NCIT

The National Center for Intermodal Transportation

Analyzing the Impact of Intermodal Facilities on the Design and Management of Uniform Format Advanced Biomass Supply Systems

FINAL REPORT

December 2012

Principal Investigators:

Sandra D. Eksioglu

Erin Searcy

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. The document is disseminated under the sponsorship of the Department of Transportation University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liabilities for the contents or use thereof.

Abstract

Using densified biomass to produce biofuels has the potential to reduce the cost of delivering biomass to biorefineries. Densified biomass has physical properties similar to grain, and therefore, the transportation system in support of delivering densified biomass to a biorenery is expected to emulate the current grain transportation system. Intermodal facilities, such as, rail ramps and in-land ports provide access to cost-efficient modes of transportation for densified biomass. This research analyzes the rail and barge transportation costs for products like grain and woodchips. This analyses helps identify the main factors that impact the delivery cost of densified biomass. This research provides a transportation-cost analysis which will aid the design and management of biofuel supply chains. This evaluation is very important because the expensive logistics and transportation costs are one of the major barriers slowing development in this industry.

Regression analysis indicates that transportation costs for densified biomass will be impacted by transportation distance, volume shipped, transportation mode used, and shipment destination, just to name a few. This study suggests:

- If a biorefinery must locate in the Southeast, then locations close to an inland port are preferable.
- If a biorefinery must locate in the Northeast, then locations close to a rail ramp are preferable.
- If a biorefinery relies on rail shipments of biomass, then locating to East would result in lower inbound transportation costs compared to the West.

Keywords Densified Biomass, Intermodal Facility, Barge Transportation, Rail Transportation, Truck Transportation, Regression Analysis

---

1. Introduction

Several studies focus on the feasibility of increasing renewable energy production in response to the Energy Independence and Security Act (EISA) of 2007. As stated in the Renewable Fuel Standard (RFS) program, the minimum level of renewable fuels used in the U.S. transportation industry is expected to increase from 9 billion gallons per year (BGY) in 2008 to 36 BGY in 2022 (EPA 2012). Renewable energy should supplant conventional fossil fuel use and consequently decrease U.S. dependence on foreign oil. A number of issues make attaining those goals a challenge including the lack of an efficient technology to convert biomass to biofuel, the uncertainty of biomass supply, and the high logistics costs for delivering biomass to biorefineries (Petrolia 2008, Hess et al. 2009).

In order to minimize logistics costs, the production of first generation corn- and soybean-based biofuels has mainly relied on local biomass resources. Raw biomass, such as baled herbaceous

biomass, is bulky, aerobically unstable, and has poor flowability properties, all of which pose logistics challenges and increase supply chain costs. In order to minimize transportation related costs, the traditional supply chain model used by corn-based biorefineries locates biorefineries within an 80 kilometer (50 mile) radius of corn farms (Aden et al. 2002). The limited amount of biomass available within this collection radius does not justify investments in large-scale biorefineries. Consequently, traditional biorefineries have low production capacities and do not benefit from the economies of scale associated with high production volumes (Searcy and Flynn 2008). This is one of the reasons why biofuels have not been cost competitive with fossil fuels. The production of first generation biofuels has also initiated a nation-wide debate on food versus fuel.

Second generation biofuels utilize agricultural and forest residues, and energy crops as feedstock. Yet, first and second generation biofuels have different properties than conventional fossil fuels, such as high acidity, high moisture content, or high oxygen content. Due to these properties, fuels with a high concentration of ethanol, such as E85, can corrode some types of metal and can make some plastics brittle over time. As a consequence, today's vehicles cannot run on highly concentrated ethanol blends. Additionally, the pipeline system currently in place for fossil fuel transportation cannot be utilized for transporting biofuels. The next generation of biofuels, referred to as drop-in fuels, is expected to overcome those challenges and will become interchangeable with conventional fossil fuels.

However, all types of biobased energy will continue to face biomass feedstock transportation and other logistics challenges, mainly due to physical characteristics of raw biomass. Recent reports published by the Idaho National Laboratory (INL) propose a commodity-based, advanced biomass supply chain design concept to support large-scale production of biofuels (Hess et al. 2009, Searcy and Hess 2010). This design concept is substantially different from the feedstock logistics model utilized by conventional biorefineries and moves preprocessing of raw biomass, e.g., operations such as drying, densification, etc., to earlier stages in the supply chain. Preprocessing increases the bulk density of the material, resulting in a densified, pellet-like product. This paper refers to the product as densified biomass as opposed to pelletized biomass, since the latter is a specific process. Handling and transportation costs for densified biomass are lower than for raw biomass. Thus, using high capacity transportation for long-hauls becomes an option worth investigating. High capacity transportation gives biorefineries the opportunity to increase the biomass collection radius past 80 kilometers (50 miles), and as a consequence, increase biomass availability and reduce feedstock supply risk. A recent study by Searcy et al. (2008) indicates that the theoretical optimum size for an ethanol plant using corn stover as a feedstock, assuming a yield of 0.32 metric tons per hectare, is approximately 220 million gallons per year (MGY). These results are consistent with Wright and Brown (2007), which states that, depending on the conversion technology used, the theoretical

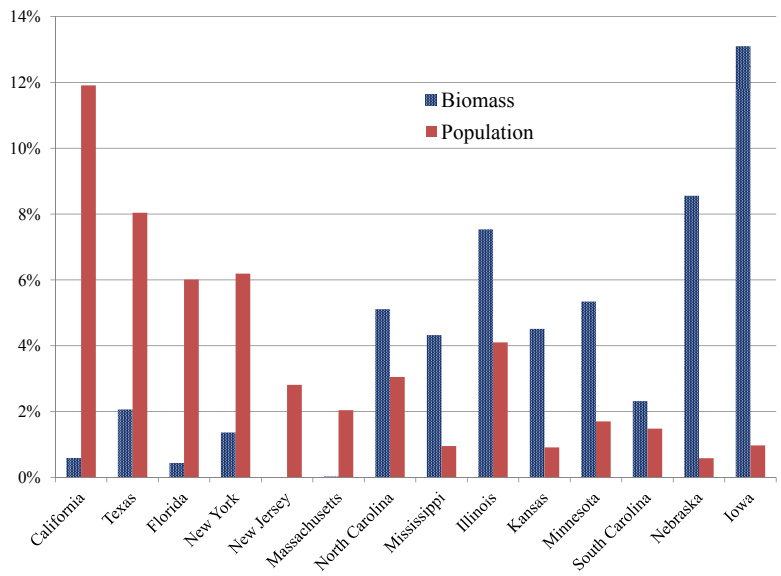


Figure 1 Distribution of biomass and population by State (Cen 2010, KDF 2012)

.

optimal size for corn-based ethanol plants is 79 MGY and 240-486 MGY for lignocellulosic-based ethanol plants. Wright and Brown (2007) assume: (a) a typical/average biomass yield per acre, and (b) biomass yield and availability are consistent within the plant-draw radius. Due to very high capital costs compared to conventional biorefineries, advanced biofuel plants should operate at high capacity in order to be economical. The annual biomass processed by such a plant is expected to be 4.7-7.8 million tons annually. This corresponds to receiving 513-852 truck shipments of biomass daily, the equivalent of receiving 120-200 rail cars daily or 9-15 barges daily. In order to supply so much biomass, transportation modes that are economical for shipping large volumes of densified biomass over long distances, such as rail and barge, should be utilized. Additionally, using barge and rail does not impact traffic in the communities around the biorefinery and consequently does not raise traffic-safety challenges.

Figure 1 presents the distribution of population and biomass by U.S. states. The figure presents only those 14 states with a big gap between the amount of biomass available and the population size. For example, 12% of the nation's population lives in California, yet only 0.59% of the available biomass for production of biofuels is found in California. Only 0.97% of the country's population lives in Iowa, yet 13% of U.S. biomass is available in Iowa. Figure 1 shows that the majority of the population lives in the East and West U.S.; however the majority of the biomass is available mainly in the Midwest and South. As a result, long-haul delivery of biomass or biofuels is needed to satisfy fuel demand.

