the journal of transport and land use http://jtlu.org
vol. 4 no. 1 [Spring 2011] pp. 71–81 doi: 10.5198/jtlu.v4i1.160

JTLU

Impacts of ethanol plants on highway networks

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Abstract: This paper describes the impacts of the ethanol industry on existing highway infrastructure in the vicinity of an ethanol production plant. To determine the impacts of plant location, the corn and soybean draw areas are estimated on the basis of crop prices. Crop production data are extracted from satellite imagery of the crop data layer produced by National Agricultural Statistics Service and the United States Department of Agriculture. The increase in truck traffic attributable to the ethanol plant is estimated for the changed flow of feedstock. A model is run for two scenarios: i) existing corn and soybean production; and, ii) increased corn and soybean production. Based on existing pavement condition and incremental traffic changes, the funds required to maintain the affected roads at their present service levels are quantified.

Keywords: Transportation; ethanol; rural; highways

1 Introduction

Planned expansion of the Spiritwood Energy Park in North Dakota includes the installation of an ethanol and biodiesel production facility. The research discussed in this paper was undertaken to estimate the impacts of this new ethanol and biodiesel plant on county roads in North Dakota and to determine the additional funds required to maintain these roads at existing service levels. The ethanol and biodiesel plant will produce 378 million liters (100 million gallons) per year of ethanol and 113 million liters (30 million gallons) per year of soybean-based biodiesel. Inbound shipments to the plant will be comprised primarily of corn, soybeans, water, yeast, and chemicals. The outbound shipments consist mainly of ethanol, biodiesel, and some byproducts. Ethanol and biodiesel are shipped either to blenders or to bulk storage facilities. The Spiritwood ethanol plant site is connected to outbound locations by rail; hence, the majority of bulk outbound shipments will be moved by rail. This study focuses only on inbound truck traffic bringing corn and soybeans to the plant from farms and grain elevators in the surrounding region.

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Ethanol plants have diverse effects on local economies, especially within the influence zone of a production plant. These effects may include increases in the production of corn and soybeans, higher profit margins for producers and elevator operators, substitutions among crops, changes in land values and rents, and increases in cattle production. A number of studies have examined these effects on local economies. Low and Isserman (2008) identify and quantify some of the consequences of an ethanol plant for local economies, observing that increases in sales and employment were two of the major direct effects. There are other indirect and induced effects as well, which are quantified by Stuefen (2005). However, none of these studies looked into the change in flow of freight in the area within the influence zone of the ethanol plant and the economic implications of this changed traffic pattern.

The logistical support required by the ethanol industry—including the movement of feedstock into the plant, feedstock storage on farms and in grain elevators, and transport of finished products to distribution centers and end users via rail and truck—is sometimes detrimental to the transportation infrastructure. Incremental increases in truck traffic, along with changes in the patterns of truck movement on rural highways and resulting road deterioration, is a cause for concern. Ethanol plants need a steady supply of corn and various other inputs to keep running. These input demands create significant increases in transportation demand, especially in the vicinities of the plants. To make the ethanol industry profitable, and because of storage constraints at plants, inventory levels are kept low. Corn is usually stored for 14 days (Foundation 2007). These low inventory levels require frequent truck movements from fields to elevators. A steadily increasing demand for corn and other feedstock by ethanol plants and an associated increase in truck movements necessitate improvements to highway pavements in order to maintain the same levels of service. At times, the demand for rail tank cars that are required for outbound shipments exceeds supply, placing additional stresses on highways.

2 Features of ethanol production

2.1 Inputs required for ethanol production

Corn, natural gas, water, yeast, chemicals, and enzymes are the principal inputs of an ethanol plant. A bushel of corn produces about 10.2 liters (2.7 gallons) of ethanol. The U.S. ethanol industry consumed roughly 824 billion kilograms (2.6 billion bushels) of corn in 2010, which the United States Department of Agriculture (USDA) suggested will be diverted from U.S. corn exports (United States Department of Agriculture 2006). Ethanol plants may pay a premium of five to ten cents per bushel above elevator prices to draw more corn, or pay premiums for better yields and high-starch corn varieties (Schill 2007). A report based on research by Shapouri *et al.* (1995) states that 25 percent of the corn needed for an ethanol plant is transported from farms, and the rest from elevators. The report also states that most of the elevators delivering corn to an ethanol plant are within a distance of 80 kilometers (50 miles). Other inputs are trucked from nearby suppliers. The output of the plant is primarily ethanol, which is transported by truck, rail, or barge to distillers or bulk terminals. The byproducts of the plant, namely carbon dioxide and distillers' grains, are usually sold locally and transported by trucks.

