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Impact of Intermodal Facilities to the Design of Supply Chains for Biorefineries

FINAL REPORT

Sandra D. Eksioglu
Department of Industrial & Systems Engineering

Daniel Petrolia
Department of Agricultural Economics

August 15, 2009

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ABSTRACT
This paper analyzes the impact that an intermodal facility has on location and transportation decisions for biofuel production plants. Location decisions impact the management of the in-bound and out-bound logistics of a plant. We model this supply chain design and management problem as a mixed integer program. Input data for this model are location of intermodal facilities and available transportation modes; cost and cargo capacity for each transportation mode; geographical distribution of biomass feedstock, and production yields; and biomass processing, and inventory costs. Outputs from this model are the number, location and capacity of biofuel production plants. For each plant, the transportation mode used, timing of shipments, shipments size, inventory size, and production schedule that minimize the delivery cost of biofuel are determined. The state of Mississippi is considered as the testing grounds for our model. Experimental results indicate that the best location for a (corn-to-ethanol) biorefinery in Mississippi is Warren County, where an in-land port is located. Results indicate that, even when the biomass available in Mississippi is enough to operate this facility, it is economical to ship corn from the Midwest using barge.

INTRODUCTION

This work is motivated by the continued growth of interest in developing cleaner, renewable energy sources. Bioenergy is such a source of energy that can help the United States to reduce its dependency on fossil fuels (*1*). Bioenergy is produced from biomass feedstocks, which are plant-derived materials including animal manure. According to the nationwide renewable fuels standard, the supply of renewable energy is expected to increase from 4 billion gallons in 2006 to 7.5 billion gallons by 2012. As a result, we anticipate that a number of biorefineries will open in the near future.

Biorefinery location decisions impact and are impacted by transportation and other supply chain related decisions. Due to the particular nature of biomass (biomass is bulky and difficult to transport), biorefinery logistics costs are high. For example, it is estimated that 20-40% of the total cost of ethanol is due to biomass supply, and 90% of these costs are due to the logistics of biomass delivery. This is the reason why 76% of ethanol is currently produced in small bioreneries located in the Midwest. In addition to the logistics challenges with biomass, biofuel transportation is also an issue. The existing pipeline system cannot be used to distribute ethanol. Therefore, ethanol is shipped in containers using rail, barge and truck. In 2005, 60% of ethanol produced was shipped by rail; 30% by truck; and 10% by barge (*2*). Biorefineries in the Midwest use containers to ship DDGS (Distiller's Dried Grains with Solubles), a byproduct of ethanol, to Asian counties where it is used as livestock and poultry feed. For every gallon of corn ethanol, about 6.34 pounds of DDGS are produced. About 10% of the DDGS produced is exported (*2*). In the Midwest, biorefineries are taking advantage of intermodal transportation to ship DDGS to Asia using containers which bring products to the United States, and would otherwise return back empty (*3*).

This paper analyzes the impact that an intermodal facility has in designing and managing the supply chain of a biorefinery. An intermodal facility is a facility where two or more transportation modes meet, such as in-land ports, sea ports, rail ramps, etc. Locating close to an intermodal facility allows for economical transportation options to replenish inventories. This is particularly important for *biofuel destination plants*. A destination plant (*4*) is usually located far from its biomass supply sources. Such a plant is usually located close to the market, and therefore, it is in need of affordable transportation of biomass. Pacific Ethanol is an example of a destination ethanol plant with five plants located in the West Coast. The company uses unit rail to ship corn from the Midwest.

We propose a mathematical model to identify the impact of an intermodal facility to the design and management of the supply chain for a biorefinery. We use the model to compare supply chain designs that take advantage of intermodal facilities with the ones that do not. Depending on the type of the intermodal facility, rail, barge, intermodal and truck can potentially be used to ship biomass and biofuels. This mathematical model integrates supply chain strategic decisions (such as, facility location) with tactical decisions (such as, transportation mode selection). For each biorefinery, the model identifies (a) shipment schedules for biomass and biofuel. That means timing of shipment, shipment amount, and transportation mode used; (b) inventory carried; and (c) production schedule.

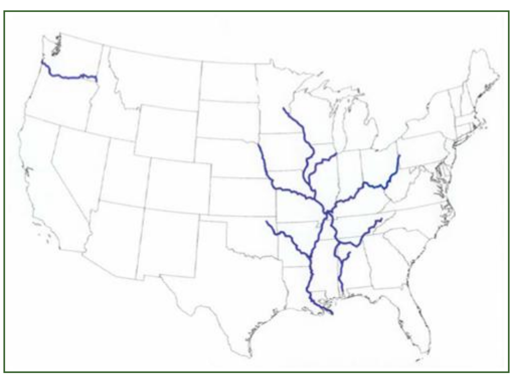
We use the state of Mississippi as the testing grounds for the models proposed. Our selection of Mississippi is motivated by two recent events: (a) the opening of the first ethanol production plant in Mississippi near the port of Vicksburg in 2008; (b) in 2007, Mississippi tripled the number of acres of land planted with corn. The plant in Vicksburg is an *ethanol destination plant*. Of the corn processed in this plant, only 30% is produced in Mississippi. The rest is purchased from corn elevators located in the Midwest. To make use of the increased supply of corn and woody biomass which is abounding in the state, we anticipate that other plants will open in the near future. Therefore, identifying potential locations for these plants and designing cost efficient in-bound and out-bound distribution chains for biorefineries is very important. The availability of well-designed supply chains will aid in attracting investors to Mississippi, potentially having a positively impact on the economy of Mississippi, and providing new job opportunities for rural Mississippians.

