Acknowledgement:
As the Associate Director of Leir Research Institute (LRI) at NJIT, the author would like to thank April Taylor and Kuo-Liang "Matt" Chang, Economists, Agricultural Marketing Service, U.S. Department of Agriculture, for their valuable, constructive and insightful comments and suggestions that have significantly enhanced the project outcome. The project is supported by USDA Cooperative Agreement (16-TMTSD-NJ-0008).

Preferred Citation:
Shi, Junmin. *Repositioning Empty Containers for Agricultural Container Logistics*,
Tuchman School of Management, New Jersey Institute of Technology, 2018.
Web: https://web.njit.edu/~jshi/index.htm

Repositioning Empty Containers for Agricultural Container Logistics

Author Contact:
Junmin (Jim) Shi • Email: Junmin.Shi@njit.edu • Phone: 973-642-7027

USDA Contact:
April Taylor • Email: April.Taylor@usda.gov • Phone: 202-720-7880

Disclaimer:
This research was supported by the U.S. Department of Agriculture's Agricultural Marketing Service, Cooperative Agreement Number 16-TMTSD-NJ-0008.
The opinions and conclusions expressed do not necessarily represent the views of the U.S. Department of Agriculture or the Agricultural Marketing Service.
All the views and any errors presented in this report are the sole responsibility of the author.

Table of Contents

EXECUTIVE SUMMARY 4
1. INTRODUCTION 6
2. STATEMENT OF PROBLEM 9
3. RESEARCH OBJECTIVES 11
4. RESEARCH METHODOLOGY & AGRIBUSINESS MODEL 12
5. DYNAMIC PROGRAMMING MODEL FOR OPTIMAL DECISION MAKING 13
6. CASE STUDY OF CORN: SPREADSHEET MODEL & COMPUTATION 15
6.1. DATA ANALYSIS: PIERS DATA 16
6.2. SPREADSHEET MODEL 19
6.3. RESULTS AND INSIGHTS: SPREADSHEET COMPUTATION 19
6.4. IMPACT OF ECR COST ON THE THRESHOLD VALUES 22
6.5. PERCENTAGE SAVING OF MULTIMODAL OVER TRUCK-ONLY 23
7. CONCLUDING REMARKS 25
REFERENCES 26
APPENDIX A: SPREADSHEET MODEL 28
APPENDIX B: TECHNICAL DETAILS 30

Table 1: Acronyms

EC	Empty Containers
SC	Supply Chain
SCM	Supply Chain Management
ECR	Empty Container Repositioning
Truck-Only	Truck only shipping mode
DP	Dynamic Programming Model
FEU	Forty-foot Equivalent Units
TEU	Twenty-foot Equivalent Units

List of Figures

Figure 1: From Harvest to Customers: How Grain Is Processed and Delivered 6
Figure 2: Containerized Grain Shipping with Transloading 7
Figure 3: Transloading between Bulk and Container 8
Figure 4: An Illustration of Transload-Transshipment Transportation System 10
Figure 5: Example: Truck-Only vs. Truck-Rail-Truck Intermodal Transportation 10
Figure 6: Seasonal Patterns and Price Tendencies of Soybeans and Corn 13
Figure 7: U.S. Corn Production and Ethanol Plant Locations 15
Figure 8: Number of Vessels used for Shipping Corn from the U.S. to other Regions 16
Figure 9: Global Market Share of Corn Exported from the U.S. in 2016 17
Figure 10: Distribution of Corn Exporting Producers by State in 2016 18
Figure 11: U.S. Major Ports for Exporting Corn in 2016 18
Figure 12 Shipping Cost Comparison: Truck-Only vs. Truck-Rail Multimodal 21
Figure 13: Cost Analysis in Shipping Volume between Truck-Only and Multimodal Shipping 21
Figure 14: Critical Value of Distance vs. ECR Cost 22
Figure 15: Critical Value of Volume vs. ECR Cost 23
Figure 16: Percentage Saving vs. Shipping Distance 24
Figure 17: Percentage Saving vs. Shipping Volume 24

List of Tables

Table 1: Acronyms 2
Table 2: Decision Criteria for Leveraging Multimodal Transportation 12
Table 3: Global Market Share of Corn Exported from the U.S. in 2016 16
Table 4: Containerized vs. Non-Containerized Shipping and the Destinations of Corn Exported from the U.S. in 2016 19
Table 5: Comparison of standard container size, volume and weight limit 20
Table 6: Mileage of Containerized Grain Movements by Rail (Waybill, 2018) 20
Table 7: Spreadsheet Model and Analysis (Snapshot of the Spreadsheet) 28
Table 8: Spreadsheet Snapshot of the Analysis (Snapshot of the Spreadsheet) 29
Table 9: Summary of Variables and Symbols used for Cost Analysis 30
Table 10: Computational Algorithm for Optimal Decision on Shipping 34

EXECUTIVE SUMMARY

Agriculture and railroads have been flourishing alongside each other. Agricultural products are the third largest commodity group moved by the railroads after coal and chemicals, accounting for 8.2% of tonnage and 9.2% of revenue, according to the Association of American Railroads. In addition, exporting agricultural commodities by containers renders competitive advantages, especially when empty containers can be repositioned at low cost.

Empty containers (EC) are a common occurrence in the container shipping industry, being mainly caused by trade or transshipment imbalance, both nationally and internationally. Empty container repositioning (ECR) is one of the most important but challenging issues faced by the container shipping industry. Not only does it impose a tremendous economic effect on stakeholders in the container transport ecosystem, but it also has a significant environmental and sustainability impact on society, since any reduction in empty container movements will reduce fuel consumption, together with congestion and emissions. Agricultural transportation can also take advantage of the potential of empty containers yielded by other commodities shipped. In this sense, leveraging empty containers to ship agricultural commodities would be a win-win solution for the ECR challenges.

Transloading is one such innovative and strategic solution, as it uses inland transportation conveyances to bring cargo to the maritime containers. In this study, we aim to develop efficient and effective solutions that can leverage EC with the aid of transloading operations. We created a logistics transportation model and derived the tipping point policies in terms of shipping volume, distance and rail shipping rate. These tipping points can be computed directly based on the formulas derived in the study. An easy-to-implement guideline based on the tipping points is included in this report to assist practitioners in making efficient decisions to leverage transloading operations. To illustrate useful insights, we considered a case study of corn by utilizing the data sources of Waybill (Public Waybill) and the JOC Group, Inc.'s Port Import Export Reporting Services (PIERS) 2016 and built a Spreadsheet Model.

The analysis further considers 1) storing commodities on-farm, and 2) dynamic trading over harvest seasons. In this case, we created a Dynamic Programming model with the logistics cost of container shipping as a major component. As a major result, it is shown the optimal policy follows a *Sell-Down-To* structure. In other words, it is optimal to sell off all the excess crop above the threshold level if the total crop after harvest is more than this threshold; otherwise, do not sell. To implement the solution, we develop an algorithm that can be programmed directly for computational purposes.

As a result of this project, the study makes the following developments and contributions:

1) We conducted analysis and created a consolidated model via incorporating multimodal shipping logistics with empty containers, storing crops with silos on-farm through harvest seasons and selling crops later.

2) We developed easy-to-implement guidelines (i.e., the tipping-point based policy) that can be used by practitioners directly.

3) We analyzed the seasonality of harvest and trading and created a Dynamic Model of inventory management, based on which we developed the optimal policy as a sell-down-to policy. The selection decision on transportation modes should be made dynamically over time. In particular, for cost saving during the peak-harvest season, there is compelling reason to use multimodal transportation, instead of using trucks as the only mode of transportation (referred to as “Truck-Only” hereafter); whereas during the low-harvest or non-harvest season, it may be preferable to utilize Truck-Only transportation.

4) We created a Spreadsheet Model to illustrate the results and findings, and to provide useful insights. For example, we conducted an extensive numerical study to illustrate the impact of distance and ECR costs.

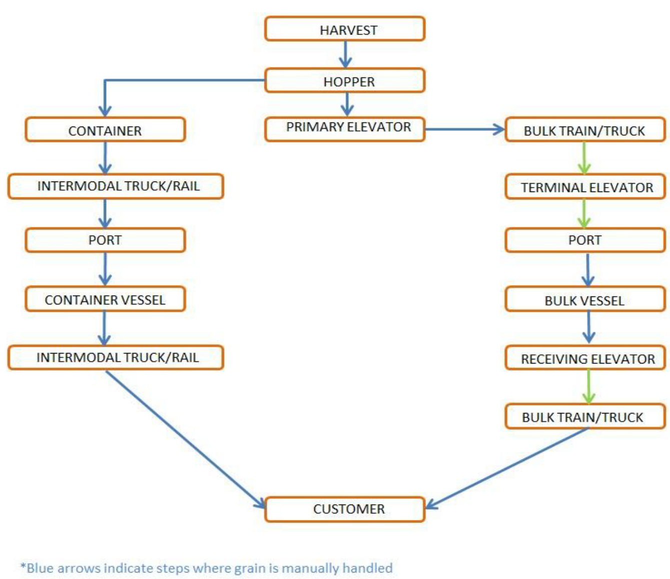
1. INTRODUCTION

Agriculture, food, and related industries contributed $1.053 trillion to the U.S. gross domestic product (GDP) in 2017, a 5.4% share. The output of America's farms contributed $132.8 billion of this sum. The overall contribution of the agriculture sector to GDP is significant, because sectors related to agriculture—forestry, fishing, and related activities; food, beverages, and tobacco products; textiles, apparel, and leather products; food and beverage stores; and food service, eating and drinking places—rely on agricultural inputs in order to contribute added value to the economy [USDA-ERS].

The U.S. grain harvest in 2019 is expected to be at least 15% more than 2018's record [Rail Freight Solutions (RFS)]. Early estimates predict a corn crop of 15.2 billion bushels, while the soybean crop is expected to reach approximately 4.1 billion bushels. North America is ready once again to feed a hungry world, and transportation is therefore a key component in the ability of U.S. farmers to competitively distribute their products in a global market.

Agriculture has long been a large participant in the transportation system. Traditionally, inland waterways and transcontinental rail lines played an important role in consolidating small wagon shipments of local grain production into larger shipments for long hauls to domestic markets along the coasts. Nowadays, continued investment underlies a successful and diverse agricultural industry that reliably serves customers across the global Supply Chain (SC). Figure 1 below depicts how grain is processed and delivered from farmers to customers. One of the efficient solution approaches is container shipping supported by intermodal trucks and rail.

Figure 1: From Harvest to Customers: How Grain Is Processed and Delivered



Source: Containerized Grain Industry Profile, 2014.

Figure 2 depicts an example of a state-of-the-art container transloading facility, and Figure 3 illustrates how grain is transloaded. In the effort to improve speed and efficiency, a variety of specialized equipment is used to handle the grain. Thus, intermodal facilities have specialized cranes for handling the containers, hopper cars, loaders, elevators and conveyors, as well as other equipment for unloading and loading railroad cars and ships quickly with a minimum of personnel.

Container shipping is advantageous in the realms of operational efficiency and transportation mobility, as well as safety, security, and value-added services. Containers can be easily loaded onto truck-beds or railroad cars for movement out of the port without time lost unloading [Bai et al. (2016)]. Additionally, container shipping can reduce the possibility of the commodity co-mingling with other cargo during transport, thus preventing contamination in transit while at the same time offering more transparent traceability of producers or shippers. This is particularly important for transporting a product that meets the standard for product segregation during handling and shipping [Marathon et al., 2006].

