Upper Great Plains Transportation Institute, North Dakota State University

An Assessment of County and Local Road Infrastructure Needs in North Dakota

Report submitted to
the 63rd North Dakota Legislative Assembly

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Preface: Presentation to the Budget Section of the North Dakota Legislature Bismarck, North Dakota - 9/20/12

I am Denver Tolliver, Director of the Upper Great Plains Transportation Institute of North Dakota State University. I am here today to present the results of the county and township road infrastructure needs study authorized by the legislature in Senate Bill 2325.

Before presenting the results of that study, I would like to briefly review the road infrastructure studies conducted by the Upper Great Plains Transportation Institute in 2010, which were presented to the legislature during the 2011 session. In doing so, I would like to provide a context for interpreting the results of the current study.

Review of January 2011 Studies and Changes

Two separate road infrastructure studies were completed by the Upper Great Plains Transportation Institute in the fall of 2010. The first study—which was initiated at the request of the Department of Commerce and the Oil and Gas Producing Counties—focused on the additional road infrastructure needs in western North Dakota as a result of recent oil development. The second and subsequent study—which was initiated at the request of a broad coalition of agricultural and local government groups—entailed a statewide analysis of the infrastructure needs of agricultural transportation routes and the county and township road system that supports commerce throughout the state. Both studies reflected 2010 conditions, traffic forecasts, and costs.

Collectively, these two studies described the road infrastructure needs for a 20-year planning horizon. The first study quantified the specific roadway investment needs attributable to the future growth of oil and gas industries in western North Dakota, while the second study reflected the baseline investment needs throughout the state for traditional industries and economic activities. These studies were not necessarily intended to be separate. This was simply a function of the varied timing and sources of the study requests.

In contrast, the study being described today is a comprehensive analysis of all needs of all county and township roads throughout the state, irrespective of which industries are served by these roads. The estimated needs reflect oil-related, agricultural, and other baseline traffic (e.g., manufactured goods and miscellaneous truck traffic)—all in one study. While the infrastructure needs are not attributed to specific industries, the results are presented separately for oil and gas producing counties and the rest of the state.

In the 2010 studies, the estimated needs for the 2012-2013 biennium for oil and gas producing counties was $356 million, $233 million of which consisted of the additional road infrastructure needs as a result of recent oil development. The estimated needs for the rest of state were $298 million, bringing the total estimate to $654 million for the 2012-2013 biennium. Again, these estimates were based on 2010 traffic forecasts and construction costs.

Since the 2010 studies were conducted, gravel costs have increased dramatically, especially in western North Dakota. For example, gravel costs have doubled in Mountrail and Ward Counties since the original studies were conducted and have increased by 150% in McKenzie County. The cost of class 27 hot bituminous pavement has increased by 43% statewide. The number of projected new oil wells during the 20-year analysis period has increased by 80% since the 2010 study. These factors need to be considered when comparing the results of the 2010 and 2012 studies, which are different in many respects. Before delving into the 2012 studies, the implementation of the 2010 study is discussed.

In the 2011 legislative session, the North Dakota legislature appropriated $142 million of new funding for county and township roads in oil and gas producing counties. All of these funds were allocated in a manner consistent with the needs identified in the 2010 study. As of last week, reimbursement claims have been filed for 85% of funds. All of the appropriated funds are expected to be expended by the end of this construction season for the purposes for which they were identified. The projects have provided major benefits for energy industries and citizens and were a critical step forward in building the road infrastructure necessary to sustain energy growth in North Dakota.

Comparison and Results of 2010 and 2012 Studies

The estimated results from the current study for the 2013-2014 biennium are: $521 million of road infrastructure needs in oil and gas producing counties and an overall total of $834 million of road infrastructure needs in all counties of the state. These needs relate specifically to county and township roads and represent a 46% increase in the estimated needs in oil and gas producing counties and a 28% increase in the overall estimated needs in all counties of the state from the 2012-2013 estimates presented in the 2010 studies.

As this comparison suggests, the estimated road infrastructure needs have increased at a lesser rate than highway construction costs and predicted oil traffic—i.e., the cost of gravel has doubled in some counties, the cost of surfacing has increased by 43%, and the number of new predicted wells is 81% greater than in the 2010 studies, yet the projected road infrastructure needs have increased by only 28%. There are several explanations for this apparent inconsistency. (1) The legislature appropriated $142 million and $76 million for county and township roads in two separate bills during the 2011 session. These appropriations have reduced the number of miles of road in poor condition and the number of miles that need reconstruction. (2) Road investment and maintenance needs do not necessarily increase in a linear manner with traffic. On paved roads, for example, we get more truck trips and axle loadings from the last inch of pavement than the first—i.e., there are economies of scale in pavement thickness.