BACKGROUND

Biomass-to-Biorefinery Supply Chain

The in-bound and out-bound parts of the supply chain of a biorefinery are different from those of traditional refineries that use crude oil. Biomass is harvested at farms, collected at facilities near the farms and then shipped to biorefineries using trucks. Ethanol is shipped by truck, barge or rail to blending facilities. Trucks are then used to ship ethanol blends such as E-10 (gasoline blended with 10% ethanol) and E-85 to gasoline retail outlets.

Different transportation modes can be used to ship ethanol. The same is true for DDGS and biomass. The choice of a transportation mode depends on the distance between origin-destination of a shipment, and the proximity to intermodal facilities (such as rail terminals, sea ports, in-land ports, etc). Due to the high cost of transporting biomass, 76% of ethanol produced in the USA comes from small-sized biorefineries located in four major corn producing states in the Midwest. Collecting and transporting biomass within a 50 mile radius is the economic threshold that has been used in the literature. Mahmudi and Flynn (*5*) show that the shipping distance (for wood chips) beyond which rail is more economical than truck is 145km (90miles). The increased demand for ethanol and economies of scale (in utilization of byproducts and distillation of ethanol) favor larger scale facilities. Larger biorefineries imply a larger number of biomass suppliers, longer transportation distances, and higher shipping volumes.



(a) Agriculture Significant Waterways

(b) BNSF Rail Map

FIGURE 1 Agriculture significant distribution corridors.

The grain handling infrastructure in the United States has been built over the years to reliably and efficiently transport billions of tons of grain and other agricultural commodities throughout the year from their production centers on-farm to domestic and international destinations hundreds of miles away. This infrastructure is currently supporting the rapid growth of the biofuels industry, especially ethanol production. The major corn producing States (Iowa, Illinois, Nebraska, Indiana, and Minnesota) are located near the Great Lakes or along the agriculturally significant waterways (Figure 1). Destination plants that have access to in-land ports and sea ports can ship corn from these Sates using barge. Barge provides large transportation capacity at a low price. Mississippi has access to the Mississippi River in the west and Tombigbee River in the east. The strategic location of the state is clearly an advantage for ethanol producers.

Railways are also major carriers of corn. For example, Burlington Northern Santa Fe (BNSF) Railway, whose rail tracks span the western part of the United States, is a major carrier for corn and other agricultural products. Rail cars are used to ship ethanol, corn and DDGS from the Midwest to the east and west coasts of the United States.

An intermodal facility is where various transportation modes meet. At an intermodal facility loads of commodities are transshipped from one mode to another such as from trucks to trains, and barges. Considering the impact of transportation costs on the production cost of biofuels, one can see why decisions on the location of a biofuel destination plant are impacted by the location of intermodal facilities. When located near to an intermodal facility, biorefineries can take advantage of affordable transportation modes and potentially reduce their transportation costs. For example, the first ethanol production plant in Mississippi is located near the port of Vicksburg. The selection of this site was motivated by the affordable cost of shipping corn by barge from the Midwest. Additionally, DDGS and ethanol can be transported along the Mississippi River to large ports in the south (such as, New Orleans) and from there DDGS can be shipped overseas and ethanol can be shipped to major cities within the United States.

Literature Review

This research is related to two main streams of literature the literature on supply chain design and management, and the literature on biomass supply chains. We give a brief summary of each stream and show how this work is related to and complement the existing literature.

Supply Chain Design and Management

An important stream of research within the supply chain design literature is identifying locations for facilities so that the total of location and transportation costs is minimized, or service levels are maximized (*6*). Earlier studies in this area were focused on the uncapacitated facility location problem (*7, 8*). Three important extensions of the basic model considered (a) facility capacities (*9*) and single sourcing requirements (*10*), (b) multiple echelons in supply chains (*11*), and (c) multiple products (*12*). A number of studies aim to comprise the facility location problem within the framework of supply chain design and management (*13, 14*). Several comprehensive reviews summarize the research accomplished in this area in the last few years (*15*).

The area of supply chain management has received a great deal of attention since 1990s. This research area deals with the management of materials, information and financial flows in a supply chain. Within this stream of research, a number of studies discus the impact of facility location on production and distribution decisions in the supply chains (*16*). Integrated supply chain design and management problems have been of interest to many researchers (*17, 18*).