2.2 Transportation requirements

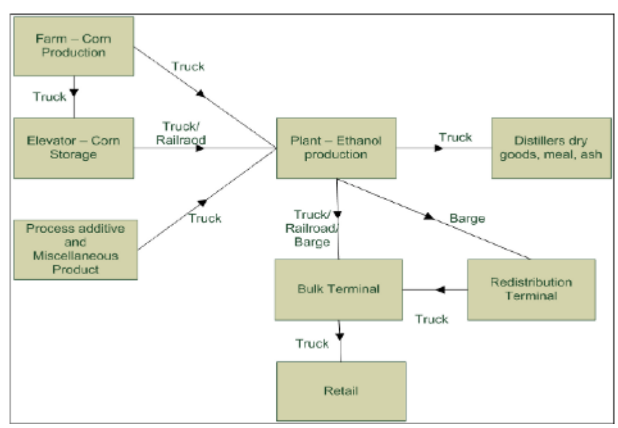
The production of ethanol, as previously noted, requires a number of inputs in the form of feedstock and process additives. The prime feedstock for ethanol production is corn; for biofuel production, soybeans are used. These feedstocks are mostly trucked from local producers, either directly from farms or from grain elevators, which are intermediaries in this supply chain. Process additives are usually brought in by truck.

The ethanol produced is primarily transported to bulk terminals via barge, rail car, or truck to be blended with gasoline. The blended gasoline is then transported by truck to retail terminals. In some instances, ethanol may be transported to another smaller terminal before it is finally blended with gasoline in the bulk terminal. If the service terminal is at a considerable distance from the ethanol plant, the ethanol is shipped by barge to redistribution terminals; it is then redistributed to bulk terminals via truck to be blended with gasoline (Reynolds 2002). Some ethanol is also shipped from the Midwest to California by rail.

Increasing the flow of corn from a single farm does not affect highway infrastructure. However, when a number of farmers within a radius of approximately 80 kilometers (50 miles) ship corn to a plant, the resulting changes in flow patterns increase pressure on key access highways. Increases in the production of corn and soybeans also increase demand for fertilizers and chemicals to enhance crop yields. Elevators not only serve as nodal points for receiving, storing, and drying grain, but play a vital role in grain marketing as well.

As shown in Figure 1, corn arrives at ethanol plants from farms as well as from elevators. Corn is shipped from farms to plant only by truck; shipments from elevators arrive mostly by truck, but may occasionally delivered by rail. Before the construction of an ethanol plant, corn is shipped by rail to final destinations. After the plant is built, corn is trucked to the ethanol plant instead. This mode shift is driven by the fact that trucking is preferred over rail transport for shorter haul distances. Hence, there are not only considerably more trucks in the vicinity of the plant, but there are also more trucks on the highway network of the state as a whole.

Figure 1: Flow pattern of corn from field to retailers.



The increased production of corn increases demand for storage and drying facilities. An ethanol plant has a fixed storage capacity; although additional storage may be built at the plant site, the additional storage facilities for corn and soybeans are primarily constructed at grain elevators and on farms (Ginder 2006). Because ethanol absorbs moisture, pipeline transportation is not possible. Barge, rail, or truck are the only transportation options for delivering ethanol to bulk terminals.

3 Impact assessment

The objective of this study was to estimate the increase in truck traffic on county roads due to the construction of a proposed ethanol and biodiesel plant. In this project, the anticipated increase in truck traffic was estimated and assigned to the highway network. The county roads that are part of the assigned path were identified and grouped based on incremental truck traffic. Although ethanol and biodiesel plants produce a variety of inbound traffic including feedstock, process additives, and various other miscellaneous products, only feedstock comprised of corn and soybeans were considered for modeling purposes, as these crops make up the bulk of inbound traffic. Our model also included the movements of empty vehicles from the plant to grain elevators and farms. The outbound movements from the plant comprise finished products, i.e., ethanol and various other byproducts, and wastes. Because the plant site in this study has rail connectivity, it was assumed that the bulk of the outbound traffic would move via rail; hence, outbound flows would produce only minimal adverse effects on highways. The broad objectives of this study were enumerated by the North Dakota Department of Transportation (NDDOT) (2008):

1. Estimate increased truck traffic on county roads within the influence zone of the proposed ethanol and biodiesel plant.
2. Identify county roads that will be affected by this additional truck traffic.
3. Identify maintenance and construction needs to preserve the existing service conditions on roads.
4. Estimate maintenance and construction costs.

3.1 Modeling base flow

The incremental truck traffic generated by the ethanol plant and the existing truck traffic comprises a measure of total truck traffic on the highway network after the plant is constructed. We develop a model to forecast this changed truck traffic. The model was run for six scenarios. The first scenario represented existing traffic levels. The second scenario represented incremental traffic generated by the ethanol plant but without any increase in corn production. The third scenario estimated traffic with the plant in operation and with increased corn production. In each of these scenarios, the highway network used for modeling purposes was subject to highway load restrictions. The fourth, fifth, and sixth scenarios were repetitions of scenarios one, two, and three respectively, but without highway load restrictions. The aggregated truck traffic was converted to equivalent single-axle loads (ESAL) values, which were used to estimate changes in service quality of pavements. In a previous study by Mitra *et al.* (2007), a statewide freight model was developed. In that study, freight flow on federal, state, and county roads within North Dakota was estimated. The model developed by Mitra et al. is used in this research. A truck traffic study was undertaken on the county roads in the vicinity of the plant at locations which are identified to be critical for the changed traffic pattern. The observed traffic counts were used to validate and update the base model (Figure 2).