Primary Data Sources and Methods

The current study uses the most current production forecasts, traffic estimates, and roadway condition data available. In September of 2011, traffic data were collected at 106 locations in western North Dakota. In addition, a special study of truck weights was conducted at the Williston weigh station. In addition to traffic data, more than 1,000 miles of paved County Major Collector routes in western North Dakota were evaluated in through field surveys. Condition assessments and detailed distress scores were developed for these segments. In addition, a series of paper surveys of county road managers has provided additional information on roadway conditions, graded roadway widths, construction and maintenance practices, and the costs of factors and inputs. The paved road construction costs used in the study reflect 2012 levels and were developed from costs provided by the NDDOT and counties.

The oil production forecasts have been provided by the Oil & Gas Division. Agricultural production forecasts utilize National Agricultural Statistics Service (NASS) data and are based on projected changes in land allocation among crops and yields per acre. The modeling process used in the study is summarized as follows:

- A detailed Geographic Information System (GIS) model of the entire state has been developed that includes the origins of inputs for oil production (e.g., fresh water, sand, scoria, and pipe), destinations for crude oil and saltwater shipments, and the capacities of each source or destination.
- Oil-related traffic is predicted for individual spacing units, while agricultural production is estimated at the township level. Both types of traffic are specifically forecast for each year of a 20-year analysis period.
- Oil-related inputs and products are routed to and from wells to minimize time and/or cost, subject to available supplies and capacities.
- The trips generated from each crop produced in each township are routed to elevators and/or processing plants to minimize cost, subject to the demands of these facilities.
- When all trips have been routed, the individual movements over each segment are summed to yield the total truck trips per year.
- Using truck characteristics and typical weights, these trips are converted to equivalent axle loads and trips per day.

An example of the resulting traffic forecast is shown below, for several of the most heavily impacted counties. In viewing this chart, it is important to note that we are starting from an elevated traffic level in 2012 that is much higher that the traffic level that existed in 2007, prior to the recent oil boom. Although truck traffic drops off later in the period, after much of the drilling has been completed, it only drops to the elevated 2012 levels. In this study, traffic is not predicted to return to the traditionally lower levels that existed prior to the recent oil boom.