Biomass Supply Chain

Ahumada et al. (*19*) provide a comprehensive review of models used to designing supply chains for agricultural products. The literature on supply chain designs for biomass is scarce. The existing literature provides models that estimate the cost of collecting, handling, and hauling biomass to biorefineries, and compare different modes of delivering biomass (*20, 5*). Only a few studies take an integrated view of the processes involved in collecting, storing, and transporting biomass. Schmidt et al. (*21*) propose a mathematical that optimizes the supply chain of biofuels. Their model considers biomass production, biomass transportation, production of biofuels and byproducts, distribution of biofuels and byproduct and plant locations. They use this model to identify potential locations for methane and ethanol production plants in Austria. Sokhansanj et al. (*22*) simulate the collection, storage, and transportation of biomass to biorefineries using EXTENDTM, a commercial simulation package.

PROBLEM FORMULATION

The purpose of this study is to show how the location of an intermodal facility impacts strategic and tactical decisions of the biofuel supply chain. Figure 2 gives a network representation of the biofuel supply chain. In this supply chain, biomass is harvested and shipped to nearby collection facilities mainly by tractors. Depending on the shipment distance from the collection facility to a biorefinery, different transportation modes can be used to ship biomass. Trucks are used for shorter distances, while, rail and barge are used for longer distances. Biofuel is shipped to blending facilities. E-10 and E-85 blends are delivered from blending facilities to gas stations.

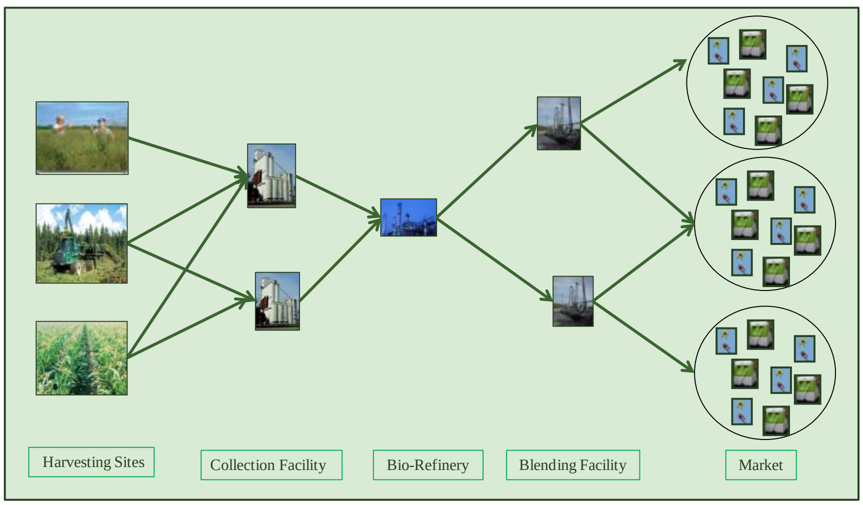


FIGURE 2 Biofuel supply chain.

In order to design the biofuel supply chain and model the flow of biomass and biofuel, we use a network flow-based approach. Figure 3 gives a network representation of the biofuel supply chain. This is a time-space network, named $G(N,A)$, where N is the set of nodes and A is the corresponding set of arcs. The nodes of G represent harvesting sites (denoted by N^H), collection facilities (N^C), biorefineries (N^B), blending facilities (N^F) and customers (N^{CS}). Let G_t (for $t = 1,2,\ldots,T$) represent the serial network within a time period. Then, $G_t = N_t^H \cup N_t^C \cup N_t^B \cup N_t^F \cup N_t^{CS}$. The arcs that connect nodes within the same time period represent the transportation arcs A^T ($A^T \subset A$). In G_t, one transportation mode (tractors) is used to ship biomass from harvesting sites to collection facilities. The same is true for shipments of biofuel from blending facilities to retail outlets. However, more than one transportation mode can be used to ship biomass from harvesting sites to biorefineries, biomass from collection facilities to biorefineries, and biofuel from biorefineries to blending facilities. Arcs that connect the same facility in two consecutive time periods represent the inventory arcs.

We consider that the structure of transportation costs TC_{ij} for arc $(i,j)\in A^T$ follows a multiple setups cost structure.

$$TC_{ij}\left(\sum_{k\in K} x_{ij}^k\right)=\begin{cases}\sigma^\delta + A^\delta\left\lceil \dfrac{\sum_{k\in K} x_{ij}^k}{U^\delta}\right\rceil + \sum_{k\in K} c_{ij}^k x_{ij}^k & if \quad \sum_{k\in K} x_{ij}^k > 0 \\ 0 & otherwise \end{cases}$$

where, $\lceil a \rceil$ denotes the smallest integer that is greater than or equal to a. c_{ij}^k represents the cost of flowing one unit of commodity $k\in K$ on arc (i,j). The commodities that flow in this network are different types of biomass (such as, forest residues, corn, corn stover, etc.), and different types of biofuels (such as ethanol, cellulosic ethanol, etc.). σ^δ is the order setup cost, A^δ is the fixed cost of a cargo container, and U^δ is the capacity of a cargo container for transportation mode δ.