The efficient and effective management of empty containers is an imperative but challenging problem in the shipping industry, which imposes a significant impact on Supply Chain Management (SCM). Shipping agricultural products with containers provides a more efficient, environmentally friendly and profitable alternative channel for both the shipper and the customer [Song and Carter, 2009].

Figure 2: Containerized Grain Shipping with Transloading

Source: by the author.

There are two standard containers commonly used in the shipping industry. The standard twenty-foot (TEU) container costs about $2,000 to manufacture, while a forty-foot (FEU) container costs about $3,000. Therefore, a twenty-foot container costs $1.71 per cubic foot to manufacture, while a forty foot container costs $0.80, which underlines the preference for larger volumes as a more effective usage of assets. Even so, the twenty-foot container remains a prime transport unit, particularly for the shipping of commodities such as grain, where it represents an optimal size when taking account of weight per unit of volume capacity of containers—around 28 metric tons [Rodrigue 2017, and Song and Carter, 2009].

Figure 3: Transloading between Bulk and Container

Source: by the author.

A container is a transport device that can move through an export, import or repositioning flow. Once a container has been unloaded, another transport leg must be found, and moving an empty container is almost as costly as moving a full container. Shipping companies need containers to maintain their operations and level of service throughout the global network. Containers arriving in a market as imports must eventually leave, either empty or full. Repositioning thus begins immediately after a container has been unloaded and discharged. Operationally, this is important, since the costs incurred are assumed by the shippers, which will continue to further impact producers and consumers throughout its value chain.

An increasing number of containers are repositioned empty because cargo cannot be found for a return leg or because the ocean carrier determines there is more value in repositioning such asset to a different market. The outcome has been a growth in repositioning costs as shippers attempt to manage the level of utilization of their containerized assets. The positioning of empty containers is thus one of the most complex problems within the global freight distribution industry, this being underlined by the fact that about 2.5 million TEU of containers are being stored empty, waiting to be used. The inventory of empty containers thus accounts for about 10% of existing container assets and 20.5% of global port handling. The major causes of this problem include:

1) **Trade imbalances,** which are probably the most important cause of the accumulation of empty containers in the global economy;
2) **Repositioning costs of EC,** which are relatively high.

Empty container repositioning costs are multiple and dynamic. They include handling and transshipping at the terminal, chassis location for drayage, empty warehousing while waiting to be repositioned, inland repositioning by rail or trucking towards a maritime terminal, and maritime repositioning. An EC takes the same amount of space on a truck, railcar or containership slot as a fully-loaded container. Shipping companies spend on average $110 billion per year in the management of their container assets (purchase, maintenance, and repairs), of which $16 billion goes on the repositioning of empties. This means that repositioning accounts for 15% of the operational costs related to container assets. To cover these costs, shipping companies have imposed surcharges on full containers on a number of export routes, according to NYSHEX[1]. These surcharges can amount to between $100 and $1,000 per TEU, and thus have become an important portion of shipping costs.

---

[1] New York Shipping Exchange, Inc. (NYSHEX) provides over-the-counter (OTC) exchange information for the shipping industry worldwide.

2. STATEMENT OF PROBLEM

Agriculture and railroads have been flourishing alongside each other. Agricultural products follow coal and chemicals as the third-largest commodity type moved by the railroads, accounting for 8.2 percent of tonnage and 9.2 percent of revenue, according to the Association of American Railroads [Prentice and Hemmes (2015)]. Exporting by containers has many competitive advantages, especially from the shipping economies of scale when moving large volumes of agribusiness products over long distances and benefiting from the leverage of empty containers [Choong et al (2002), Rasul (2014)].

Empty containers are commonly witnessed in the container shipping industry, and these are mainly caused by trade or transshipment imbalance, both nationally and internationally. In the past decade, thousands of containers have been returned empty to their Asian ports of origin, with no compensation for the empty shipments.[2] However, shipping companies recognize the value of using these containers for U.S. agricultural exports instead of sending them back empty. This approach provides a more efficient, environmentally friendly and profitable alternative channel for both the shipper and the customer.

Because empty containers are typically stacked up in large volumes near to ports and are thus easily accessible for other usage, *Empty Container Repositioning* (ECR) is one of the most important but challenging issues pertaining to the container shipping industry [Choog et al. (2002), Song and Dong (2015)]. Not only does this situation impose a tremendous economic effect on stakeholders in the container transport chain, but it also brings a significant environmental and sustainability impact on society, since any reduction in empty container movements would reduce fuel consumption, congestion and emissions. Agricultural transportation can therefore take potential advantage of the empty containers yielded by other commodity shipping. In this sense, leveraging empty containers to ship agricultural commodities would be a win-win solution for the ECR challenges.

Transloading is one such strategic solution to containerized agricultural exports, as it uses inland transportation conveyances to bring grain and other agricultural products to the maritime containers. Transloading refers to the process of physically moving the cargo from one conveyance to another with the aid of transloading facilities such as elevators and conveyers [Thomson (2012)]. Transloading is most commonly used when shipping internationally, as well as across different types of geographical challenges. The entire process will sometimes call for a limited and short amount of warehousing, on a need by need basis [UPDS (2016)].

In contrast, transshipment is the process of transporting a shipment (usually in containers) from one intermediate location to another, from one method of transportation (vessel, airplane) to another (railcar, truck-bed) [Thomson (2012)]. This can sometimes cause delays as one mode of transportation can lead to minor scheduling issues. It can also limit destinations, as some railroads might not be accessible in certain areas. Transloading has become widely accepted and has been adopted by many companies for many reasons:

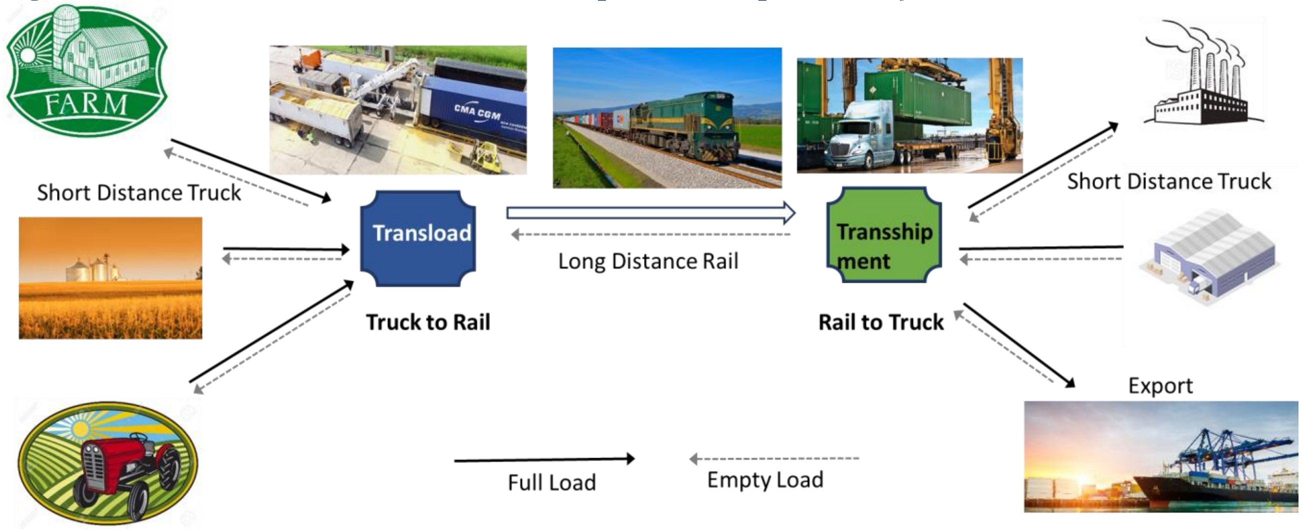
1) **Flexibility**: The use of different modes of transportation allow for flexibility. Transport your cargo anywhere with any method that works best for your route and business.
2) **Efficient & Timely Transportation**: The entire process is simplified through proper planning and management. Define routes and methods beforehand and move your shipments to their destinations quickly and orderly.

---

[2] It is important to note that often carriers prefer to ship the container back empty. The additional time it takes to access the export and deliver it at destination ties up the equipment longer than the carrier would like. But, moving an empty container allows the carrier to service the U.S. importer more quickly.

3) **Lower Costs**: Because transloading is a much more efficient form of transportation, it helps reduce domestic freight spend. Consolidated loads and flexible modes of transport also allow for lower costs.

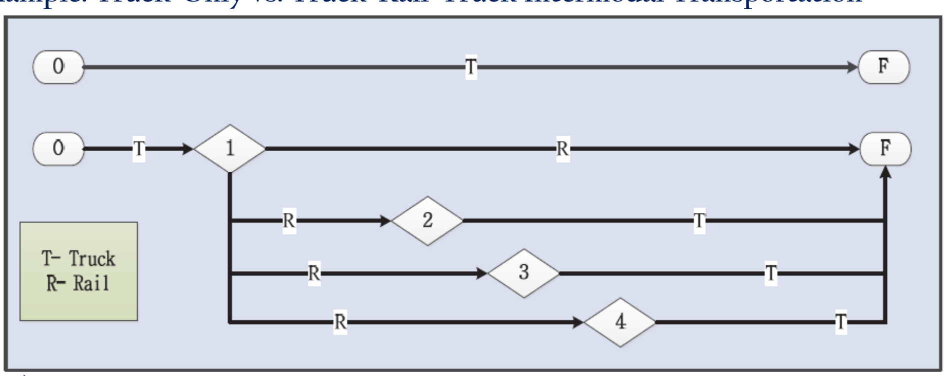
Figure 4: An Illustration of Transload-Transshipment Transportation System



Source: by the author.

Figure 4 depicts a typical example of logistics of a transloading transportation chain. The agricultural commodity (e.g., grain or corn) is first loaded in bulk at the farm site and hauled by trucks over a short distance to a nearby transloading depot. Then the product is transloaded from the truckload into empty containers at the transloading facility. The loaded container will then be moved to railcars, which travel a long distance to another rail terminal. The long distances involved in conveying containers has the potential advantage of lowering the transportation cost. The loaded container is next transshipped to trucks, by which it is transported to the next destination, e.g., export terminals for maritime container shipping. Sometimes an on-dock rail service allows the container to be delivered directly to the terminal.

Figure 5: Example: Truck-Only vs. Truck-Rail-Truck Intermodal Transportation



Source: Rasul (2014).

Operationally, transloading typically occurs at a depot near the farm that has transloading facilities such as elevators or conveyers. After the agricultural product is transloaded from truck to EC, the loaded containers will be hauled via rail and then go through the transportation network. Figure 5 depicts some simple examples of Truck Only and Truck-Rail-Truck intermodal movements. In actual fact, there are multiple ways to ship agricultural commodities from the location of origin "O" to the final location "F": "*Truck Only*" and "*Truck-Rail*" transloading, where the transloading from truck to rail occurs, takes place at Depot 1 that has transloading facilities, and then the transshipment from rail to truck can occur at different Depots, as denoted by 2, 3 and 4, reflecting different traveling mileages of truck and rail. In the interests of speed and efficiency, a variety of specialized equipment and facilities are used to handle crops with the aid of transloading infrastructures.

