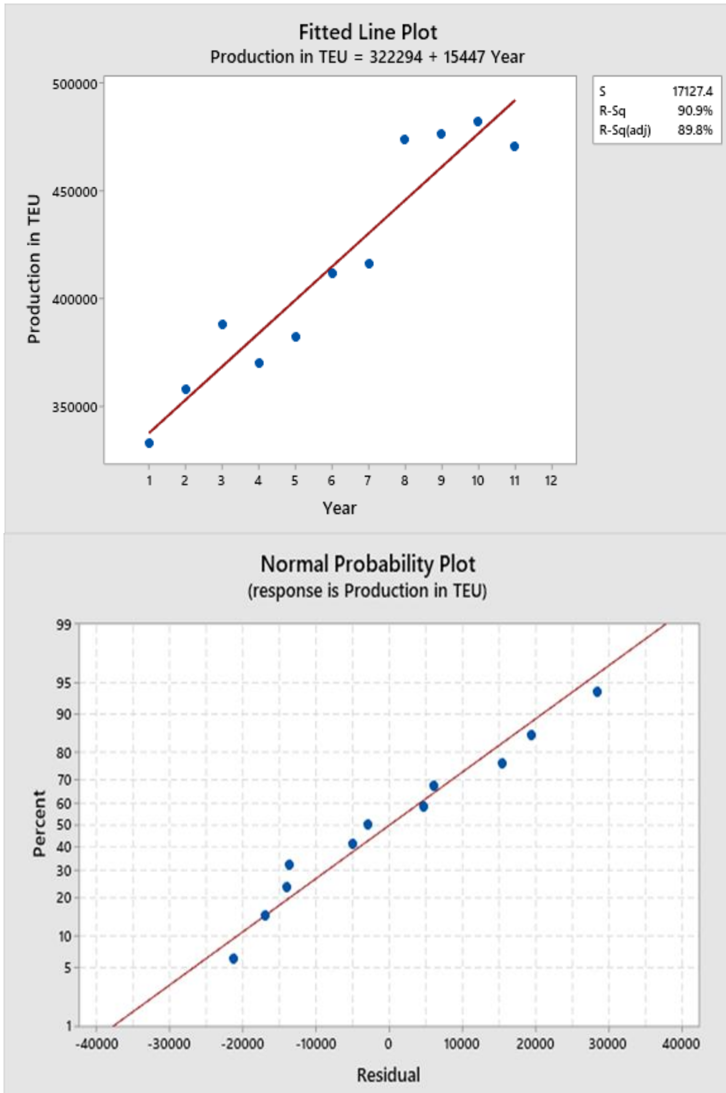


Figure 33. Soybean production volume in Minnesota

The regression equation was obtained as:

Production in TEU = 32294 + 15447 Year

i.e., μ = 322,294 TEU and σ = 17,127 TEU (one standard deviation (s.d.) was approx. ~19% of the mean).

Based on the information of regression model, the following scenarios are built to incorporate the demand volume variations:

- There is 60% probability that empty container demand will grow as predicted, i.e. within one standard deviation(s.d.)
- There is a 25% probability that empty container demand will fall by more than 19% (more than one s.d.) but not more than two s.d., i.e. between one s.d. and two s.d. of the predicated volume
- There is 15% probability that empty container demand will grow by more than 19% (more than one s.d.) but not more than two s.d., i.e. between one s.d. and two s.d. of the predicted volume

6.6.4. Scenario Analysis

In order to determine the effect of change in empty container volume at the elevators on potential depot locations in the proposed system, the following three cases were solved independently (1) demand volumes stay within the prediction range (2) demand for empty containers falls by more than one standard deviation or, (3) demand grows by more than one standard deviation at the port node throughout the time horizon considered in the study. Long term trade predictions and projections are helpful but unfortunately they cannot be very accurate. The problem becomes critical when region and depot owners are forced to make decisions on the number and location of inland facilities to be opened in the beginning of the time horizon with imperfect information on the future demand volume. Yet, facility location decisions are long-term and need to be made early in the study horizon so that facilities can be built when they are required.