Locating biorefineries closer to demand rather than supply is not a new concept. Pacific Ethanol, for example, is located closer to demand in California, and Oregan. The company receives shipments of corn by rail from the Midwest. Using high capacity transportation modes such as unit rail and barge, for high-volume and long-haul shipment of biomass results in increased biomass supply at biorefineries. Increases in cost due to the long-haul transportation of biomass should be compensated by the savings coming from the economies of scale in biofuel production, savings resulting from shorter transportation distances to deliver biofuel to customers and the reduced risk innate to having access to a larger pool of suppliers.

The goal of this research is to analyze the impact of locating a biorefinery near an intermodal facility such as a rail ramp or an on-land port. These location decisions allow a biorefinery to have access to rail and barge transportation which are cost efficient modes of transporting denisfied biomass. The existing literature details transportation-cost analysis for densified biomass in the form of pellets, cubs and bales when shipped by trucks (Sokhansanj and Turhollow 2004, Badger and Fransham 2006, Sokhansanj and Turhollow 2006, Rogers and Brammer 2009). Literature discussing pipeline transportation (Searcy et al. 2007, Ileleji et al. 2010, Judd et al. 2011), and rail transportation of biomass (Mahmudi and Flynn 2006, Searcy et al. 2007, Bonilla and Whittaker 2009, Sokhansanj et al. 2009, Ileleji et al. 2010, Judd et al. 2011) has also been explored. Rail transportation studies mainly discuss distance-based fuel costs and load/unload costs per ton of biomass. However, our research suggests that no studies exist on transportation of densified biomass by barge. Our research contributes to the existing literature by providing a thorough analysis of the main factors which impact transportation cost for densified biomass in the U.S. through barge and rail. Some of the biggest factors affecting cost include railcar ownership, railway service provider, competition with other transportation modes, and shipment origin and destination. This research proposes a number of regression equations which can be used to estimate rail transportation costs. These equations are developed using actual tariffs charged by railway companies for products which have similar characteristics to denisfied biomass. This is important because the data set used consist of existing tariffs similar to what biofuels industry will be facing.

The numerical analysis presented below uses transportation cost data available for products with physical characteristics similar to densified biomass, such as grain and woodchips. Our research assumes that, due to similar physical characteristics, loading, unloading, and transportation activities for densified biomass are very similar to these products, and consequently, transportation costs for densified biomass will be affected by the same factors. High capacity transportation and hauling densified biomass over long distances can easily leverage on the existing transportation and handling equipment designed for the well-established grain industry. Rail transportation is expected to be the mode of choice for long distance and high-volume biomass transportation because rail

transportation costs are lower than truck transportation costs. Also, because of the rail network is larger and it is easier to access than barge, this paper mainly focuses on rail transportation.

2. Background on Transportation of Bulk Products

Grains in the U.S. are shipped to domestic and foreign markets through barge, rail and truck. Barge is the most cost-efficient mode of transportation. Thus, if available, barge is a strong competitor to railroads for long-distance movement of grain. While portions of the Corn-Belt states have suitable access, many other regions where biomass is plentiful do not have navigable waters. The size of rail networks and their easy of access makes rail transportation preferable to barge for long-haul and high-volume shipments of grains. For these reasons, the biomass supply system of the developing biofuels industry should rely on rail transportation; thus, this paper concentrates on analyzing rail transportation costs.

2.1. Rail Transportation

The majority of U.S. rail transportation is handled by four Class I railway companies. In the East are Norfolk Southern (NS) and CSXT Corporation, and in the West are Burlington Northern Santa Fe Corporation (BNSF) and Union Pacific Railroad Company (UP) (CBO 2006). Rail transportation costs are impacted by various factors, including but not limited to government acts and policies, which commodity is transported, and the viability of alternative forms of transportation, whether intermodal or intramodal.

Rail transportation has a lower per-ton-kilometer cost compared to truck transportation. Rail transportation has an advantage compared to barge transportation due to its ease of accessibility and the rail network's larger size. Therefore, rail is the transportation mode of choice for long distance and high-volume shipments of bulk products, such as agricultural products. However, the limited capacity of the rail transportation network is a major disadvantage, mainly due to the high investment costs required to build and maintain rail lines and the fact that railroads are privately owned as opposed to, for example, highways constructed and maintained by the government (CBO 2006). Typically, private companies are reluctant to make capital investments in anticipation of future demand for their services.

In order to improve the productivity of rail lines and increase equipment utilization, railway companies offer lower tariffs for aggregate shipments. Aggregate shipments reduce the number of railcar switching in freight yards and lower the in-transit time and inventory-carrying costs (CBO 2006). Thus, railway companies can maintain their service level with significantly fewer resources. These incentives encourage shippers to use shuttle and unit trains. However, a unit train cannot be loaded and unloaded at every rail ramp, and certain infrastructure requirements should be met to operate them. Usually, the infrastructure necessary to operate a unit rail is built by

blenders, refiners, and third-party providers. Infrastructure developments are typically slow due to the high investment requirements and the long process of securing construction permits. Meeting the requirements set by RFS will increase the flow of biomass to biorefineries and the flow of biofuels to markets, and companies could take advantage of the existing railway infrastructure. However, an increase in the number of unit train origins and destinations will still be necessary to facilitate the increased flow in railways.

2.2. Barge Transportation

Barge has historically been used to ship agricultural products such as corn, feed grains, sorghum, and soybeans, from the Midwest to the Gulf Port along U.S. agricultural waterways. Exported agricultural products, such as oats, are also transported along these waterways from the Gulf Port to the North. The Mississippi River is the backbone of this system: 86% of all the operating barges move along this river.

Typically, barges move in groups called tows, which are pushed along by a towboat. The size of a tow is impacted by the number of locks along the river. For example, on the lower Mississippi River, where there are no locks, between 30 and 40 barges are commonly pushed by a single towboat. The weight of the load on a barge depends on the depth of the river where the barge will be. The travel time of barge from its origin to its destination depends on the number of locks along the path, the weight of the load, and most importantly, the horsepower, or HP, of the towboat. The U.S. Army Corps of Engineers (2002, 2009) provides data about the daily operating costs for towboats with different HP and barges of different types. The main towboat-related costs are replacement costs, daily operating costs, administrative costs, port costs, and crew-related costs, such as wages, fringe benefits, food, and transportation. The main barge-related costs are replacement and administrative costs. Table 1 presents the daily operating costs of a towboat as a function of its HP.

Table 1 **Daily operating costs for a towboat as a function of its horsepower.**

HP	Replacement Costs (in $)	Operational Costs (in $)	Fuel Costs (in $)	Total Costs (in $)
400-600	450	3,770	590	4,810
600-1,200	500	4,160	1,060	5,720
1,200-1,800	590	4,380	1,770	6,740
1,800-2,400	700	4,720	2,480	7,900
2,400-3,000	940	6,490	3,190	10,620
3,000-4,000	1,030	6,920	4,130	12,080
4,000-6,000	1,520	7,810	5,900	15,230
6,000-8,000	2,400	8,360	8,260	19,020
8,000-11,000	3,730	9,130	11,210	24,070

The same report by the U.S. Army Corps of Engineers summarizes the daily costs for barges of different dimensions and types, such as an open hopper with dimensions of $175' \times 25' \times 12'$ and a covered hopper with dimensions of $195' \times 35' \times 12'$ (2009). Depending on its size, a covered barge can carry between 1,500-2,000 tons of grains. The main cost components considered in the report are administrative and replacement costs. Total daily costs for a covered hopper with dimensions $195' \times 35' \times 13/14'$, which operates 330 days a year, are estimated to be $359. Our study uses this number as the operating cost per barge.

We use the daily cost estimates per towboat presented in Table 1 and the daily cost estimates per barge to calculate the daily cost of using one tow with 3,000 HP to push 15 barges. Such a tow typically traverses 161 kilometers (100 miles), each day. Our study assumes that each barge carries 1,500 tons of densified biomass, and the minimum shipment amount require to use barge is 1,400 tons. This is an incentive to send shipments of at least 1,400 tons, because the customer pays as if shipping 1,400 tons, even for smaller shipments. This data allows us to estimate the cost in $/day of moving one ton of densified biomass. We then calculate the total cost, $/ton, for trips of different duration (Table 2).