3. RESEARCH OBJECTIVES

The overall objective for this research is to explore the economics of transloading containerized agricultural exports and the costs of ECR. The specific objectives for this project are listed as follows:

i). **Describe the major factors that impact empty container movements**
In general, the surplus of ECs in the U.S. is caused by an imbalance of trade or transportation, either nationally or internationally. Agricultural exporters may obtain empty containers via repositioning within the U.S. to a location more accessible to agricultural production or storage. We shall focus on the agricultural sector to find the relevant factors impacting EC movements and examine the underlying opportunities for improving the container shipping industry.

ii). **Outline and identify the optimal decision making for major stakeholders in the agricultural transportation supply chain**
We will communicate with leading stakeholders in the supply chain, such as farmers and farmers' co-ops, container shipping industries, exporters and third-party logistics providers, to find out their current and future needs.

iii). **Conduct data analysis of ECR issues to derive insight**
We collect and analyze transportation data from targeted industry stakeholders within the agricultural industry—farmers, distributors, shippers and exporters. We refer to public transportation data such as the Grain Transportation Report issued by USDA, including prices, deliveries, movements, sales, and freight rates. Based on the available data, we build analytical models and spreadsheet models that are used to derive useful managerial insights.

iv). **Develop strategic solutions**
Our major objective is to develop strategic solutions for the logistics, especially by solving the ECR issues. In particular, we look into the transloading strategy and show how it can be leveraged to optimize the transportation cost. In addition, we investigate the tipping points on when and why transloading does not work for the industry. It is also our objective to lead our interaction with the industry through the project toward a case study that can be useful for both academia and industry [Yin (2013)].

v). **Develop and design business management tools for the agricultural export community**
Our project aims to develop and design a set of tangible and efficient business management tools (e.g., a computational algorithm) for the agricultural export community. The results and the project's deliverables can also help USDA or other government entities to better understand the needs of the agricultural export supply chain.

With all the objectives listed above, we proceed to broaden our study to consider the following issues and their impact on ECR solutions:

1) **Storage of Crops with Silos on-Farm**
The market of agricultural commodities is characterized by seasonality, which affects the market price and also causes transportation fluctuation seasonally. This can affect the agricultural export market. Mitigating the risk pertaining to uncertain demand and fluctuating prices

becomes strategically imperative [Shi et al. (2019)]. As one solution, inventory or storage can be introduced and implemented for better business solutions.

2) **Dynamic Decision for Seasonality**
Seasonality is one of the most important features of agricultural transportation. It is basically caused by the crop harvest season, seasonal demand from the international export market competitors, and weather restrictions on crops and transportation. Each crop has its own unique production cycle of planting, growing, and harvesting, all of which influence the price of the market. How can transportation decisions be made dynamically so as to capture the seasonality and other fluctuations of the agribusiness? This remains a challenging issue for farmers and farmers' cooperatives [Shi et al. (2019), Cheung and Chen (1998), Crainic et al. (1993)].

To investigate the efficiency of storage and the impact of harvest seasonality, we consider a periodic decision-making problem faced by a farmer, a farmers' co-op and a shipper, via a dynamic programming model, based on which we develop useful insights for potential business solutions.

4. RESEARCH METHODOLOGY & AGRIBUSINESS MODEL

The project and its analysis have been completed based on different datasets, such as publicly available data, our collected data from the industry (e.g., shipping cost rates) and the PIERS dataset shared by USDA. In terms of methodology, we have leveraged the following quantitative methodology through the project:

1) Hypothesis test: to test some statistically significant factors;
2) Regression analysis and forecasting;
3) Dynamic optimization and simulation;
4) Sensitivity analysis to obtain useful managerial insights.

Based on these analytical computations, we provide the following criteria that can help a farmer or shipper select a more cost-effective multimodal transportation option instead of the traditionally more expensive Truck-Only option.

Table 2: **Decision Criteria for Leveraging Multimodal Transportation**

Decision Criteria: Leveraging Multimodal Transportation vs Truck-Only Shipping
1) If the rail shipping distance is further than the threshold distance as computed in Equation (A.4), as given in "Appendix B" (included with this report), then Multimodal Transportation is more economic than Truck-Only shipping; or
2) If the rail shipping rate is less than the threshold rate as computed in Equation (A.5) as given in "Appendix B", then Multimodal Transportation is more economical than Truck-Only shipping; or
3) If the shipping volume is larger than the threshold volume as computed in Equation (A.6) as given in "Appendix B", then Multimodal Transportation is more economical than Truck-Only shipping.

The developed Decision Criteria, as exhibited in Table 2, can be leveraged directly by the agricultural export community. The set of computations can be used to guide the decision making to properly leverage multimodal transportation or not. It can also be used to gauge sensitivity to some of the parameters (e.g., the Unit transload cost per ton, ECR cost, etc.). The application of the results will be illustrated in the Case Study of corn in Section 6. The detailed computation has been coded into a Spreadsheet Model, as illustrated in Appendix B (included with this report).

5. DYNAMIC PROGRAMMING MODEL FOR OPTIMAL DECISION MAKING

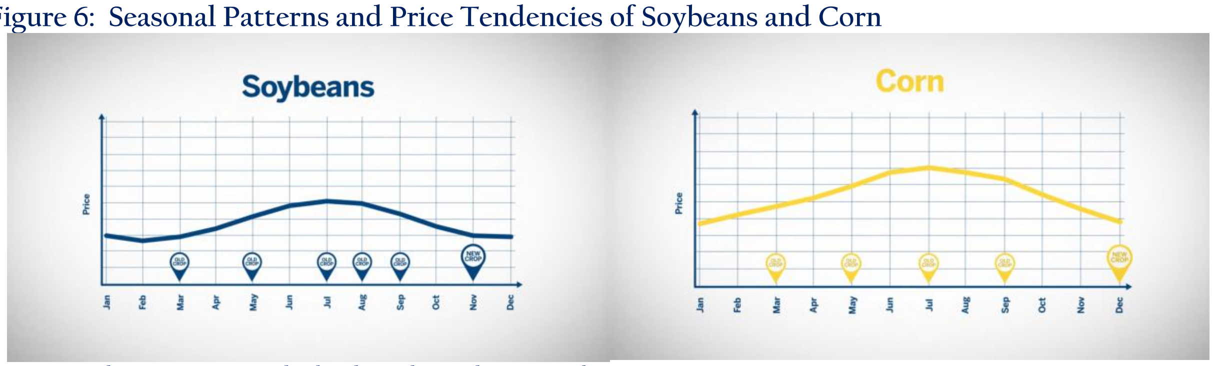
Traditionally, harvested crops are shipped to the market immediately without storing. In this case, the decision that has to be made by farmers or farmers' cooperatives is simple as to the transportation means, e.g., Truck-Only or Multimodal transportation. Nowadays, though, the agribusiness has become more complicated, especially when pursuing a sustainability objective. One example is that farmers or farmers' cooperatives can store their harvested crops on farms. Hence in addition to the transportation decision, they also need to make operational decisions, such as how much to trade and ship, and how much to store. In what follows, we extend our previous model to consider the following two major factors:

1) Storing crops on-farm;
2) Making decisions dynamically as to when and how much to sell stored crops while considering the seasonality of harvest and price.

The agricultural commodity market is characterized by seasonality in terms of harvest, demand (which further affects its price), and the associated transportation. The seasonality feature becomes even more significant in the agricultural export market.

The seasonal pattern and price tendency of agricultural commodities can obviously be seen by observing its market behavior. For the example of soybeans, as shown in Figure 6, harvest begins in September and continues through October into mid-November. Soybeans tend to follow a pattern where prices begin to decline in the July-August time frame, continuing through to bottom out in February, before bouncing up and then reaching their seasonal highs in the summer. Soybean meal and soybean oil have the same seasonal tendencies as soybeans. With corn, as shown in Figure 6, the most pronounced seasonal trend is the tendency for prices to be near their highest level around July because of the uncertainty around new crop production, and then to decline from mid-summer into the harvest season [Understanding Seasonality in Grains, CME Group].

Figure 6: Seasonal Patterns and Price Tendencies of Soybeans and Corn



Source: Introduction to Grains and Oilseeds, Understanding Seasonality in Grains, GME Group

To mitigate the risk pertaining to uncertain harvest and demand, as well as the fluctuating market prices, inventory or storage is one of the possible solutions [Rasul (2014)]. Indeed, storing crops on-farm could mitigate the congestion of shipping that often occurs during harvest season.[3] Three reasons frequently given for storing grain are (1) postponing taxes, (2) avoiding harvest delays and (3) capturing higher

[3] Some farmers find the benefits of on-farm storage, http://www.hpj.com/ag_news/some-farmer-s-findthe-benefits-of-on-farm-storage/article_bd423167-5c15-53d3-b989-1866dca6c3cf.html

prices.[4] Recently, experts at Grain Systems Inc. (GSI) have commented that on-farm grain storage continues to grow and should be a key component of any farmer's grain marketing plan.[5]

For agricultural transportation, seasonality is also one of the most important features. It is basically caused by the crop harvest season, seasonal demand from the market, and weather restrictions on transportation. How should transportation decisions be made dynamically to capture the seasonality and other fluctuations of the agribusiness? We consider a periodic decision-making problem to develop business solutions for farmers and shippers [Shi et al. (2019), Cheung and Chen (1998), Crainic et al. (1993)].

Dynamic Programming (DP)

Dynamic programming (DP) is a sophisticated mathematical optimization method that was developed by Richard Bellman in the 1950s and has found many applications in numerous fields, from aerospace engineering to economics and business [Bellman (1957) and Bertsekas (2017)]. It refers to simplifying a complicated problem by decomposing it into simpler sub-problems in a recursive (one iteration after another) manner. While some decision problems cannot be taken apart this way, decisions that span several points in time do often break apart recursively. In the context of supply chain management, many planning and control problems involve a sequence of decisions that are made over time. The initial decision is followed by a second, the second by a third, and so on. The process continues perhaps infinitely. Because the word dynamic describes situations that occur over time, and programming is a synonym for planning, the original definition of dynamic programming was "planning over time". In a limited sense, our concern is with decisions that relate to and affect phenomena that are functions of time. This is in contrast to other forms of mathematical programming that often, but not always, describe static decision problems.

As one of the main results based on the Dynamic Programming model, we provide the following result for the optimal trading and shipping policy:

Optimal Trading and Shipping Policy: Sell-Down-To Policy

Optimal Policy: For each harvest season, there exists an optimal storage level, such that it is optimal to sell down to this level only; namely, it is optimal to sell only the difference in volume between the total available storage right after the harvest, minus this sell-down-to storage level (if the difference is positive); otherwise, no selling.

Computational Algorithm: Since the optimal decision is based on the proposed sell-down-to level, it is critical to compute this sell-down-to level. The decision maker needs to compute these storage sell-down-to levels dynamically in each season. To facilitate the computing, an iterative Computational Algorithm is provided in Table 10 in Appendix B (included with this report).

In view of the above result, at the peak-harvest season there is compelling reason to utilize multimodal transportation, instead of Truck-Only, for cost saving; whereas during the low-harvest season, it might be preferable to utilize Truck-Only transportation.