The binary variables z_{ij}^δ and integer variables r_{ij}^δ are introduced to model this network flow-based problem with multiple setups cost function as a mixed integer program (MIP).

$$z_{ij}^\delta = \begin{cases} 1 & if \quad \sum_{k\in K} x_{ij}^k > 0 \\ 0 & otherwise \end{cases} \qquad \text{and} \qquad r_{ij}^\delta = \left\lceil \frac{\sum_{k\in K} x_{ij}^k}{U^\delta} \right\rceil$$

In the objective function for $(i,j)\in A^T$ we have: $TC_{ij}\left(\sum_{k\in K} x_{ij}^k\right)=\sum_{k\in K} c_{ij}^k x_{ij}^k + \sum_{\delta\in\Delta}\sigma^\delta z_{ij}^\delta + \sum_{\delta\in\Delta} A^\delta r_{ij}^\delta$

In the set of constraints we added constraints (9) and (10) to ensure that if a transportation mode is being used, then an integer number of containers are used; and the total amount shipped is less than or equal to the capacity of the cargo container.

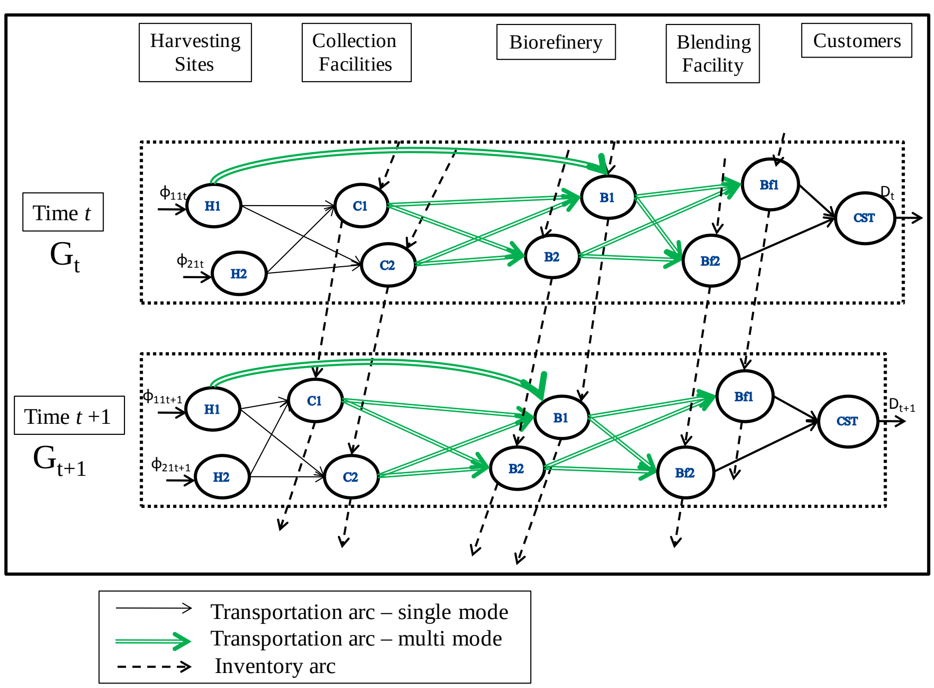


FIGURE 3 Network representation of the fiofuel supply chain.

The decision variables are: x_{ij}^{k} which represents the flow of commodity *k* on arc $(i,j)\in A$. y_{il}^{1} is a binary variable that takes the value 1 if a biorefinery of size *l* ($l\in S^1$) is located at node *i* ($i\in N^B$), and takes the value 0 otherwise; y_{il}^{2} is a binary variable that takes the value 1 if the collection facility of size *l* ($l\in S^2$) located at node *i* ($i\in N^C$) is being used, and takes the value 0 otherwise.

Other *notations* used are: c_{ij}^{k} represents the cost of flowing commodity *k* on arc (i,j); ψ_{il} is the amortized annual cost of constructing and operating a biorefinery of size *l* at node *i*; SB_l is the storage capacity of a biorefinery of size *l*; SC_l is the storage capacity of a collection facility of size *l*; CP_l is the production capacity of a biorefinery of size *l*; $\beta_{k\kappa}$ is the conversion rate of biomass *k* to biofuel κ; λ_i^k is the amount of biomass type *k* available at harvesting site *i*. This amount is a function of the total land available, production yield, and the proportion of biomass that can be used to produce biofuel. D_i^k is the demand for biofuel *k* of customer $i\in N^{CS}$. *M* is a very large number.

