Upper Great Plains Transportation Institute

Road Investment Needs to Support Agricultural Logistics and Economic Development in North Dakota

January 10, 2011

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Summary

According to the Agricultural Statistics Service, North Dakota leads the United States in the production of spring wheat, durum wheat, sunflower, barley, dry edible beans, canola, and flaxseed. In 2009, the total market value of agricultural goods produced in the state exceeded $5.5 billion. Because of the importance of agriculture to the state's economy, this report focuses specifically on the investment needs of roads used to haul agricultural goods to market. The purpose of the study is to analyze changes in agricultural production and logistics and the importance of roadway investments to the distribution of crops produced in North Dakota.

Important changes have occurred during the last two decades that have implications for agricultural logistics and roadway investment needs:

(1) Yields have been increasing over time resulting in more crop volume and movements from a given land area.

(2) Crop mix has been changing over time resulting in greater densities of production.

(3) The number of elevators has decreased over time resulting in fewer delivery options.

(4) Shipments have become more concentrated at a fewer number of elevators. Consequently, longer farm-to-elevator hauls are required.

(5) More grains are being transshipped from smaller to larger elevators resulting in longer combined truck trips.

(6) The location of in-state processing and biofuels production has resulted in more intrastate truck (as opposed to interstate rail) movements.

(7) Funding for county and local roads exclusive of oil extraction funds has gown only modestly over time (when measured in real dollars).

(8) In contrast, construction prices have increased dramatically over time for asphalt and gravel roads. Collectively, these factors are stressing the county and local road systems used to market and distribute North Dakota products.

This study is based on a detailed crop production and distribution model in which the crops produced in each county subdivision are moved to elevators and in-state processing plants to minimize distance. Because trucking cost is typically measured on a per-mile basis, minimizing the distance of agricultural goods movements is parallel to minimizing trucking cost on a system-wide basis.

The model minimizes the total or route trip distance including transshipments from one elevator to another or from an elevator to an in-state processing plant. The demands at elevators are derived from reports to the Public Service Commission, while the demands at ethanol plants are derived from confidential surveys. Since crop supplies and demands are known, the objective of the distribution model is to predict truck movements to minimize the ton-miles of transportation needed to satisfy elevator and plant demands. In effect, the model identifies a logistically-efficient set of truck movements that minimizes use-related vehicle depreciation and maintenance and fuel consumption. However, the model does not predict that each grower will deliver his or her crops to the closest elevator. Instead, crops are moved to meet the demands of shuttle-train elevators, plants, and other facilities. The key predictions from the model are: (1) agricultural goods require roughly 600 million ton-miles of transportation annually, and (2) the average predicted trip distance to elevators and in-state processors (including transshipment distances) is 26 miles.

Once the trips are predicted, they are assigned to the highway network and traffic statistics are compiled for thousands of individual road segments included in agricultural distribution routes. Once the traffic forecasts have been accumulated, the investment needs of each road segment are analyzed and the results accumulated. In addition to specifically analyzing agricultural logistics routes, the investment needs for other local roads not significantly affected by agricultural goods movements are estimated so that the total statewide need can be quantified.

The estimated investment needed for county and local paved roads totals $100.5 million annually on a statewide basis. Approximately $59 million of these needs relate to agricultural haul roads. The remainder corresponds to other county and local roads. In addition, $110 million are needed annually for local unpaved roads. Approximately, $43.6 million of these needs relate to agricultural haul roads. The remainder corresponds to other local roads, especially township roads. Altogether, the total estimated statewide need is $211.5 million per year, including $100.5 million of paved road investment needs and $110.0 million of unpaved road investment needs.

The estimates developed in this study do not include the specific roadway investment needs attributable to the future growth of oil and gas industries in western North Dakota. Rather, the estimates presented in this report reflect the baseline investment needs throughout the state. The projected oil-related infrastructure needs presented in a separate report (Additional Road Investments Needed to Support Oil and Gas Production and Distribution in North Dakota) are in addition to the estimates presented in this study.

1. Overview of Study

The purpose of this study is to analyze changes in agricultural production and logistics and the importance of roadway investments to the distribution of crops produced in North Dakota. According to the Agricultural Statistics Service, North Dakota leads the United States in the production of spring wheat, durum wheat, sunflower, barley, dry edible beans, canola, and flaxseed. In 2009, the total market value of agricultural goods produced in the state exceeded $5.5 billion. The top three commodities by value are: wheat ($1,822 million), soybeans ($1,074 million), and corn ($708 million). According to the United States Department of Commerce, the agriculture sector of North Dakota is responsible for approximately 11 percent of the state's total economic output.

Because of the importance of agriculture to the state's economy, this report focuses specifically on the investment needs of roads used to haul agricultural goods to market. The vital importance of transportation to agriculture is eloquently expressed in a 2010 joint study by the United States Departments of Agriculture and Transportation, which notes:

> *An effective transportation system supports rural economies, reducing the prices farmers pay for inputs, such as seed and fertilizer, raising the value of their crops, and greatly increasing their market access. The economies of rural areas are intertwined. As agriculture thrives, so does its supporting community. Providing effective transportation for a rural region stimulates the farms and businesses served, improving the standard of living ... because it (agriculture) is so capital-intensive, it generates much more economic activity in the community than just the jobs it creates.*[1]

Although this study focuses on roads used for agricultural distribution, generalized estimates of investments for other roads are presented to provide a context for interpreting the results. However, the estimates presented in this report do not include the specific roadway investment needs attributable to the future growth of oil and gas industries in western North Dakota. A separate report (Additional Road Investments Needed to Support Oil and Gas Production and Distribution in North Dakota) includes forecasts of future infrastructure needs in western North Dakota, based on specific production scenarios. The estimates presented in this report reflect the baseline investment needs throughout the state. Note that the projected oil-related infrastructure needs cited in the separate report are in addition to the estimates presented in this study. Only county and local roads are considered in this analysis. Investment needs for state highways have already been estimated by the North Dakota Department of Transportation.

[1]The United States Departments of Agriculture and Transportation, *Study of Rural Transportation Issues*, April 2010.

The report begins with an overview of important trends in agricultural production and logistics that create a context for analyzing investment needs in agricultural haul roads. After this overview, the primary data and methods used in the study are described, followed by a presentation of results and implications.

2. Background Trends

Many important changes have occurred during the last two decades that have implications for agricultural logistics and roadway investment needs. The key factors driving this study are summarized below:

1. Yields have been increasing over time resulting in more crop volume and movements from a given land area.
2. Crop mix has been changing over time resulting in greater densities of production.
3. The number of elevators has decreased over time resulting in fewer delivery options.
4. Shipments have become more concentrated at a fewer number of elevators.
5. From trends 3 and 4, it follows that longer farm-to-elevator hauls are required.
6. More grains are being transshipped from smaller to larger elevators resulting in longer combined truck trips.
7. The location of in-state processing and biofuels production has resulted in more intrastate truck (as opposed to interstate rail) movements.
8. Funding for county and local roads exclusive of oil extraction funds has gown only modestly over time (when measured in real dollars).
9. In contrast, construction prices have increased dramatically over time for asphalt and gravel roads.

The last two factors relate specifically to roadway funding limitations and their effects on roadway infrastructure. Each of the key factors is highlighted in the following sections.

2.1. Yield Increases

Due to increases in crop and production technology and improvements in management practices, crop yields in North Dakota have increased during the past 20 years. The degree of increase varies from year to year due to weather conditions, but the underlying trend is upward.

Figure 1 depicts the statewide yield trends for corn, soybeans, and spring wheat. In 1990, corn averaged 80 bushels per acre throughout the state. However, corn yields rose to 115 bushels per acre in 2009, down from a high of 124 bushels per acre in 2008. Soybean yields have remained relatively consistent throughout the period. Statewide average wheat yields have increased slightly during the past 20 years, with the average yield in the 1990s being 31.85 bushels/acre versus 36.45 bushels/acre in 2000. Discussions with industry and research contacts indicate that yields are expected to continue to increase in the future primarily due to seed technology and genetics.

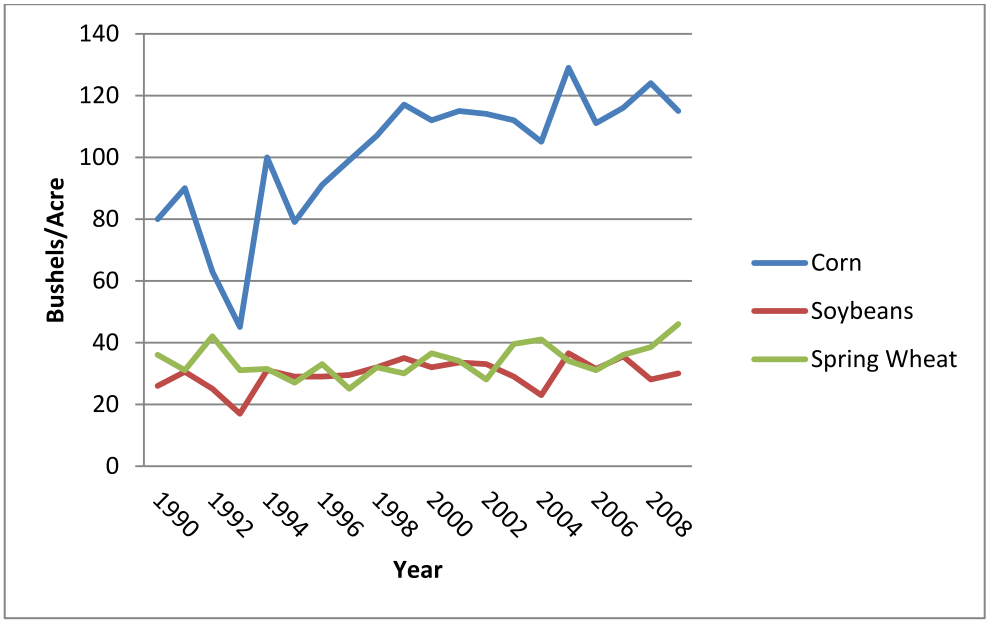

Figure 1 Statewide Yield Trends for Corn, Soybeans and Spring Wheat (1990-2009)

2.2. Changes in Crop Mix

A second production factor that has increased the volume of grain shipped in North Dakota is the changing crop mix. In 1990, roughly 60 percent of the crop land in North Dakota was planted to wheat (Figure 2). In 2009, this number was 45 percent. Over the same period, corn acres have increased from 5 to 10 percent of cropland and soybean acres have risen from 2 to 20 percent of crop land in North Dakota. The shift from wheat to soybeans does not contribute to increased truck volume because the yields are similar. However, the shift from wheat to corn production results in increased truck volumes because the relative yield of corn is more than double that of wheat on a statewide basis.

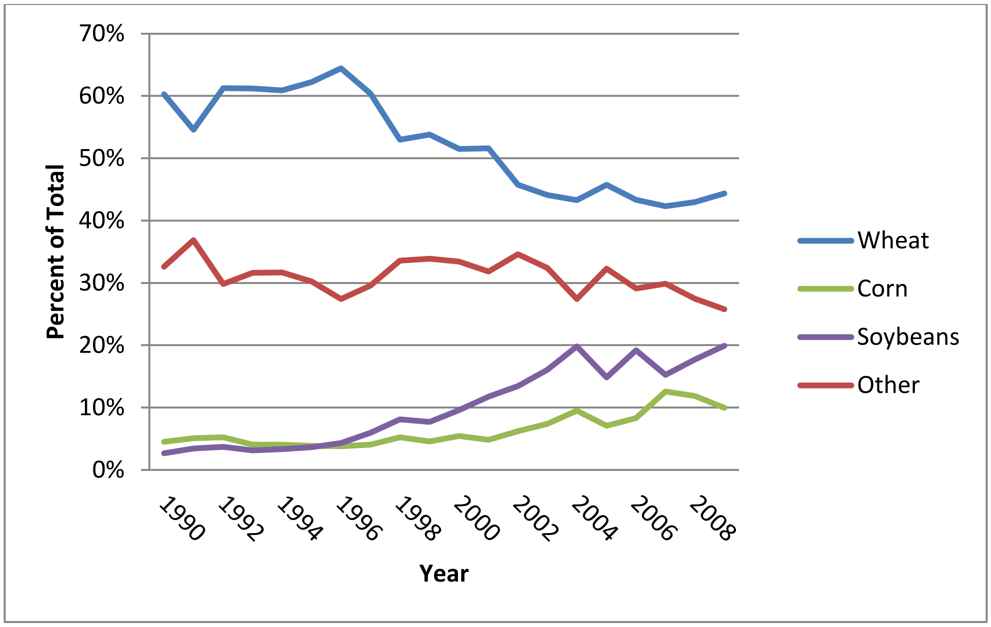

Figure 2 Statewide Percentages of Planted Acres for Corn, Soybeans and Spring Wheat

While Figure 2 illustrates changes in crop mix statewide, there are significant variations at the regional level, although the trends are similar. The figures presented in Appendix A depict specific changes in the proportions of acres devoted to the production of wheat, corn, soybeans and other crops at the Crop Reporting District (regional) level.