To make a decision on inland depot facilities and determine an optimal set of required depots (under the observed probability of the random occurrence), we analyzed the agent based model using the above mentioned three scenarios. Table 17 shows the results:

Table 17. Results of scenario analysis in millions

Occurrence probability	Number of depots opened	Total driven empty miles by truck	Total driven empty miles by train	System cost
Elevator demand remains as predicted i.e. 60%	5 (t = 20)	264M	584M	$1011M
Elevator demand Falls by 25%	3 (t = 20)	89M	296M	$779M
Elevator demand grows by 10%	2(t = 20)	119M	312M	812M

Five inland depots were opened in the region in the time horizon, when the demand of empty containers at elevator grows by 60% as predicted. The model open three depots facilities if demand falls at elevators. Facilities open when international grain demand at elevator increases since additional depots are required to increase the availability of empty containers to these elevators. Counter-intuitively, facilities also open when the demand at elevators is low and regional container repositioning is observed. After performing tests on this result, it was found that facilities open in this case to optimize the empty miles and transportation cost in the network and not to provide much of the system capacity. The agent based modelling gives the advantage of opening dominant facilities in the beginning of the time horizon when relative cost of opening facilities is lower and later respond to the scenario by opening only additional facilities required in the time horizon.

6.6.5. Discussions and Conclusions

The empty container supply chain is a dynamic market system involving container, elevator, depot, intermodal terminals and port agents in the study region. ABM provides a valuable opportunity to understand policy, investment and service level change in simulations designed to inflict and assess market impacts. A simulation of Minnesota empty container supply chain interactions and decisions for soybean shipments was designed was devised in an ABM application. The goal was to develop a reasonable representation of market behavior in a proof-of-concept model and further to use the model for scenario analyses which serves as a valuable decision making tool.

The agent based modeling approach determines an initial set of depots to be opened in the beginning of the time horizon. The model opens the inland depots with the highest probability of remaining optimal under all possible realizations of the future demand patterns. In case if depot is not utilized for a specific period of time, the model decided to close those underutilized depot. The approach minimizes total expected system costs in opening new inland depots in the region and repositioning empty containers in the network within the time horizon. The agent based modeling approach helps in lowering the risk of investment made in building inland depots. It helps the stakeholder groups to understand and visualize the concept and increase their willingness to undertake and evaluate the new proposed system.

7. DISCUSSIONS AND CONCLUSIONS

Competitive and reliable transportation services are fundamental in the ability of U.S. agriculture's success in a global market. Recent statistics show an increasing trend in world grain traded via container. Analysis shows that, although it is a relatively small part of the U.S. grain market, container exports of grain have begun to attract more attention from investors and shipping lines as a viable mode of international grain trade. The distant proximity of major grain production areas to the largest container inland terminals remains the largest challenge for the industry. The inbound container movements are primarily driven by population density and economic geography, which is why so many containers end up in locations such as Chicago, IL or Memphis, TN. There and many diverse, high-value agriculture products close to these and other ports, mostly within 600-700 miles from the ports, but gaining access to containers to support agricultural exports has historically been a major challenge for shippers. The ability of the U.S. grain industry to adapt to a dynamic market through inland depot and terminal investments that increases the container storage capacity and availability for the match-back traffic, will prove challenging but potentially advantageous in longer-term benefits associated with market diversification and an expanded customer base.

For this research study, the region of Minnesota has been used for the purpose of demonstration and case study analysis. There is an ever-increasing domestic and global movement of agricultural products in containers. Minnesota has vibrant clusters of production manufacturing, forest products, retail, processed foods, and heavy machinery. Many of these products have the potential to move as containerized freight. Trucking costs will continue to increase and adversely impact regions dependent on long-distance trucking for acquiring empty containers which further slacken exports and affect the profit margin of exporters. Development of inland depots and expansion of intermodal terminals will not only increase the availability of containers in the region but will also reduce the empty container repositioning cost.