Next, we give the MIP formulation of this problem.

$$\min \quad \sum_{(i,j)\in A}\sum_{k\in K} c_{ij}^{k}x_{ij}^{k} + \sum_{i\in N^F}\sum_{l\in S^1}\psi_{il}y_{il}^{1} + \sum_{\delta\in\Delta}\sum_{(i,j)\in A^T}\sigma^{\delta}z_{ij}^{\delta} + \sum_{\delta\in\Delta}\sum_{(i,j)\in A^T}A^{\delta}r_{ij}^{\delta}$$

Subject to:

$$\sum_{j:(i,j)\in A} x_{ij}^{k} - \sum_{j:(j,i)\in A} x_{ij}^{k} = \begin{cases} 0 & i\in N^C\cup N^F; k\in K \\ D_i^k & i\in N^{CS}; k\in K \end{cases} \qquad (1)$$

$$\sum_{j:(i,j)\in A} \beta_{k\kappa}x_{ij}^{k} - \sum_{j:(j,i)\in A} x_{ij}^{\kappa} = 0 \qquad i\in N^B; k,\kappa\in K \qquad (2)$$

$$\sum_{j\in N^C\cup N^B} x_{ij}^{k} \le \lambda_i^k \qquad k\in K, i\in N^H \qquad (3)$$

$$\sum_{l\in S^1} y_{il}^{1} \le 1 \qquad i\in N^F \qquad (4)$$

$$\sum_{l\in S^2} y_{il}^{2} \le 1 \qquad i\in N^C \qquad (5)$$

$$\sum_{k\in K}\sum_{i\in N^H\cup N^C} x_{ij}^{k} \le \sum_{l\in S^1} SB_l y_{jl}^{1} \qquad j\in N^B \qquad (6)$$

$$\sum_{k \in K}\left(\sum_{j \in N^F} x_{ij}^k - x_{il}^k + x_{fi}^k\right) \le \sum_{l \in S^1} CP_l y_{il}^1 \qquad i \in N_t^B, l \in N_{t+1}^B, f \in N_{t-1}^B, t = 1,\ldots,T \quad (7)$$

$$\sum_{k \in K}\sum_{i \in N^H} x_{ij}^k \le \sum_{l \in S^2} SC_l y_{jl}^2 \qquad j \in N^C \quad (8)$$

$$\sum_{k \in K} x_{ij}^k - M z_{ij}^\delta \le 0 \qquad (i,j) \in A^T; \delta \in \Delta \quad (9)$$

$$\sum_{k \in K} x_{ij}^k - U^\delta r_{ij}^\delta \le 0 \qquad (i,j) \in A^T; \delta \in \Delta \quad (10)$$

$$x \ge 0 \quad (11)$$

$$y, z \in \{0,1\} \quad (12)$$

$$r \in Z^+ \quad (13)$$

The objective here is to identify locations for biorefineries, transportation modes to use, transportation schedule, and biofuel production schedule, which minimize the total of biofuel delivery cost to customers. Constraints (1) are the flow conservation constraints at collection facilities, blending facilities and customers. (2) are the flow conservation constraints at biorefineries. Constraints (3) indicate that the amount of biomass shipped from a harvesting site is limited by the amount of biomass available. Constraints (4) and (5) ensure that at most one biorefinery and one storage facility of a particular size is open in a given location. (6) are the storage capacity constraints and (7) are the production capacity constraints for biorefineries. (8) are the storage capacity constraints for collection facilities. We have explained above the need for constraints (9) and (10). (11) are the non-negativity constraints, (12) are the binary constraints, and (13) are the integrality constraints.

CASE STUDY

In order to validate the model proposed above, we use the state of Mississippi as a testing ground. In the following subsections we describe the sources of data used, and discuss our computational experiments. Due to the availability of the data, we consider corn to be the biomass used to produce ethanol. In fact, corn is the biomass used for 90% of the ethanol produced in the USA.

Input Data

The amount of corn produced in Mississippi is provided by National Agricultural Statistics Services (NASS), offered by United States Department of Agriculture (USDA). NASS provides this information at the county level for each state. This is the reason why the counties (rather than individual farms) are considered as harvesting sites in our experiments. Corn production is seasonal. In Mississippi corn is harvested from August to October. We anticipate that 10% of the corn produced is used for ethanol production. This information is used to estimate λ_i^k, the amount of corn available for ethanol in a time period.

We consider forty-five out of the eighty-four counties in Mississippi, as biomass harvesting sites. In order to make this selection, we use the amount of corn produced in a county as a threshold. Only counties with more than 1,000 acres of land dedicated to corn production are considered. In addition to the harvesting sites located in Mississippi, we consider three additional sites located in the Midwest. One of these sites is located in Illinois, one in Ohio, and one in Iowa. Corn from the Midwest is shipped to Mississippi by train or barge.

Each county in Mississippi is considered to be a candidate location for collection facilities and biorefineries. We identified 15 blenders located in Mississippi and assumed that ethanol could be shipped to any of these locations. The following are the candidate production capacities for a biorefinery: 10 million gallons a year (MGY) at a cost of $88 million; 20 MGY at a cost of $141 million; 30 MGY at a cost of $193 million; 40 MGY at a cost of $226 million; and 60 MGY at a cost of $310 million. For each investment we calculate the annual equivalent cost using a 15% interest rate and 20 years project life.