For computational purposes, Table 10 in Appendix B provides an efficient and easy-to-implement way to solve and make optimal logistics and trading decisions.[6]

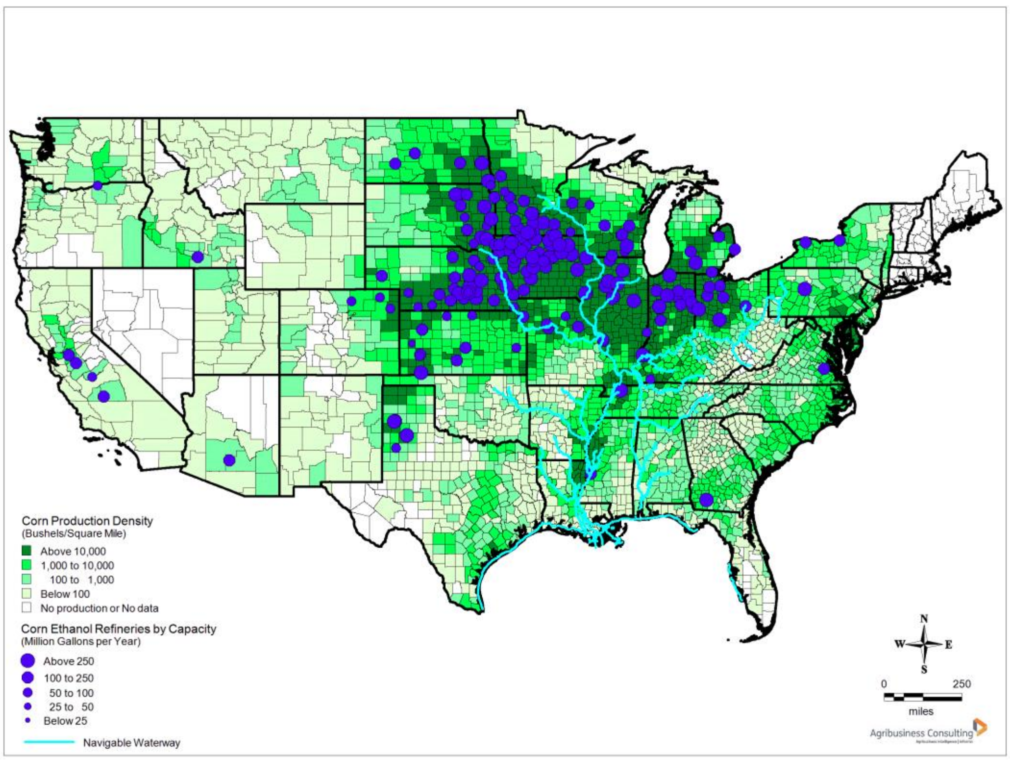
[4] http://agebb.missouri.edu/mgt/storage.htm
[5] http://www.grainsystems.com/about-us/news-press-releases/gsi-release-why-on-farm-grain-storage-makes-sense.html

6. CASE STUDY OF CORN: SPREADSHEET MODEL & COMPUTATION

Based on the consultation with USDA, we consider a real case of a U.S. corn exporter [Yin (2013)]. Before deliberating the analysis, we first show the whole picture of the U.S. corn planting and export network.

The corn production area has expanded throughout the past decade, moving westward and along the lower Mississippi River, with the highest productive area located in the Midwest, as shown in Figure 7. In 2017 U.S. farmers harvested 14.6 billion bushels or 371 million metric tons of corn, up more than 12 percent over that decade. The most productive states include Iowa, Illinois, Nebraska, Minnesota and Indiana, which account for roughly 60 percent of U.S. corn production. Iowa and Illinois together account for over 30 percent of the total U.S. corn production. [Agribusiness Consulting, Oct. 2018]. In terms of corn usage, much of it goes to ethanol plants, and most of those plants are located near the high-density corn production areas of the Midwest, as depicted in Figure 7.

Figure 7: U.S. Corn Production and Ethanol Plant Locations



---

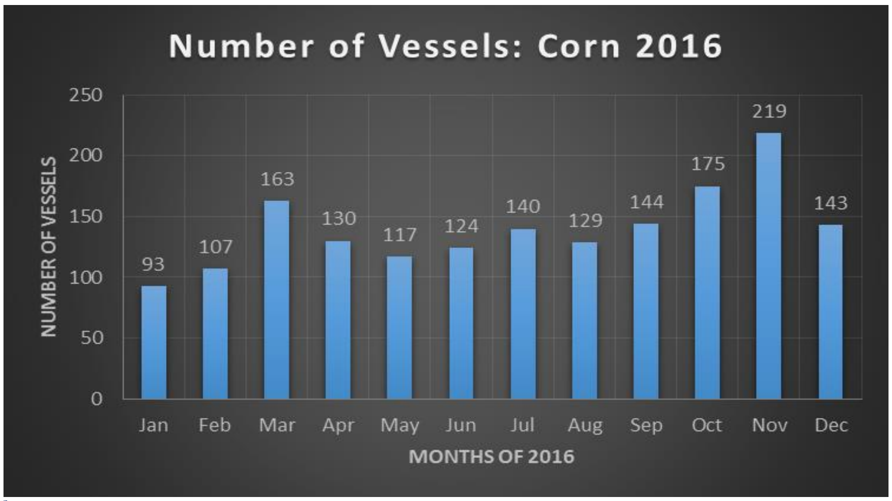
[6] It can be programmed with commonly used computer software, such as Matlab, R, SAS, etc.

Source: USDA and IEG Vantage

6.1. DATA ANALYSIS: PIERS DATA

Based on PIERS 2016 datasets, we have provided descriptive statistics. Figure 8 depicts the number of vessels used for shipping corn from the U.S. to other countries in each month throughout 2016.

Figure 8: Number of Vessels used for Shipping Corn from the U.S. to other Regions



Source: PIERS 2016 data

It is observed that

- The number of vessels used monthly for shipping corn ranges roughly from 100 to 200;
- The busy months are Oct. and Nov., mainly caused by the harvest seasons.

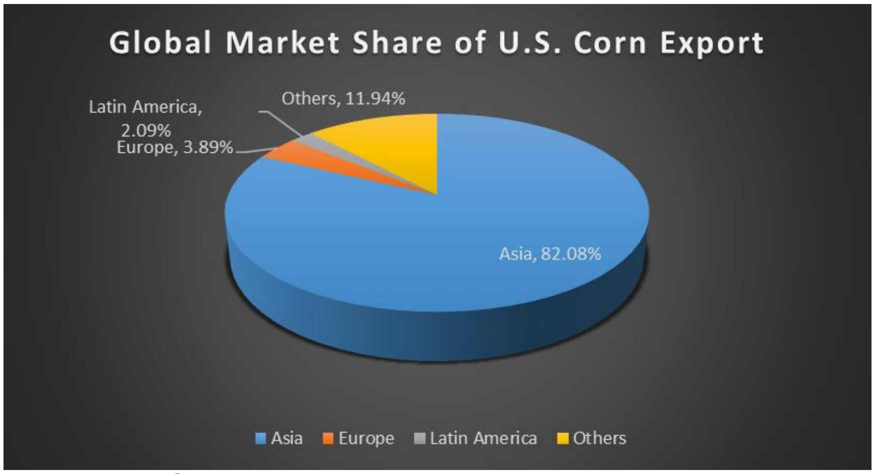
Table 3 shows the global market share of corn exported from the US in 2016. Figure 9 depicts the corresponding pie chart of the statistics.

Table 3: **Global Market Share of Corn Exported from the U.S. in 2016**

Destination	Percentage	TOTAL VALUE
Asia	82.08%	1,375,279,606
Europe	3.89%	65,228,694
Latin America	2.09%	34,961,621
Others	11.94%	200,101,260
Grand Total	**100.00%**	**1,675,571,181**

Source: PIERS 2016 data

Figure 9: Global Market Share of Corn Exported from the U.S. in 2016



Source: PIERS 2016 data

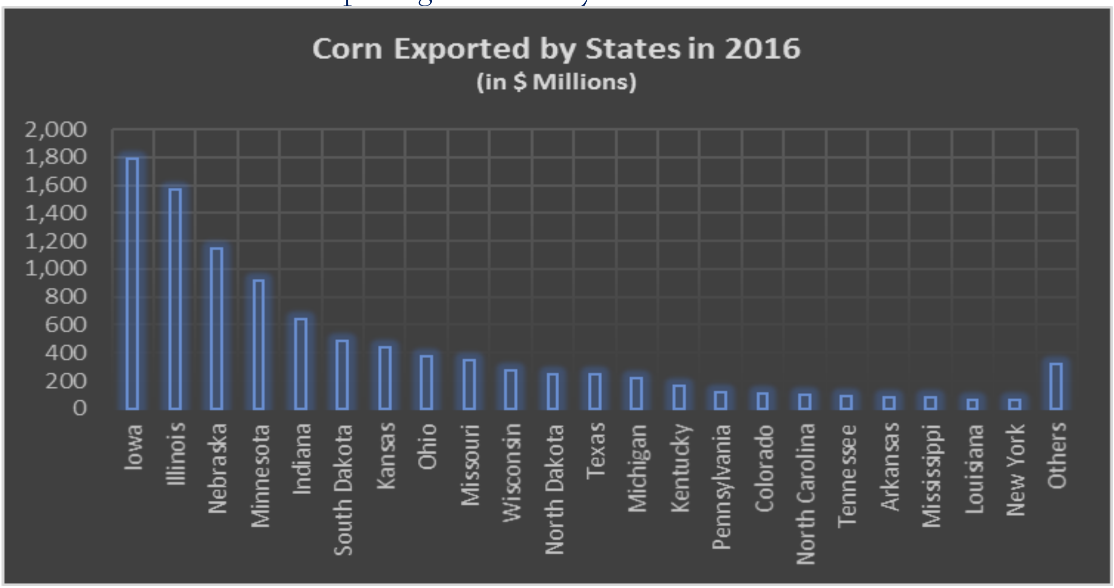
It is shown that

- Asia is the major importer of U.S. corn, accounting for 82.08 percent;
- Latin America takes a small share, only 2 percent of the U.S. corn exports, although the maritime shipping distance is the shortest.

Figure 10 depicts the distribution of corn producers by state for the exported corn in 2016. The total value of exported corn in 2016 was $9,876.7 million. In particular, it is further revealed that:

- Iowa is the leading corn exporting state, with a total value of $1,790.5 million, which accounts for almost 20 percent of all exported corn;
- The top three states are Iowa, Illinois and Nebraska, each of which exported over $1000 million. The total value of corn exported by these top three states accounts for 45.54 percent of the total exported value.

Figure 10: Distribution of Corn Exporting Producers by State in 2016

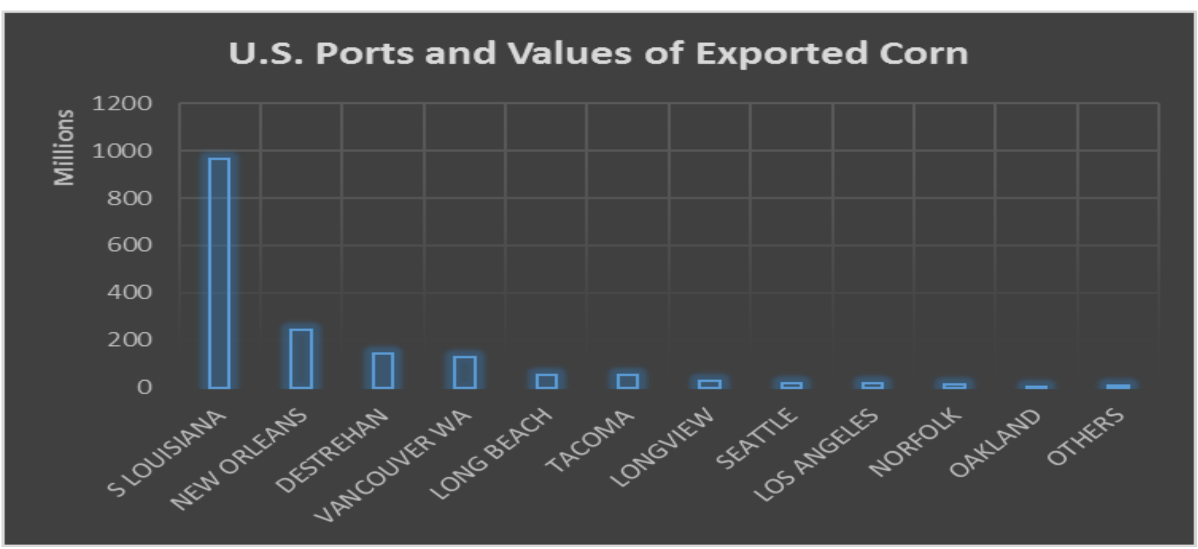


Data sources: USDA, Economic Research Service; USDA, Foreign Agricultural Service, Global Agricultural Trade System.