Table 2 Total costs for barge shipments as a function of trip duration.

HP	Trip duration (in days)						
	3	5	8	10	15	20	30
	Total Costs (in $/ton)						
400-600	1.36	2.27	3.62	4.53	6.80	9.06	13.59
600-1,200	1.48	2.47	3.95	4.94	7.40	9.87	14.81
1,200-1,800	1.62	2.69	4.31	5.39	8.08	10.78	16.17
1,800-2,400	1.77	2.95	4.72	5.90	8.86	11.81	17.71
2,400-3,000	2.13	3.56	5.69	7.11	10.67	14.23	21.34
3,000-4,000	2.33	3.88	6.21	7.76	11.64	15.52	23.29
4,000-6,000	2.75	4.58	7.33	9.16	13.74	18.32	27.49
6,000-8,000	3.25	5.42	8.68	10.85	16.27	21.69	32.54
8,000-11,000	3.93	6.55	10.47	13.09	19.64	26.18	39.27

Other transportation-related costs with barges include penalties charged if agreements are not met. One example is the demurrage charge, incurred if a barge is not loaded or unloaded within the timespan agreed upon.

Agricultural Marketing Services (AMS), part of the U.S. Department of Agriculture (USDA), publishes weekly reports of the latest volume and price charged for moving grain by barge. Shipping rates, unlike transportation costs, fluctuate from one period to the next. These rates are typically at their lowest in the first and second quarter of the year, and they reach their highest level during and right after the harvesting season due to the increased demand for barge shipments. Barge

operators base their prices on the percent-of-tariff system. The institution that used to set tariffs for barges is no longer around. Despite this, rates are still given in percentage of the benchmark tariff set in 1976 (USD 2010). Each segment of the Mississippi River has its own tariff benchmark. Tariffs increase the further north of the Gulf of Mexico shipment originates.

Table 3 presents the average barge freight rates charged during the months of April and October 2011 for shipments along the Mississippi River (AMS 2012). The table also presents the distance in kilometers from an inland port to the mouth of the river in the Gulf Port, according to the U.S. Army Corps of Engineers (2009). Barge-freight rates depend on the distance traveled.

Table 3 Barge freight rates charged ($/ton) along the Mississippi River

Port	Distance	Freight Rate	
		April 2011	Oct. 2011
Minneapolis, MN	3,347	NA	32.55
St. Paul, MN	3,321	23.57	27.48
Hannibal, MO	2,341	19.91	24.08
St. Louis, MO	2,100	12.47	17.46
Memphis, TN	1,359	10.46	13.03

A shipments of 15 barges pushed by a towboat with 3,000 HP would take, on average, 18 days to travel from Minneapolis and St. Paul to Gulf Port and about 7.5 days from Memphis to Gulf Port. Based on Table 3, the freight rate for an 18-day trip is about $13/ton, and the freight rate for a 7.5-day trip is about $5.50/ton. The difference between the values in Table 2 and Table 3 occurs because Table 2 presents the shipper's costs, while Table 3 presents the market price (the tariffs charged) to customers.

2.3. Truck Transportation

Trucks are often used to ship agricultural products despite the fact that the cost per ton and per kilometer traveled by truck is higher compared to rail and barge. The main reasons for using trucks are ease of accessability, large transportation network, and high transportation network capacity. Different from barge and rail, highway infrastructure is larger and reaches many remote areas where agricultural products are cultivated.

The main source of data on truck rates is AMS (2012). AMS provides weekly reports about grain transportation, which summarize the per kilometer rate charged for a truck load in different regions of the U.S.. Table 4 presents the truck rates we use in our analysis. A typical truck load weighs 26 tons.

Table 4 Truck Transportation Costs per Truck Load.

Region	Distance Traveled		
	40 kilometers (25 miles)	161 kilometers (100 miles)	322 kilometers (200 miles)
National Average	$3.74	$3.29	$3.18
North Central	$3.37	$3.15	$3.06
South Central	$4.22	$3.28	$3.26

3. Regression Analysis of Rail Shipment Tariffs

Our study uses a stepwise regression analysis to better understand the main factors which impact the tariffs charged by railway companies for single car and unit train shipments. The multi-variable, linear regression models are widely used for prediction and forecasting (Rawlings et al. 1989, Montgomery and Runger 2011, Montgomery et al. 2012). MacDonald (1987) uses regression analysis of rail rates for agricultural products, such as, corn, soybeans and wheat, to evaluate the impact of intramodal competition on rates charged by railway companies.

This study analyzes transportation costs for feed grains and woodchips since these commodities have similar physical characteristics to the densified biomass feedstock. Therefore, estimates of logistics-related costs for these products are a good representation of densified biomass logistics-related costs. Most of the data in this study was collected from CSXT and BNSF websites since these companies are the major transportation service providers for grains (USD 2010). Details about the regression models we developed appear below.

The data includes tariffs charged per rial-car shipments for several origin-destination points. These tariffs differ by product type, distance between the origin and destination, type of railcar used, railcar capacity, railcar ownership, and fleet size. In order to keep pace with the unpredictability of fuel costs, railway companies charge a fuel surcharge. Its purpose is to recover the incremental fuel costs when fuel prices exceed a threshold fuel price, also known as the strike price.However, the analysis in this paper does not consider fuel surcharges. The type of railcar that is typically used for transporting grain is covered hoppers, and hoppers or gondolas are used for woodchips shipments. The public tariffs used in this study were effective October 2011.

In order to validate our model, we analyzed the residuals and calculated the corresponding mean squared error (MSE) based on (Montgomery and Runger 2011). The analyzed residuals were found to be normally distributed. By dividing the data into two sets, our research sought to validate the regression equations developed. Initially, we used 70% of the data set to develop the regression equations; then, we validated these regressions using the data remaining. The MSE calculated for all the regression equations presented in this section ranged from 1% to 5%. Table 5 presents the list of variables used in the regression equations.

Table 5 Variable Declaration:

Definition of Dependent Variables	
Y^1_{CSXT}	tariff charged by CSXT per railcar, for single car shipment of grains.
Y^2_{CSXT}	tariff charged by CSXT per railcar, for single car shipment of woodchips.
Y^3_{CSXT}	tariff charged by CSXT per railcar, for 65-cars unit train shipment of grains.
Y^4_{CSXT}	tariff charged by CSXT per railcar, for 90-cars unit train shipment of grains.
Y^1_{BNSF}	tariff charged by BNSF per railcar, for single car shipment of corn.
Y^2_{BNSF}	tariff charged by BNSF per railcar, for unit train shipment of corn.
Definition of Independent Variables:	
X_1	railway distance per shipment.
X'_1	highway distance per shipment.
X_2	indicator variable which equals 1 if more than 1 railway company is to deliver a shipment, and equals 0 otherwise.
X_3	indicator variable which equals 1 if the railcar is owned by the railway company, and equals 0 otherwise.
X_4	indicator variable which equals 1 if the origin of a shipment is located far from an in-land port, and equals 0 otherwise.
X_5	indicator variable which equals 1 if the destination of a shipment is far from an in-land port, and equals 0 otherwise.
X_6	indicator variable which equals 1 if the capacity allowances are high, and equals 0 otherwise.
X_7	indicator variable which equals 1 if the destination of a shipment is in the Southeast U.S., and equals 0 if the destination of a shipment is in the Northeast U.S..
X_8	indicator variable which equals 1 if the destination of a shipment is in the Northwest U.S., and equals 0 if the destination of a shipment is in the Southwest U.S..
X_9	indicator variable which equals 1 if the number of railcars used by a shipment is more than or equal to 65 cars, and equals 0 otherwise.
X_{10}	indicator variable which equals 1 if the number of railcars used by a shipment is more than or equal to 90 cars, and equals 0 otherwise.
X_{11}	indicator variable which equals 1 if the tariff (Y) is charged by CSXT, and equals 0 if charged by BNSF.