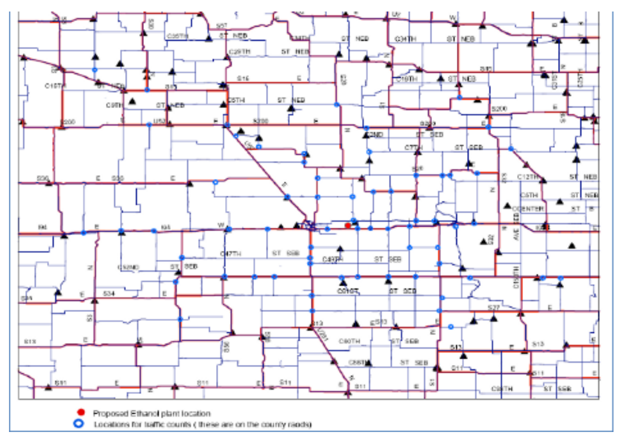


Figure 2: Truck count locations near the proposed plant.

3.2 Modeling changes in traffic flow

To determine the impacts of facility location, corn and soybean draw areas are estimated. As mentioned above, many ethanol plants pay five to ten cents per bushel above the local market price to draw corn to their facilities (Schill 2007). The higher prices encourage farmers and elevators to sell directly to the ethanol facility rather than ship their products to terminal markets via rail and truck.

Agricultural Price Basis

To estimate the draw area, the basis change due to the facility location was estimated (Figure 3). In agricultural marketing, "price basis" refers to the difference between the local spot price for a commodity and the corresponding price at a terminal market. This difference is due to transportation costs, holding costs, and local conditions of supply and demand. As mentioned above, ethanol plants often pay above the local market price to draw commodities to their facilities, which results in a lower price basis than the ethanol plant\s nearby competitors. The extent to which the ethanol facility is able to set its prices above those of its surrounding competitors defines the distance from which the facility can draw corn.

It is assumed that producers maximize delivered price received. Delivered price is equal to the cash price at the elevator or facility minus the cost of trucking to the facility. For the purposes of the draw area calculation, grain will flow to the facility with the higher delivered price. We use the truck cost model developed by Berwick and Farooq (2003) to estimate the truck haulage rate. In this truck cost model, the trucking cost is divided into variable cost and fixed cost. The variable cost is subdivided into variable cost associated with fuel, which also includes the costs of tires and maintenance, and the variable cost associated with labor.

To estimate the expected basis change, historical basis data was collected for all elevators and other facilities within a 280 kilometer (175 mile) radius of the proposed ethanol facility. The data reflects the pricing decisions made by existing elevators as well as by other grain processors including ethanol facilities and corn sugar processors. Commodity price data were obtained through Cash Grain Bids, Inc. Additional data was obtained from the North Dakota Agricultural Statistics Service, the United States Bureau of Labor Statistics, and the United States Department of Agriculture. The basis model is estimated as follows:

$$\begin{aligned}\text{Basis}=&\alpha_0+\alpha_1\text{TransCost}+\alpha_2\text{Yield}\\ &+{}_3\text{Quantity}+\alpha_4\text{US}+\alpha_5\text{Interest}\\ &+{}_6\text{PNW}+\alpha_7\text{MPLS}+\alpha_8\text{Shuttle} \qquad (1)\end{aligned}$$

Where:

TransCost = Distance to the nearest processor multiplied by the BLS price index for #2 diesel fuel (base year 2003)

Yield = county crop production from National Agricultural Statistics Service (NASS)

Quantity = Quantity demanded at nearest facility US = United States Corn Production (billion bushels)

Interest = Interest rate

PNW = Distance to terminals in Pacific Northwest

MPLS = Distance to terminals in Minneapolis

Shuttle = Shuttle train elevator indicator variable (1=Shuttle, 0=non-shuttle)

The parameters estimated in the basis model are shown in Table 1. The basis model estimates a local corn price basis change of 0.5 cent per kilogram (15 cents per bushel) in the local county. Based upon these estimates, the draw area was calculated by dividing the basis change by the trucking cost per mile. The draw area was calculated to be within an 83.2 kilometer (52 mile) radius of the facility.

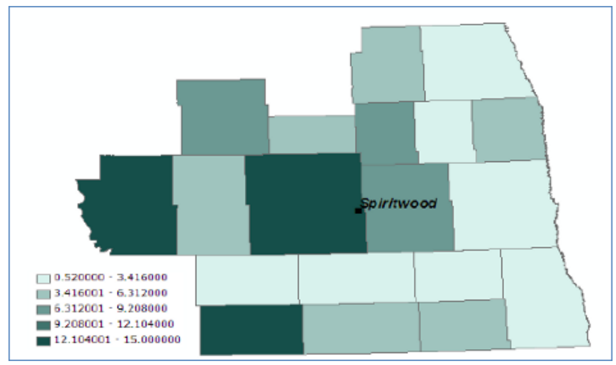


Figure 3: Estimated corn basis change due to facility location.