The American Coalition for Ethanol (ACE) handbook for year 2005 estimates that the potential ethanol use in Mississippi is 168 MGY. This amount is calculated considering the total gas consumption in Mississippi, and assuming that E10 is used in all gas stations.

Transportation of corn and ethanol in short distances within Mississippi is assumed to be completed by truck. Shipments (by barge or rail) from the Midwest arrive at counties that have an intermodal facility. We identified counties that have an in-land port on the Mississippi River or the Tennessee Tombigbee River, and counties that have access to a rail ramp.

The Agricultural Marketing Service (AMS) (*23*), which is provided by USDA, posts quarterly reports about grain transportation using trucks. Truck rates depend on the distances traveled and the shipment's origin/destination regions. For example, the rate charged for distances less than 25miles is $0.104/mile/ton; $0.083/mile/ton for distances within 100miles; and $0.073/mile/ton for distances within 200miles. Rates charged in the southern part of the United States are different from the northeast or northwest. We consider that a truck car carry up to 36tons of corn, and up to 8,000gal of ethanol.

AMS also provides shipping rates for grains using barge along the Mississippi River. These rates do vary by quarter. Barge rates average to $0.016/mile/ton.

Companies such as CSX Transportation (CSXT) and BNSF presents on their websites the price charged per rail car (with corn and ethanol) for different origin-destination pairs of rail ramps. These prices depend on the capacity/size of the rail car; shipment type (single car versus unit train); ownership of the equipment; etc. We used the data provided for corn shipments originating in the Midwest (South) whose destination is South (Midwest) and performed regression analyses. We built two regression lines, one for each of the following transportation options:

(a) Less than 48 <u>single cars</u>; each with a capacity of 4,000-4,999 cubic feet (100ton of corn); railroad owned or leased equipment.
(b) Less than 65 cars <u>unit train</u> shipment; railcar capacity of 4,000-4,999 cubic feet; shipper owned or leased equipment.

There are a number of other factors that affect the price charged by a railroad company. Distance (in miles) between the origin and destination is a factor. We run a regression in order to quantify the impact of distance (the independent variable) to rail transportation costs (the dependent variable) within each of the two transportation options defined above. The regression equations for corn under option (a) is

$$y=2.1738x+1127.80.$$

Where, \$1127.8 is the fixed cost of a railcar (A^{δ}), and \$2.1738 is charged per mile traveled (c_{ij}^{k}). The value of R^2 for this regression is 96.5% and the *p*-value for the independent variable is 1.45*E*-71. That means distance is a significant factor when estimating rail transportation costs.

The regression equations for corn under option (b) is y=2.1738x+1827.81. The value of R^2 for this regression is 96.5% and the *p*-value for the independent variable is 1.45*E*-71.

The regression equations for ethanol under option (a) is y=1.15x+3444.86. The value of R^2 for this regression is 75% and the *p*-value for the independent variable is 1.03*E*-12.

The regression equations for ethanol under option (b) is y=1.15x+2044.86. The value of R^2 for this regression is 96.5% and the *p*-value for the independent variable is 1.45*E*-71.

Other input data used in this paper (such as processing costs, conversion rates, etc) are the same with Eksioglu et al. (*24*).

Computation Result

Using the data collected, we generate a base scenario for testing our model. Next, we change the values of some input data one at a time to generate additional test problems. We use CPLEX 9.0 callable libraries to solve the MIP problems for each scenario we test. CPLEX is a commercial LP/MIP solver.

In our experiments we consider that the total amount of corn available in Mississippi is 1,316,000 dry tons per year. This amount was calculated based on corn production in the state in the last 5 years. Considering that 10% of the corn produced is used for ethanol, and conversion rate of corn to ethanol is 119.5 gal/dry ton, we estimate that the maximum annual ethanol from corn production in Mississippi is 15.7MGY. Therefore, it is expected that biorefineries with a capacity of 10MGY will mainly use corn which is available in the state. For larger capacities, corn will be shipped from the Midwest. We expect that location decisions for biorefineries with a capacity larger than 10MGY will be impacted by the location of an intermodal facility.

Table 1 presents the break-even of ethanol delivery cost for different values of production capacity and transportation cost. When production capacity is fixed, the delivery cost increases with the increase in unit transportation costs (c_{ij}^{k}). When the transportation costs remain the same, the delivery cost decreases with the increase in the annual production of ethanol from 10MGY to 60MGY.