3.1. Single Car Shipments of Grains

CSXT's website offers the grain-shipment data, which include barley, corn, rye, milo, sorghum, wheat, emmer, millet, and soybeans. We collected data for single car shipments of grains from the Midwest, including Illinois, Indiana, Kentucky, and Ohio, to the Southeast, composed of Alabama, Florida, Georgia and Louisiana, and to the Northeast, including Delaware, Indiana, Kentucky, New York, and Pennsylvania, along CSXT rail lines. The total number of tariffs charged per origin-destination of a shipment considered in this analysis is 1,165. CSXT uses covered hoppers to ship grains.

Table 6 summarizes the regression equations we developed for single car grain shipments by CSXT. The first regression equation presents the relationship between railway distances and tariffs. Railway distances are one of the most important factors impacting tariffs charged by railway companies. The value of the adjusted R^2, at 29%, and the $p-$value for X_1 indicate that railway

Table 6 Regression Equations for Single Car: Grain Shipments by CSXT.

Regression Equation	Adjst. R^2	p-val.
Y^1_{CSXT} = 2,248 + 1.12*X_1	29%	$2E^{-22}$
Y^1_{CSXT} = 2,011 + 1.37*X'_1	59%	$2E^{-44}$
Y^1_{CSXT} = 1,967 + 1.31*X'_1 + 232*X_2	61%	0.1%
Y^1_{CSXT} = 1,796 + 1.31*X'_1 + 232*X_2 + 321*X_3	66%	0.1%
Y^1_{CSXT} = 1,746 + 1.06*X'_1 + 211*X_2 + 315*X_3 + 26*X_4 + 440*X_5	73%	1.0%
Y^1_{CSXT} = 1,594 + 1.12*X'_1 + 207*X_2 + 315*X_3 + 55*X_4 + 436*X_5 + 229*X_6	75%	0.1%
Y^1_{CSXT} = 1,560 + 0.99*X'_1 + 157*X_2 + 316*X_3 + 69*X_4 + 465*X_5 + 290*X_6 + 230*X_7	77%	0.1%

distances are an important factor to consider in determining railcar tariffs. The value of the intercept, \$2,248, represents the fixed shipment cost charged per rail car, and the coefficient, \$1.12, represents the corresponding rate charged per kilometer traveled.

We re-run this regression by considering highway distance between origin-destination points instead of railway distance. We collected highway distances using GoogleMaps. The increase in the value of adjusted R^2 to 59% and the $p-$value for X'_1 indicate that highway distance between an origin-destination pair better explains the tariffs charged by CSXT than the corresponding railway distance. The study offered similar results from the regression analysis for other products shipped by CSXT. Different from the railway network, the highway network is larger and provides more routing options, so the highway distance is closer to the geographical distances per origin-destination pair. This is why CSXT pricing schemes rely on geographical distances rather than railway distances. This finding also suggests that transport by truck is a viable competitor to CSXT.

We ran a regression to capture the impact that railway ownership has on tariffs. For certain origin-destinations, CSXT uses, for a certain number of kilometers, rail lines owned by smaller, regional railway companies. The adjusted R^2, when we include X_2 in our model, increased to 61%, and the $p-$value for both independent variables remained smaller than 0.1%. Tariffs increase by \$232, on average, per railcar for shipments that use regional railways. This additional charge is a reflection of CSXT's payments to other companies for railway rights when using their rail lines.

The value of adjusted R^2 increases to 66% when railcar ownership is included in the regression. This regression indicates that a shipper is charged, on the average, an additional \$321 to use a railcar owned by CSXT.

In order to quantify the impact of barge-transportation availability on the tariffs charged by CSXT, our study develops a regression model using X_4 as an independent variable. X_4 is an indicator variable which equals 1 if the origin of a shipment is located far from an inland port, and equals 0 otherwise. It is important to define the meaning of the term far from an inland port. We performed three regression analysis updating the values of X_4 as follows. First, X_4 was set to 1

for those origin-destination data points where the distance from the shipment origin to the closest inland port was more than 161 kilometer (100 miles), and 0 otherwise. Second, X_4 was set to 1 for those origin-destination data points where the distance from the shipment origin to the closest inland port was more than 201 kilometer (125 miles), and 0 otherwise. Finally, X_4 was set to 1 for those origin-destination data points where the distance from the shipment origin to the closest inland port was more than 241 kilometer (150 miles), and 0 otherwise.

Our study also experimented with the distance between the destination point of a shipment and the closest inland port by introducing the indicator variable X_5. We performed several experiments to define this variable. We first set X_5 equal to 1 for those origin-destination data points where the distance from the shipment destination to the closest inland port was more than 80 kilometers (50 miles), and 0 otherwise. We re-run the regression for cases when the value of X_5 was set to 1 when the distance between the destination of a shipment and the closest inland ports were 161, 241 and 322 kilometers (100, 150 and 200 miles respectively).

We found that the regression in which the value of X_4 was set to 1 when the distance from the shipment origin to the closest inland port was more than 161 kilometers (100 miles) and the value of X_5 was set to 1 when the distance from the shipment destination to the closest inland port was more than 241 kilometers (150 miles). Adding these variables to the regression model gave the highest value of adjusted R^2 with a value of 73%.

We also ran a regression which considered the iteration between variables X_4 and X_5. However, this interaction was not found significant for $\alpha = 1\%$, and it was not added to the equation. The results from this regression indicate that barge transportation is a valid competitor with rail. Barge becomes a competitor for those shipments where the travel distance from the shipment's origin to an inland port is fewer than 161 kilometers (100 miles), or the travel distance from the the destination point to an inland port is fewer than 241 kilometers (150 miles). The discount received for shipments where the origin is close to an inland port is, on average, \$26, and for shipments where the destination is close to an inland port is, on average, \$440. These results echo findings from Laurits (2009, 2010).

We also include in the regression equation the indicator variable X_6 in order to quantify the impact of capacity allowances on tariffs. Adding this variable resulted in an increase of adjusted R^2 to 75%.

Weekly reports provided by AMS (2012) indicate that the majority of grains shipped to the Southeast U.S. are exported to different international markets. For example, 63% of corn exported is shipped out of the Mississippi Gulf. We ran a regression equation which includes the indicator variable X_7 in order to quantify the change in tariffs, if any, for shipment destined to the Southeast. The value of adjusted R^2 for this regression increased to 77%, and the p-value for all the independent

variables is smaller than 0.1%. Based on this regression equation, the tariff charged for railcar shipments to the Southeast is, on average, $230 higher as compared to the Northeast. This reflects the higher demand for rail shipment since many Southeast ports serve the international market.

3.2. Single Car Shipments of Woodchips

We collected data about wood chip shipments from the Midwest, including Illinois, Indiana, Kentucky, and Ohio, to the Southeast, focusing on Alabama, Florida and Georgia, along CSXT rail lines. The total number of origin-destination data points used in this analysis is 508. Table 7 presents the regression equations developed.

We ran a regression to understand the relationship between the tariff charged for railcars owned by CSXT and the highway distance between the origin and the destination of a shipment. This regression equation indicates that, on average, the tariff charged per kilometer per rail car is $0.81. This equation, compared to the corresponding equation developed for grains, shows that the fixed cost for shipment of woodchips is higher. Some of the reasons for wood chip's higher costs are its poor flowability and heavy load weight. Compared to other agricultural products (for example soy bean) woodchips have poorer flowability properties which makes loading and unloading shipments more difficult.

Table 7 Regression Equations for Single Car: Wood Chip Shipments by CSXT.

Regression Equation	Adjst. R^2	p-val.
$Y^2_{CSXT} = 2{,}968 + 0.81{*}X'_1$	30%	$5E^{-24}$
$Y^2_{CSXT} = 2{,}431 + 0.68{*}X'_1 + 271{*}X_2 + 537{*}X_3 + 93.3{*}X_4 + 140{*}X_5$	64%	0.1%
$Y^2_{CSXT} = 2{,}121 + 0.68{*}X'_1 + 271{*}X_2 + 692{*}X_3 + 93.3{*}X_4 + 140{*}X_5 + 310{*}X_6$	71%	0.1%

We developed a regression equation to estimate the impact of railcar ownership, rail line ownership, and barge competition in relation to the price charged per railcar. The second equation in Table 7 indicates that an average of $271 is added to the tariff charged per railcar shipment of woodchips if rail lines owned by regional railways are used; an average of $537 is added to the tariff charged when the railcar is owned by CSXT; an average of $93 is added to the tariff charged when the origin of a shipment is more than 161 kilometers (100 miles) away from an inland port; and an average of $140 is added to the tariff charged when the destination of a shipment is more than 241 kilometers (150 miles) away from an inland port. The two-way interactions between variables X_1 through X_5 were not statistically significant; therefore, these interactions were not added to the equation.