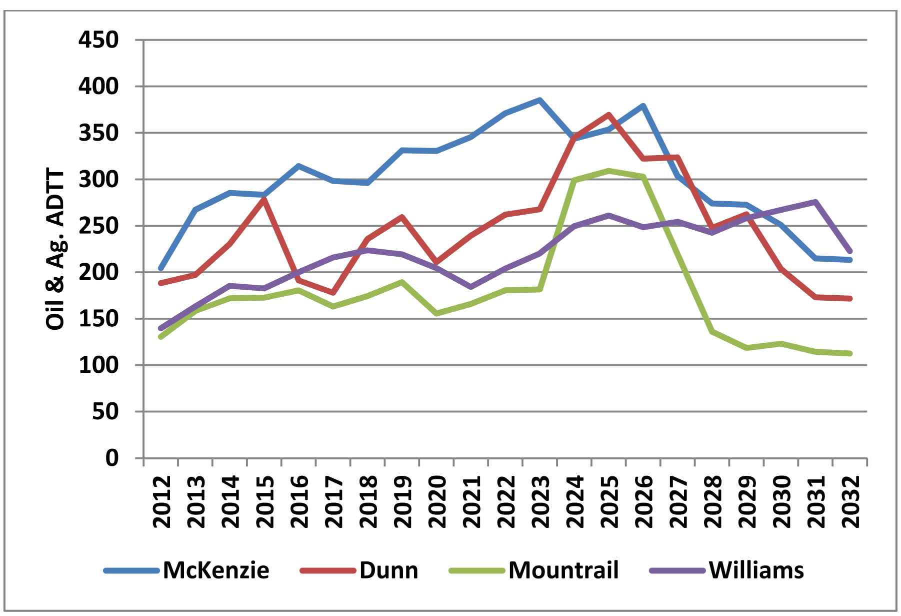

Illustration of Traffic Patterns in Heavily Impacted Areas

Analysis Models

Unpaved Road Analysis Procedures

The unpaved road analysis procedures are based on practices and costs from surveys of counties and townships. All counties in the state and roughly 130 townships responded to our surveys. The procedures are based on changes in the frequency of graveling and blading as truck traffic increases. As traffic increases, it is possible that some counties may consider alternatives to gravel surface roads, such as asphalt surfacing or base stabilization and armor coat treatments. As truck traffic reaches elevated and high levels, the costs of intermediate improvements (e.g., base stabilization and armor coating) may be comparable to the costs of more extensive graveling and blading.

In this study, we do not recommend particular treatments, as there is no consensus regarding the cost-effectiveness of these alternatives. Rather, we let the increased costs of more frequent graveling and blading serve as a proxy for other improvements that a county may elect to implement.

Paved Road Analysis Procedures

The paved road analysis procedures are the same ones used to analyze state highways. They are based on AASHTO procedures. The key factors are: (1) road structure; (2) current surface condition; (3) truck volumes, by type of truck; (4) truck loads and distribution of weights to axles; and (5) frequency and magnitude of overloads. The process is as follows: road condition is forecast for each year of the 20-year analysis period based on expected truck traffic until the condition reaches a critical level. Then, an improvement is simulated. The possible improvements are: (1) reconstruction, (2) resurfacing, and (3) resurfacing and widening. In the study, 92 miles are reconstructed and 414 miles are widened. Preservation and routine maintenance costs are included in the estimates.

Summary of Results

The results of the study are summarized below. Results for individual counties are presented in the main report.

By Funding Period and Region (millions of 2012 dollars)

Region	**2013-2014**	**2015-2016**	**2013-2032**
Oil Producing Counties	$521	$389	$3,484
Other Counties	$311	$382	$3,495
Total Statewide	$834	$772	$6,979

By Funding Period and Road Type (millions of 2012 dollars)

Road Type	**2013-2014**	**2015-2016**	**2013-2032**
Unpaved	$471	$471	$5,033
Paved	$363	$301	$1,946
Total Statewide	$834	$772	$6,979

Summary of Results

This report responds to the North Dakota legislature's request for a study of the transportation infrastructure needs of all county and township roads in the state. In this report, infrastructure needs are estimated using the most current production forecasts, traffic estimates, and roadway condition data available. Agricultural and oil-related traffic is modeled in detail at the sub-county level. Oil-related traffic is predicted for individual spacing units, whereas agricultural production is estimated at the township level.

A detailed Geographic Information System (GIS) model has been developed for the entire state that includes the origins of key inputs to the oil production process (e.g., fresh water, sand, scoria, and pipe), destinations for crude oil and saltwater shipments, and the capacities of each source or destination. The origins of movements on the highway network include railroad stations where sand, pipe, and other inputs are transferred from rail to truck. The destinations of crude oil shipments include refineries and railroad and pipeline transfer facilities. In the model, the estimated capacities of transfer sites are expressed in throughput volumes per day, while the capacities of material sources are expressed in quantities of supplies available during a given time period.

Using the GIS model, inputs and products are routed to and from wells to minimize time and/or cost, subject to available supplies and capacities. An analogous model is used to predict the trips of each crop produced in each township to elevators and/or processing plants, subject to the demands of these facilities. When all trips have been routed, the individual movements over each road segment are summed to yield the total truck trips per year. Using truck characteristics and typical weights, these trips are converted to equivalent axle loads and trips per day. These two factors, in conjunction with the condition ratings and structural characteristics of roads, are used to estimate the improvements and maintenance expenditures needed for the expected traffic. While the focus is on agricultural and oil-related activities, other movements (such as farm inputs and shipments of manufactured goods) are included in the analysis through the use of baseline estimates derived from previous surveys.

Projected Traffic Effects

As shown in Figure A, the average daily truck trips (ADTT) attributable to agricultural and oil-related traffic on county and local roads in McKenzie, Williams, Dunn, and Mountrail Counties (four of the most heavily impacted oil producing counties in the state) are projected to increase by 73%, 87%, 96%, and 137%, respectively, between 2012 and 2025. These impacts will not be uniformly distributed. Rather, they will be concentrated on specific roads. After 2025, truck traffic is expected to wane and approach 2012 levels again by the end of the analysis period (2032). These fluctuating trends result mostly from the timing and phasing of drilling operations, changes in the production rates of wells over time, and assumptions about the extent and pace of gathering pipeline construction. In this comparison, it is important to note that 2012 traffic levels represent much higher levels than existed prior to the rapid growth of oil traffic that started in 2008 and 2009. These elevated levels are projected to continue for the duration of the analysis period.