2.3. Changes in Elevator Numbers and Locations

To illustrate key trends, statistics were compiled on the numbers and locations of grain elevators in North Dakota from 1990 to 2009. Specifically, the North Dakota Public Service Commission's grain movement database was used to compile statistics on the number of licensed elevators in the state. The grain movement database assigns a unique identifier to each elevator served by each railroad. A small number of elevators are represented twice because they are served by more than one railroad.

During the 1990-2009 period when increasing yields and changes in crop mix were resulting in more output per acre and greater volumes were being shipped from farms to elevators, the number and size of elevator facilities were changing. As shown in Figure 3, the number of elevators shipping grains or oilseeds has decreased over the past 20 years. In 1990, 458 elevators shipped grains or oilseeds. By 2009, this number had decreased to 311 elevators. The elimination of elevators has resulted in fewer delivery options for farmers marketing grain.

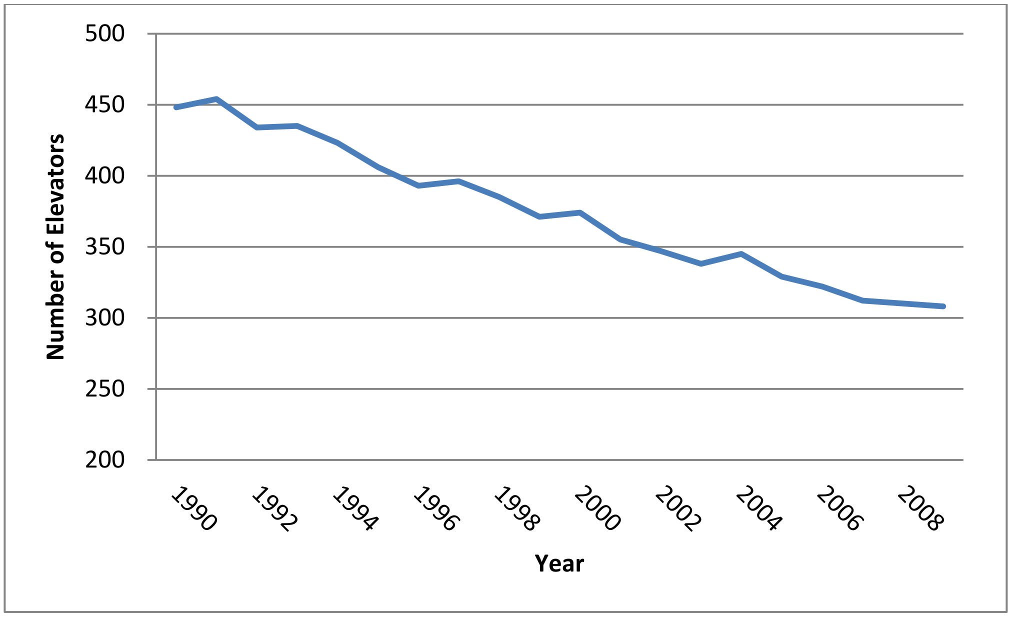

Figure 3 Number of Elevators Shipping Grain in North Dakota by Year (1990-2009)

2.4. Trends in Elevator Throughput

While the total number of elevators has decreased, the amount of grain handled by these facilities has increased. Figure 4 shows that the average tonnage shipped from elevators in North Dakota was relatively constant throughout the mid-1990s. From 1998 to present, there has been an increase in the average tonnage shipped from elevators in the state. In comparison, the median elevator throughput has remained constant over the past 20 years.

2.5. Shuttle Elevators

In the late 1990s, shuttle-train programs were introduced wherein an elevator may receive a reduced rail rate if it is able to meet certain conditions and satisfy minimum grain shipment volumes designated by the railroads. "Shuttle loading facilities influence commodity movement by rail, both in and out of state. They also impact the highway system, since trucks must move commodities to the shuttle facility for rail loading."[2]

Figure 5 shows the average tons shipped from shuttle and non-shuttle elevators in North Dakota. Prior to the shuttle-train program, elevator throughput statewide averaged 31,930 tons in the 1990s. This volume has remained relatively unchanged for non-shuttle elevators through this decade. However, for shuttle elevators, throughput volume has increased from 74,600 tons in 1997 to 240,640 tons in 2009.

[2] North Dakota Department of Transportation, *Rail Plan Update*, 2007.

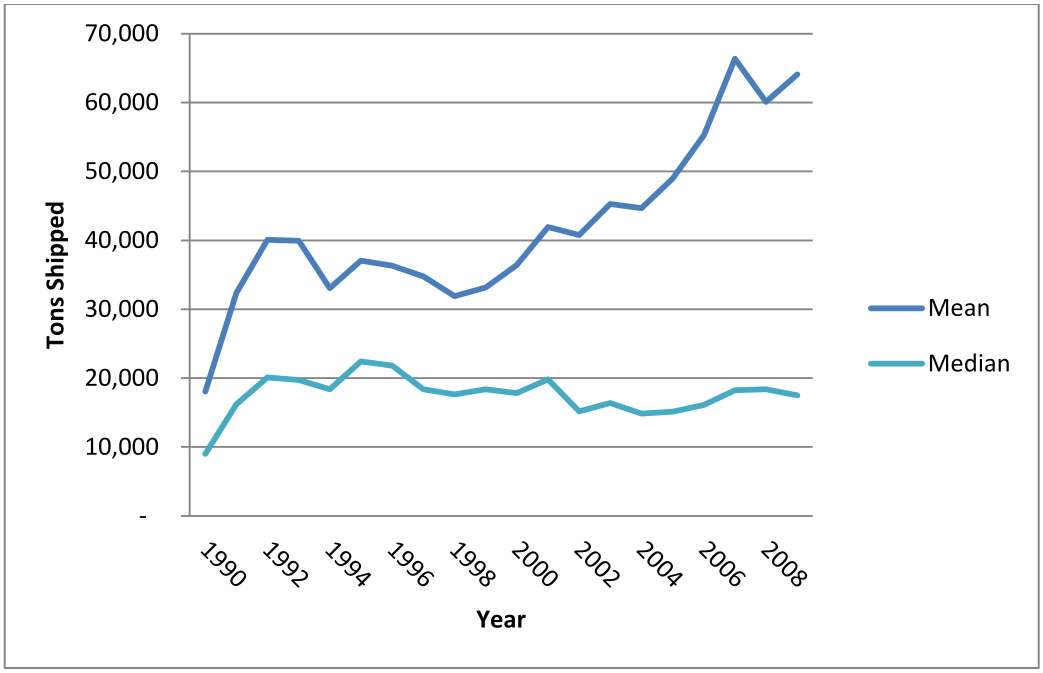

Figure 4 Mean and Median Tons Shipped by ND Elevators (1990-2009)

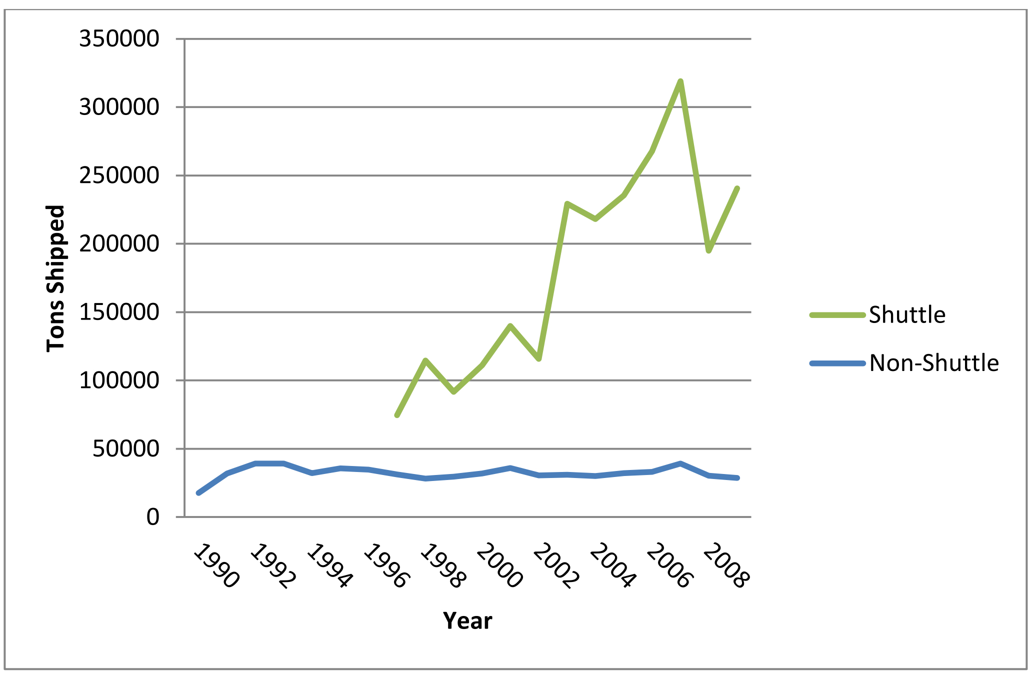

Figure 5 Mean Tons Shipped from Shuttle and Non-Shuttle Elevators (1990-2009)

2.6. Transshipments

In addition to higher volumes of grain being handled at shuttle elevators, there has been a recent increase in the amount of bushels transshipped within the state. These types of movements represent an elevator-to-elevator shipment, such as a satellite elevator shipping to a shuttle elevator. Figure 6 depicts the amount of grain transshipped via truck and rail over the past 20 years.

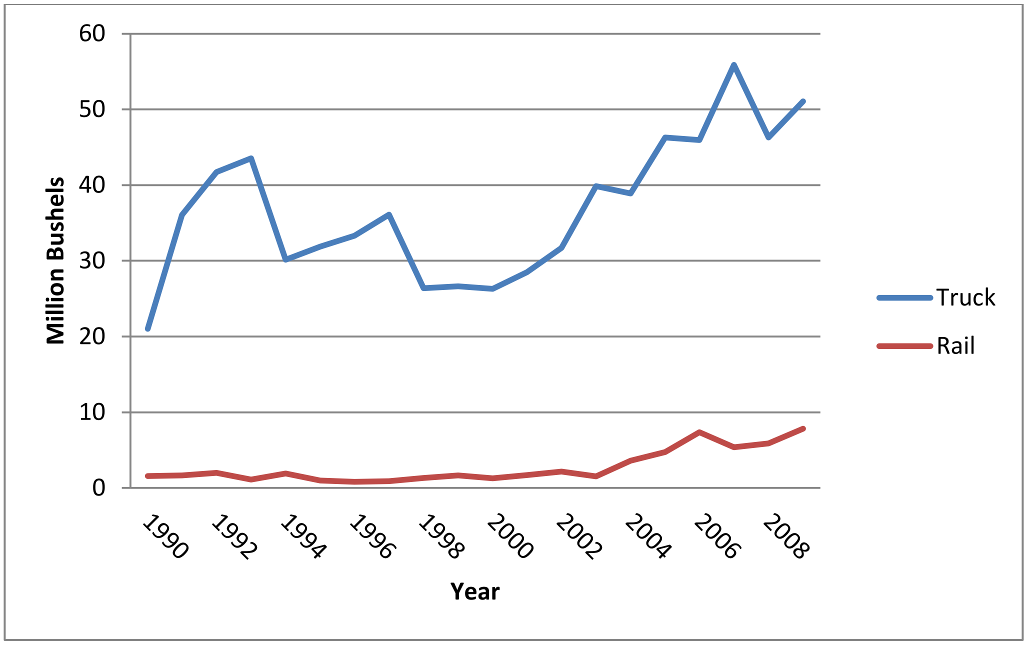

Figure 6 Bushels Transshipped in North Dakota by Mode (1990-2009)

2.7. Funding For Roads

Trends in roadway capital investment in current and constant 1994 dollars are illustrated in Figure 7. These represent only the funds invested or spent by local governments—e.g., county, township, and municipal governments. The period from 1994 to 1996 saw relatively little increase in local road funding as measured in constant 1994 dollars. However, an increase in capital investment occurred in 1996 to 1997, with the following five years from 1997 to 2001 exhibiting stable funding in constant dollars. However, capital outlays increased dramatically during 2002. The dramatic increase in 2002 was a singular event. Since 2003, capital funding (as measured in 1994 dollars) has generally decreased.