CSXT uses railcars of two different capacities for shipment of woodchips, which include, railcars with less than 6,000 cubic feet capacity and railcars with more than 6,000 cubic feet capacity. The

third equation in Table 7 calculates the impact of railcar capacity in tariffs using variable X_6, which equals 1 for railcars of capacity less than 6,000, and equals 0 otherwise. An average of \$310 is added to the tariff charged for using higher capacity railcars.

3.3. Unit Train Shipments of Grain

CSXT provides monetary incentives for shipments that consist of more than 65 railcars, and for shipments that consist of more than 90 railcars. In these cases, a dedicated unit train is used to deliver a shipment from its origin to its destination. To develop the regression equations presented below, we collected data from CSXT website. This data corresponds to grain shipments from the Midwest (Illinois, Indiana, Kentucky, and Ohio) to the Southeast (Alabama, Florida, Georgia and Louisiana) and to the Northeast (Delaware, Indiana, Kentucky, New York and Pennsylvania).

The total number of tariffs (per origin-destination of a shipment), collected for grain shipments on 65-cars unit trains, is 1,165. Table 8 presents the regression equations developed, the corresponding adjusted R^2, and p-values for the independent variables.

Table 8 Regression Equations for 65-Cars Unit Rail: Grain Shipments by CSXT.

Regression Equation	Adjst. R^2	p-val.
$Y^3_{CSXT} = 1{,}588 + 1.37{*}X'_1$	63%	0.01%
$Y^3_{CSXT} = 1{,}551 + 1.37{*}X'_1 + 198{*}X_2$	69%	0.01%
$Y^3_{CSXT} = 1{,}474 + 1.37{*}X'_1 + 207{*}X_2 + 115{*}X_3$	70%	0.01%
$Y^3_{CSXT} = 1{,}439 + 1.12{*}X'_1 + 196{*}X_2 + 101{*}X_3 + 122{*}X_4 + 421{*}X_5$	74%	0.01%
$Y^3_{CSXT} = 1{,}338 + 1.12{*}X'_1 + 201{*}X_2 + 107{*}X_3 + 107{*}X_4 + 419{*}X_5 + 227{*}X_6$	77%	0.01%
$Y^3_{CSXT} = 1{,}325 + 0.99{*}X'_1 + 157{*}X_2 + 130{*}X_3 + 80{*}X_4 + 440{*}X_5 + 263{*}X_6 + 236{*}X_7$	79%	0.01%

The total number of origin-destination data points collected for grain shipments on 90-cars unit trains is 672. Table 9 presents the regression equations developed, the corresponding adjusted R^2, and p-values for the independent variables.

Table 9 Regression Equations for 90-Cars Unit Rail: Grain Shipments by CSXT.

Regression Equation	Adjst. R^2	p-val.
$Y^4_{CSXT} = 1{,}185 + 1.31{*}X'_1$	58.9%	0.01%
$Y^4_{CSXT} = 1{,}168 + 1.31{*}X'_1 + 76{*}X_2$	59%	0.01%
$Y^4_{CSXT} = 1{,}120 + 1.31{*}X'_1 + 46{*}X_2 + 156{*}X_3$	60%	0.01%
$Y^4_{CSXT} = 1{,}098 + 0.99{*}X'_1 + 45{*}X_2 + 172{*}X_3 + 71{*}X_4 + 487{*}X_5$	68%	0.01%
$Y^4_{CSXT} = 977 + 0.99{*}X'_1 + 60{*}X_2 + 117{*}X_3 + 82{*}X_4 + 474{*}X_5 + 233{*}X_6$	70%	0.01%
$Y^4_{CSXT} = 497 + 1.18{*}X'_1 + 54{*}X_2 + 127{*}X_3 + 102{*}X_4 + 300{*}X_5 + 222{*}X_6 + 435{*}X_7$	72%	0.01%

3.4. Single Car Shipments of Corn

The data used to develop the regression equations presented in this section is available at BNSF's website. The tariffs collected are charged for corn shipments from the Midwest, including Iowa, Minnesota and Nebraska, to the Northwest, such as, Oregon and Washington, and to the Southwest, comprised of Arizona, California, New Mexico, Oklahoma and Texas. Corn is shipped using covered hoppers cars. BNSF lists tariffs charged for single railcar shipments, which represent shipments that consist of fewer than 25 railcars. BNSF lists railcar tariffs for shipments that consist of 25-110 railcars and shipments with 110-120 railcars. We collected data for 15,497 different origin-destinations shipments of fewer than 25 railcars. Table 10 summarizes the regression equations developed.

Table 10 Regression Equations for Single Car: Corn Shipments by BNSF.

Regression Equation	Adjst. R^2	p-val.
Y^1_{BNSF} = 3,140 + 0.75*X_1	50%	0.01%
Y^1_{BNSF} = 3,148 + 0.75*X_1 - 450*X_2	51%	0.01%
Y^1_{BNSF} = 3,050 + 0.75*X_1 - 542*X_2 + 205*X_6	52%	0.01%
Y^1_{BNSF} = 2,835 + 0.81*X_1 - 426*X_2 + 500*X_6 - 1,462*X_8	79%	0.01%

The first equation developed presents the relationship between the tariff charged and the distance traveled along BNSF's rail lines. We also ran a regression where the independent variable was highway distance rather than the railway distance between the origin and the destination of a shipment (the value of R^2 decreased). Highway distance, rather than railway distance, can better explain the tariffs charged by CSXT, but this is not the case with BNSF. This can be explained by looking at the railway networks of these two companies. The distances traveled along BNSF lines from the Midwest to the West are longer than the distances traveled along CSXT lines from the Midwest to the East. Therefore, for shipments to the West, using trucks is not cost efficient. Also, BNSF's rail network is stretched out, compared to CSXT. Thus, the railway distance between the origin and destination of a shipments is close to the corresponding geographical distance. These reasons explain why the railway distance between the origin and destination of a shipment comprises 50% of the tariff charged by BNSF.

Since the two Class I railway companies that serve the West U.S. are BNSF and UP, BNSF tariffs are provided for shipments where the origin and/or destination rail ramp is owned/operated by BNSF. The regression estimates the impact of using ramps owned by other railway companies on the tariffs charged by BNSF. The adjusted R^2 slightly increases to 51%.

We did not run a regression on X_3 because BNSF does not provide tariffs for shipper-owned railcars. Thus, all tariffs presented must be for railroad-owned cars. We also did not run a regression on X_4 and X_5 since barge shipments from the Midwest to the West are not an option.

BNSF tariffs depend on the capacity of a railcar. Variable X_6 equals 1 if the railcar capacity of a shipment is greater than 5,000 cubic feet, and equals 0 otherwise. Including this independent variable in the regression equation slightly increased the value of the adjusted R^2 to 52%, while maintaining the p-values for the independent variables less than 0.01%.

A regression tests the impact of the shipment's destination on the tariffs charged. Adding X_8 to the regression equation increases the value of the adjusted R^2 to 79%. This regression equation suggests that shipping corn from the Midwest to the Northwest is, on average, $1,462 cheaper compared to shipping corn to the Southwest. The difference in price could be explained by the flow of shipments to these destinations. The volume shipped to the Southwest destinations is higher because of the higher population there and the existence of international ports.

3.5. Unit Train Shipments of Corn

Similar to CSXT, BNSF provides price incentives to shippers for unit train shipments with 110 to 120 railcars. Table 11 summarizes the results from the regression analysis, which considers the impact of the railcar capacity by including X_6). However, the variable was not found statistically significant.

Table 11 Regression Equations for Unit Rail: Corn Shipments by BNSF.