TABLE 1 Barge: Production Capacity versus Transportation Costs

Annual Ethanol Production (MGY)	Increase in Transportation Costs						
	0%	25%	50%	75%	100%	125%	150%
	Delivery Cost of Ethanol (in \$/gal)						
10	3.06	3.14	3.22	3.3	3.38	3.46	3.54
20	2.79	2.88	2.97	3.06	3.15	3.24	3.33
30	2.71	2.79	2.87	2.95	3.03	3.11	3.19
40	2.58	2.67	2.76	2.85	2.94	3.03	3.12
60	2.51	2.6	2.69	2.78	2.87	2.96	3.05

In order to understand the decrease in the delivery cost of ethanol as the annual ethanol production increases, we distributed the total delivery cost among its major cost components. Based on the results from Table 2 one can see that as the annual production of ethanol increases, (assuming 0% increase in transportation costs) total biomass transportation costs increase, and investment costs decrease. The increase in transportation costs is due to the fact that biomass needed is shipped from sites located further away (Midwest). The decrease in investment costs is due to economies of scale in production.

TABLE 2 Barge: Distribution of the Delivery Cost of Ethanol

Costs	Annual Ethanol Production (MGY)				
	Delivery Cost of Ethanol (in $/gal)				
	10	20	30	40	60
Total	3.060	2.793	2.703	2.582	2.510
Biomass Trans.	0.126	0.138	0.145	0.150	0.155
Ethanol Trans.	0.217	0.217	0.217	0.217	0.217
Inventory of Biomass	0.415	0.415	0.415	0.415	0.415
Investment	1.403	1.126	1.029	0.904	0.826
Harvesting	0.651	0.651	0.651	0.651	0.651
Processing	0.245	0.245	0.245	0.245	0.245

TABLE 3 Barge: Distribution of Shipments between Midwest and Mississippi

Annual Ethanol Production (MGY)	Tr. C 0% Ethanol (in $/gal)	Midwest	MS	Tr. C 150% Ethanol (in $/gal)	Midwest	MS
10	3.06	52.52%	47.48%	3.54	24.77%	75.23%
20	2.79	67.96%	32.04%	3.33	61.13%	38.87%
30	2.71	73.10%	26.90%	3.19	71.32%	28.68%
40	2.58	76.84%	23.16%	3.12	74.66%	25.34%
60	2.51	84.56%	15.44%	3.05	82.71%	17.29%

Next, we analyze the distribution of shipments (among different transportation modes) as the annual production of ethanol increased. As stated above, there is enough corn in Mississippi to insure the biomass supply for an annual ethanol production of 10MGY. However, results in Table 3 indicate that even in this case, 52.52% of shipments come from the Midwest using barge. With the increase in the annual production of ethanol (from 10MGY to 60MGY) the additional corn needed comes with barge from the Midwest. The amount of corn shipped from the Midwest decreases with the increase in transportation costs. For example, when annual production of ethanol is 10MGY, increasing transportation costs from 0% to 150% reduces the amount of corn shipped from Midwest by 53% (from 52.52% to 24.77%).

Results from Tables 1 to 3 indicate that biorefineries should take advantage of barge shipments. For the experiments presented in these tables, the location selected for the biorefinery is Warren County. There is an in-land port and a rail ramp in this county. Also, this county is located next to Yazoo County which is the largest producer of corn in Mississippi. Warren is surrounded by other counties that have a high annual corn production. It is interesting to note that even when the amount of corn in Mississippi is large enough to supply the biorefiery, the facility will receive shipments from the Midwest using barge. This is due to two major factors:

(a) since corn in Midwest is harvested in a different period than in Mississippi, receiving shipments from the Midwest during the non-harvesting months reduces biomass inventories, and as a consequence inventory holding costs; (b) barge is an inexpensive shipment mode for shipping corn in long distances.

Considering these findings we wanted to see what would happen if barge shipments were not available. Mississippi is strategically located on the Agricultural Significant Waterways (see Figure 1). It is interesting to see what happens if this option was not available, as it is the case with a number of other states. Results in Tables 4 assume that rail is used to ship corn from the Midwest. When barge is not available, the delivery cost of ethanol slightly increases. This increase is mainly due to transportation costs. In the case when the annual production of ethanol is 10MGY, corn is supplied from Mississippi only. This is due to the fact that rail shipments are more expensive compared to barge. For the experiments presented in Table 4, the location selected for the biorefinery is Warren County since there is a rail ramp in this county.

TABLE 4 Rail: Distribution of Shipments between Midwest and Mississippi

Annual Ethanol Production (MGY)	Tr. C 0%	Midwest	MS	Tr. C 150%	Midwest	MS
	Ethanol (in $/gal)			Ethanol (in $/gal)		
10	3.09	0.00%	100.00%	3.63	0.00%	100.00%
20	2.90	46.63%	53.37%	3.48	38.31%	61.69%
30	2.83	63.93%	36.07%	3.45	58.87%	41.13%
40	2.72	70.85%	29.15%	3.36	69.15%	30.85%
60	2.66	78.89%	21.11%	3.31	78.85%	21.15%

TABLE 5 Shipment Distribution

Gal/dt	Ethanol Deliv. Cost (in $/gal)	Shipment Distribution				
		Midwest	MS	Truck	Rail	Barge
120	2.49	75.22%	24.78%	24.70%	0.09%	75.21%
115	2.55	76.38%	23.62%	23.61%	0.03%	76.37%
110	2.61	77.31%	22.69%	22.73%	0.00%	77.27%
105	2.69	78.47%	21.53%	21.43%	0.12%	78.45%
100	2.76	79.39%	20.61%	20.64%	0.00%	79.36%
95	2.84	80.32%	19.68%	19.62%	0.07%	80.30%
90	2.95	81.48%	18.52%	18.47%	0.07%	81.46%