As shown in Figure 8, expenditures for road maintenance and traffic services have increased over time, especially in current dollars. However, the increase has been modest in real terms, approximately 1.5 percent per year from 1994 through 2007.

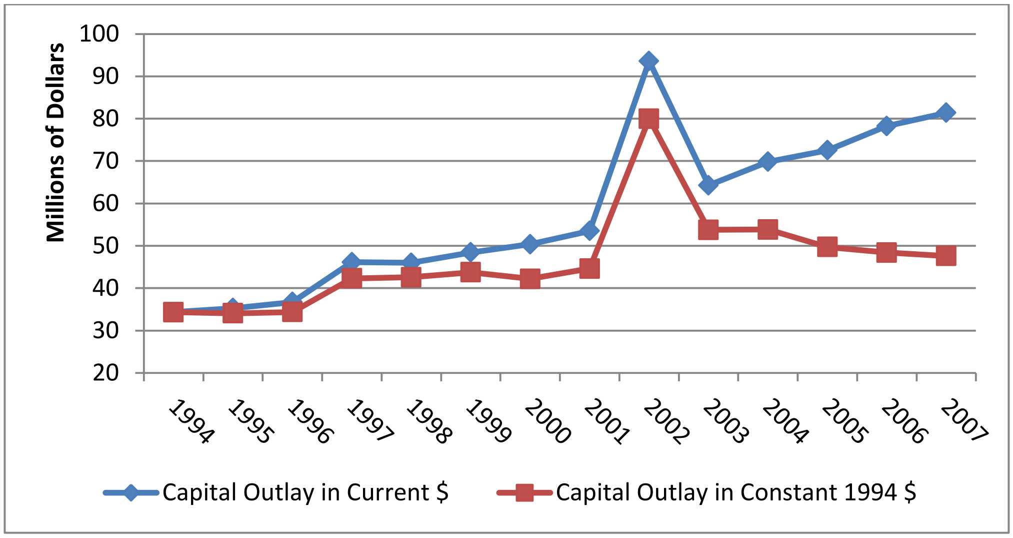

Figure 7 Capital Outlays for Roads in North Dakota in Current and Constant 1994 Dollars[3]

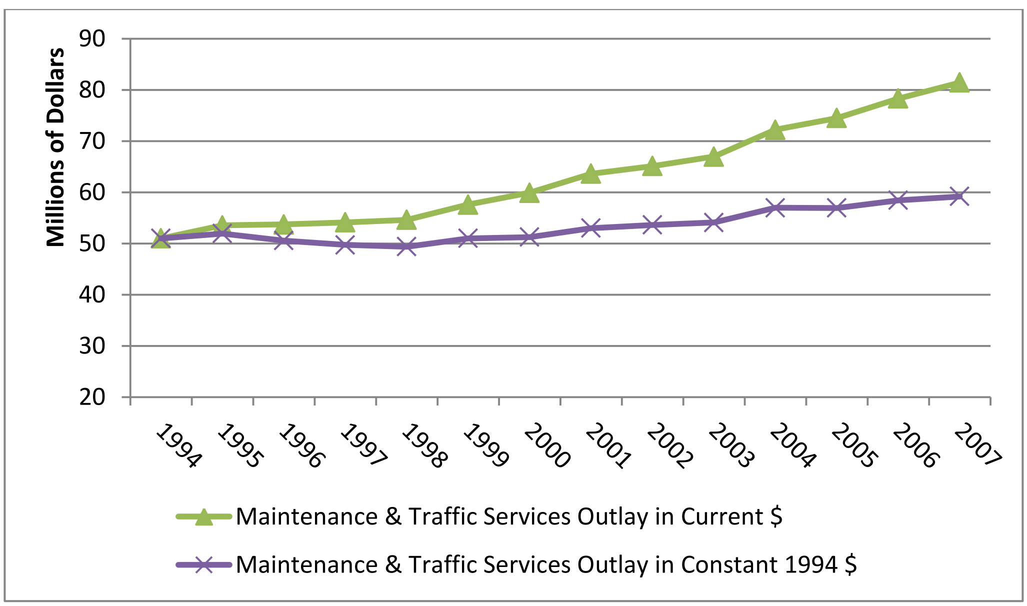

Figure 8 Outlays for Road Maintenance and Traffic Services in North Dakota

[3]Sources: United States Department of Transportation - Federal Highway Administration, 1994-2009 and the Bureau of Labor Statistics, 1994-2009.

2.8. Road Construction Prices

Although general inflationary trends are reflected in Figures 7 and 8, cost increases have strongly affected roadway construction and maintenance. In particular, construction prices have increased dramatically over time for asphalt and gravel roads. Throughout the last decade, increases in petroleum prices have been the primary contributor to increased construction costs at the state level. According to the Federal Highway Administration, in addition to higher fuel prices, consolidation of the construction industry, localized shortages of materials, shortages of skilled labor, regulatory restrictions, increased technical requirements in contracts, and other factors have contributed to higher construction bid prices.

Figure 9 shows the Producer Price Index for material and supply inputs to highway construction at the national level for the past 20 years. The price index does not include the cost of labor or administration, and focuses primarily on the components and materials used in road construction. As the figure shows, construction costs have increased throughout the entire period. However, the rate of increase has been much more pronounced from 2003 to 2008. During this period, the construction cost index increased from 136.6 to 222.4. Increases in construction costs result in fewer roadways being improved at a constant revenue level.

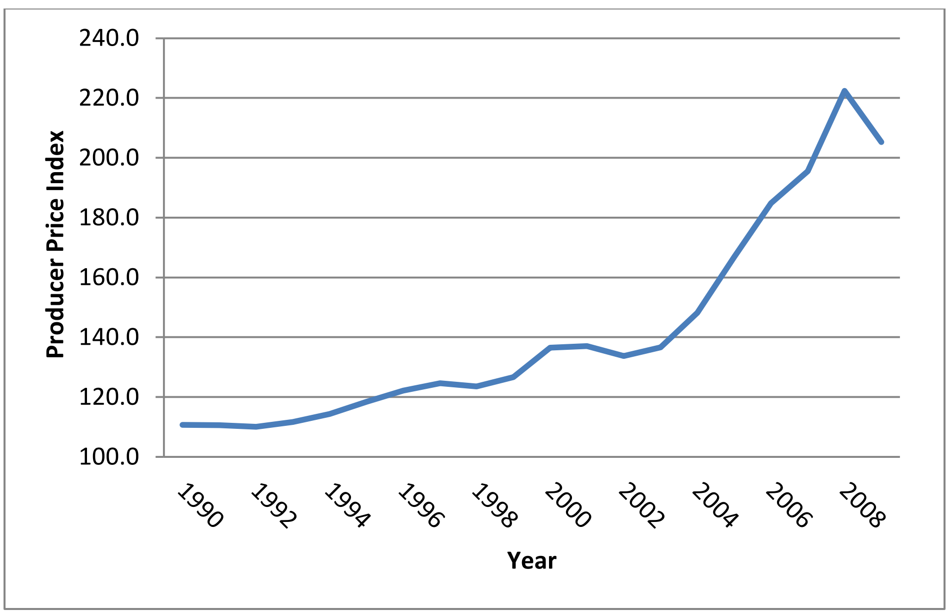

Figure 9 Producer Price Index for Material and Supply Inputs to Highway and Street Construction[4]

[4] Source: Bureau of Labor Statistics, 1990-2009.

The purpose of this section of the report has been to describe key trends in agricultural production and logistics, as well as trends in road funding and construction costs. The analysis depicts a set of factors that are collectively stressing the county and local road systems used to market and distribute North Dakota products. With this background, the report transitions to a description of the primary data and methods used to predict agricultural traffic flows and roadway investment needs.

3. Analysis Models and Data

The estimates presented in this report have strong analytical foundations. The study features the integration of four main models: (1) a crop production and location model; (2) a crop distribution model, in which movements or flows are predicted from crop-producing zones to elevators and processing plants; (3) a traffic model in which predicted flows are assigned to individual road segments; and (4) a road investment model, in which truck traffic and road characteristics are used to estimate investment needs. Models 1 and 3 are based on Geographic Information System (GIS) data and procedures, while the crop distribution model (Model 2) is grounded in mathematical programming logic. The road analysis model is based on highway planning and economic-engineering methods.

The first three types of models are summarized in the following sections. Roadway analysis methods for paved and gravel roads are described later in the report.

3.1. Crop Production and Location Model

In the analysis, it is vital to know not only the quantities of crops produced but their locations. More precise location information enables refinements in trip forecasting and the analysis of individual roadway segments. To provide greater accuracy, crop production estimates are generated for 1,340 county subdivisions in North Dakota.[5] USDA's 2009 crop satellite image is used for this purpose.

Using satellite imagery, the square miles of land devoted to the production of each crop in each county subdivision is estimated using GIS technology. However, the satellite image is only a snapshot of cultivation at a particular time. It is not an inventory of harvested crops. Moreover, it is an approximation subject to analytical limitations.

For these reasons, the predicted square miles devoted to crop production in each subdivision are adjusted based on the 2009 county production values published by the North Dakota Office of the National Agricultural Statistics Service (NASS). In this process, the predicted production of each crop in each subdivision is apportioned based on its share of cultivated land area within the county. For example, if five percent of the total

[5] For the most part, subdivisions are synonymous with organized townships.

cultivated acres in a county devoted to barley production lies within a certain township, this subdivision is assumed to produce five percent of the barley harvested in the county. This method implicitly assumes that barley yields are the same everywhere in the county.

While the estimates are subject to limitations, there is a high degree of accuracy in the predicted crop locations. In effect, the estimates are the most accurate possible without detailed field surveys, which are beyond the scope of this study. As discussed later, the predicted crop production levels in each county subdivision represent the zonal supplies of the distribution model.

3.2. Market Demands

The markets for the agricultural commodities produced in North Dakota are defined as processing plants within the state or elevators that ship crops out of state to various domestic and export locations. The demands at elevators are compiled from monthly reports submitted to the North Dakota Public Service Commission. The demands at ethanol plants are derived from several sources including: (1) reported shipments from North Dakota elevators to in-state processors, (2) the stated productive capacities of the plants, and (3) confidential survey information that describes the percentages of corn acquired from the local drawing areas around the plants and expected production volumes.

In effect, the demands at elevators and ethanol plants are known with high levels of confidence. The same cannot be said for all other demand sources. The lower boundary of demand at the Ladish Malt Plant in Spiritwood is known from the inbound shipments of barley from elevators in North Dakota. In the network model, this target is allowed to increase in relation to local supply in the nearby area. Consequently, the estimated demand at the facility should be close to actual levels. Less data are available regarding the final demands of specialty crops such as dry edible beans, peas, and lentils. Nonetheless, the demands for crops at specific locations are known with high levels of confidence overall.

3.3. Network Representation of Crop Distribution System

Terminology is important when describing the objectives and results of the crop distribution model. Such a model is comprised of a set of nodes and paths that connect the nodes. Shipments flow from node-to-node via the paths.

A path (such as one leading from a crop-producing subdivision to an elevator) is typically comprised of many individual road segments. Each segment (or link) is demarcated by two intersections or junctions in the road network. In many instances, two or more paths may be chained to form a trip chain or route. For example, a trip route may include a path from a crop-producing subdivision to an elevator, and a path from that elevator to a processing plant.

3.3.1. ***Nodes***

The nodes consist of three types: origin, intermediate, and destination. The county subdivisions where the crops are produced are origin nodes. The elevators and in-state processing plants are destination nodes. However, elevators may also serve as intermediate nodes. As an intermediate or transshipment node, an elevator may receive shipments directly from subdivisions or from other elevators. Subdivisions may ship directly to in-state markets (e.g., ethanol plants).

Terminal elevators are defined as those that export crops out of state. A shuttle-train facility is a terminal elevator. Other elevators may function as terminal elevators when they export grains and oilseeds from the state. However, in other cases, these elevators function as intermediate or transshipment facilities.