Figure 11 depicts the major U.S. ports used for exporting corn to all other regions in 2016. In particular, it is shown that

- In view of the global exports, the Port of South Louisiana is the port used to export the most corn, accounting for 57.62 percent of the value of all exported corn;
- The top four ports are South Louisiana, New Orleans, Destrehan and Vancouver WA, each of which exported over $100 million worth of corn. The total value of corn exported through these top four ports accounts for almost 89 percent of all exported value.

Figure 11: U.S. Major Ports for Exporting Corn in 2016



Source: PIERS 2016 data

Table 4 compares the values of exported corn via containers and other means, and for each of which it also shows the destinations. In particular, it is revealed that

- The percentage of corn exported via containerized shipping is relatively small, accounting for only 8.72 percent of all the exported values. This implies a promising market with potential savings in logistics costs for leveraging containers to export corn;
- For both containerized and non-containerized shipping, Asia is overwhelmingly the major market for exported corn, accounting for 8.15 percent and 73.93 percent, respectively.

Table 4: Containerized vs. Non-Containerized Shipping and the Destinations of Corn Exported from the U.S. in 2016

Destination	Exported Value	Percentage of Total Exported Value
Containerized	**$ 146,129,415.00**	**8.72%**
Asia	$ 136,612,054.00	8.15%
Europe	$ 2,640,733.00	0.16%
Latin America	$ 6,269,117.00	0.37%
Others	$ 607,511.00	0.04%
Non-Containerized	**$ 1,529,441,766.00**	**91.28%**
Asia	$ 1,238,667,552.00	73.93%
Europe	$ 62,587,961.00	3.74%
Latin America	$ 28,692,504.00	1.71%
Others	$ 199,493,749.00	11.91%
Grand Total	**$ 1,675,571,181.00**	**100.00%**

Source: PIERS 2016 data

6.2. SPREADSHEET MODEL

To analyze for the Corn Case Study, we design a set of concrete and efficient business management tools with a Spreadsheet Model based on the developed Decision Criteria exhibited in Table 2 on page 12 of this report. The spreadsheet is available upon request.

To numerically illustrate the efficiency of a multimodal transportation system, we apply the Spreadsheet Model to materialize the analysis in Appendix A (included with this report), "*Agribusiness Model: Empty Container Application*". The data and parameters used in the analysis are based on the Grain Transportation Report issued by USDA, along with some other sources, including a third-party logistics provider for the truck and rail shipping rates.[7] In Appendix A, Table 7 and Table 8 present snapshots of the Spreadsheet Model and Analysis.

6.3. RESULTS AND INSIGHTS: SPREADSHEET COMPUTATION

An Excel Spreadsheet model was created to computationally show the effectiveness of multimodal shipping with transloading. In the spreadsheet model, we collect and apply the parameters from different data resources, including academic literature, third-party logistics providers, and related statistical

[7] Source: Transportation and Marketing Programs/AMS/USDA
https://www.ams.usda.gov/sites/default/files/media/GTOR1stQtr2018Quarterly.pdf

reports. In particular, we set the unit shipping cost for Truck load as $0.10 per ton per mile;[8] the unit shipping cost for rail load as $0.05 per ton per mile;[9] the unit transloading cost is $6.90 per ton;[10] the grain volume is set at 800 tons;[11] the drayage distance (miles) for Truck-Only shipping is 1,000 miles;[12] the drayage distance (miles) for trucking in multimodal shipping is 100 miles and the drayage distance (miles) for rail in multimodal shipping is set at 1,000 miles. The transloading capacity of a standard container is according to Table 5, and the drayage distance is according to Table 6.

Table 5: **Comparison of standard container size, volume and weight limit**[13]

Container Type	Capacity (m^3)	Maximum Payload (kg)	Tare Weight (kg)	Maximum Gross (kg)
TEU (20')	33.2	28,260	2,220	30,480
FEU (40')	67.7	28,860	3,640	32,500

Table 6: **Mileage of Containerized Grain Movements by Rail (Waybill, 2018)**

Origin SPLC	Destination SPLC	Avg. miles
Chicago - 380000	Tacoma - 846200	2469.8
Chicago - 380000	Los Angeles - 883000	2352.2
Chicago - 380000	Los Angeles - 883710	2258.825
Chicago - 384020	Tacoma - 846203	2231.4
Chicago - 384020	Tacoma - 846206	2231.2
Chicago - 384020	Tacoma - 846209	2263.152
Chicago - 384020	Los Angeles - 883710	2201.583
Chicago - 384020	Los Angeles -	2220.54

Table 6 exhibits the Waybill samples for mileage of containerized grain movements by rail. As shown, the average shipping mileage for a one-way trip from Chicago to Tacoma is between 2200 and 2400 miles. The average trip from Chicago to LA is between 2200 and 2350 miles.

[8] Based on literature, the rate varies between $0.03 and $0.14 per ton per mile, with a median of $0.10.

[9] This is related to the shipping volume. The regression analysis shows that $y = 2.5492 * V^{-0.584}$; please see Rasul (2014).

[10] This includes the EC repositioning cost per ton, cited as $4.00 plus the transloading cost from bulk to container cited as $2.90 per ton.

[11] Assumed to be a typical farmer with a harvest of 800 tons of corn.

[12] Referring to Waybill, 2018.

[13] James a'Beckett, The Export Task – Shipping Considerations for Global Markets, Grain Trade Australia, 2014 http://agriculture.vic.gov.au/__data/assets/pdf_file/0010/292186/8-Containerised-Grain-Industry-Profile_December-2014-Update_MASTER.pdf

Figure 12 Shipping Cost Comparison: Truck-Only vs. Truck-Rail Multimodal

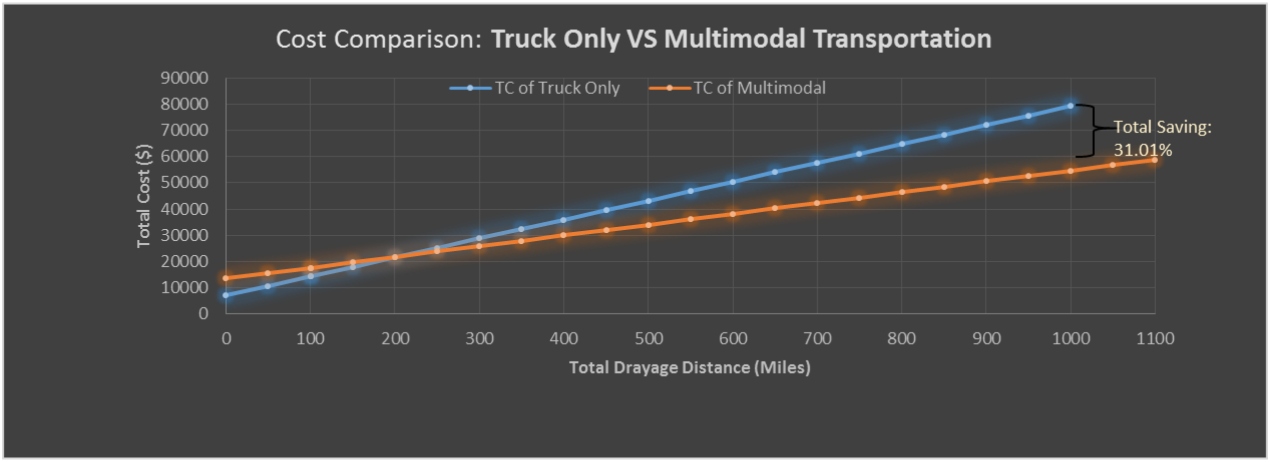


Figure 12 depicts the total cost (TC) of the two different shipping modes in terms of total drayage distance. It is shown that the total costs of the two modes cross over at a distance of 204.69 miles, which includes the first 100 miles of truckload only and 104.69 miles of railcar thereafter. It can be concluded that given the shipping volume is fixed, the shipper would choose multimodal shipping if and only if the drayage distance is further than 204.69 miles.

Further, the total saving by Multimodal mode is 31.01 percent if the total drayage distance is 1,000 miles.

Figure 13: Cost Analysis in Shipping Volume between Truck-Only and Multimodal Shipping

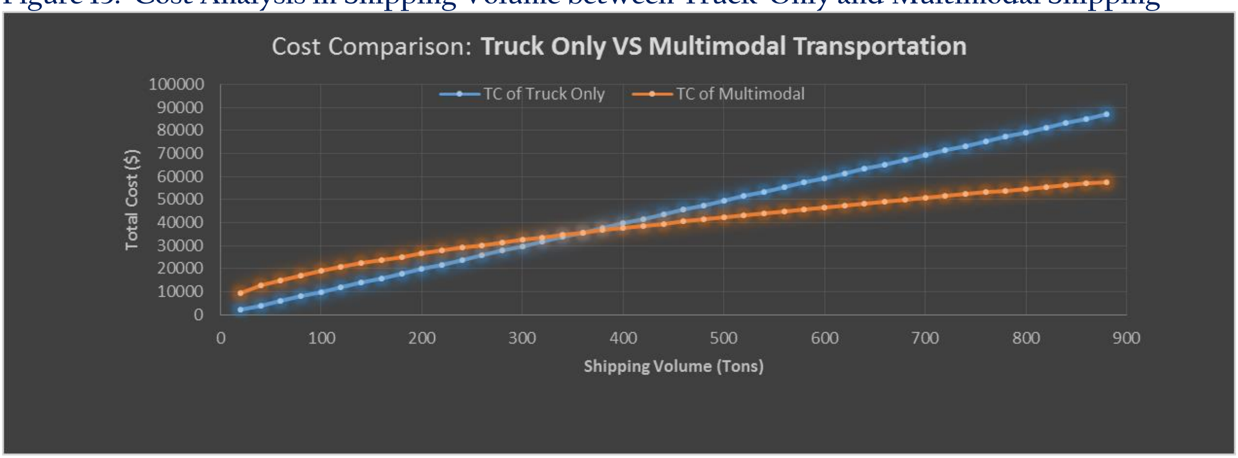


Figure 13 depicts the Total Cost (TC) of the two different shipping modes in terms of shipping volume. Given the drayage distance is fixed, it is shown that the total costs of the two modes cross over at volume 358.84 tons. In this case, we recommend that the shipper would choose Multimodal shipping if and only if the shipping volume is more than 358.84 tons.

The above analysis is based on a static setting. To facilitate dynamic decision making, we shall further conduct sensitivity analysis (what-if) based on this model by varying the shipping parameter values, such as shipping rate, distance, etc.

6.4. IMPACT OF ECR COST ON THE THRESHOLD VALUES

Based on the Spreadsheet Model as presented in Appendix A (included with this report), we conduct a sensitivity analysis on the impact of ECR cost from $1 to $8 per ton along a single route. In addition, we consider two scenarios:

- Scenario 1: (Distance Factor = 0.9):
  The drayage distance for Truck-Only is 10 percent shorter than the total drayage distance for Multimodal shipping.
- Scenario 2: (Distance Factor = 1.1):
  The drayage distance for Truck-Only is 10 percent longer than that of Multimodal shipping.