As transportation costs, local yield, and interest rates increase, the local basis widens. The two variables for geographic location, MPLS and PNW, serve as proxies to the crop production in North Dakota. The primary location of corn production is in the southeast portion of North Dakota, which is near the Minneapolis, Minnesota market. The facility is closer to the Minneapolis market; we assume that the increase of local corn production bids down the price, and therefore the basis widens.

Table 1: Parameter estimates.

Variable	Parameter Estimate	t Value
Intercept	−49.555 84	−5.75
TransCost	−0.000 110 02	−3.75
Yield	−0.037 66	−3.86
Quantity	0.050 79	4.45
US	0.769 66	2.92
Interest	−6.674 76	−58.86
PNW	0.040 52	5.88
MPLS	−0.054 33	−7.28
Shuttle	1.746 24	2.81

Adj. $R^2 = -0.7793$

Modeling framework

The overall modeling framework is shown in Figure 4. The data for crop production are extracted from satellite imagery. The trip attraction data are estimated from the ethanol plant's annual production capacity. The estimated yearly demand for corn was 378 million liters (100 million gallons) for the ethanol plant and 75.6 million liters (20 million gallons) of soybeans for the biodiesel plant. The trip production and attraction estimates were used in a gravity model to generate the origin-destination (OD) table for crop transport trips between farm and plant. These trips fell into three categories: i) farm to plant directly, ii) farm to elevator, and iii) elevator to plant. The commodity OD data were converted to truck OD data using the payload statistics (truck type and corresponding payloads) obtained from a survey conducted by Vachal and Tolliver (2001), which showed that inbound movement was dominated by four truck configurations: two-axle single-unit (2A-SU), three-axle single-unit (3A-SU), four-axle single-unit (4A-SU), and five-axle semitrailer (3-S2).[1] Table 2 shows the percentages of different truck types used for hauling different crops. The estimated truck OD data are assigned across the highway network using a least-cost-path algorithm.

At the time of data collection, a prospective planning report released by the NASS estimated an increase of 50 percent in North Dakota's corn production in 2007 (Service 2007). To adequately reflect highway impacts under differing conditions, two scenarios were estimated. The first represented corn transportation using current production levels, and the second represented corn transportation following the estimated 50 percent increase in production. Estimating two scenarios allowed the degree of highway impacts under varying levels of corn production to be estimated. Corn production generates more truck trips than the production of other commodities such as wheat or soybeans, due primarily to greater inbound fertilizer needs and higher yield per acre resulting in a greater number of outbound truck trips.

Table 2: Percentages of truck types.

	Truck Types (percentages)			
Crop Types	2A-SU	3A-SU	4A-SU	3-S2
Corn	8	34	14	43
Soybeans	9	41	14	35

[1] Semitrailer trucks are frequently used to transfer corn and soybeans from elevators to plants.

4 Modeling steps

4.1 Trip generation

Based on the crop production pattern and the existing highway network topology, transportation analysis zones (TAZs) were delineated as shown in Figure 5. In this freight flow model, the elevators served as special generators. The geographic information system (GIS) data available on the highway network in the study area included federal, state and county roads; data on link attributes included posted speed, functional class, and load restriction. Trip generation data for the TAZs was not available in the county crop production data published by the NASS, and the Commodity Flow Survey (CFS) data did not include information on crop movement from farms to elevators. To overcome the problem of unavailable data, satellite imagery of "Crop Layer," developed by NASS and the USDA (2004), was used to develop trip generation data. This satellite imagery is a rasterized GeoTIFF layer of the crops grown in the state. For this project, the crop layers for corn and soybeans were extracted from the mosaic layer as shown in Figure 6. Each of these layers is composed of raster cells of 30 x 30 meters resolution. The raster crop layers were converted into GIS vector "shapefile" polygons and overlaid with the TAZ polygons in an ARCGIS© Map application as shown in Figure 7. A spatial analysis tool using Arc Object and Visual Basic scripting developed by Mitra *et al.* (2007) was used to analyze the individual crop layers and estimate the crop coverage in each of the TAZ polygons within the draw area of the ethanol plant. The spatial analysis tool allowed the selection of individual TAZ polygons, and the selected polygons were used to clip the crop layer vector shapefile. Next, the area of the clipped crop layer shapefile was calculated and added to the selected section as an attribute of the respective crop area.

The crop coverage area estimated by the spatial analysis tool was calibrated with the NASS and USDA's annual report of county crop production. The yield data used to estimate production was obtained from the North Dakota Agricultural Statistics Service's crop yield report.