Table 5 presents the break-even of ethanol delivery costs for different values of conversion rate. This table also presents the distribution of shipments between Midwest and Mississippi, and among different transportation modes as the conversion rate changes from 120 to 90 gallons/dry ton. The annual production of ethanol is assumed 40MGY. The increase in the delivery cost of ethanol (as the conversion rate decreases) is mainly due to the increase in transportation and processing costs. As conversion rate decreases, larger amount of biomass feedstock need to be processed in order to produce the same amount of ethanol. Increasing the amount of biomass feedstock used will increase the cost of delivering and the cost of processing the additional biomass.

SUMMARY OF RESULTS AND CONCLUSIONS

This paper analyses the impact of intermodal facilities in the design and management of the biofuel supply chain. We model this supply chain design and management problem as a mixed integer program. We use the state of Mississippi as a testing bed for our model.

The data used to validate the model and perform the computational analyses is collected from a number of sources such as USDA reports, BNSF and CSXT railways websites, and research articles. Due to the availability of data on transportation costs, we consider only one major source of biomass feedstock (corn) and one biofuel (ethanol). The same model can be used to design the supply chain of a biorefinery if other biomass feedstock sources are being used and other biofuel types are produced.

Experimental results indicate that the existence of an intermodal facility has an impact on decisions about where to locate a biorefinery especially in the case when the biomass available in the region is not enough to keep the plant operating. Moreover, it is interesting to see that long distance transportation of biomass (corn) with barge would be preferable even if the biomass available in the state was enough to operate the facility.

We also investigated the impact of other factors such as conversion rate and transportation costs on the delivery cost of ethanol. Experimental results indicate that changes in these factors did not affect the decisions about where to locate the biorefinery. The county that was selected in all scenarios is Warren.

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PROJECT DISSEMINATION

No awards have been received for the work completed in this project. For this project we received $13,499 as matching funds from the Office of Research and Economic Development at MSU.

So far, we have received additional funding ($77,621) from NCIT for the period May 2009 – May 2010. These funds will be used to continue the research started in this project. We are working with Sumesh Arora, the Director of Strategic Biomass Initiative at Mississippi Technology Alliances (MTA), to have the tools built in this model used by potential biofuel production plants locating in Mississippi. In collaboration with Sumesh, we completed a proposal which we submitted to MTA. The work of the proposal submitted to MTA is an extension to the currently completed project.

The research completed in this project was presented at 2009 Industrial Engineering Annual Meeting. The paper submitted for this presentation was published in their proceedings. We also have submitted a paper for the 2010 Transportation Research Board 89th Annual Meeting to be held in Washington, D.C. January 10-14, 2010. The paper if accepted will be published at the Transportation Research Record, a journal of Transportation Research Board. The graduate student working on this project gave 2 poster presentations of this work.

Ekşioğlu, S.D., S. Zhang, S. Li "Analyzing the Impact of Intermodal Facilities to the Design of the Supply Chains for Biorefineries," IIE Annual Conference, Miami, FL, May 2009.

S. Zhang, S. Li, S. D. Ekşioğlu "Analyzing the Impact of Intermodal Facilities to the Design and Management of Biofuels Supply Chain." 1st Transportation Workshop, Feb. 6, 2009, Mississippi State, MS.

S. Li , S. Zhang, S. D. Ekşioğlu "Analyzing the Impact of Intermodal Facilities to the Design of Supply Chains for Biorefineries," 2009 MSU Biofuels Conference, Aug. 6-7, Jackson, MS.

1. Would you consider your project to be basic research, advanced research, or applied research?	Applied Research
2. Number of transportation research reports/papers published	1 conference proceeding published 1 journal paper submitted
3. Number of transportation research papers presented at academic/professional meetings	1 research paper presentation 2 poster presentations

	Undergraduate	**Graduate**
4. Number of students participating in transportation research projects		2

5. Number of transportation seminars, symposia, distance learning classes, etc. conducted for transportation professionals	
6. Number of transportation professionals participating in those events	

In December 2008, Dr. Jin and Dr. Eksioglu gave a workshop titled "Logistics and Supply Chain Management." This was a 2 day workshop which was delivered to a group of 14 professionals from companies located in Mississippi.

In February 6, 2009, Transportation Working Group held the "1st Transportation Workshop." There were 22 poster presentations in this workshop. We had a number of faculty and students from MSU participating and attending the workshop.

During Aug. 2008 to May 2009, the Transportation Working Group organized six transportation related seminars. Each seminar was attended by 25-30 students and faculty. Information about these seminars can be found in the following website:
http://www.bagley.msstate.edu/research/workinggroups/transportation/index.php