For each scenario, we compute the tipping-point value, which is the crossover point between Truck-Only shipping and Multimodal shipping. Hence, the tipping-point is the reference point for choosing between two shipping approaches. In what follows, Figure 14 and Figure 15 numerically visualize the Decision Criteria as exhibited in Table 2. The results can be used to facilitate shippers when making decisions on the choice between Truck-Only shipping and Multimodal shipping.

Figure 14: Critical Value of Distance vs. ECR Cost

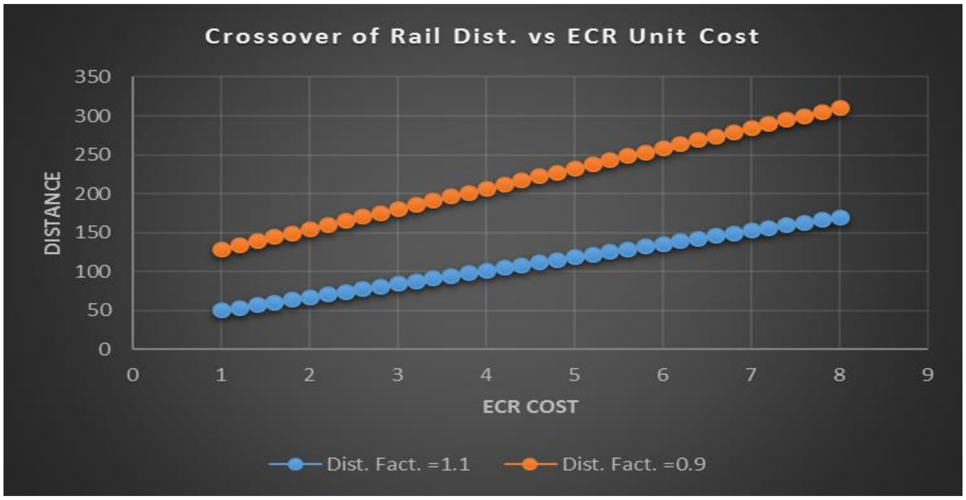


Figure 14 presents the tipping-point values as the ECR cost varies from $1 to $8. There are two curves: the orange one presents Scenario 1 (for Distance Factor = 0.9) while the blue one is Scenario 2 (for Distance Factor = 1.1). For each scenario, its curve cuts the space into two halves: above the curve and below the curve.

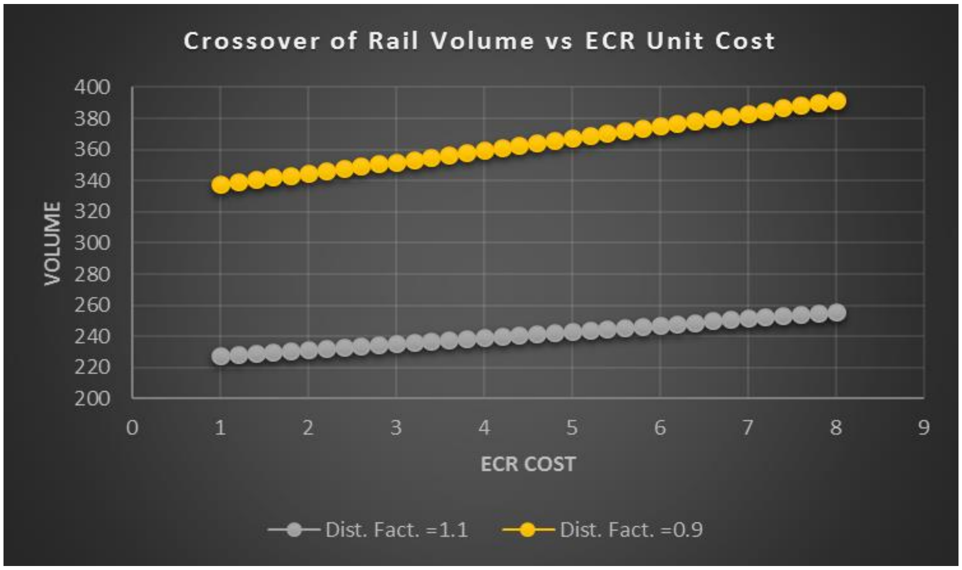
1) For the area above the curve (namely, the total drayage is further than the tipping point), it is optimal to choose Multimodal shipping;
2) For the area below the curve (namely, the total drayage is shorter than the tipping point), it is optimal to choose Truck-Only shipping.

For example, when the ECR cost is $5.00, if the total drayage distance is 300 miles, which is above both tipping points (240 and 120 miles for Scenaros 1 and 2, respectively), then obviously it is optimal to choose Multimodal shipping.

- The tipping-point value of the drayage distance increases steadily as the ECR cost increases. In other words, when it becomes less costly to access EC, it is preferable to choose Multimodal shipping.

- The tipping-point value of distance decreases as the Distance Factor gets bigger; namely, the higher the ratio of Truck-Only drayage over the total drayage of Multimodal shipping, the lower the tipping-point value. Therefore, it is preferable to select Multimodal shipping rather than Truck-Only shipping if the total drayage distance of the former becomes relatively larger than the latter.

Figure 15: Critical Value of Volume vs. ECR Cost



For the same setting, Figure 15 depicts the tipping-point values of the shipping volume. For example, when the ECR cost is $5.00, if the total shipping volume is 300 tons, that is, below the tipping point of 364 tons for Scenario 1, but above the tipping point of 220 tons for Scenario 2, then obviously it is optimal to choose Truck-Only shipping for Scenario 1 but Multimodal shipping for Scenario 2. This numerical study reveals the following takeaways:

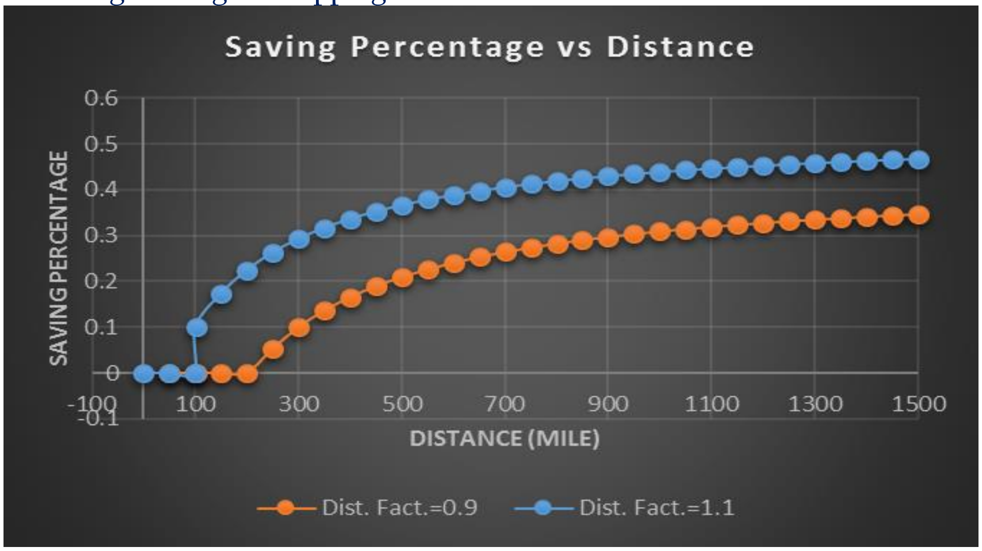
- The tipping-point value of shipping volume increases steadily as the ECR cost increases. In other words, when it becomes less costly to access EC, it is preferable to choose Multimodal shipping.
- The tipping-point value of the shipping volume decreases as the Distance Factor gets bigger; namely, the higher the ratio of Truck-Only drayage over the total drayage of Multimodal shipping, the lower the tipping-point value. Therefore, it is preferable to select Multimodal shipping rather than Truck-Only shipping if the total drayage distance of the former becomes relatively larger than the latter.

6.5. PERCENTAGE SAVING OF MULTIMODAL OVER TRUCK-ONLY

Multimodal shipping can potentially save on logistics costs over Truck-Only shipping. In what follows, we shall numerically illustrate the saving efficiency in term of Percentage Saving.[14]

[14] Percentage Saving = (Cost of Truck-Only Shipping minus Cost of Multimodal Shipping) / Cost of Truck-Only Shipping * 100% (if Multimodal shipping provides a lower cost).

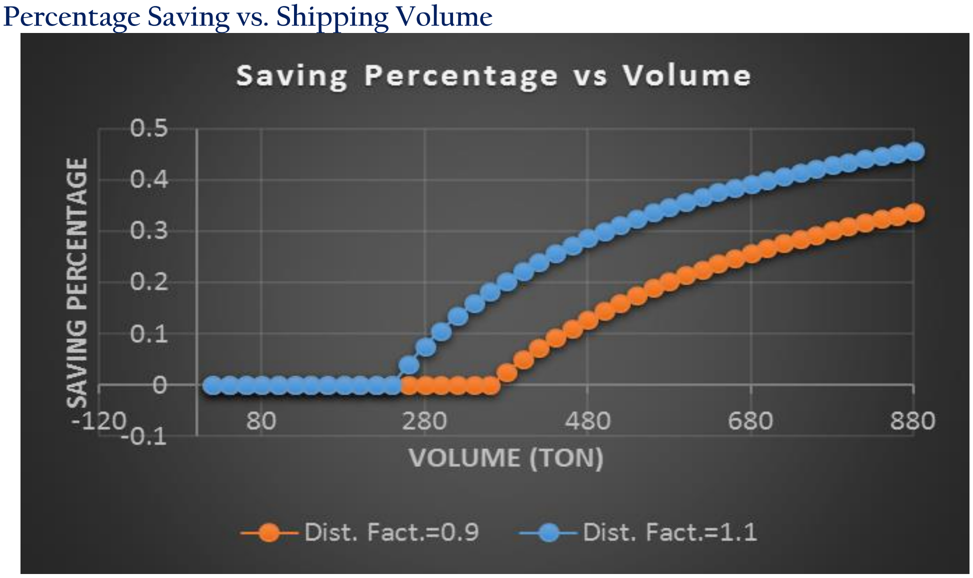
Figure 16: Percentage Saving vs. Shipping Distance



For each of the two scenarios studied above, Figure 16 depicts the Percentage Saving where the shipping distance varies from 0 to 1,500 miles.

- The percentage saving of Multimodal over Truck-Only increases as the shipping distance increases. In other words, more is saved by choosing Multimodal shipping if the shipping distance increases.
- The Percentage Saving increases as the Distance Factor gets bigger; namely, the higher the ratio of Truck-Only drayage over the total drayage of Multimodal shipping, the more significant becomes the cost saving.

Figure 17: Percentage Saving vs. Shipping Volume



Similarly, Figure 17 depicts the Percentage Saving when the shipping volume varies from 0 to 880 tons. It provides the following observations:

- The Percentage Saving of Multimodal over Truck-Only increases as the shipping volume increases. In other words, when shipping more crops you save even more by choosing Multimodal shipping.

- The Percentage Saving increases as the Distance Factor gets bigger; namely, the higher the ratio of Truck-Only drayage over the total drayage of Multimodal shipping, the higher the cost saving.

7. CONCLUDING REMARKS

A variety of shipping options are necessary to meet global demand for U.S. agricultural exports. Two main choices presented to the market are either bulk or containerized transportation. A surplus of empty containers is typical in the U.S. container shipping market, mainly due to trade or transshipment imbalance, both nationally and internationally. This study has examined the practical application of repositioning empty containers for use by the agricultural shipping industry. Operationally, transloading is one of several innovative solutions for containerized agricultural shipping, as it uses inland transportation conveyances to bring cargo to the maritime containers. In this study, we have developed efficient and effective decision-support tools to leverage ECs with the aid of transloading operations. To this end, we have created a logistics transportation model and derived the tipping point policies in terms of shipping volume, distance, cost of ECR and the rail shipping rate. Easy-to-implement guidelines based on these tipping points has been included in this report. To illustrate useful insights, we have considered a case study of corn transportation by leveraging several data sources and building a Spreadsheet Model. We have further considered a dynamic trading strategy to address the seasonality of harvest and market price based on a Dynamic Programming model. It has been shown that the optimal policy follows a Sell-Down-To structure. To implement the solution, we have developed an algorithm that can be programmed directly for computational purposes.