This research presents a realistic appraisal of the current status of export moves in Minnesota, and of future opportunities and challenges for Minnesota-based shippers. The volume of containerized agriculture shipments from Minnesota indicates a strong and sustained demand by the state for developing container pools and expanding intermodal freight terminals. Many businesses seek enhanced opportunities to access the efficiencies inherent in containerized freight shipping, including decreased shipping costs, greater predictability of delivery times, and reduced roadway congestion.

7.1. Strategic Planning and Decision-Making for Establishing Inland Depots

The proposed modeling framework can be easily adapted and utilized in other regions of Upper Midwest and North America where comparable growth in agricultural trade volume is observed. Many rural Agriculture production areas, including Upper Midwest, have competitive and service problems, shortcomings that are limiting our export growth and even threatening some industries. 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.

Investing in infrastructure is one of the most promising strategies for accommodating the growing demand for container shipments in United States. Improved infrastructure can reduce transportation cost, especially for moving large volumes of cargo over long-haul distances on rail and inland waterway sectors. The proposed system can be adapted to account for opening inland depots to store empty containers. The use of Greenfields for the development of these new depots is not prudent as there is already pressure to save productive agricultural lands and open spaces to advance sustainable development. This has highlighted the need to remediate and use Brownfield sites for any such commercial use of land. This should also support rejuvenating the physical environment, restoring the economies of urban areas, and reviving communities in towns and cities. The recovery of Brownfields is a way of saving land, especially Greenfield land, which is often habitable and suitable for agriculture and which can help to promote sustainable environments. A comprehensive database of the brownfield sites is prepared to select suitable sites for establishing new container depots. Multi attribute weighted Linear combination in ArcGIS is used to perform the analysis. The analysis resulted in 90 potentially suitable Brownfield sites with the total of 2050 acers.

Now, in order to find optimal locations amongst the suitable brownfield sites, for establishing new empty container storage depots, we developed a quantitative model that solves a depot location-allocation problem, taking into consideration the existence of inventory and capacity constraints of the depots under deterministic demand patterns. The model assesses the capacity of depots for handling future empty container volumes. The cost of repositioning empty containers is calculated, and the cost savings are compared with the base case, while maintaining the customer service level. In terms of empty vehicle miles traveled in the region to satisfy regional demand and supply for empty container volumes, results show that with the proposed system, Case 2 shows a 40% reduction in empty vehicle miles. The robustness and effectiveness of the proposed system is evaluated under varying conditions of the model input parameters, such as demand-supply patterns and projected volumes. We tested the model for different scenarios and the analysis shows that, if new customer clusters evolve, the region would need three additional inland depots to optimize the network of proposed system with the savings of 24% on empty miles travelled and

29% on the total system cost compared to the existing scenario. If the demand and supply of soybean remain as predicted all the depots which were opened in the earlier periods would remain effective with the investment justified. Another scenario was tested for change in trade volumes and the analysis shows that if the trade volumes in the region remain static opening inland depots would save 30% in empty miles travelled and 24% in costs by next twenty years, over the existing system. When trade volumes drop to 25% of the projected volumes, savings from inland depots are still significant at 30% in empty miles travelled and 12% in total system costs. The deterministic mathematical model has been demonstrated to significantly reduce empty vehicle miles traveled and total system costs in the study region, yielding benefits to regional exporters which will further support the growth of U.S. economy.