A simplified grain distribution system is depicted in Figure 10. As the figure shows, farm producers from various subdivisions or townships may ship directly to a shuttle-train elevator, or to a smaller elevator located closer to the subdivision. The smaller elevator, in turn, may transship some of the grain it procures to the shuttle-train facility; which, in turn, ships large quantities by rail to markets located out of state. A similar network can be drawn by substituting a processing plant for the shuttle elevator. In this case, the primary outbound product will be ethanol, vegetable oil, malt, or flour.

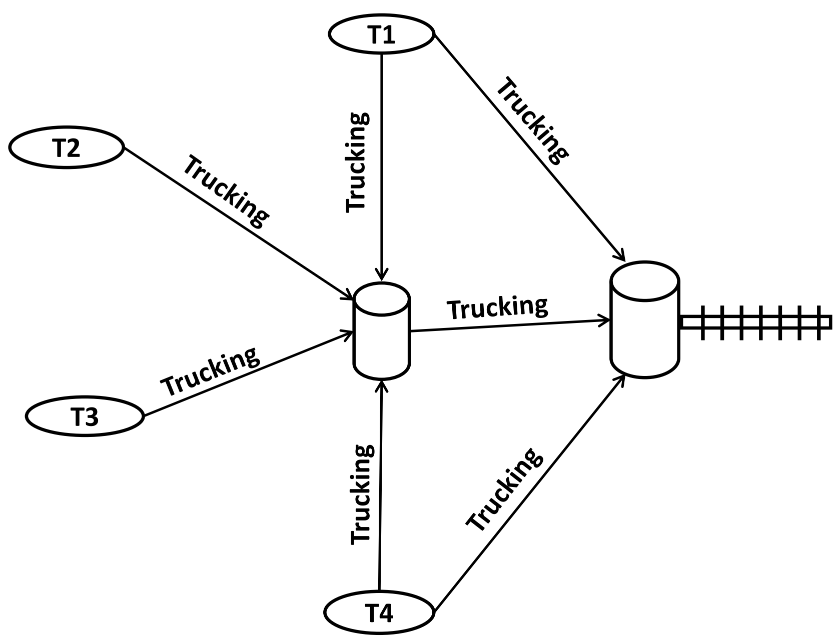

Figure 10 Crop Flows in Elevator Network

There are several types of truck shipments in a grain distribution network. A producer may haul crops to a smaller elevator in trucks owned and operated by the farm. At a later date, the grain may be trucked to a shuttle-train elevator or plant in commercial trucks. Alternatively, the farm producer may truck directly to a shuttle facility or plant. All types of flows are simulated in the model.

3.3.2. *Paths and Segments*

At a microscopic level, a path may consist of many individual road segments. For example, a subdivision-to-elevator path may include local gravel roads, paved county major collectors, and state arterial highways. In the GIS model, the fastest path through the network is identified from each subdivision to the nearest 10 to 20 elevators.[6] Because there are more than 150,000 unique road segments in the North Dakota GIS file, the input files are enormous and require extensive computable time. However, in the final analysis, flows are accumulated by individual road segments—which allow for greater detail in the roadway investment analysis.

3.4. Criteria and Objectives of Crop Distribution Model

The objective of the distribution model is to predict crop flows that minimize time or distance, while meeting the demands of in-state processing plants and terminal elevators. The fastest-path algorithm is used to generate paths from subdivisions to elevators and plants, and from elevator-to-elevator. Because some of the paths extend to distant elevators, the fastest-path criterion seems most reasonable. Over a short distance, a truck operator may follow a shorter zigzag path. However, for longer trips, truckers will quickly move toward the major collector/arterial network where the speeds are faster and more consistent.[7]

In identifying the fastest paths, maximum speeds are specified for each road segment based on the functional classification and surface type (e.g., paved or gravel). The maximum speeds range from 75 mph on Interstate highways to 10 mph on unimproved roads. While the fastest path criterion is the best for identifying paths over long distances, the predicted travel times are not accurate. The only information available is the speed limit, or the assumed speed for local roads or trails.

In reality, maximum speeds may not be consistently attainable or may vary greatly due to weather, traffic, and operating conditions. Thus, the selection of one path over another (e.g., a direct movement from a subdivision to one elevator versus another one) is based on

[6] In a few areas, the density of the elevator system is not sufficient to allow the connection of each crop-producing zone to 20 facilities.
[7] The shortest-path algorithm yields slightly shorter trip distances than the fastest-path algorithm—i.e., less than 2 percent on average. Thus, the selection of one method over the other does not significantly affect the results.

distance—i.e., the shortest of the two fastest alternative paths. Shorter distances minimize fuel consumption and use-related vehicle depreciation. Moreover, in contrast to the predicted trip times, the distances are relatively accurate and do not vary during the year.

3.4.1. *Minimum Distance Criterion*

The objective of the mathematical programming model is to minimize the distance of moving all agricultural commodities to plants or final elevators, from where they are shipped out of state. In effect, the model identifies an optimal or logistically efficient set of truck movements. These movements minimize use-related vehicle depreciation and maintenance, as well as fuel consumption. In many cases, the predicted movements may also minimize travel time. Because trucking cost is typically measured on a per-mile basis, minimizing the distance of agricultural goods movements is parallel to minimizing trucking cost on a system-wide basis.[8]

3.4.2. *Total Trip Distance*

The model minimizes the total or route trip distance including transshipments from one elevator to another or from an elevator to an in-state processing plant. Transshipments may occur when production in the primary draw area is not sufficient to meet the elevator's demands. In these cases, grains or oilseeds may be delivered by farmers from remote townships to elevators located on the periphery of the larger facility's draw area. These deliveries are processed at the smaller facilities and then resold to the shuttle- or unit-train elevator and shipped by commercial truck to that facility. In this case, the trip chain extends from the township to the shuttle- or unit-train elevator via the smaller elevator en-route. In many cases, a shuttle elevator or ethanol plant may contract with elevators to collect, process, and reship grain. In interpreting the results, it is important to recall that the route distance represents the total trip distance from farm to plant or terminal elevator, where the terminal elevator is one that ships the commodity out of state.

3.4.3. *Contextual Factors*

The realism of the crop distribution model depends on several factors. It assumes that price competition exists among elevators. As a result, a primary market or draw area surrounds each facility. Within this zone, crops are most likely to be delivered to the elevator or plant. Of course, the primary draw areas of shuttle-train and unit-train elevators may be larger than the draw areas of smaller elevators. Nevertheless, price relationships reflect the capability of smaller elevators to resell grains and oilseeds to larger elevators. For

[8] The prime interest of this study is estimating the ton-miles of agricultural goods movements via particular routes, as opposed to the trucking cost involved in delivering grains and oilseeds to markets. However, the predicted flow pattern is the same as that which would result from minimizing the average trucking cost per mile.

example, the price at a so-called satellite elevator that routinely resells grain to a shuttle elevator may reflect the price at the larger elevator plus the trucking cost from the smaller elevator to the larger one, plus the handling and processing cost at the smaller facility. These competitive relationships, along with truck cost factors, create tendencies for producers to deliver to closer elevators. These tendencies are intensified by higher fuel prices. Although diesel fuel prices have dropped since 2008, they have been on an upward trend since March of 2009. Although higher crop prices at shuttle elevators are attractive, higher fuel prices create greater impedances to long-distance travel.

3.4.4. *System versus Local Criteria*

Clearly, every farm producer will not deliver to the closest elevator, and the model does not predict this will occur. Rather, movements are restricted by elevator demands, which represent the known outbound shipments from each facility in crop year 2009-2010. Elevator volumes are reflections of the competitive landscape and market draw areas discussed previously. When an elevator's demand is fulfilled, no additional inbound movements are simulated. Even if the elevator is the most attractive facility for a producer on the fringe of its draw area, the producer's grains or oilseeds are shipped to another elevator whose demand must be filled.

In this model, the demands are known (and assumed to be fixed). The objective is to find the pattern of flows that moves the known supplies of crops from subdivisions to elevators and plants with the fewest ton-miles, while meeting the known demands of the facilities. This is far different from saying each farm producer delivers his or her crops to the closest elevator.

4. Predicted Flows

The predicted tons of each major crop are shown in Table 1, as well as the weighted-average lengths of haul. Note that the average distance includes the movement from farm to first elevator or plant, as well as any subsequent movements from the first elevator to other facilities—i.e., transshipments. In effect, it is the total trip distance discussed in Section 3.4. It reflects trips from farms to in-state processors, as well as to elevators. The oilseed category in Table 1 includes sunflowers and canola, while the other crop category includes dry edible beans, oats, and other specialty crops.

Approximately 21.89 million tons of crops are analyzed in this study. The total predicted distance of these movements (including transshipment distances) is 26.2 miles.[9] However, there are significant variations among crops. The average trip distance for barley reflects a

[9] When the shortest path algorithm is used (instead of the fastest path algorithm) in the initial selection of routes, the weighted-average distance drops to 25.6 miles.

spatial disconnect between supply and demand. Much of the barley grown in 2009 was cultivated in the north-central region including Bottineau County. However, most of the major demand sources are plants and elevators in eastern North Dakota, necessitating longer hauls than for other commodities. The weighted-average route distance for commodities other than barley is 21 miles, suggesting that the longer barley hauls significantly inflate the average.

Table 1. Predicted Tons of Agricultural Freight and Average Trip Lengths

Crop	Annual Tons	Average Trip Distance (mi.)
Barley	1,681,418	87.8
Corn	5,102,252	21.1
Oilseeds	578,929	26.6
Other	547,028	39.7
Soybeans	4,144,969	23.1
Beans	562,124	30.8
Wheat	9,268,699	18.1
All Crops	21,885,419	26.2

The predicted ton-miles of agricultural goods are shown in Tables 2 and 3, respectively. In Table 2, the predicted ton-miles are listed by type of pavement. In some cases, the owner (state or local government) is indicated. As the table shows, agricultural goods required roughly 600 million ton-miles of transportation during crop year 2009-2010. More than half of these ton-miles occurred on principal arterial highways, most of which are owned and maintained by the North Dakota Department of Transportation. The next greatest concentration of flows is on county major collectors: approximately 132 million ton-miles. Sixty-five percent of these ton-miles travel paved county major collector (CMC) roads (Table 4). The remaining 35 percent move on gravel CMC roads.

Table 2. Predicted Ton-Miles of Agricultural Freight by Road Type

Surface Type	Ton Miles	Percent
Paved: High-Type (State)	319,449,945	56.4%
Paved (County and Local)	99,563,913	17.6%
Graded & Drained	2,807,777	0.5%
Gravel	141,222,015	25.0%
Trail	2,233,471	0.4%
Unimproved	720,330	0.1%
All Roads	565,997,453	100.0%

Table 3. Predicted Ton-Miles of Agricultural Freight by Roadway Class

Functional Class	Ton-Miles	Percent
Principal Arterial	319,871,952	57%
Minor Arterial	3,804,845	1%
Major Collector	132,333,047	23%
Minor Collector	621,758	0%
Local	109,365,851	19%
All Roads	565,997,453	100%

Table 4 Distribution of Agricultural Ton-Miles Among Paved and Graveled County Major Collector Roads

Surface Type	Ton-Miles	Percent of Ton-Miles
Gravel	46,866,136	35.4%
Paved	85,459,102	64.6%
Trail	7,808	0.0%

With this overview of agricultural goods movements, the report now turns to the estimation of road impacts; starting with unpaved roads. Only county and local roads are considered in this analysis. Investment needs for state highways have already been estimated by the North Dakota Department of Transportation.

5. Unpaved Road Analysis

5.1. Cost and Practices Data

Survey responses from a 2009 study were used to compile gravel cost, gravel overlay thickness, application frequency, and blading frequency and cost. When survey responses were unavailable, the district average was used to represent the costs and practices.

The **gravel overlay thickness** represents the quality of the gravel surface as well as roadway condition. Responses indicate that the statewide average gravel thickness is 932 cubic yards/mile. However, there is substantial variation from one part of the state to another. Gravel loss factors such as weather conditions, traffic volume, traffic speed in addition to gravel cost and availability factors are likely reasons for the variations.

The **gravel interval** represents the quality of the gravel surface as well as the roadway condition and maintenance practices. Responses indicate that the statewide average gravel interval is 6 years, with 5 years being the most frequent response. However, there is substantial variation from one part of the state to another. Gravel loss factors such as weather conditions, traffic volume, traffic speed in addition to gravel cost and availability factors are likely reasons for these variations.

As mentioned above, cost and availability of quality gravel likely impact the decisions of counties with respect to overlay thickness and timing. As was observed with the gravel overlay thickness and interval, wide variations in gravel cost were reported, both statewide as well as within regions. The statewide average was $6.54 per cubic yard, ranging from $3.00 to $14.00 per cubic yard.