The mathematical model used for trip generation is

$$t_i^c = a_i^c \times y_i^c \times p^c \tag{2}$$

$$p^c = \frac{d^c}{\sum_i \left(a_i^c \times y_i^c\right)} \tag{3}$$

Where:

c = crop index (1 = Corn, 2 = Soybeans)
i = production TAZ number

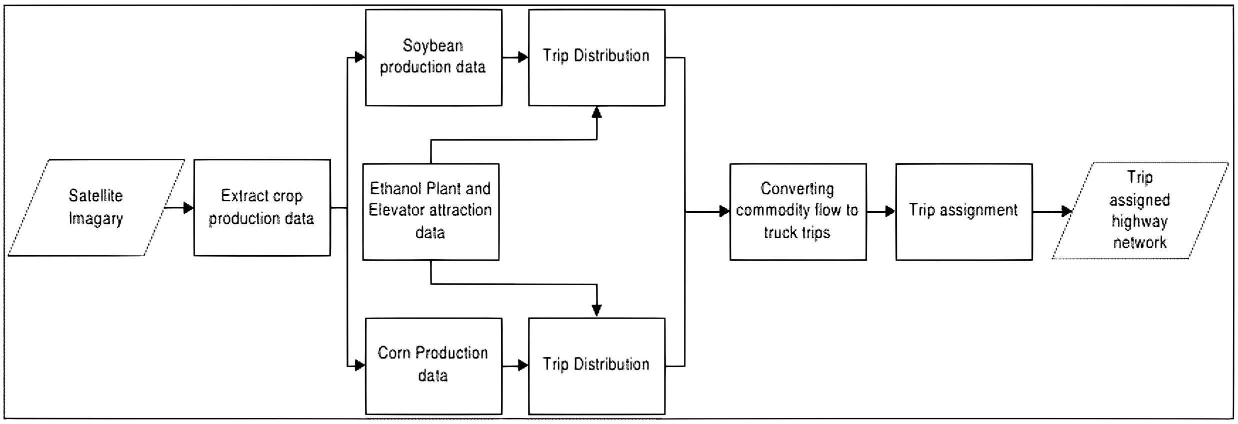


Figure 4: Framework for the analysis of traffic changes.

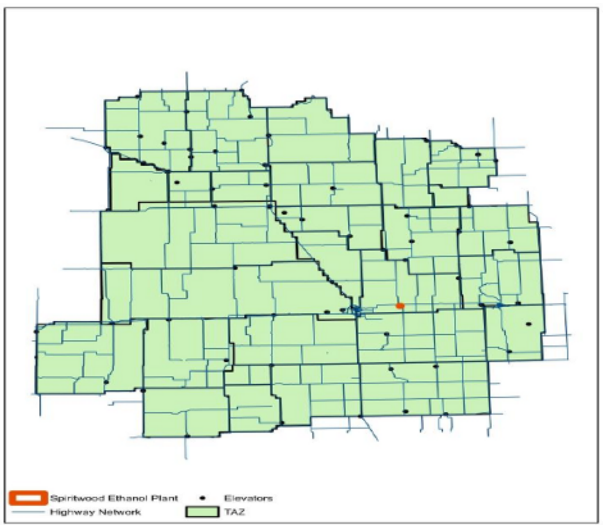


Figure 5: TAZs, elevators, and highway network in the vicinity of the plant.

t_i^c = amount of crop c produced in TAZ i

a_i^c = planted area of crop c in TAZ i obtained from satellite imagery

y_i^c = yield of crop c in TAZ i as published in the NASS annual report

p^c = correction factor for crop c

d^c = total crop c produced in base year 2003 as published in the NASS annual report

4.2 Distribution

In this model there were three predominant grain movements or flows: i) from farms to satellite elevators; ii) from farms to the ethanol plant; and iii) from satellite elevators to the ethanol plant. Bitzan *et al.* (1996) described farmers' priorities in choosing an elevator and provided the trip length distribution of crop movements from farms to elevators. The survey found that elevator board price is the most important factor for a farm when choosing an elevator, followed by grading practice, quality of service, and the influence of the local community.

In a study of the impacts of grain terminals on rural highways, Tolliver (1989) stated that the distribution of crop transport trips from farms to elevators can be estimated using an optimization model or a spatial interaction model. The optimization model can be used to minimize transportation costs, or to maximize the profit of the crop growers.

As has been stated by Sorratini (1999), linear programming gives a lower bound of freight movement, whereas the trade model gives an upper bound. Linear programming can give better results if the industries concerned in the model are few, the goods are of low value with a high proportion of transportation cost, and there are few demand zones. A spatial interaction model, specifically a gravity model, offers more flexibility than the linear programming model. Evans (1973) did research to find a relation between the gravity model and linear programming for trip distributions. The research showed that the deterrence factor, which is a decreasing function of cost, can take an exponential form where $e^{-\beta c}$ is the calibration factor and c is the generalized transportation cost from zone i to zone j.