Multimodal or intermodal transportation of agricultural products can include a variety of shipping forms. In addition to the railcar container hauled by trains, containerized crops can also be transported through the nation's inland waterway system [Agribusiness Consulting, Oct. 2018]. Therefore, the model, analysis and major results can also be applied to such extensions.

REFERENCES

[1] Agribusiness Consulting, Oct. 2018, Containerized Exports via the Inland Waterway System: An Opportunity for Agriculture? http://www.soytransportation.org/newsroom/ContainerizedShippingOnInlandWaterways_FullReport.pdf

[2] Bai, Y., Higgins, C., Kemmsies, W., & Rezvani, A. (2016). Transportation Cost Modeling of International Containerized Soybean Exports in United States (Rep.). New Brunswick, NJ: Rutgers, the State University of New Jersey. December, 2016. http://dx.doi.org/10.9752/TS207.04-2017

[3] Bellman, Richard (1957), *Dynamic Programming*, Princeton University Press. Dover paperback edition (2003), ISBN 0-486-42809-5.

[4] Bertsekas, D. P. (2017), *Dynamic Programming and Optimal Control* (4th ed.), Athena Scientific, ISBN 978-1-886529-08-3. In two volumes.

[5] Cheung, RK and Chen, C.Y. (1998). A Two-Stage Stochastic Network Model and Solutions Methods for the Dynamic Empty Container Allocation Problem. *Transportation Science* **32**(2), 142-162.

[6] Choong, ST, Cole, MH and Kutanoglu, E (2002). Empty container management for intermodal transportation networks. *Transportation Research Part E*, **38**(6), 423-438.

[7] Clott, C., Hartman, B. C., Ogard, E., & Gatto, A. (2015). Container repositioning and agricultural commodities: Shipping soybeans by container from US hinterland to overseas markets. *Research in Transportation Business & Management*, *14*, 56-65.

[8] Containerised Grain Industry Profile, December 2014, Department of Economic Development, Jobs, Transport & Resources, State Government Victoria.

http://agriculture.vic.gov.au/__data/assets/pdf_file/0010/292186/8-Containerised-Grain-Industry-Profile_December-2014-Update_MASTER.pdf

[9] Crainic, TG, Gendreau, M and Dejax, P (1993). Dynamic and Stochastic Models for the Allocation of Empty Containers. *Operations Research* **41**(1), 102-126.

[10] GME Group Introduction to Grains and Oilseeds, Understanding Seasonality in Grains.

https://www.cmegroup.com/education/courses/introduction-to-grains-and-oilseeds/learn-about-corn-production-use-and-transportation.html

[11] Luo, M., Fan, L., & Liu, L. (2009). An econometric analysis for container shipping market. Maritime Policy & Management, 36(6), 507-523.

[12] Marathon, N., VanWechel, T. and Vachal, K. (2006). Transportation of U.S. Grains: A Modal Share Analysis, 1978-2004. United States Department of Agriculture, Agricultural Marketing Service, Transportation and Marketing Program.

[13] New Export Container Grain Loading Capabilities in Detroit for the 2016-2017 Harvest, Rail Freight Solutions (RFS).

[14] O'Reilly, J. "The Rail/Ag Connection: An American Revival", Inbound Logistics, June 2011, http://www.inboundlogistics.com

[15] Peng, W. Y. & Chu, C. W. (2009). A comparison of univariate methods for forecasting container throughput volumes. Mathematical and Computer Modelling, 50(7), 1045-1057.

[16] Prentice, B. E. & Hemmes, M. (2014, March). Grain containerization: Trends, issues and restrictions. In Proceedings. 55th Annual Meetings of the Transportation Research Forum.

[17] Prentice, B. E. & Hemmes, M. (2015). Containerization of Grain: Emergence of a New Supply Chain Market. *Journal of Transportation Technologies*, *5*(02), 55.

[18] Rasul, I. (2014). Evaluation of Potential Transload Facility Locations in the Upper Peninsula (UP) of Michigan.

[19] Rodrigue, Jean-Paul, The Repositioning of Empty Containers, The Geography of Transport Systems, 4th edition, 2017, New York: Routledge.

[20] Shi, J., M.N. Katehakis, B. Melamed, Y. Xia (2014), "Optimal Continuous Replenishment for a Production-Inventory System with Compound Poisson Demands and Lost-sales", *Operations Research*, **6** (5): 1048 - 1063.

[21] Shi, J., Y. Zhao, K. Kiwanuka and A. Chang "Optimal Selling Policies for Farmer Cooperatives", *Production and Operations Management Society* (POMS), Forthcoming, 2019.

[22] Song, D. P. & Carter, J. (2009). Empty container repositioning in liner shipping. *Maritime Policy & Management*, 36(4), 291-307.

[23] Song, D. P., & Dong, J. X. (2015). Empty Container Repositioning. *In International Series in Operations Research and Management Science (Vol. 220, pp. 163-208). doi:10.1007/978-3-319-11891-8_6*

[24] Thomson, D. M. (2012). Transloads: Freight Movement Efficiencies in the Next Decade. In 2012 Joint Rail Conference, pp. 793-803. American Society of Mechanical Engineers.

[25] Union Pacific Distribution Services (UPDS), How Transloading Works, 2016-06-03.

[26] USDA-ERS, United States Department of Agriculture, Economic Research Service, Ag and Food Sectors and the Economy, https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/ag-and-food-sectors-and-the-economy.aspx

[27] Vachal, Kimberly, Mark Berwick, US Soybean Export Council, and Illinois Farm Bureau. "Exporting Local Grains Via Container from an Illinois River Agricultural Hub." (2008).

[28] Yin, R. K. (2013). *Case study research: Design and methods*. Sage publications.

[29] New Export Container Grain Loading Capabilities in Detroit for the 2016-2017 Harvest, Rail Freight Solutions (RFS).

APPENDIX A: SPREADSHEET MODEL

Accompanying file: *Microsoft Excel Worksheet* (Available upon request)
USDA - Multimodal Transloading Cost Analysis – Final.XLSM

The following table presents a snapshot of the Spreadsheet Model and Analysis:

Table 7: Spreadsheet Model and Analysis (Snapshot of the Spreadsheet)[15]

USDA Agreement (16-TMTSD-NJ-0008) Transload Transportation Cost Analysis	
This Spreadsheet Model is an Analytical Tool on multimodal transloading cost analysis	
Date: 7/31/2018 (V1.0); 12/1/2018 (V2.0); 6/10/2019 (V3.0)	
There are two options for shipping V tons of grain from O to F: Truck Only vs Truck-Rail Multimodal	
All Analysis is carried out based on ton, in lieu of container unit.	
Truckload	
Unit Shipping Cost fee per ton-mile	**$0.10**
Railcar	
Unit Cost per ton per mile	**$0.05**
Empty Container Reposition Cost Per Ton	**$4.00**
Transload	
Unit Cost per ton for Transloading	**$2.90**
Unit Cost per ton	**$6.90**
Volume (tons)	**800**
Distance factor shorten by Truck line from Railway	**0.9**
Distance for Truck-Only (miles)	**990**
Distance of Truck in Multimodal (miles)	**100**
Distance of Rail in Multimodal (miles)	**1000**

The parameters, as listed in Table 7, need to be set up first so that the decision over which is the better transportation mode and its performance can be analyzed via this Spreadsheet Model. Some parameters, such as the shipping cost per ton-mile for both truck and rail can be obtained via consultation with a

[15] In this study, we set u_t =\$0.1, u_r =\$0.05, h =\$6.90, V =800 tons, D^t =1000 miles, $D^{m,t}$ =100 miles and $D^{m,r}$ =1000 miles.

third-party logistics company. Some parameters, such as the volume, will be determined by the farmer or farmers' cooperatives directly.

Table 8: Spreadsheet Snapshot of the Analysis (Snapshot of the Spreadsheet)

1. Truck Only Transportation	
Total Shipping Cost	$79,200.00
Total Shipping Cost of Truck-Only mode	**$79,200.00**
2. Multimodal Transportation	
Truck Shipping Cost	$8,000.00
Rail Shipping Cost	$41,123.43
Transloading Cost	$2,320.00
Empty Container Repositioning Cost	$3,200.00
Total Shipping Cost of Multimodal	**$54,643.43**
Total Saving (Cost of Multimodal minus Truck-Only)	**$24,556.57**
Percentage Saving	**31.01%**
By formulas Obtained via Model/Analysis	
Tipping-point value of Mileage	**204.69**
Tipping-point of Unit Rail Cost	**0.08**
Tipping-point of Volume	**358.84**

The Computation is conducted via the Spreadsheet Model. As shown in Table 8 above,

- The critical value of drayage mileage is 204.69 miles. In other words, if the shipping distance is more than 204.69 miles, it is preferable to use Multimodal shipping; otherwise, it is more cost-effective to choose Truck-only shipping;
- The critical value of the unit rail shipping cost rate is $0.08 per ton-mile. In other words, if the rail shipping cost rate is lower than $0.08, it is preferable to use Multimodal shipping; otherwise, it is more cost-effective to choose Truck-only shipping;
- The critical value of the shipping volume is 358 tons. In other words, if the volume of crops to be shipped is more than 358 tons, it is preferable to use Multimodal shipping; otherwise, it is more cost-effective to choose Truck-only shipping;
- For the current settings, Multimodal shipping is more preferable to that using Truck-only, enabling a 31.01% saving on the shipping cost.

APPENDIX B: TECHNICAL DETAILS

1. Agribusiness Model: Empty Container Application

In this section, we consolidate the analysis to show the effectiveness of transloading. In particular, we incorporate the cost of repositioning an empty container to the farmer's ramp, and also assume that the Truck-Only route is of a different distance from the multimodal route. For the former, we shall introduce a cost parameter k to denote the unit repositioning cost per ton usage of container; therefore, the total repositioning fee to carry V tons of grain one way is $K = V \times k$. Practically, the container repositioning cost is charged in terms of container units other than the volume of shipment. For ease of analysis, here we use the shipping volume V directly. Actually, for shipping volume V , the number of containers used is $n = \left\lceil \frac{V}{v} \right\rceil$ where v is the capacity of a standard container and $\lceil x \rceil$ denotes the ceiling integer, which is the least integer greater than or equal to x . For example, the ceiling of 30.1 is $\lceil 30.1 \rceil = 31$ As shown in Table 5, $v = 33.2 \text{ m}^3 \times \mathit{Density}$ for a standard TEU container. In this sense, for computational convenience, we can use $K = V \times k$ (as a simple linear function of the drayage volume V) to compute the total repositioning cost.

To model the traveling distances between truck and rail, we introduce a *distance factor* α , such that $D^t = \alpha \times (D^{m,t} + D^{m,r})$. When $\alpha = 1$, it means the total haulage distance of Truck-Only is the same as the total distance of the Multimodal route. In general, when $\alpha > 1$ (< 1), it implies that the Truck-Only shipping route has a longer (shorter) distance compared with Multimodal shipping.