Regression Equation	Adjst. R^2	p-val.
Y^2_{BNSF} = 2,734 + 0.45*X_1	54%	0
Y^2_{BNSF} = 2,706 + 0.46*X_1 + 224*X_2	55%	0
Y^2_{BNSF} = 2,549 + 0.58*X_1 + 355*X_2 - 637*X_8	71%	0

3.6. Lessons Learned from Regression Analysis

The following are some important observations that we made from the regression analysis presented above.

Lesson 1: The main factors which impact the tariffs charged by railway companies are transportation distance and rail line ownership. In all the regression equations presented above, only independent variables X_1 and X_2 were statistically significant. Collectively, these two variables explain 51% to 69% of the tariffs charged per rail car shipment.

Lesson 2: Truck transportation is viable competition for CSXT, but this is not necessarily the case for BNSF. The difference can be explained by looking at the railway network for each of these two railway companies. The rail network of BNSF is stretched out; lines to ship from the Midwest

to the West U.S. are longer than the distances traveled along CSXT lines from the Midwest to the East. Therefore, for shipments to the West, using trucks is not attractive.

Lesson 3: Barge transportation is viable competition for CSXT shipments from the Midwest to the Southeast U.S. Agricultural products move from the Midwest to the Southeast using main agricultural waterways which often run parallel of CSXT rail lines. For this reason, the independent variables X_4 and X_5, which represent vicinity to inland ports, were found significant in all the regression equations this study developed for CSXT. We did not consider these variables when developing regression equations for BNSF since barge shipment was not an alternative.

Lesson 4: Unit train shipments are cost efficient compared to single car shipments. In Equation (1) we use variables X_9 and X_{10} to show the impact that unit train shipments have on the tariffs charged by CSXT. The value of the adjusted R^2 for this regression is 80%, and the p-values for the independent variables are less than 0.01%. Based on this regression, the tariff charged per rail car of a unit train shipment with 65 to 90 railcars is, on average, \$310 less than the tariff charged per railcar of a single car shipment. The tariff charged per railcar on a unit train shipment with more than 90 railcars is, on average, \$824 less compared to the tariff charged per railcar on a single car shipment.

$$Y^3_{CSXT} = 1,654 + 1.12 * X_1 + 175 * X_2 + 193 * X_3 + 83 * X_4 + 416 * X_5 + 278 * X_6 - 310 * X_9 - 514 * X_{10} \tag{1}$$

Lesson 5: Shipments along CSXT rail lines are cheaper as compared to shipments along BNSF rail lines. The regression equation (2) expresses the tariffs charged by railways companies as a function of distance traveled, rail line ownership, and the railway company that provides the service. The value of adjusted R^2 for this equation is 70%, and p-values are less than 0.01% for all the independent variables. This equation indicates that on average CSXT charges \$295 less per rail car than BNSF. CSXT tariffs are smaller due to competition with truck and barge shipments (see Lessons 2 and 3).

$$Y = 2,767 + 0.75 * X_1 + 283 * X_2 - 295 * X_{11}. \tag{2}$$

Among the Class I railways, BNSF has the highest fuel surcharges listed in 2007, 2008, and 2009 (IE2 2010). However, BNSF tariffs are lower compared to other western railway companies (IE2 2010).

Lesson 6: Tariffs charged by BNSF and CSXT for shipments in the South, including either the Southeast or Southwest, are more expensive than shipments to the North U.S. This is mainly due to the higher demand for rail service to these destinations because of the high-volume shipped from main export ports located in the South.

4. Analysis of Transportation Costs

This section compares transportation costs based on the transportation mode, transportation distance, the volume shipped and the destination of a shipment. We use the public rail, barge, and truck tariffs which were effective in October 2011, which allows for a fair comparison of tariffs among different modes of transportation.

We analyze transportation costs to the East and West U.S. separately for two reasons. First, barge transportation is not available for shipments to the West. Second, rail transportation tariffs differ. For shipments from the Midwest to the East and Southeast, we compare truck with rail using CSXT and barge. For shipments from the Midwest to the West, we compare truck to rail shipments by BNSF. Figures 2 and 3 present transportation costs for different distances and modes of transportation.

This study discusses transportation costs for grains in relation to available data. BNSF does not provide tariffs for transportation of woodchips, and CSXT only provides tariffs for single car shipments of woodchips. The lack of data for woodchips can be explained by the low, or nonexistent, demand for unit train shipments of woodchips, in particular from the Midwest to the West.

In order to calculate truck transportation costs in dollars per truckload as a function of the distance traveled, our study used the national average rates listed in Table 4. We then calculated the costs per ton of grain shipped considering that semi trucks have a cargo capacity of 26 tons.

Table 3 indicates that transportation costs for barge depend on the distance traveled; however, the relationship is not linear. Based on the public tariffs presented in this table, an average tariff per ton shipped equals $1.5 for 161 kilometers (100 miles) traveled. This is the rate we use to build the graphs in Figures 2 and 3.

The type of rail car considered is a jumbo hopper car, with a cargo capacity of 112 tons. For grains, we use Equation (3) to estimate the cost of a single car shipment by CSXT, (4) to estimate the cost per railcar on a 65-cars unit train operated by CSXT, (5) to estimate the cost per railcar on a 90-cars unit train operated by CSXT, (6) to estimate the cost of a single car shipment by BNSF, and (7) to estimate the cost per railcar on a 110- to 120-cars unit train operated by BNSF.

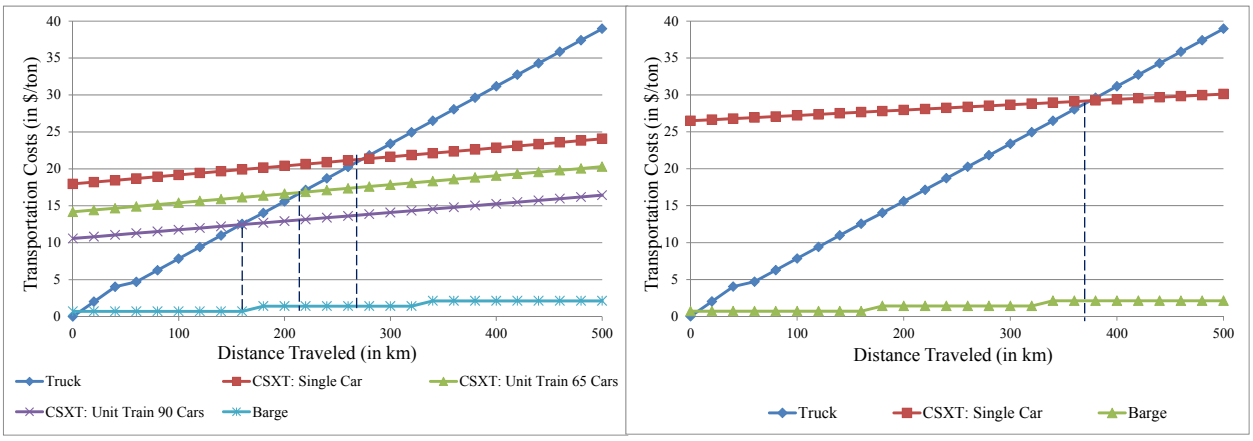
$$Y^3_{CSXT} = 2,011 + 1.37 * X'_1 \tag{3}$$

$$Y^4_{CSXT} = 1,588 + 1.37 * X'_1 \tag{4}$$

$$Y^5_{CSXT} = 1,185 + 1.31 * X'_1 \tag{5}$$

$$Y^2_{BNSF} = 3,140 + 0.75 * X_1 \tag{6}$$

$$Y^2_{BNSF} = 2,734 + 0.45 * X_1 \tag{7}$$



(a) Grains (b) Wood Chips

Figure 2 Transportation costs as a function of distance traveled: Midwest to East and Southeast USA.

For woodchips, Equation (8) estimates the cost of a single car shipment by CSXT.

$$Y^2_{CSXT} = 2,968 + 0.81 * X'_1 \tag{8}$$

Figure 2 (a) indicates that for grain shipments from the Midwest to the East, when barge is not an option, truck is the best mode of transportation for distances up to 161 kilometers (100 miles). For longer travel distances, unit trains with 90 cars are more economical. However, when the volume shipped is too small to justify the use of a unit train, then truck is the best alternative for transportation distances up to 282 kilometers (175 miles). For longer distances, single rail car shipments of grain are the most economical choice.