The final activity used in estimating county level costs is the blading interval. The blading interval is representative of the counties' maintenance activities. Factors such as traffic volume, speed, and weather conditions influence the frequency and necessity of road maintenance.

5.2. Cost Estimation

The survey responses were the primary tool used to estimate district level costs. A spreadsheet model was constructed to calculate annualized gravel road improvement and maintenance costs for varying levels of gravel thickness, intervals, overlays, and blading intervals.

5.3. Classification

The network flow model generated agricultural related truck trips by impacted segment. This number was added to the baseline average daily traffic (ADT) to obtain the total ADT for impacted sections. Using the predicted ADT volumes, unpaved segments were classified by traffic volumes: 0-50, 50-100, 100-150 and 150-200. No gravel roads in this analysis exceeded 200 ADT. It is assumed that as traffic levels increase, the amount and/or frequency of gravel application and blading will increase to preserve surface condition.

Table 5 Miles of Gravel Road Included in the Analysis by ADT Class

ADT Class	ADT Range	Miles
1	0-50	5,466
2	50-100	4,804
3	100-150	15
4	150-200	1

5.4. Maintenance and Improvement

As mentioned above, as traffic increase on gravel roads, the frequency of maintenance activities must increase to preserve surface condition. Using the cost model, annualized costs were calculated for 5, 4, and 3 year gravel application intervals. Based upon these annualized estimates, improvement costs for the three gravel ADT classes are estimated and presented in Table 6. While the first phase of the analysis considers only the roads impacted by agricultural traffic, the remaining roads must also be maintained. The annual cost estimates for these roads and the total estimates are also presented in the table below.

Table 6 Annual Cost Estimates for Gravel Roads in North Dakota ($2010)

Category	Miles	Cost
Ag Impact	10,286	$43,627,275
Other	48,782	$67,319,298
Total	59,068	$109,946,573

6. Paved Road Analysis

The factors that drive the paved road analysis are: (1) the number of trucks that travel the road segment, (2) the types of trucks and axle configurations used to haul agricultural commodities, (3) the structural characteristics of the roads in agricultural logistics routes, (4) the widths of the roads, and (5) their current surface conditions. Each of these factors is discussed in the following sections of the report.

6.1. Truck Types

A previous survey of elevators revealed the types of trucks used to haul grains and oilseeds and the frequencies of use. As shown in Table 7, approximately 56 percent of the inbound volume is transported to elevators in five-axle tractor-semitrailer trucks. Another four percent arrives in double trailer trucks—e.g., Rocky Mountain Doubles. Another twelve to thirteen percent arrives in four-axle trucks equipped with triple or tridem rear axles.

After considering entries in the other category, the following assumptions were made. Sixty-two percent of the grains and oilseeds arriving at elevators in North Dakota will arrive in combination trucks, as typified by the five-axle tractor-semitrailer. The remaining 38 percent will arrive in single-unit trucks, as typified by the three-axle truck.

Table 7 Types of Trucks Used to Transport Grain to Elevators in North Dakota

Truck Type	Percentage of Inbound Volume
Single unit three-axle truck (with tandem axle)	25.15%
Single unit four-axle truck (with tridem axle)	12.55%
Five-axle tractor-semitrailer	54.96%
Tractor-semitrailer with pup (7 axles)	3.62%
Other	3.72%

6.2. Truck Axle Weights

Truck loads are transmitted to the pavement through the truck's axles and wheels. Therefore, axle configurations and weights are important in this study. The pavement design equations of the American Association of State Highway and Transportation Officials (AASHTO) are used to analyze axle impacts. These same equations are used by most state transportation departments in the United States. The equations are expressed in *equivalent single axle loads* (ESALs). In this metric, the weights of various axle configurations (e.g., single, tandem, and tridem axles) are converted to a uniform measure of pavement impact. With this concept, the service life of a road can be expressed in ESALs instead of truck trips.

6.2.1. *Effects of Axle Weights*

An ESAL factor for a specific axle represents the impact of that axle in comparison to an 18,000-pound single axle. The effects are nonlinear.[10] For example, a 16,000-pound single axle followed by a 20,000-pound single axle generates a total of 2.19 ESALs, as compared to two ESALs for the passage of two 18,000-pound single axles.[11] An increase in a single-axle load from 18,000 to 22,000 pounds more than doubles the pavement impact, increasing the ESAL factor from 1.0 to 2.44. Because of these nonlinear relationships, even modest illegal overloads (e.g., 22,000 pounds on a single axle) can significantly reduce pavement life.

6.2.2. *ESAL Factors*

ESAL factors are estimated for the prototypical grain trucks mentioned earlier. This calculation is illustrated for a tractor-semitrailer weighing 80,000 pounds with a weight distribution of 12,000 pounds on the front (steering) axle and 34,000 pounds on each of the tandem axles. The ESAL factor for a 34,000-pound tandem axle is 1.07, which suggests that its impact is only marginally greater than the impact of an 18,000-pound single axle. The ESAL factor for the 12,000-pound single axle is 0.177 and the overall ESAL factor for the truck is $0.177 + 1.07 \times 2 = 2.32$. This means that for every loaded mile the truck travels it is consuming a small part of a pavement's life, as measured by 2.32 units or ESALs. A similar calculation for a 50,000-pound three-axle truck (with a tandem rear axle) yields an ESAL factor of 1.68—i.e., 0.61 + 1.07.

The AASHTO ESAL factors were originally estimated when tire pressures were much lower than they are today. As shown in Figure 11, modern tire pressures increase the

[10] The relationship between ESALs and axle loads is approximately a fourth power relationship.
[11] These calculations reflect a light pavement section with a structural number of 2.0 and a terminal serviceability (PSR) of 2.0.

ESAL factor by as much as 20%. In effect, the true ESAL factor of a tractor-semitrailer is 2.78 per loaded mile. All ending calculations in this study reflect adjustments for higher tire pressures.

The use of single instead of dual tires on drive and trailer axles may further impact the ESAL factor. With 6 inches of wander (e.g., lateral variation in the placement of tires on pavements), the use of single tires on drive and trailer axles may increase the ESAL factor by as much as 50%.[12] In this study, only the steering axle of the truck is assumed to be equipped with single tires. Therefore, no adjustments are necessary.

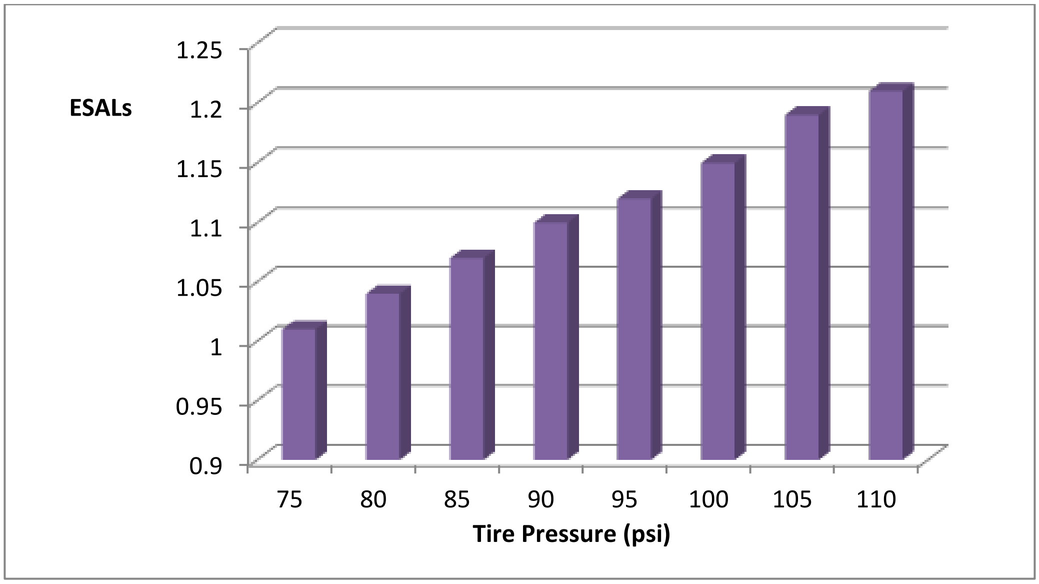

Figure 11 Effects of Tire Pressure on ESAL Factor
Source: Transportation Research Board. *Truck Weight Limits: Issues & Options*, Special Report 225, 1990. Figure 4-8.

6.3. Surface Conditions

Roads conditions are often assessed by examining the distress and roughness of the surface layer. Table 8 shows the results of a 2008 survey of county road managers in which they were asked to rate the current conditions of the roads in their counties, by functional class—i.e., county major collector or local road. The survey results have been weighted by the miles in each class and county. As the table shows, approximately nine percent of county major collector miles are in poor or fair-to-poor condition. In comparison, 42.5 percent of county local road miles are in poor or fair-to-poor condition. Most of the miles

[12] Transportation Research Board. *Truck Weight Limits: Issues & Options*, Special Report 225, National Academies Press, 1990.

in each classification are rated as fair. Less than 5 percent of county local road miles are in good condition.

Table 8 Percent of Miles by Condition Level and Functional Class

Surface Condition	County Major Collector	Local Roads
Good	26.98	4.51
Good/Fair	4.61	.
Fair	59.63	52.99
Fair/Poor	3.11	4.41
Poor	5.68	38.09

6.4. Structural Numbers

The capability of a paved road to accommodate heavy truck traffic is reflected in its structural rating, which is measured through the structural number (SN). The structural number is a function of the thickness of the surface and base layers and the materials of these layers. The surface layer is typically composed of asphalt while the base layer is comprised of aggregate material. The amount of cracking and deterioration of the surface layer is considered in the structural number of an aging pavement. Moreover, the conditions of base layers and underlying soils are important considerations when assessing seasonal load limits and the year-round capabilities of roads.

The average thicknesses of pavement layers in county and local paved roads are shown in Table 9. These values represent weighted means derived from a 2008 survey. The estimates have been weighted by the miles of county major collector and local road in each reporting county.

Table 9 Weighted-Average Layer Thicknesses of County Collector and Local Roads in North Dakota

	County Major Collector	Local Road
Base layer thickness (inches)	5.1	3.9
Surface layer thickness (inches)	4.1	4.0

When estimating in-service structural numbers, a badly deteriorated layer is likely to be assigned a lower coefficient.[13] For example, the average in-service structural number of a

[13] The pavement design guide of the American Association of State Highway and Transportation Officials (AASHTO, 1993) suggests the use of asphalt surface coefficients ranging from 0.15 to 0.40 for in-service pavements, based on the extent of longitudinal patterned (e.g., alligator) cracking and transverse cracks. As a point of reference, a new asphalt surface is typically assigned a structural coefficient of 0.44. For aggregate base layers, the AASHTO guide suggests using coefficients of 0.0 to 0.11, depending upon the extent of degradation

county major collector in poor condition with substantial distress may be computed as 5.1 inches of base × 0.07 + 4.1 inches of asphalt × 0.20 = 1.2. Similarly, the average in-service structural number of a county local road in poor condition with substantial surface layer distress may be 1.1 (e.g., 3.9 inches of base × 0.07 + 4.0 inches of asphalt × 0.20).[14]

6.5. Potential Improvements to County Collector and Local Roads

The types of potential road improvements analyzed in this study are reconstruction and resurfacing. If a pavement is not too badly deteriorated, normal resurfacing is a cost-effective method of restoring the structural capacity of a road. In this type of improvement, a new asphalt layer is placed on top of the existing pavement. The thickness of the layer may vary. However, it may be as thick as five inches. Without extensive truck traffic, a relatively thin overlay (e.g., 2 to 3 inches) can often be effectively applied.

Reconstruction entails the *replacement* of a pavement in its entirety—i.e., the existing pavement is removed and replaced by one that is equivalent or superior. Reconstruction includes drainage work and shoulder improvements, as well as the widening of substandard lanes. In contrast, resurfacing leaves the pavement intact. In lieu of replacement, hot mix asphalt is placed on the existing surface in a quantity needed to return the pavement to an acceptable level of serviceability and *restore* its structural strength

6.5.1. *Reconstruction*

A road may be reconstructed for several reasons. (1) The pavement is too deteriorated to resurface. Roads in the poor and very poor classifications fall into this group. (2) The road has a degraded base that will provide little structural contribution to a resurfaced pavement. (3) The roadbed is comprised of poor soils that are susceptible to moisture. In this case, reconstruction is necessary to provide year-round service at the maximum legal weight. (4) The road is too narrow to accommodate thick overlays without widening. In this case, reconstruction may be the only alternative that does not reduce capacity or potentially affect safety.