As the trip production and trip attraction data were available, the gravity model was found to be most suitable for determining trip distribution. CUBE© modeling software was used to build the freight flow model. The model was run for six scenarios, as discussed earlier. Based on information obtained from NASS that estimated North Dakota's corn production would increase by 50 percent in 2007, in the third scenario

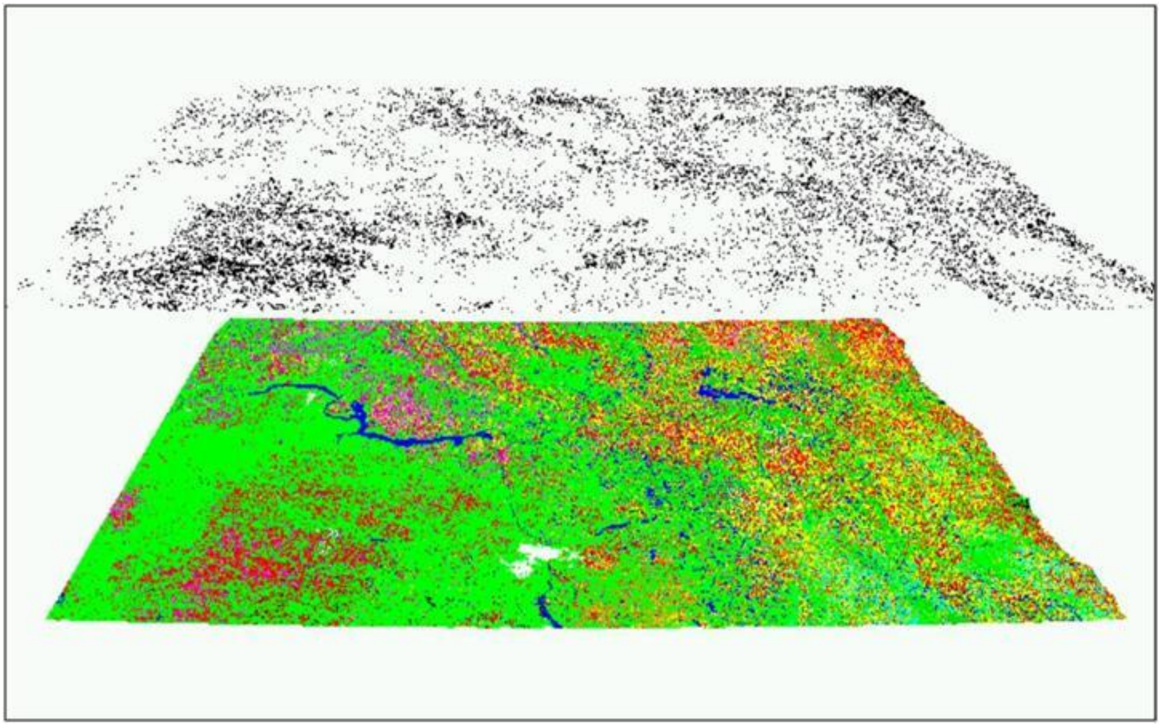


Figure 6: Individual crop layer extracted from the mosaic layer.

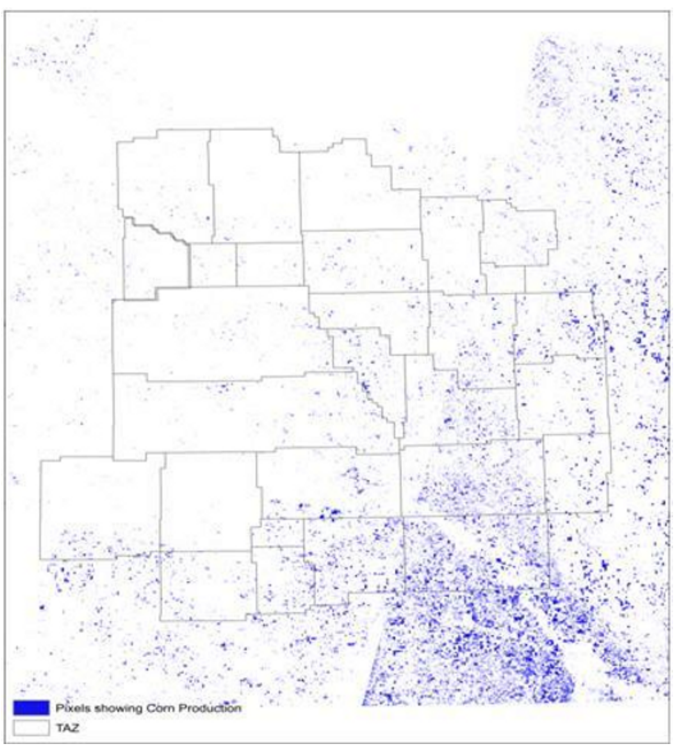


Figure 7: The TAZ shapefile overlaid with the corn crop layer.

the model was built with the incremental traffic generated by the plant and with increased corn production.