Consider a scenario where barge is a viable alternative for grain shipments from the Midwest to the Southeast, and the quantity shipped is larger than 1,400 tons. Assume that the origin and the destination of a shipment are located along the river which is not unreasonable since barge is typically used for shipping grain to export ports in the Southeast, such as New Orleans, and many corn elevators have access to inland ports. If available, barge is always the most economical transportation option.

Figure 2 (b) indicates that to ship woodchips from the Midwest to the East where for which barge is not an option, truck is the best mode of transportation for distances up to 386 kilometers (240 miles). For longer travel distances, single car shipments with CSXT are more economical. However, when it is available, barge remains the most economical transportation mode.

Figure 3 indicates that for grain shipments from the Midwest to the West truck is the best mode of transportation for distances up to 338 kilometers (210 miles). For longer travel distances, a unit

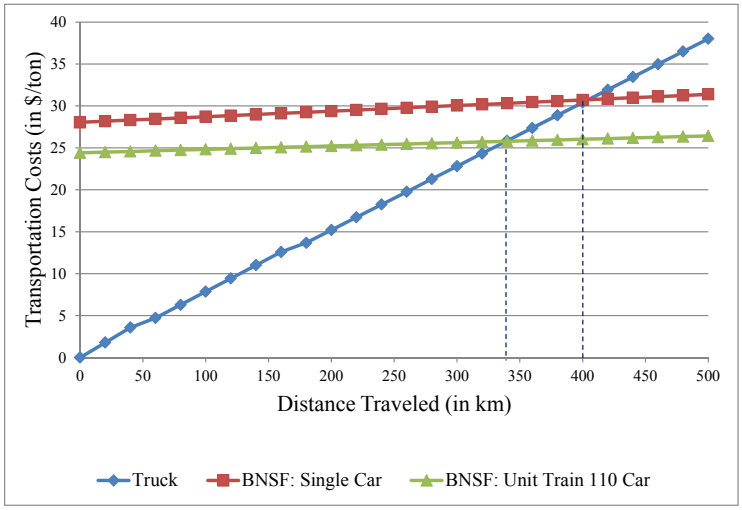


Figure 3 Transportation costs as a function of distance traveled: Midwest to West USA.

trains with 110 cars is more economical. If the volume shipped does not justify using a unit train, then truck is the best alternative for transportation distances up to 402 kilometers (250 miles). For longer distances, single rail car shipments of grain are most economical.

Transportation costs do depend not only on distance traveled, but also transportation volume. In order to analyze the impact of volume and distance on costs we create a number of scenarios. Each scenario corresponds to a particular transportation volume. Table 12 presents the scenarios created. We chose our scenarios in such a way that the volume shipped corresponds to either a full truckload, or a unit train load, etc.

Table 12 Scenario definitions.

Scenario	Quantity (in tons)	Nr. of Trucks	Nr. of Rail Cars	Nr. of Barges
1	26	1	1	1
2	112	4	1	1
3	1,500	58	14	1
4	7,280	280	65	5
5	10,080	388	90	7
6	12,320	474	110	7
7	14,560	560	130	10
8	20,160	776	180	14
9	24,640	948	220	17

Tables 13 and 14 present total transportation costs for grains in each scenario using different modes of transportation. These costs are presented as a function of distance traveled. The distances in the tables are close to the breakpoints identified in Figures 2 and 3, so the impact of transportation distances on costs is easy to see. In these tables, the numbers in red represent the minimum cost per scenario and distance traveled.

Table 13 Transportation Costs (in $ 1,000) based on distance and quantity shipped from the Midwest to East and Southeast.

	Truck Distances (in kilometers)				CSXT Distances in kilometers				Barge (in kilometers)	
Scenario	145	193	241	322	145	193	241	322	145	322
1	0.3	0.4	0.5	0.6	2.2	2.3	2.3	2.5	1.9	4.2
2	1.4	1.7	2.1	2.7	2.2	2.3	2.3	2.5	1.9	4.2
3	19.4	22.8	28.5	36.7	30.9	31.9	32.8	34.3	2.0	4.5
4	94.2	110.5	138.2	178.1	116.1	120.4	124.7	131.8	9.8	21.8
5	130.5	153.1	191.3	246.6	123.7	129.3	135.0	144.5	13.6	30.2
6	159.5	187.1	233.8	301.4	167.8	174.8	181.8	193.5	16.6	36.9
7	188.5	221.1	276.4	356.2	232.2	240.8	249.3	263.6	19.7	43.7
8	261.3	306.5	383.1	493.8	247.3	258.7	270.0	288.9	27.2	60.5
9	319.0	374.1	467.7	602.7	335.7	349.7	363.6	386.9	33.3	73.9

Important findings for shipments from the Midwest to the East, derived from the results of Table 13, include:

- If barge transportation is available and the volume shipped justifies the use of a barge (see Scenarios 3 to 9), then barge is the least expensive transportation mode.
- If barge transportation cannot be used and the volume shipped justifies the use of a single rail car (see Scenarios 2 through 9), then rail is the least expensive mode of transportation when the distance traveled is 274 kilometers (170 miles) or longer. For shorter distances, truck transportation is the least expensive option.
- If the volume shipped is less than 30 tons, then truck is the least expensive transportation option.
- If the volume shipped justifies the use of a unit train of 65 cars (see Scenarios 4 through 9), then rail transportation is the least expensive mode of transportation for distances longer than 193 kilometers (120 miles).
- If the volume shipped justifies the use of a unit train with 90 cars (see Scenarios 5 through 9), then rail transportation is the least expensive mode of transportation for distances longer than 145 kilometers (90 miles).

Important findings from the results of Table 14 for shipments from the Midwest to the West include:

- Truck is the least expensive transportation mode if the distance traveled is up to 322 kilometers (200 miles), regardless of the volume shipped.
- If the volume shipped is as much as to 26 tons, a full truckload, then truck transportation is least expensive for distances up to 2,414 kilometers (1,500 miles).
- If the volume shipped justifies the use of a single rail car, then rail transportation is least expensive for distances longer than 402 kilometers (250 miles).

Table 14 Transportation costs (in $ 1,000) based on distance and quantity shipped from the Midwest to West.

	Truck Distances (in kilometers)					BNSF (in kilometers)				
Scenario	322	483	1,083	1,672	2,755	322	483	1,083	1,672	2,755
1	0.7	1.0	2.2	3.4	5.6	3.4	3.5	3.9	4.4	5.2
2	2.7	4.1	9.2	14.2	23.4	3.4	3.5	3.9	4.4	5.2
3	38.0	56.9	127.7	197.2	325.0	47.3	49.0	55.3	61.4	72.7
4	184.2	276.4	620.0	957.1	1,577.1	227.7	219.7	256.6	285.1	337.6
5	255.1	382.7	858.4	1,325.3	2,183.7	304.2	315.0	355.3	394.8	467.5
6	311.8	467.7	1,049.2	1,619.8	2,668.9	316.6	324.5	354.0	383.0	436.3
7	368.5	552.7	1,239.9	1,914.3	3,154.2	384.2	394.5	433.0	470.8	540.2
8	510.9	766.3	1,719.0	2,653.9	4,373.0	553.2	569.5	630.4	690.1	799.9
9	623.6	935.4	2,098.4	3,239.5	5,337.9	633.2	649.0	708.1	766.1	872.7

- If the volume shipped justifies the use of a unit train, then rail transportation is least expensive for distances longer than 338 kilometers (210 miles).

5. Conclusions

This research indicates that having access to intermodal facilities, such as, rail ramps and in-land ports provides access to cost-efficient modes of transportation for biorefineries. The regression equations presented in this paper identify the main factors that impact the tariffs charged by railway companies for high-volume and long-haul shipment of agricultural products that have physical characteristics similar to densified biomass. Some of the most important factors identified are distance traveled, quantity shipped, railcar ownership, railway ownership, and shipment destination. These factors collectively explain as many as to 80% of the rail tariffs charged per rail car.