In the last phase we wanted to analyze the demand patterns and its effect on optimal locations and capacity constraints for opening new depots. To analyze probable randomness in empty container demand volumes at elevator sites and its influence on the optimal depot location allocation, an agent based model is used. The potential sites chosen in the case study are all capacity constrained Brownfield locations. With the use of agent based modelling we wanted to relax this constrained capacity to see the potential for depot expansions if additional Greenfield land could be obtained at the over utilized depot sites. Assuming the additional land may be obtained around the selected brownfield sites at higher costs, we doubled the capacities at all the potential locations. For this purpose, we scaling up the initial fixed cost of the additional land by 150%. Analysis shows that it will be economical for the region to open more capacity-restricted inland depots on available Brownfield sites than choosing fewer capacity-unrestricted sites. Due to the high cost in purchasing the Greenfield sites and fewer depots in the region, both the system costs and the empty vehicle miles traveled in empty container repositioning practice would increase. The agent based modeling approach helps in lowering the risk of investment made in building inland depots. It helps the stakeholder groups to understand and visualize the concept and increase their willingness to undertake and evaluate the new proposed system.

This research presented a strategic model for inland empty container depot development in the region of Minnesota with increasing trade volumes and trade imbalances. It examined the issue with a focus on agricultural exporters. Results indicate the potential for inland depots to reduce empty vehicle miles traveled and associated costs and improve the system's efficiency. In the short term, the concept may seem costly to the parties involved. However, when viewed in the long term, congested highways, overcrowded intermodal terminals, and the increasing cost of repositioning empty containers for inland exporters, especially in consideration of associated external costs, would justify the cost of building new inland depots. Considering the anticipated increase in trade volumes and the chronic and evolving imbalance of global trade, the proposed system seems to be a promising solution to the empty container shortage problem in the study region.

Our preliminary modeling is an initial step toward a larger-scale exploration of system-wide decision making for the optimization of agricultural 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 investment strategies that can minimize empty repositioning cost and increase containerized exports, thereby making U.S. exports more competitive in the face of emerging competition with other nations.

7.2. Future Research

This research develops a methodological framework that can serve as a long-term reference to aid in the understanding and evaluation of investment decisions for establishing inland depots and support various research efforts related to agricultural transportation and logistics. For practitioners, agent based modelling coupled with GIS routing are currently implemented into a computer-aided decision support tool (Netlogo) that can automate a regional network of empty container movements. The model minimizes total system cost while meeting empty container demands for exporters. In future development, decision makers can use the adapted model to identify the set of strategies to best improve the logistics infrastructure and to make informed decisions on investments.

In the research undertaken here, a new concept has been proposed for improving the empty container availability and optimizing regional empty container management. The proposed system has been tested for feasibility and viability under varying parameters. This proposed system is a novel approach to efficiently manage the empty container transportation network, realizing cost savings and better service, benefiting all the stakeholders' involved. Considering the dynamic nature of freight industry and continuously evolving global supply chains, the research study has enormous potential to expand and be adapted. Despite the benefits of improving business profitability and social welfare, our analysis does have its limitations. Some of the limitations are listed below to further research and explore the scope of the concept.

- Implementation – Stakeholders involved in the regional empty container repositioning includes shippers, ocean carriers, port terminal operators, port authorities, depot owners, and the state/regional government authorities. Every stakeholder is focused on their own benefits and risks introduced from the change in the current system. But the consensus amongst the stakeholders can be reached by devising a method that can weigh interests and objectives perceived by them. The strategies that affects the stakeholders' gain and increase the internal process efficiency should be analyzed based on the different criteria of benefits, costs and risks.

- Operational Cost – This research considers the fixed cost of opening inland depot facilities. Future studies may add a parameter of operating cost of depots in the objective function and evaluate the number of depots opened in the time horizon.
- Factors of congestion and match-backs, or their related cost are not taken into consideration. Congestion and capacity issues in the regional transportation network, including rail, are disregarded due to their complexity and the limitation of available data.
- This research estimates the availability of empty containers from data of importers and import businesses in the region. A survey should be done to collect detailed dataset of demand volumes of empty containers needed for agricultural export. Both deterministic and agent based modelling analysis will improve with the comprehensive dataset.
- This research proposing inland depots at high volume agricultural production regions has been proven effective at a regional level. Future Studies could expand this study to include analysis at national levels. The proposed concept of establishing inland depots for storing empty containers near the grain storage and the tool developed in this research with the use of mathematical and agent based models, can be used by stakeholders and policy makers all levels.

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