6.5.2. *Feasibility of Overlays on Narrow Roads*

The graded width determines if a substantial new asphalt layer can be placed on top of the road without compromising its capacity. As the top of the road is elevated due to overlays,

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and contamination of aggregates with fine soil particles or abrasions.

[14] In comparison, the average in-service structural number of a county major collector in fair condition may be 1.6 (e.g., 5.1 inches of base × 0.08 + 4.1 inches of asphalt × 0.28). Similarly, the average in-service structural number of a county local road in fair condition may be 1.4 (e.g., 3.9 inches of base × 0.08+ 4.0 inches of asphalt × 0.28).

a cross-sectional slope must be maintained.[15] Consequently, the useable width may decline. Typically, this is not an issue for wider roads (e.g., 34-feet or more in width). However, for narrower roads, it may result in reduced lane and shoulder widths and/or the elimination of shoulders. In the ultimate case, the narrowest roads cannot be resurfaced. The probabilities of crashes increase when roadway widths are narrowed.[16]

6.5.3. *Improvement Logic*

In this study, segments with higher traffic volumes are considered for reconstruction because of width and operational concerns. Unfortunately, detailed information regarding graded widths could not be obtained for this study. Only aggregate values were obtainable. Without knowledge of the widths of individual segments, reconstruction improvements are allocated to segments in counties with insufficient roadway widths based on traffic until a modest level of traffic is reached.

At a minimum, reconstruction will prevent the loss of width. It may also provide for minor widening, shoulder and drainage improvements. As a result, reconstruction may enhance capacity (as measured in vehicles per hour) because of wider lanes and shoulders. Shoulder improvements may enhance safety. Last but not least, reconstruction will remove spring load restrictions and allow year-round operation at gross vehicle weights of 80,000 pounds or greater.[17] The allocation of reconstruction dollars to roads with higher traffic levels will maximize capacity and ride-quality benefits for all travelers.

Roads not selected for reconstruction are eligible for resurfacing. However, the thickness and cost of the overlay depends upon the expected truck traffic level.

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[15] Roads are "crowned" or elevated in the center primarily for drainage. With a cross-sectional slope, water readily drained off the crowned surface and into the ditches.

[16] For purposes of reference, a 24-foot graded width allows for an initial design of two 11-foot lanes with some shoulders. However, the lane widths and shoulders cannot be maintained as the height of the road is elevated during resurfacing. To illustrate, assume a 4:1 cross-sectional slope for both the initial construction and subsequent overlays. In this case, each inch of surface height results in a loss of approximately eight inches of top width. Thus, a road with an existing surface thickness of four inches may suffer an ultimate top-width loss of five feet with a new four-inch overlay. The upshot is that lanes and shoulders must be reduced to fit the reduced top width. In the case of a road with a 24-foot graded width, shoulders must be eliminated and lanes reduced to 10 feet or less.

[17] A thick structural overlay may remove spring load restrictions and allow year-round operation at the maximum legal weight. However, this result cannot be guaranteed. The outcome depends upon the existing road and its underlying soils. Old aggregate bases in roads that have never been reconstructed may be largely ineffective. Given the depths of the bases reported in the survey (i.e., from 2 to 6 inches) and their low implied coefficients, these bases are unlikely to provide significant structural contributions to a resurfaced pavement. Moreover, the bases may be degraded and contaminated with fines. In such cases, structural overlays are not guaranteed to remove spring load restrictions.

6.5.4. *Reconstruction of Segments in Agricultural Routes*

According to a 2008 survey, approximately seven percent of all miles of county major collector road clearly have insufficient graded widths to accommodate future overlays without substantially narrowing the roads. Another seven percent of the miles of county major collector road may have insufficient graded widths to accommodate future overlays without substantially narrowing the roads. However, it is impossible to verify this percentage without detailed field work. According to the same survey, approximately 86 percent of all miles of county local road have insufficient graded widths to accommodate future overlays without substantially narrowing the roads. This does not mean that the roads will be closed. However, it does mean that many miles of road will have no shoulders and 10- or 11-foot lanes.

Reconstruction is expensive, costing $1.25 million per mile. Thus, it can only be justified on roads with significant traffic volumes. Without knowledge of the widths of individual segments, reconstruction improvements are allocated based on overall traffic with a minimum frequency of grain trucks per day, subject to the overall constraints of 14 percent of impacted county major collector miles and 86 percent of impacted county local road miles. These constraints correspond to the statewide proportions of county major collector and county local road miles that are candidates for reconstruction due to insufficient widths.

Altogether, 147 miles of road with significant agricultural traffic met the minimum traffic thresholds for potential reconstruction. These segments represent are only a small portion of the 6,375 miles of paved county and local road in the state and the approximately 3,957 miles of paved roads used for agricultural logistics. However, some of the 6,375 miles of county and local paved road have only one or two predicted grain trucks per day, coupled with light ADT; and, therefore, are not candidates for reconstruction.

In addition to wider roads, reconstruction is expected to provide year-round heavy-hauling capabilities. Since the vast majority of these segments are located in paths that feature county major collectors, access to key facilities (such as plants and large elevators) may be improved. Further, the allocation of reconstruction dollars to roads with higher traffic levels will maximize capacity and ride-quality benefits for all travelers.

6.5.5. *Resurfacing of Segments of Agricultural Routes*

Those roadway segments not selected for reconstruction are evaluated for overlays. The thickness of the overlay is a function of the grain truck traffic plus some allowance for other trucks traveling the roadways. These percentages are derived from the 2008 survey mentioned earlier.

Based on the estimated ESAL demand for the next 20 years, a new structural number is computed that considers the effective structural number of the existing surface and base layer at the time of resurfacing.[18] As shown in Table 10, the median overlay thickness needed on road segments in primary agricultural routes is four inches. For segments with lower truck traffic volumes, overlays of 2.5 to 3.0 inches will typically suffice. On the most heavily impacted miles, a 5-inch overlay may be needed. However, these segments are relatively few and are ones where considerable grain traffic is channeled in approaches to large facilities.

Table 10 Estimated Surface Thicknesses for Major County Collector Segments in Agricultural Logistics Routes

Weighted Percentiles of Distribution	Inches of New Asphalt Surface Layer
90th	4.7
75th (Upper Quartile)	4.0
50th (Median)	4.0
Mean	3.9
25th (Lower Quartile)	3.7

The resurfacing cost of each segment is estimated from the inches of overlay needed and a projected 2011 unit cost of $70,000 per inch per mile, which is applicable to two-lane rural roads.[19] With this unit cost, a four-inch overlay costs $280,000 per mile. A three-inch overlay costs $210,000 per mile, etc.

6.6. Routine Maintenance

Routine maintenance costs on paved roads include activities performed periodically (such as crack sealing, seal coats, and striping), as well as annual activities (such as patching). The cost relationships in Table 11 have been derived from a South Dakota Department of Transportation study, with the original cost factors updated to 2010 levels and annualized. For example, the annualized seal-coat cost would allow for at least two applications during a typical 20-year life-cycle for roads with ADT of 200 or more.

[18] The assumed structural coefficient of a deteriorated surface layer (that now serves as a base layer) is 0.14, while the assumed structural coefficient of the original base layer is 0.7. For local roads, this calculation results in a median residual structural number of 0.7. The analogous number for county major collectors is 1.0.

[19] This unit cost was derived from the North Dakota Department of Transportation's 2009 cost for a structural overlay—i.e., the DOT's average cost of $340,000 per mile was divided by five inches to obtain $68,000 per mile. This value was then indexed to 2011 assuming a three percent inflationary increase in construction costs.

Table 11 Routine Maintenance Cost Factors for Paved Roads by Traffic Level

ADT Traffic Range		**Annualized Cost of Road Maintenance Activities**			
Lower	Upper	Crack Sealing	Seal Coat	Striping	Patching
1	99	$540	$2,340	$76	$900
100	199	$540	$2,340	$113	$900
200	299	$720	$3,150	$126	$900
300	399	$720	$3,150	$126	$900
400	499	$576	$3,285	$140	$900
500	599	$480	$3,285	$144	$900
600	699	$480	$3,285	$162	$900
700	-	$480	$3,285	$162	$900

6.7. Highlights of Paved Road Analysis

There are approximately 6,375 miles of paved road under the jurisdiction of county, township, and municipal governments in North Dakota. However, not all of these segments are significantly affected by agricultural traffic. Some of the segments have only a few predicted tons that do not amount to a full truckload. These segments are not specifically analyzed as part of an agricultural distribution route. Instead, they are reclassified as non-agricultural segments.

As shown in Table 12, the annualized cost of maintaining and improving roads significantly impacted by agricultural traffic is $58.9 million. There are 2,417 miles remaining, which are not significantly impacted by agricultural transportation. The cost of improving and maintaining these miles is estimated to be $41.6 million annually.

Table 12. Paved County Collector and Local Road Miles and Cost by Impact Type

Category	Miles	Annualized Cost
Ag Impact	3,958	$58,883,223
Other	2,417	$41,580,950
Total	6,375	$100,464,172

The annualized cost in Table 12 reflects reconstruction, resurfacing, and annual maintenance cost. Annual maintenance cost was calculated for any segment with agricultural truck traffic. The estimated annualized maintenance cost of these 3,958 miles is $18.5 million over the 20-year period (Table 13). Of the 3,958 miles significantly impacted by agricultural traffic, 147 miles were selected for reconstruction due to deficiencies in roadway width. The estimated annualized cost of these reconstruction improvements is $9.2 million. An additional 2,541 miles were selected for resurfacing over the 20-year analysis period at an estimated annualized cost of $31.2 million. Those segments with only one agricultural truck per day were not analyzed specifically to determine the pavement thickness, because it is assumed that the agricultural traffic will have no impact on the resurfacing decision. Rather, these segments are reclassified as non-impacted routes for purposes of resurfacing and their resurfacing costs are included with that group. The total estimated annualized cost for agriculture impacted roads is $58.9 million.

Table 13 Ag Impacted Paved Miles Improved and Maintained by Improvement Type

	Miles	Annualized Cost
Reconstruction	147.0	$9,192,586.55
Resurfacing	2,541	$31,240,378.00
Maintenance	3,958	$18,450,258.00
Total		$58,883,222.55

Table 14 shows the miles and annualized improvement and maintenance costs of roads not significantly impacted by agricultural traffic. In this analysis, the 2,417 miles not reflected in the maintenance cost estimate for agricultural routes are assumed to be maintained at an estimated annualized cost of $9.3 million, which reflects an average cost of $3,856 per mile per year. Moreover, all 2,417 non-impacted miles are assumed to receive a resurfacing treatment during the analysis period. In addition, those segments with only one agricultural truck per day that did not receive a resurfacing or reconstruction improvement in the agricultural analysis are included with this category. Altogether, 3,687 miles of road not significantly affected by agricultural traffic are assumed to receive a standard resurfacing improvement at an estimated annualized cost of $32.3 million. For these non-impacted roads, it is assumed that a 2.5-inch overlay of each segment will provide reasonable service for 20 years in the absence of significant agricultural truck traffic. In total, the cost of maintaining and improving paved local roads that were not significantly impacted by agricultural traffic is estimated to be $41.6 annually.

Table 14 Non-Impacted Paved Miles Improved and Maintained by Improvement Type

Improvement Type	Miles	Annualized Cost
Resurfacing	3,687	$32,261,075
Maintenance	2,417	$9,319,875
Total		$41,580,950

Comparatively, the estimated resurfacing cost of agricultural distribution routes is 40 percent greater than the estimated resurfacing cost of non-agricultural routes on a per-mile basis. Comparatively, the estimated maintenance cost of agricultural distribution routes is 21 percent greater than the estimated maintenance cost of non-agricultural routes on a per-mile basis. These differences reflect higher levels of truck traffic and average daily traffic on these routes. Since 90 percent of the paved county-road miles in agricultural distribution routes are major collectors, these comparisons reinforce the current investment priorities of counties.

7. Conclusion

The purpose of this study is to analyze changes in agricultural production and logistics and the importance of roadway investments to the distribution of crops produced in North Dakota. The essential objective was to quantify the funding level required to maintain and improve the existing local road network.

In this study, a very detailed network model was developed to predict and route crop movements from 1,340 county subdivisions to elevators and ethanol plants. The predicted flows were used to specifically analyze investment needs for agricultural haul roads. In addition, the investment needs for other local roads not significantly affected by agricultural goods movements were estimated so that the total statewide local roadway needs could be quantified.