To analyze the shipping costs of different modes, we shall compare the total shipping costs of "Truck-Only" shipping mode and "Truck-Rail" shipping mode with transloading from Truck to Rail. Table 9 presents relevant variables that will be used later as building blocks for our model.

Table 9: **Summary of Variables and Symbols used for Cost Analysis**

r , t , m	Rail, truck, and Multimodal, respectively;
V ,	Grain volume (tons);
k , K	Empty Container Repositioning cost per ton one way, and the total repositioning fee is $K = V \times k$;
D^t , $D^{m,t}$, $D^{m,r}$	Drayage distance (miles) for Truck-Only shipping, truck in Multimodal shipping, rail in Multimodal shipping, respectively;
α	Distance factor, $D^t = \alpha \times (D^{m,t} + D^{m,r})$
$C_S^{m,t}$, $C_S^{m,r}$	For Multimodal shipping, shipping cost of truck, shipping cost of rail, respectively;
h , T	Unit transloading cost per ton, the total transloading cost $T = V \times h$
u_t , $u_r(V)$	Unit shipping cost for truck load, rail load per ton per mile, respectively; fuel surcharge or emission fee is included;
TC^t	For Truck-Only shipping, total shipping cost;
TC^m	Total cost of Multimodal shipping, $TC^m = C_S^{m,t} + C_S^{m,r} + T + K$.

For "Truck-Only" mode, the total cost can be formulated as

$$TC^{t} = V \times D^{t} \times u_{t} = \underbrace{\alpha \times (D^{m,t} + D^{m,r})}_{\text{Total Drayage Distance by Truck}} \times V \times u_{t}, \quad \text{(A.1)}$$

where α is the drayage distance factor between the total mileages via Truck Only shipping and the total mileages by Multimodal shipping, such that $D^{t} = \alpha \times (D^{m,t} + D^{m,r})$. Typically, α is smaller than 1. For the trivial case with $\alpha = 1$, the traveling distances of the two modes are the same. The total cost of the "Truck-Rail" Multimodal shipping is

$$TC^{m} = \underbrace{C_{S}^{m,t} + C_{S}^{m,r}}_{\text{Total Shipping Cost}} + \underbrace{T}_{\text{Transloading Cost}} + \underbrace{K}_{\text{EC Repositioning Cost}}, \quad \text{(A.2)}$$

where the transloading cost $T = V \times h$, empty container repositioning cost $K = V \times k$, truck shipping cost $C_{S}^{m,t} = V \times D^{m,t} \times u_{t}$, and rail shipping cost $C_{S}^{m,r} = V \times D^{m,r} \times u_{r}(\mathrm{V})$. Substituting these terms into Eq. (A.2) above, and performing some basic algebra, we further have

$$TC^{m} = V \times \left[D^{m,r} \times u_{r}(\mathrm{V}) + D^{m,t} \times u_{t} + h + k \right]. \quad \text{(A.3)}$$

To compare Truck-Only shipping with Multimodal shipping of the truck-rail type, we roughly check into Eq. (A.1) with Eq. (A.3). In this fashion, we shall compute the crossover point between the Truck-Only mode and the Multimodal mode. To this end, we first set TC^{t} given in Eq. (A.1) to be equivalent to TC^{m} given in Eq. (A.3). Accordingly, we have the following result after simplifying further:

$$\alpha \times \; D^{m,t} + D^{m,r} \; \times u_{t} = D^{m,r} \times u_{r}(\mathrm{V}) + D^{m,t} \times u_{t} + h + k.$$

Consequently, the tipping point (a.k.a *crossover point*) between Truck-Only shipping and Multimodal shipping can be expressed as

$$\bar{D}^{m,r} = \frac{(1-\alpha) u_{t} D^{m,t} + h + k}{\alpha u_{t} - u_{r}(\mathrm{V})}. \quad \text{(A.4)}$$

This provides the criterion for choosing the best shipping mode, either Truck-Only or Multimodal, in order to save cost. The tipping point of $\bar{D}^{m,r}$ as given above shows that it decreases in the drayage volume V, and increases in both the unit transloading fee h and empty container repositioning cost k.

The rail shipping rate of $u_{r}(V)$ reflects the economies of shipping volume in such a way that $u_{r}(V)$ is decreasing in V. In other words, the more volume there is to transport, the lower is the shipping rate per ton per mile. Some of the extant literature assumes a constant elasticity function, e.g., $u_{r}(V) = 2.5492 \times V^{-0.584}$, as assumed in Rasul (2014) based on real-data regression analysis. The critical value of the rail shipping rate can be computed as

$$\overline{u}_r = \frac{\left[\alpha \;\; D^{m,r} - \;\; 1-\alpha \;\; D^{m,t}\right]\times u_t - h - k}{D^{m,r}} \tag{A.5}$$

$$= \alpha \times u_t - \frac{1-\alpha \;\; D^{m,t} \times u_t + h + k}{D^{m,r}}$$

The critical value of the volume is computed from $u_r(V) = \overline{u}_r$, which is given by

$$\overline{V} = u_r^{-1}\left(\alpha \times u_t - \frac{1-\alpha \;\; D^{m,t} \times u_t + h + k}{D^{m,r}}\right), \tag{A.6}$$

where $u_r^{-1}(x)$ is the inverse function of $u_r(x)$. For instance, considering the aforementioned example [Rasul (2014)] with $u_r(V) = 2.5492 \times V^{-0.584}$, the critical value of volume to leverage multimodal transshipment is $\overline{V} = \left(\frac{\overline{u}_r}{2.5492}\right)^{-\frac{1}{0.584}}$, where $\overline{u}_r$ is given by Eq. (A.5).

The criteria are summarized as follows:

Decision Criteria for Leveraging Multimodal Transportation[16]

Decision Criteria: Leveraging Multimodal Transportation vs. Truck-Only Shipping

4) If the rail shipping distance is longer than $\overline{D}^{m,r}$ as computed in Eq. (A.4), then Multimodal transportation is more economical than Truck-Only shipping; or
5) If the rail shipping rate is less than $\overline{u}_r$ as computed in Eq. (A.5), then Multimodal transportation is more economical than Truck-Only shipping; or
6) If the shipping volume is larger than $\overline{V}$ as computed in Eq. (A.6), then Multimodal transportation is more economical than Truck-Only shipping.

2. Dynamic Programming Model for Optimal Decision Making

The market for agricultural commodities is characterized by seasonality, which affects the market price and causes transportation fluctuation seasonally. As one solution to mitigate such volatility, inventory or storage can be introduced and implemented for better business solutions. Frequently, three reasons are given for storing grain: postponing taxes, avoiding harvest delays and capturing higher prices.[17] Recently, experts from Grain Systems Inc. (GSI) commented that on-farm grain storage continues to grow and should be a key component of any farmer's grain marketing plan.[18] Storing crops on-farm could mitigate the congestion of shipping that often occurs during harvest seasons.

[16] To facilitate these methods with the obtained datasets, we have leveraged the following computer tools: Excel Spreadsheet, R language and Matlab.

[17] http://agebb.missouri.edu/mgt/storage.htm

[18] http://www.grainsystems.com/about-us/news-press-releases/gsi-release-why-on-farm-grain-storage-makes-sense.html

In what follows, we build a *Dynamic Programming* (DP) model and derive the optimal policy. The potential decision makers could be U.S. agricultural exporters or carriers. In particular, we consider multiple harvest seasons, indexed as $n = 1, 2, \ldots, N$, where, without causing notational confusion, N is adopted to denote the total business horizon. Typically, the harvested grain, under proper storage conditions, can be stocked up in silos for a few years. Bearing in mind the concerns about perishability, if the grain is durable for 4 years one can simply set $N = 4$. The harvested grain or crop can be sold to the market directly in the current season, or be held in storage to defer the selling to future seasons [Shi et al. (2019)]. For each harvest season n, let I_n, Q_n, V_n denote the initial storage level, harvest quantity and selling volume, respectively. The harvest Q_n in each season n is random due to weather conditions or other factors such as infestation or fertilization inefficiency. Furthermore, let $f_n(I_n)$ denote the optimal total expected profit from season n to the end of horizon N. Then, $f_n(I_n)$ is given by the following Dynamic Programming Equation:

$$f_n(I_n) = \mathbb{E}_{Q_n}\left[\max_{V_n \le I_n + Q_n} \underbrace{p_n V_n}_{\text{Total Revenue}} - \underbrace{TC^m \wedge TC^t}_{\text{Lower Shipping Cost}} + \beta_n \underbrace{f_{n+1}(I_{n+1})}_{\text{Profit-to-go}}\right] - \underbrace{c_n I_n}_{\text{Storage Cost}}, \quad \text{(A.7)}$$

where p_n is the unit selling price, c_n the unit inventory carrying cost, β_n the discounting factor reflecting the financial value of time. For the transportation cost, TC^t and TC^m represent the total shipping cost by "Truck-Only" and by "Multimodal", respectively; they are given by Eq. (A.1) and Eq. (A.2) and $TC^m \wedge TC^t$ denotes the smaller value of both. The operator $\mathbb{E}_{Q_n}[\bullet]$ denotes the expectation with respect to the random harvest Q_n. For the end of the season, we simply assume the salvage value of any leftover inventory to be zero, i.e., $f_{N+1}(I_{N+1}) = 0$ [Shi et al. (2014) and Shi et al. (2019)].

According to the above DP model, we have the following results. The results can be proved by backward induction, which is a commonly used tactic to solve the DP model.

Lemma 1: (Property of the Profit Function)

> For each harvest season n, the total expected profit function $f_n(I_n)$ is increasing and concave in I_n. □

With the aid of Lemma 1 above, we develop the optimal decision criterion as summarized in **Theorem 1.** (Optimal Trading Policy – Sell-Down-To Policy). The following provides a recap of the result.

Theorem 1: (Optimal Trading Policy – Sell-Down-To Policy)

> For each harvest season n, there exists an optimal storage level $I_n^* \ge 0$, such that it is optimal to sell down to I_n^*; namely, it is optimal to sell a volume of $I_n + Q_n - I_n^*$ if $I_n + Q_n \ge I_n^*$; otherwise, no selling. The iterative Computational Algorithm is provided in Table 10.

In view of Theorem 1, for the peak-harvest season there is compelling reason to utilize Multimodal transportation, instead of Truck-Only, for cost saving; whereas for the low-harvest season, it might be preferable to utilize Truck-Only transportation.

For computational purposes, the following algorithm provides an easy to implement and efficient way to solve for the optimal logistics and trading decisions. It can be programmed with commonly used computer software, such as Matlab, R, SAS, etc.

Table 10: Computational Algorithm for Optimal Decision on Shipping

Computational Algorithm (Optimal Decision Making)

STEP 1. Initialization:

Set up the time horizon with total harvest seasons N;

For terminal condition, for any I_{N+1}, set $f_{N+1}(I_{N+1}) = 0$;

Starting with the last harvest season $n = N$.

STEP 2. Iteration: For each harvest season $n = N,\ N-1,\ \dots,\ 1$ (backward)

STEP 2(a) Collecting Data at the Beginning of Season n;

Consolidate $f_{n+1}(I_{n+1})$ from the previous loop of computation;

Collecting harvest quantity, market price, initial inventory level, quoted truck load cost, rail load cost, etc.

STEP 2(b) Compute tipping point of $\bar{V}$ by Eq. (A.6);

Referring to Table 2, make the logistics decision to use Truck-Only or Multimodal.

STEP 2(c) For any I_n, compute $f_n(I_n)$ by Eq. (A.7);

Make the optimal trading decision V_n^* attaining the optimal of Eq. (A.7);

STEP 3. Report: Return the optimal solutions