While McKenzie, Williams, Dunn, and Mountrail Counties are expected to see the largest traffic increases, most counties in the state will be impacted by growth in agricultural or energy-related traffic between 2012 and 2032. In many areas of the state, increased truck traffic will result from changes in agricultural production levels and practices and changes in the grain elevator system. The estimates presented in this study reflect projected increases in corn and soybean production and higher yields per acre, which result in more truck trips from a given land area. The concentration of traffic at shuttle train elevators is an important factor.

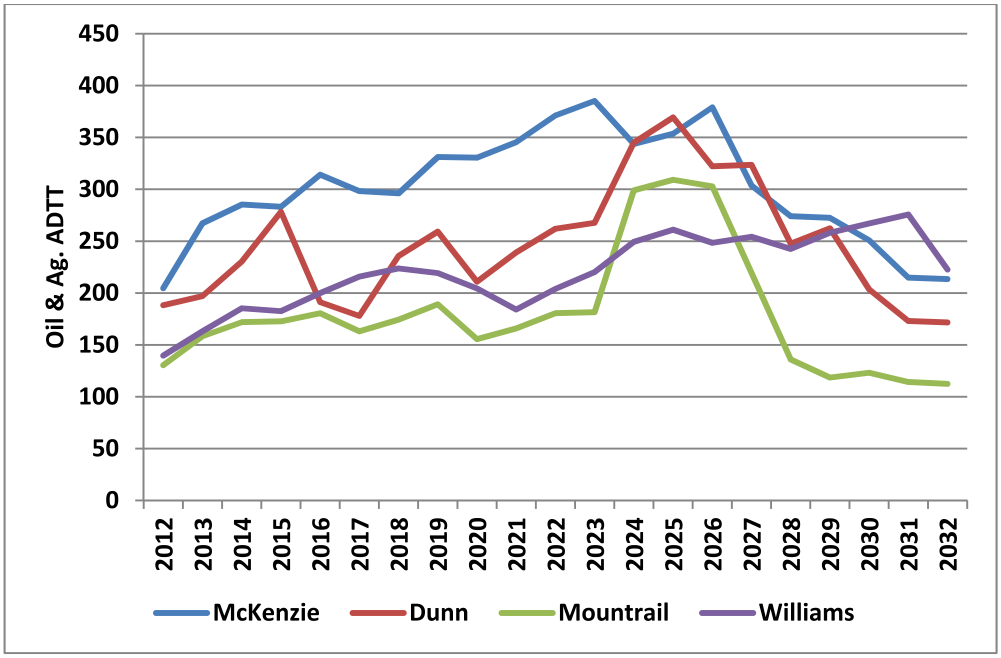

Figure A: Projected Trends in Average Daily Truck Trips for the Most Heavily Impacted North Dakota Counties

Unpaved Road Analysis

The following types of improvements to unpaved roads are analyzed in this study: increased graveling frequency, intermediate improvements, and asphalt surfacing. On heavily impacted gravel surface roads, the gravel interval decreases and the number of bladings per month increase as traffic grows. For example, a non-impacted road has an expected gravel cycle of 5 years and a blade interval of once per month, while an impacted section has an expected gravel cycle of 2 to 3 years and a blade interval of twice per month. The effective difference is a doubling of the gravel maintenance costs over the same time period.

As shown in Table A, the predicted statewide infrastructure needs are $5 billion for the next 20 years. Approximately 53% of these needs can be traced to the 17 oil and gas producing counties.

Paved Road Needs

As shown in Table B, $1.95 billion in paved road investment and maintenance expenditures will be needed during the next 20 years. Roughly 43% of these expenditures will be needed in the oil and gas producing counties of western North Dakota. Much of the investment ($363 million) will be needed during the next biennium, as a result of rapid growth in energy-related traffic and catch up expenditures in the oil patch.