Statewide, estimated needs total $100.5 million annually for county and local paved roads. Approximately $59 million of these needs relate to agricultural haul roads. The remainder corresponds to other county and local roads. Also, statewide, estimated needs total $110 million annually for local unpaved roads. Approximately, $43.6 million of these needs relate to agricultural haul roads. The remainder corresponds to other local roads, especially township roads. Thus, the total estimated statewide need is $211.5 million per year, including $100.5 million of paved road investment needs and $110.0 million of unpaved road investment needs.

In conclusion, it is important to note that the study has limitations, most of them due to a short time frame (i.e., 40 days), difficulties in obtaining data, and a limited budget, which precluded any field work. All crop flows could not be represented in the distribution model because of difficulties and delays in getting data. Therefore, the total ton-miles shown in Table 3 may be somewhat understated. Based on information available, it is likely that more than 95 percent of all crop ton-miles are reflected in the estimates.

One of the issues not addressed in this study is the effect of spring load restrictions on farm producers, elevators, and plants. This is an issue that should be revisited and the major county collectors in agricultural logistics routes should be evaluated individually to assess the need for and cost of potential reconstructions or thicker overlays. Although county-wide surface conditions were available from a previous survey, these values could not be assigned to individual segments without additional interviews and modeling. As a result, it is quite possible that many additional miles of county and local road may need reconstruction because of poor condition. These detailed analyses were not possible within a 40-day window. While further study is recommended, this report has identified the minimum threshold of county and local road investment needs.