The tariffs charged by CSXT for shipments which are destined to the Southeast U.S. are higher compared to tariffs charged for shipments sent to the Northeast because of higher demand for rail services for shipments to the Southeast. Many ports in the Southeast are also double as the main export points for grains.

The tariffs charged for unit train shipments along the BNSF and CSXT rail lines are less than what's charged for single car shipments. Railway companies give monetary incentives to customers for high-volume shipments. For example, CSXT averagely charges $3.78 less per ton when using a unit train with 65 cars versus a single car shipment. This difference is $7.50 per ton when shipping a unit train with 90 cars. This difference for BNSF is, on average, $4.50 per ton. The biofuels industry could benefit from these monetary incentives by using unit trains for high-volume shipments of biomass. The regression analysis indicates that the tariffs charged by CSXT for the movement of a rail car are smaller than the tariffs charged by BNSF. The tariffs charged by CSXT are smaller due to rail's competition with truck and barge. The distance a shipment must travel along BNSF rail lines is typically long. Thus, truck transportation is not a viable competition to BNSF.

Barge shipments are more cost efficient compared to truck and rail. These costs depend on the size of a shipment and the trip's duration. The biofuels industry should take advantage of barge shipments if available. Building biorefineries next to inland ports is one location strategy that could drastically reduce supply chain costs by using barge, rather than truck or rail, for inbound and outbound shipments.

To summarize and contextualize the discussion presented above, this study suggests:

- If a biorefinery must locate in the Southeast, then locations close to an inland port are preferable.
- If a biorefinery must locate in the Northeast, then locations close to a rail ramp are preferable.
- If a biorefinery relies on rail shipments of biomass, then locating to East would result in lower inbound transportation costs compared to the West.

References

2006. Freight rail transportation: Long-term issues. Congress of the United States, Congressional Budget Office (CBO). Available at: www.cbo.gov/doc.cfm?index=7021.

2009. Distances between united states ports. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Available at: http://www.nauticalcharts.noaa.gov/nsd/distances-ports/distances.pdf.

2010. Review and analysis of cron rail rates. Informa Economics. The National Corn Growers Association. Memphis, TN. Available at: http://ncga.eweb3.socket.net/files/pdf/RailRateReportJune2010.pdf.

2010. Study of rural transportation issues. U.S. Department of Agriculture (USDA). Available at: www.ams.usda.gov/AMSv1.0/ruraltransportationstudy.

2010. U.s. census data. Available at: http://2010.census.gov/2010census/.

2012. Bioenergy: Knowledge discovery framework. U.S. Department of Energy: https://www.bioenergykdf.net/.

2012. Renewable fuel standard (rfs). U.S. Environmental Protection Agency. Available at: www.epa.gov/otaq/fuels/renewablefuels/index.htm.

Aden, A., M. Ruth M, K. Ibsen, J. Jechura, K. Neeves K, J. Sheehan, B. Wallace, L. Montague, A. Slayton, J. Lukas. 2002. Lignocellulosic biomass to ethanol process design and economics utilizing co-current dilute acid prehydrolysis and enzymatic hydrolysis for corn stover. NREL/TP-510-32438. Golden, Co: National Renewable Energy Laboratory.

AMS. 2012. Grain transportation report. Agricultural Marketing Services of the U.S. Department of Agriculture. Available at: http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5098844.

Badger, Phillip C., Peter Fransham. 2006. Use of mobile fast pyrolysis plants to densify biomass and reduce biomass handling costsa preliminary assessment. *Biomass and Bioenergy* **30**(4) 321–325.

Bonilla, David, Carly Whittaker. 2009. Freight transport and deployment of bioenergy in the u.k. Transport Studies Unit University of Oxford: Working paper N 1043.

Economics, Informa. 2009. Shallow-draft/inland vessel operating costs. Army Corps SDIVOC ReportFY2009.

Hess, J., K. Kenney, L. Ovard, E. Searcy, C. Wright. 2009. Uniform-format solid feedstock supply system: A commodity-scale design to produce an infrastructure-compatible bulk solid from lignocellulosic biomass. INL/EXT-08-14752. Available at: www.inl.gov/bioenergy/uniform-feedstock.

Ileleji, Klein E., Shahab Sokhansanji, John S. Cundiff. 2010. *Biofuels from Agricultural Wastes and Byproducts*, chap. Chapter 7: Farm-Gate to Plant-Gate Delivery of Lignocellulosic Feedstocks from Plant Biomass for Biofuel Production. Wiley-Blackwell, 117–160.

Judd, Jason, Subhash C. Sarin, John S. Cundiff. 2011. Cost analysis of a biomass logistics system. *ASABE Meeting Presentation*.

Laurits, R. 2009. A study of competition in the u.s. freight railroad industry and analysis of proposals that might enhance competition: Revised final report. Christensen Associates, Inc. A report prepared for The Surface Transportation Board (STB). Available at: www.stb.dot.gov/stb/docs/CompetitionStudy/Executive20Summary.pdf.

Laurits, R. 2010. An update to the study of competition in the u.s. freight railroad industry: Final report. Christensen Associates, Inc. A report prepared for The Surface Transportation Board (STB). Available at: www.stb.dot.gov/stb/docs/CompetitionStudy/Final/January/202010/20Report.pdf.

MacDonald, James M. 1987. Competition and rail rates for the shipment of corn, soybeans, and wheat. *The RAND Journal of Economics* **18**(1) 151–163.

Mahmudi, H., P. Flynn. 2006. Rail vs truck transport of biomass. *Applied Biochemistry and Biotechnology* **129**(1) 88–103.

Matheny-Katz, M. 2002. Barge and towboat operating costs. Federal Interagency Vessel and Shipping Costs Workshop.

Montgomery, Douglas C., Elizabeth A. Peck, G. Geoffrey Vining. 2012. *Linear Regression Analysis*. 5th ed. Wiley Series in Probability and Statistics, Wiley.

Montgomery, Douglas C., George C. Runger. 2011. *Applied Statistics and Probability for Engineers*. 5th ed. Wiley.

Petrolia, D. R. 2008. The economics of harvesting and transporting corn stover for conversion to fuel ethanol: A case study of minnesota. *Biomass and Bioenergy* **32**(7) 603–612.

Rawlings, John O., Sastry G. Pantula, David A. Dickey. 1989. *Applied Regression Analysis: A Research Tool*. 2nd ed. Springer.

Rogers, J.G., J.G. Brammer. 2009. Analysis of transport costs for energy crops for use in biomass pyrolysis plant networks. *Biomass and Bioenergy* **33**(10) 1367–1375.

Searcy, E., P. Flynn. 2008. The impact of biomass availability and processing cost on optimum size and processing technology selection. *Applied Biochemistry and Biotechnology* **154** 271–286.

Searcy, E., P. Flynn, E. Ghafoori, A. Kumar. 2007. The relative cost of biomass energy transport. *Applied Biochemistry and Biotechnology* **137**(1) 639–652.

Searcy, E., J. R. Hess. 2010. Uniform-format feedstock supply system design for lignocellulosic biomass: A commodity-scale design to produce an infrastructure-compatible biocrude from lignocellulosic biomass. DRAFT, INL/EXT- 10-20372.

Sokhansanj, S., S. Mani, A. Turhollow, A. Kumar, D. Bransby, L. Lynd, M. Laser. 2009. Large-scale production, harvest and logistics of switchgrass (panicum virgatum l.)- current technology and envisioning a mature technology. *Biofuels, Bioproducts and Biorefining* **3**(12) 124–141.

Sokhansanj, S., A. F. Turhollow. 2004. Biomass densification - cubing operations and costs for corn stover. *Applied Engineering in Agriculture* **20**(4) 495–499.

Sokhansanj, S., A. F. Turhollow. 2006. Economics of producing fuel pellets from biomass. *Applied Engineering in Agriculture* **22**(3) 421–426.

Wright, M., R.C. Brown. 2007. Establishing the optimal sizes of different kinds of biorefineries. *Biofuels, Bioproducts and Biorefining* **1** 191–200.