Table A: Summary of Unpaved Road Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2012 Dollars)

	Region		
Period	**Oil Producing Counties**	**Rest of State**	**Statewide Total**
2013-2014	$243	$227	$471
2015-2016	$243	$227	$471
2017-2018	$255	$231	$486
2019-2020	$267	$234	$501
2021-2022	$267	$234	$501
2023-2032	$1,376	$1,228	$2,604
2013-2032	$2,652	$2,382	$5,033

* Results may not sum due to rounding.

Table B: Summary of Paved Road Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2012 Dollars)

	Region		
Period	**Oil Producing Counties**	**Rest of State**	**Statewide Total**
2013-2014	$278	$84	$363
2015-2016	$146	$155	$301
2017-2018	$111	$166	$277
2019-2020	$54	$145	$199
2021-2022	$43	$102	$146
2023-2032	$200	$460	$660
2013-2032	$832	$1,113	$1,946

* Results may not sum due to rounding.

As detailed in the report, a total of 92 miles of paved county and township roads in North Dakota must be reconstructed because of poor condition. Another 414 miles are candidates for widening. An additional 4,805 miles will need resurfacing during the next 20 years. Increased expenditures for preservation and maintenance will be needed to optimize the investments and preserve the lives of the pavements. Some of the segments that are candidates for widening may have to be reconstructed instead because of local conditions and widening constraints.

Roughly 7% of the expected infrastructure cost is due to reconstruction. Sixteen percent is attributable to widening. Resurfacing accounts for 47%. Another 30% is linked to routine maintenance. The infrastructure needs of County Major Collectors comprise 87% of the estimated need.

Total Statewide Needs

As shown in Table C, the combined estimate of infrastructure needs for all county and township roads is $7 billion over the next 20 years. Half of this estimate relates to projected needs in the oil and gas producing counties of western North Dakota. Unpaved road funding needs comprise approximately 72% of the total. If averaged over the next 20 years, the annualized infrastructure need is equivalent to $350 million per year. Much of this projected need ($834 million, or 12% of the 20-year total) falls in the 2013-2014 biennium.

The values shown in Tables A-C do not include the infrastructure needs of Indian Reservation roads, Forest Service roads, or city streets within municipal areas. The infrastructure needs of Indian Reservation roads are analyzed separately in the report and detailed results are presented for county and township roads.

Table C: Summary of All Road Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2012 Dollars)

	Region		
Period	**Oil Producing Counties**	**Rest of State**	**Statewide Total**
2013-2014	$521	$311	$834
2015-2016	$389	$382	$772
2017-2018	$366	$397	$763
2019-2020	$321	$379	$700
2021-2022	$310	$336	$647
2023-2032	$1,576	$1,688	$3,264
2013-2032	$3,484	$3,495	$6,979

* Results may not sum due to rounding.

Comparison to 2010 Studies

Two studies of county and township road infrastructure needs were presented to the North Dakota legislature in January of 2011. In those studies, the additional infrastructure needs due to oil development were estimated separately from the baseline infrastructure costs necessary to support agricultural logistics and other traffic. Together, those estimates totaled $669 million for the 2013-2014 biennium. However, the estimates in the January 2011 studies were based on 2010 construction costs and significantly lower estimates of the number of new wells drilled during the analysis period. The projected number of new wells has risen by roughly 80% since the 2010 studies were conducted, while highway construction costs per mile have increased substantially. Collectively, these changes explain the higher estimates of road infrastructure needs for the 2013-2014 biennium presented in this study.

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1. Overview of Study

In Senate Bill 2325, the Upper Great Plains Transportation Institute (UGPTI) was directed by the North Dakota legislature to analyze "the transportation infrastructure needs of all county and township roads in the state." This effort includes an update of information presented to the legislature during the 2011 session.

In 2010, under the direction of the Governor, UGPTI estimated the additional county and local road investment needs in western North Dakota as a result of rapid growth in oil production. [1] The oil study was quickly followed by an analysis of the investments needed to facilitate agricultural logistics.[2] The results of both studies were presented to the legislature in January of 2011.

This study extends and updates the 2011 studies. It combines the effects of agricultural- and oil-related traffic and other economic activities on county and local roads, using the most current production forecasts and traffic and roadway condition data.

2. Data Sources

The primary sources of data for this study include: (1) traffic counts taken in high impact areas, (2) roadway condition assessments and survey data, (3) localized agriculture and oil production forecasts, (4) forecasts of input supplies at specific locations, (5) transfer sites and capacities, (6) markets for intermediate and final products, and (7) vehicle weights and transportation costs.