8. Appendix A. Regional Trends in Crop Production North Dakota

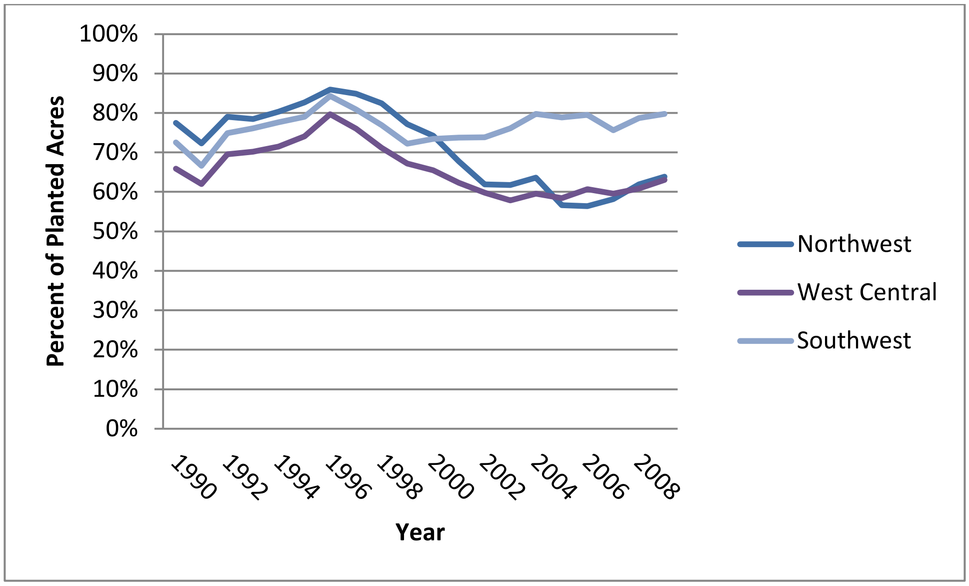

Figure 12 Percentage of Acres Planted to Wheat in Western North Dakota 1990-2009

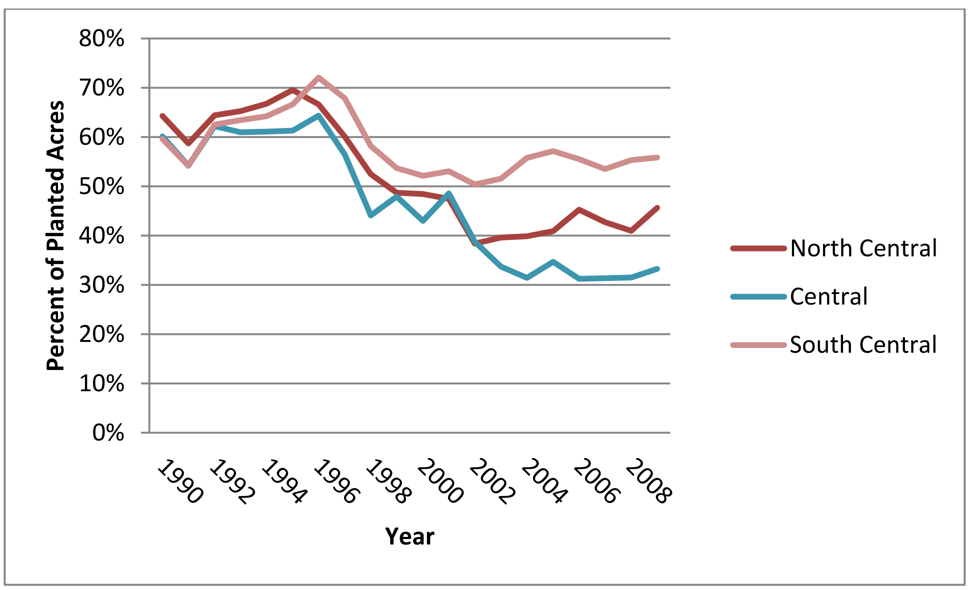

Figure 13 Percentage of Acres Planted to Wheat in Central North Dakota 1990-2009

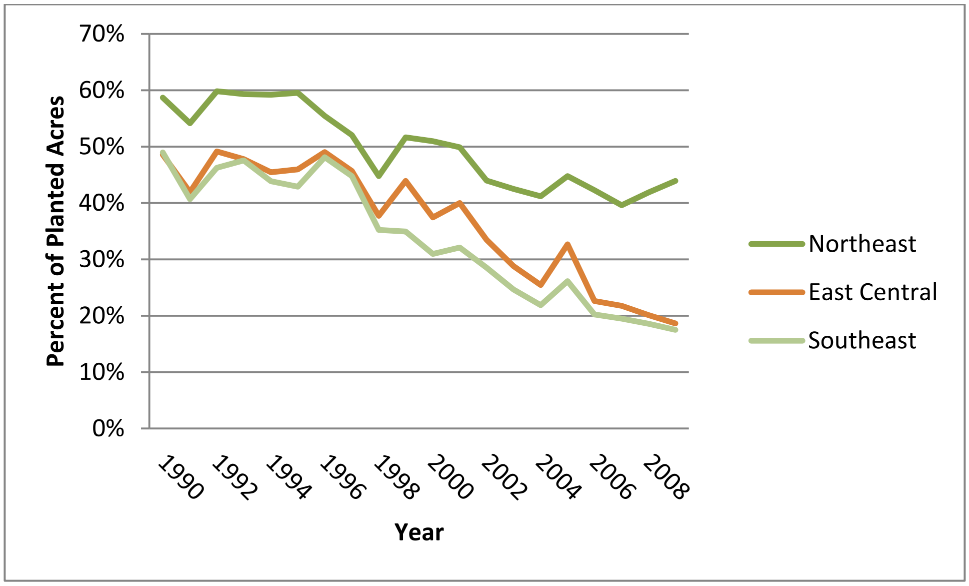

Figure 14 Percentage of Acres Planted to Wheat in Eastern North Dakota 1990-2009

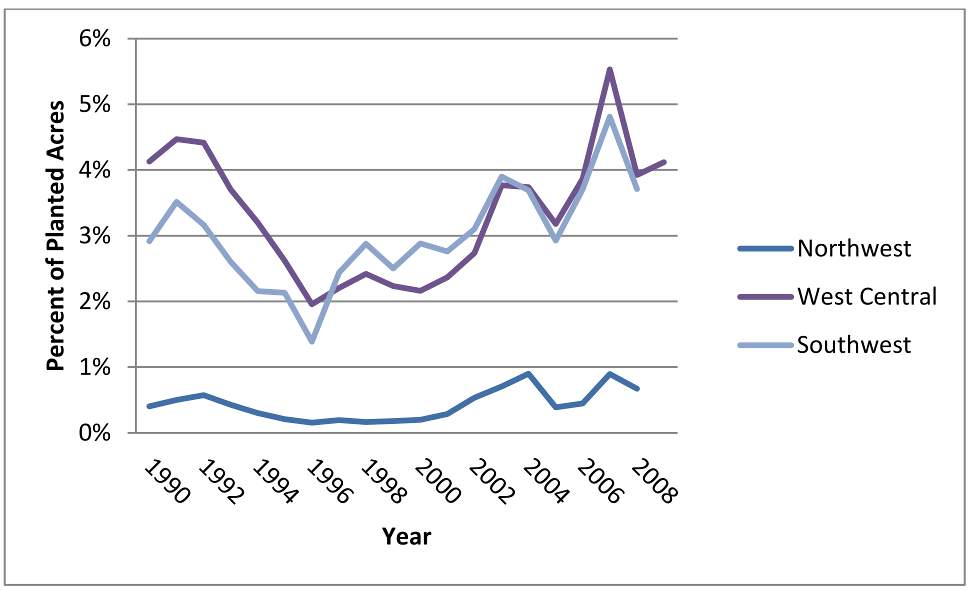

Figure 15 Percentage of Acres Planted to Corn in Western North Dakota 1990-2009

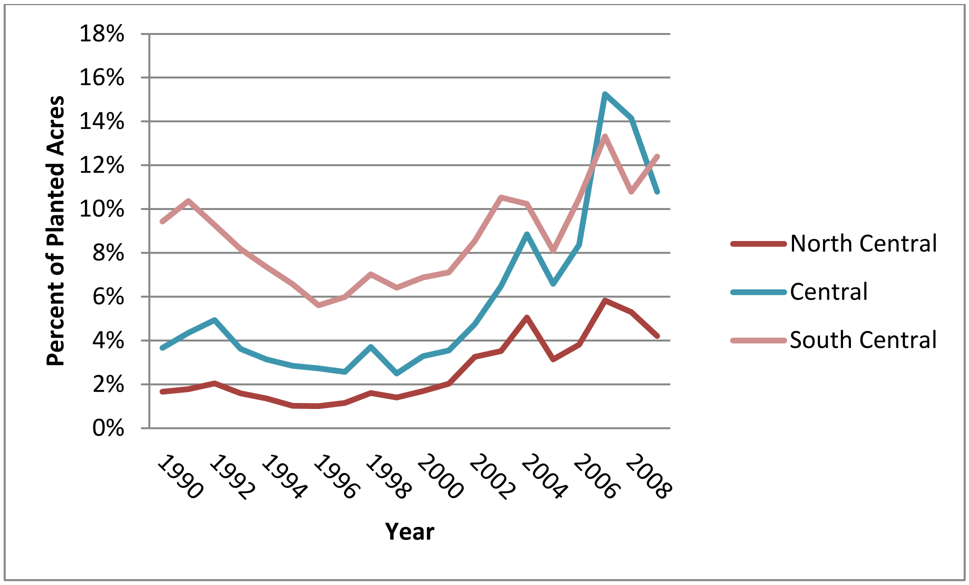

Figure 16 Percentage of Acres Planted to Corn in Central North Dakota 1990-2009

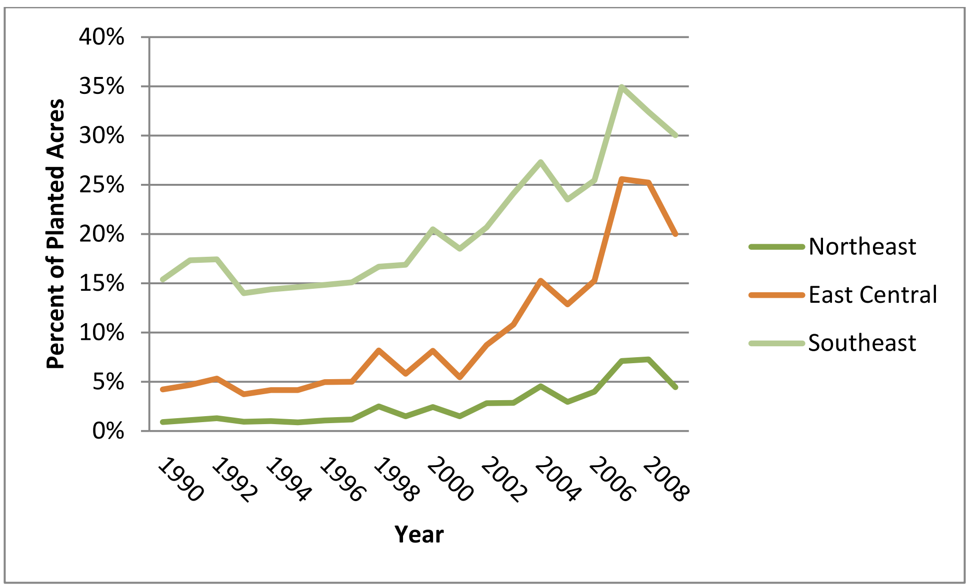

Figure 17 Percentage of Acres Planted to Corn in Eastern North Dakota 1990-2009

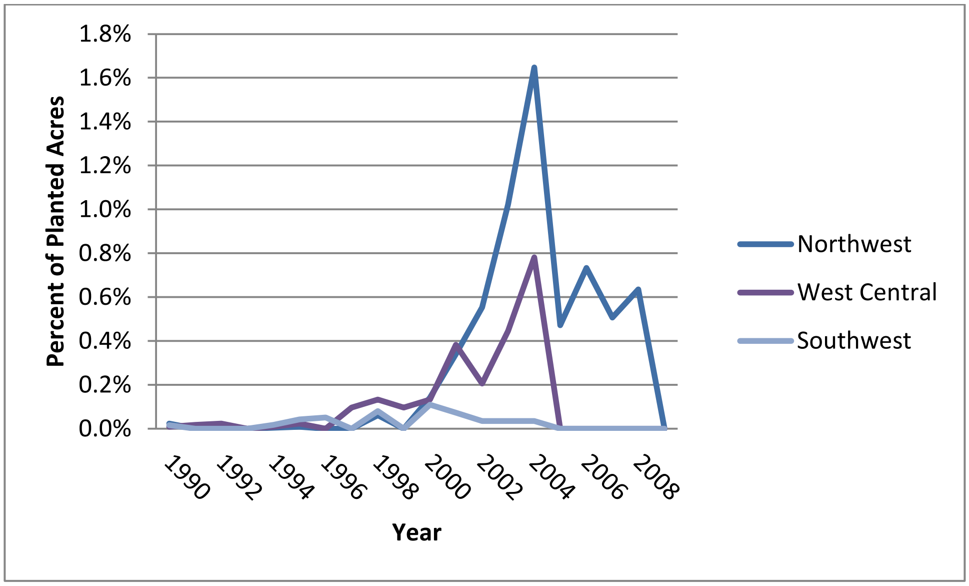

Figure 18 Percentage of Acres Planted to Soybeans in Western North Dakota 1990-2009

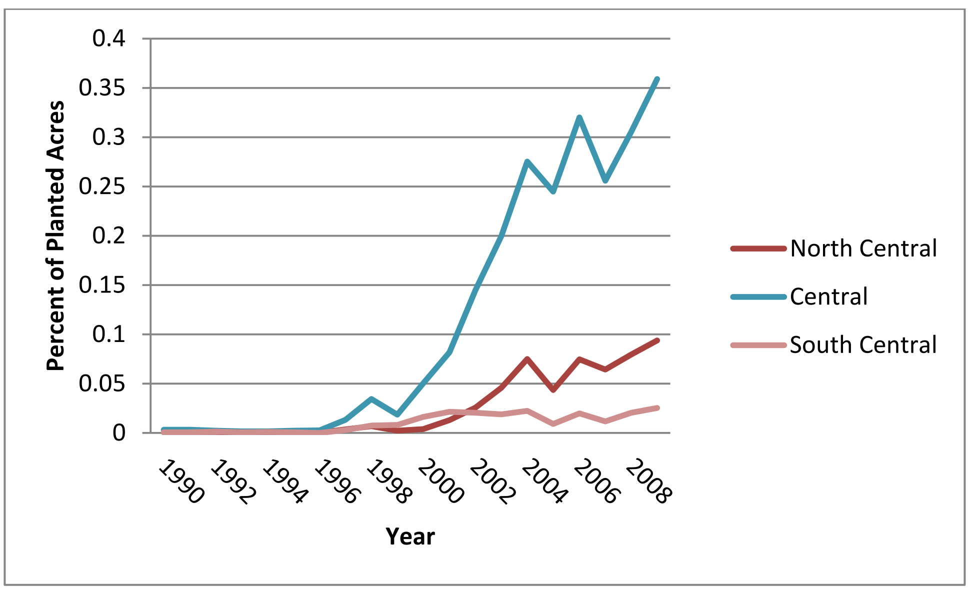

Figure 19 Percentage of Acres Planted to Soybeans in Central North Dakota 1990-2009

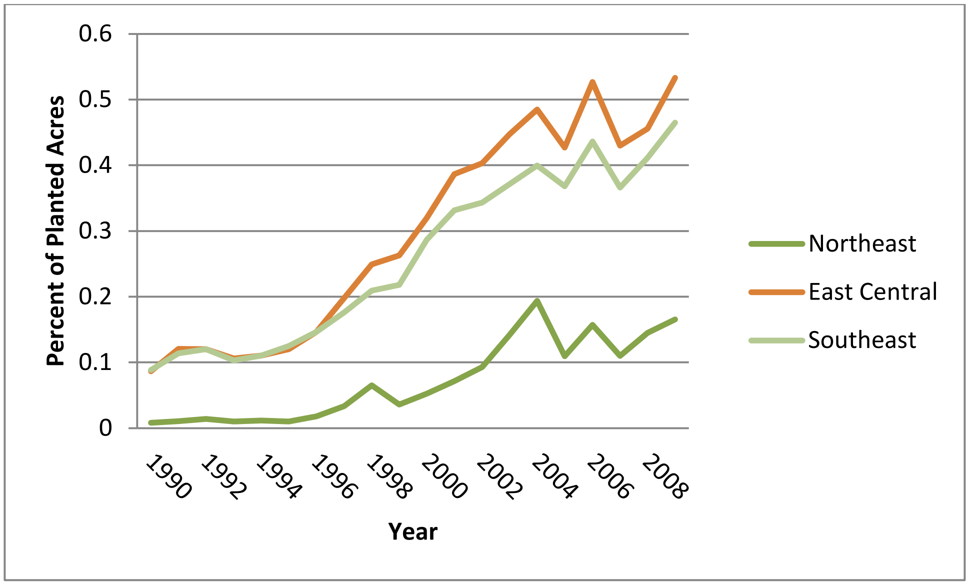

Figure 20 Percentage of Acres Planted to Soybeans in Eastern North Dakota 1990-2009

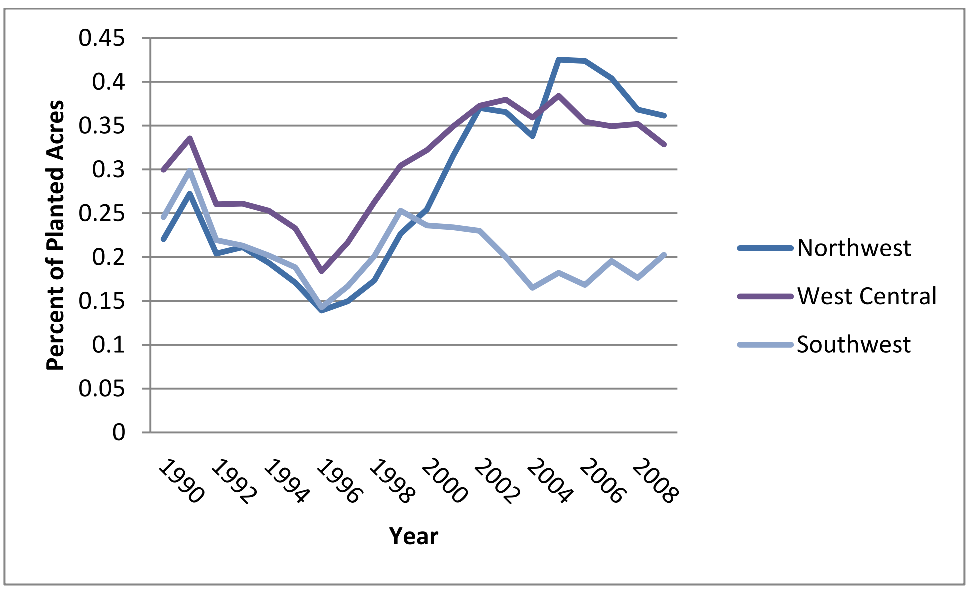

Figure 21 Percentage of Acres Planted to Other Commodities in Western North Dakota 1990-2009

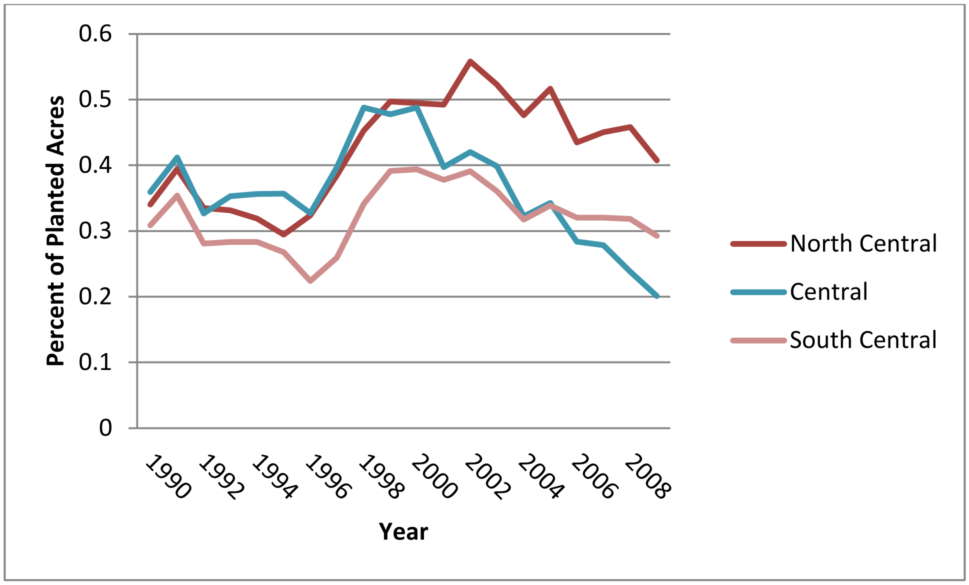

Figure 22 Percentage of Acres Planted to Other Commodities in Central North Dakota 1990-2009

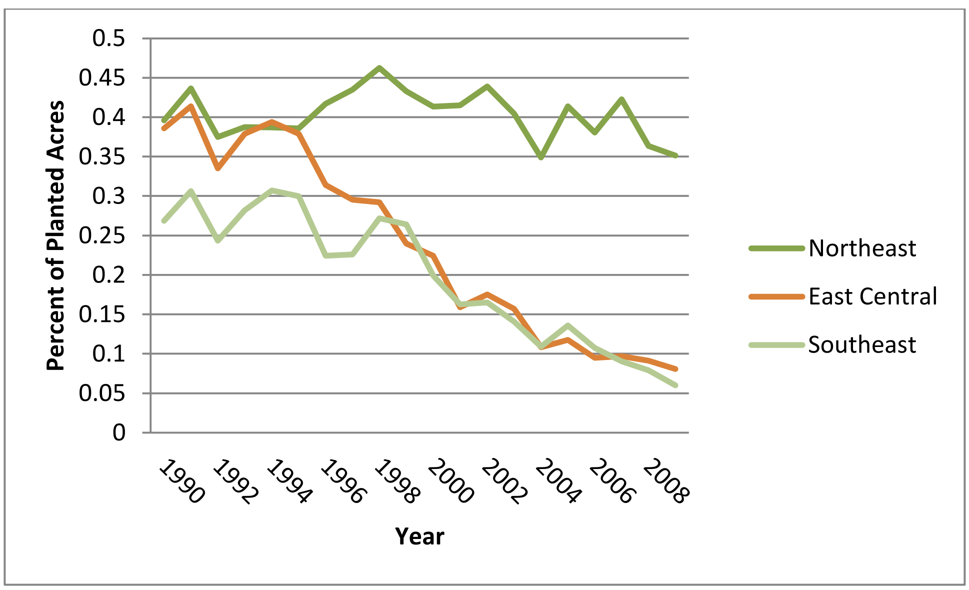

Figure 23 Percentage of Acres Planted to Other Commodities in Eastern North Dakota 1990-2009