In the gravity model, distance was assumed as the impedance factor. During the calibration process, the friction factors were calculated and calibration accomplished by matching the model and the observed trip length distribution (TLD). The regional elevator survey by Vachal and Tolliver (2001) gave the necessary data for the observed TLD. An iterative CUBE© program, similar in approach to gravity model calibration used by Mao and Demetsky (2002), was developed to estimate the value.

$$X_{\mathrm{ij}}^{c} = \frac{P_i^c A_j^c F_{\mathrm{ij}}}{\sum_j^n A_j^c F_{\mathrm{ij}}} \forall c \tag{4}$$

Where: X_{ij}^{c} = flow of crop c in ton from TAZ i to TAZ j

P_i^c = crop c production in TAZ i

A_j^c = attraction of crop c at TAZ j

c = Soybeans, Corn

$F_{ij} = f\left(t_{ij}\right) = \frac{1}{t_{ij}^{\beta}}$, t_{ij}= travel impedance based on distance, β= calibration factor.

4.3 Assignment

The estimated commodity trip matrix was converted into truck trips using the truck mix and payload information from previous surveys. This estimated OD matrix was assigned to the highway network using "all or nothing" assignments. In this model, congestion was not an issue because of low volume to capacity ratio, and the assignment was done using a least-cost-path algorithm.

The cost function used in the assignment of agricultural freight is expressed as:

$$C = f(D, T, P) \tag{5}$$

Where

C = cost in dollars for hauling ton-mile of agricultural freight

D = length of the link in miles

T = distance / speed limit

P = weighted payload of the truck mix used in hauling agricultural freight

$$C = \frac{c_d \times d + c_t \times t}{p_i} \tag{6}$$

C_c = trucking cost excluding labor, C_t = cost of labor per hour

The assigned truck traffic is an estimate of the increased truck trips on the highway network in the vicinity of the ethanol plant. Adding this incremental traffic to existing traffic yields an estimate of total traffic volume on the highways within the study area. The output of this model is shown in Figure 8. The flow pattern is presented in the public input meeting, organized by Department of transportation, where representatives of the counties are invited to discuss the results of the study. A Delphi survey was done to validate the flow pattern. Some calibration of the model was required to match the survey results.

5 Economic implications

Information on existing county roads was gathered and used to estimate the structural number (SN) of the pavement. Two load types were used for analysis: in the first type, existing traffic loads were used for estimation; in the second load type, the incremental traffic was added to the existing traffic volume for analysis. Equivalent Single Axle Loads (ESALs) of the two load types were used to estimate the loss of road life. The performance period of the pavement was estimated using the basic design equation used for pavement design as recommended in the American Association of State Highway and Transportation Officials (AASHTO) guide for design of pavement structures (1993).

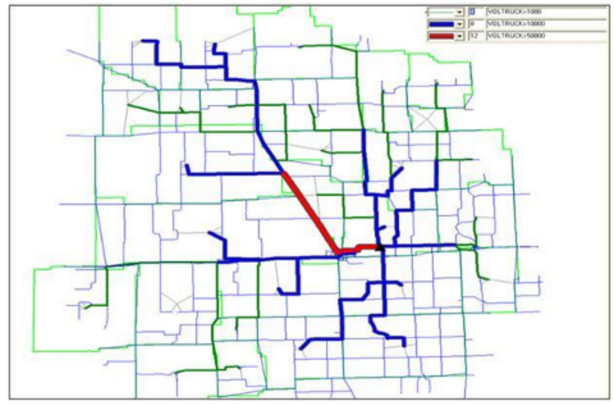


Figure 8: Incremental truck traffic assigned to highway network.

$$\log_{10}(W_{18}) = Z_R \times S_0 + 9.36 \times \log_{10}(\mathrm{SN}+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta \mathrm{PSI}}{4.2-1.5}\right)}{0.40 + \frac{1094}{(\mathrm{SN}+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07 \tag{7}$$

where

W_{18} = predicted number of 79.9 kilo-Newton (18-kip) equivalent single axle load applications

Z_R = standard normal deviate,

S_0= combined standard error of the traffic prediction

ΔPSI = difference between the initial design serviceability index, p0 and the design terminal serviceability index, pt ,

M_R= resilient modulus (psi)

Using the desired total serviceability loss, the resilient modulus, the structure number of the pavement the cumulative two directional ESAL were estimated. Using the previously estimated ESAL for the two load types, existing traffic and changed traffic, the performance period of the pavement was estimated. The difference of these performance periods is an estimate of the loss of pavement life as shown in Table 3.

Next, the equivalent pavement depth required to accommodate increased truck volumes was estimated using the AASHTO model (American Association of State Highway Transportation Officials 1993) The timing of maintenance and rehabilitation of the pavement was determined using the pavement performance curve shown in Figure 9. This study showed that 521 kilometers (326 miles) of county roads within the 120 kilometer (75 mile) radius of the ethanol plant would be expected to experience significant increases in truck trips (North Dakota Department of Transportation 2008).