2.1 Traffic Data

Traffic was counted and classified in western North Dakota in September of 2011 at 106 locations, primarily on County Major Collector (CMC) routes. Road segments in 15 of the 17 oil producing counties were included in the sample, which focused on high volume oil routes. Count locations were based on the 2010 oil impact study as well as survey maps provided by county road managers. As shown in Table 1:

- The observed trips exceeded 255 vehicles per day at half of the 106 sites in the survey
- The average traffic level surpassed 1,000 vehicles per day at 5% of the locations
- The median ratio of trucks to total vehicles was 30%
- The percentage of trucks topped 40% at three-fourths of the locations sampled

For comparative purposes, the ratios of trucks on collector highways in the state system are shown in the last column of Table 1. As the column shows, the median percentage of trucks is 14% on rural collector highways maintained by the North Dakota Department of Transportation. In comparison, the heavily impacted county roads included in the oilfield survey have higher percentages of trucks

[1] Tolliver, D. and A. Dybing. "Additional Road Investments Needed to Support Oil and Gas Production and Distribution in North Dakota," Upper Great Plains Transportation Institute, Dec. 2010; http://www.ugpti.org/resources/reports/details.php?id=o6.
[2] Tolliver, D. and A. Dybing. "Rural Road Investment Needs to Support Agricultural Logistics and Economic Development in North Dakota," Upper Great Plains Transportation Institute, Dec. 2010; http://www.ugpti.org/resources/reports/details.php?id=o7.

than rural collector highways throughout the state. Such high truck volumes on county roads were rare prior to the oil boom.

Table 1: Summary of Traffic Data Collected in Western North Dakota Compared to Truck Traffic on State Rural Collector Highways

Percentiles	Average Daily Trips (ADT) on County Oil Routes	Percent Trucks	
		County Roads in Oil Patch	State Rural Collectors
Maximum	2,305	79%	55%
95th	1,069	59%	42%
90th	932	52%	32%
75th	548	41%	19%
Median	256	30%	14%
25th	128	19%	9%
10th	63	15%	8%

2.2 Road Condition Data

Road condition information was collected using two methods: (1) a survey instrument and (2) independent condition assessments. The survey was sent to all counties outside of the oil producing region. In the survey, county road supervisors or engineers were asked to identify the surface types of roads and rank their conditions on a 1 to 5 scale, with 1 representing excellent. Guidelines on scoring were given to the respondents with the intent of minimizing subjective condition scoring. Non-respondents were contacted via telephone, and if still no response, UGPTI staff collected condition data for the paved roads in that county.

In oil producing counties, a data collection method similar to the one used in the 2010 study was employed. In order to validate survey responses and compile current condition information, an independent consultant was hired to conduct assessments of more than 1,000 miles of paved CMC routes in western North Dakota. Conditions were assessed using a 100 point deduct scoring method, which is consistent with the method used by the North Dakota Department of Transportation. A sample scoring sheet can be found in Appendix A. The end result of the two efforts was a population dataset of county road conditions with every mile of paved road rated by condition. Roughly 40% of the paved road miles have condition ratings of 3 or greater, meaning that these roads are in fair or poor condition.

2.3 Graded Width

Information on graded roadway width was collected through surveys and visual verification. This information is important because the width determines whether a structural overlay is feasible or more costly improvements are necessary. A structural overlay may not be feasible if the increased elevation of the road following resurfacing results in a significant reduction in pavement width.

As shown in Table 2, 42% of all miles of county and local paved roads in North Dakota could not accommodate a thick overlay without a loss of lane and/or shoulder width. The problem is worse in oil and gas producing counties, where 53% of roadway miles cannot accommodate a structural overlay without widening.

Table 2: Miles of County and Local Paved Road with Sufficient Widths to Accommodate Thick Overlays without Significant Losses of Pavement Width

Oil and Gas Producing Counties	47%
Other Counties	62%
All Counties	58%

Note that many of the miles of road deemed insufficient may be able to accommodate a thin overlay before they are widened. In fact, many of the segments with lower traffic densities may not need to be widened during the next 20 years. Only those segments with the highest traffic levels (that require a thick overlay) must be widened. The remaining segments will eventually have to be widened (after 2032) at the time of the second overlay.

2.4 Cost Data

A cost and practices survey was sent to each of the 53 counties in North Dakota. The purpose of the survey was to determine component costs and existing maintenance and improvement practices. Cost factors include the cost of gravel, trucking, placement, blading, and dust suppressant. Maintenance practices include information on gravel overlay intervals, regraveling thickness, blading intervals, and dust suppressant usage, as well as asphalt overlay frequency. Oil producing counties were asked to specify the differences in maintenance between oil-impacted and non-impacted roads. The survey and instructions are presented in Appendix B.

Paved road improvement costs were obtained from the North Dakota Department of Transportation (NDDOT) and include costs for reconstruction, resurfacing, and widening. Some adjustments were made for differences in terrain and operating conditions in western North Dakota versus the rest of the state. Many of these adjustments came from discussions with county road officials. A reconstruction cost of $1.5 million per mile for two-lane rural roads is used to estimate improvement costs in western North Dakota, where higher frequencies of trucks and specialized vehicles result in the need for wider shoulders and/or turning lanes and rolling terrain affects construction costs. A cost of $1.25 million per mile is used for reconstruction in the remainder of the state.

All paving and reconstruction costs presented in this study include preliminary engineering and construction engineering costs. Preliminary engineering costs typically range from 5% to 10% of the bid price, while construction engineering is approximately 15% of the price.

2.5 Agricultural Data

2.5.1 Spatial Location Data

The base unit of production used in the agricultural model is the township, or county subdivision. Township shapefiles were obtained from the North Dakota Geographic Information System (GIS) Hub. However, organized townships do not exist in all North Dakota counties. Townships were selected for use as a geographic and not an organizational boundary. Where unorganized townships exist, a placeholder boundary was created to represent a geographic area similar in size to a township.

2.5.2 Production Data

Crop production data by county was obtained from the National Agricultural Statistics Service (NASS) website. This data provides the number of acres planted and harvested, as well as yields and total production by county, crop, and production practice. The most current data available at the time of the analysis was from 2010. County level data is not sufficient for use in a traffic model as it is too aggregated to accurately assign traffic to individual roadways, especially at the county level. To further disaggregate this data, the United States Department of Agriculture's (USDA) Crop Data Layer (CDL) was utilized.

The CDL is essentially a satellite image of land use in North Dakota, with individual crop types represented by different colors. Each pixel of the image represents a 30 meter by 30 meter area. Used in conjunction with GIS software packages, the CDL provides data regarding the total number of acres of each crop produced in each county subdivision. In this study, the acreage data was aggregated to the county level and compared against known NASS data for accuracy. Analysis using the CDL is precise with respect to geographic area, but is only a snapshot of production in time and does not provide production data (e.g., bushels or pounds harvested).

In this study, NASS county level data is used to approximate sub-county level yield and production rates. For example, if a township is located within Barnes County, the Barnes County average wheat yield is used to approximate the actual township yield. The end result of these processes is the total production by crop for each township in the state of North Dakota. For use in traffic forecasting, township crop production estimates are converted to truck trips, based on each commodity's weight and density.

2.5.3 Market Demands

Demand points for grain within the state include elevators, processors, and ethanol facilities. Elevator locations were obtained from a shapefile maintained by UGPTI, which was compared against the North Dakota Public Service Commission's (NDPSC) licensed elevator report. Throughput information was obtained from the NDPSC Grain Movement Database, which provides the quantity of each commodity shipped through an elevator by mode and destination.

A list of processors and ethanol facilities was obtained from the North Dakota Department of Agriculture. Demand volumes for each ethanol facility were obtained from the Renewable Fuels Association website, and were based upon output capacities at the facilities.

2.6 Oil Data

2.6.1 Spatial Location Data

The base unit of production used in the oil model is the spacing unit. A spacing unit is typically a one mile by two mile geographic area, although exceptions exist. For the purpose of this study the 1,280 acre spacing unit was utilized. GIS shapefiles of oil spacing units were obtained from the Oil & Gas Division of the North Dakota Industrial Commission.

2.6.2 Drilling-Related Movements

Data on the number of trucks by type were compiled from input provided by the North Dakota Department of Transportation, and the Oil & Gas Division. As shown in Table 3, the total number of truck movements is estimated to be 2,300 per well, with approximately half of them representing loaded trips.