Table 3: Estimated loss of pavement life. (North Dakota Department of Transportation 2008)

County	Total km
Barnes	54.4
Cass	33.28
Dickey	40.64
Griggs	8
LaMoure	54.88
Sargent	15.52
Steele	1.12
Stutsman	44.64
Traill	7.68
Barnes	59.84
Cass	96.8
LaMoure	14.4
Ransom	20.8
Stutsman	53.12
Stutsman	16.96

Loss in years:
Less than 1 year: 260 km;
1–5 years: 244 km;
5–10 years: 16.96 km

Figure 10 shows the amount, in km, of the increased truck traffic in four different categories.

Using the empirical pavement cost model available from NDDOT, the cost of additional pavement depth required to accommodate the increased truck volumes on the county roads in the five counties affected the most was estimated as shown in Table 4. The cost estimation is done for two scenarios, with and without highway load restrictions.[2] The deterioration caused by increased truck traffic would require an additional investment of \$8.05 million to maintain the roads in the existing service condition in the load-restricted case. Without the highway load restrictions, the estimated road maintenance cost would be \$12.65 million. This loss of pavement life comes at the end of the of the pavement life cycle, hence the estimated cost can be discounted to estimate the net present value (NPV). Assuming a pavement life of 17 years and an interest rate of four percent, the NPV of the additional maintenance cost is \$4.13 million for the load-restricted case and \$6.49 million without highway load restrictions (Levinson *et al.* 2004).

[2] A seasonal load restriction is imposed on the county roads, during the spring thaw cycle, generally during for the month of March, April and May.

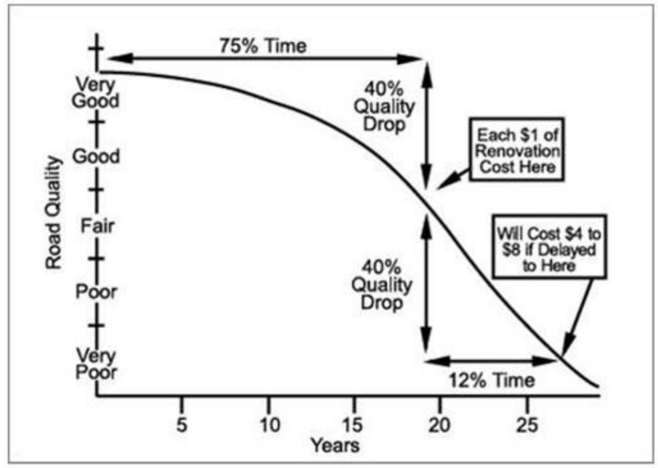


Figure 9: Pavement performance curve (North Dakota Department of Transportation 2008).

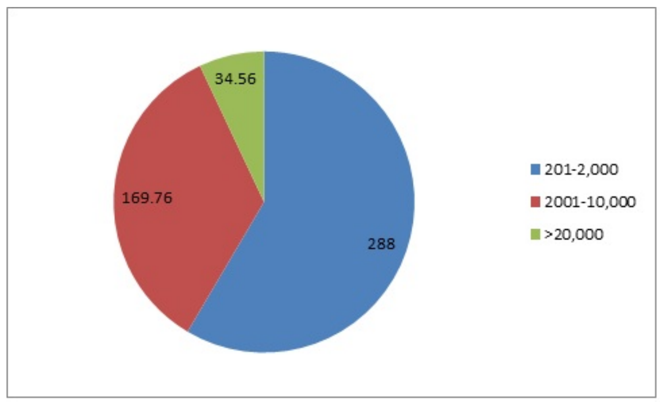


Figure 10: Kilometers of highway in different truck traffic increment category (North Dakota Department of Transportation 2008).

Table 4: Impacts of incremental truck traffic on the county highway system (North Dakota Department of Transportation 2008).

County	Cost Increment by County		Difference
	with load restrictions	without load restrictions	
Barnes	3 400 000	5 800 000	2 400 000
Cass	500 000	500 000	0
Ransom	550 000	550 000	0
Stutsman	3 500 000	5 700 000	2 200 000
Traill	100 000	100 000	0
Total	8 050 000	12 650 000	4 600 000

6 Conclusion

Potential benefits of the expansion of the United States' ethanol industry include reducing the country's dependence on foreign oil and improving air quality. However, public investments must be made if these benefits are to be realized. Ethanol production causes increased traffic on existing highways, which accelerates pavement deterioration. State and local governments must incur additional costs to maintain highways at existing service levels. This study assessed the expected increases in construction and maintenance costs to individual counties needed to compensate for the damage caused by truck movements generated by ethanol and biodiesel plants. Highway costs are not often taken into account in cost-benefit studies of ethanol or biodiesel plant construction. Before establishing a new plant, these secondary effects on highways should be taken into consideration and detailed analyses should be conducted to assess significant outcomes. Although this study was carried out in the state of North Dakota, it should be easy to transfer the methodology to similar studies in other states.

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