Locations for each of these input sources were geocoded for use in the GIS routing model. Sand and pipe transload locations were obtained from the NDDOT, discussions with county road managers, railroad company websites, and visual examination of satellite imagery. Freshwater sources were obtained from the North Dakota State Water Commission, including capacity information. In addition to existing freshwater sources, water depot locations and expected opening dates were obtained from the Western Area Water Authority.

2.6.3 Production Related Movements

Outbound movements include crude oil shipments to transload facilities and saltwater movements to disposal wells. Crude oil may be transported to refineries, rail transload facilities, or pipeline transload facilities. Locations for rail transload facilities were obtained from the NDDOT, BNSF Railway and CP Railway websites, and websites for individual transload facilities. To ensure that no locations were omitted, the track was visually inspected using Google Earth throughout the entire oil patch. Pipeline locations were obtained from the North Dakota Pipeline Authority, and verified through individual pipeline company websites, maps and posted tariffs.

Table 3: Drilling Related Truck Movements

Item	**Number of Trucks**	**Inbound or Outbound**
Sand	100	Inbound
Water (Fresh)	450	Inbound
Water (Waste)	225	Outbound
Frac Tanks	115	Both
Rig Equipment	65	Both
Drilling Mud	50	Inbound
Chemical	5	Inbound
Cement	20	Inbound
Pipe	15	Inbound
Scoria/Gravel	80	Inbound
Fuel trucks	7	Inbound
Frac/cement pumper trucks	15	Inbound
Workover rigs	3	Both
Total – One Direction	1,150	
Total Truck Trips	**2,300**	

The county average initial production (IP) rate was used to approximate the IP at individual well sites, and was obtained from the Oil & Gas Division. The production curve for Bakken wells was used to represent annual production levels, beginning with the county average IP rate. The curve represents a steep decline in production in the first two years of production, with decreases occurring at a decreasing rate thereafter. Saltwater production is estimated using an average ratio of 2 barrels of oil to 1 barrel of salt water. Saltwater disposal locations were obtained from the Oil & Gas Division GIS server.

Outbound movements of oil may be transported by either truck or small diameter pipe to the transload facility. Data on transportation modes for existing wells was obtained from the Oil & Gas Division. With respect to future wells, discussions with the Oil & Gas Division resulted in the assumption that three-fourths of new wells would be connected to pipelines for transport to transload facilities within three years of drilling. There are obvious exceptions to this rule, as pad drilling techniques may place multiple wells in service within a small geographic area in a short timeframe, thereby increasing the likelihood of collector pipeline usage to minimize transportation cost. However, this technology is not being used throughout the entire oil patch, and the original assumption should be sufficient to describe the impacts of crude oil transportation on county and local roads.

2.6.4 Existing and Forecasted Well Locations and Production

Existing producing well locations were obtained from the Oil & Gas Division GIS Server. Each well was classified by the completion date, which indicates when it would likely have gone into production. The production curve described above was used to estimate current production on previously completed wells. The mode of outbound transport by year was chosen using the procedures mentioned above.

3. Network Assignment Methodology

Two groups of models are used in this study to individually estimate traffic generated by agricultural- and oil-related movements. Both groups of models operate under the same methodology, but as forecasting and locations change based upon commodity movements, each model will be discussed in detail. The results of these two sets of models are aggregated to the segment level, which provides a total traffic estimate and a forecast for individual segments.

3.1 Agriculture Model Group

The agriculture model features the integration of three 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; and (3) a traffic model in which predicted flows are assigned to individual road segments. Models 1 and 3 are based on 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.

This study utilizes a GIS based optimization model. Each individual movement is routed to a destination satisfying site specific demands within constrained capacities, while minimizing overall distribution cost. Agricultural and oil related movements are modeled separately, and the results aggregated to the road segment level.

3.1.1 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.[3] USDA's 2010 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 2010 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 5% of the total cultivated acres in a county devoted to barley production lies within a certain township, this subdivision is assumed to produce 5% 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.

3.1.2 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.

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

Nonetheless, the demands for crops at specific locations are known with high levels of confidence overall.

3.1.3 Network Representation of Crop Distribution System

The network 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.

3.1.3.1 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 1. 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.

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.

3.1.3.2 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.[4] Because there are more than 150,000 unique road segments in the North Dakota GIS file, the input files are enormous and require extensive computing time. However, in the final analysis, flows are accumulated by individual road segments—which allow for greater detail in the roadway investment analysis.

[4] 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.

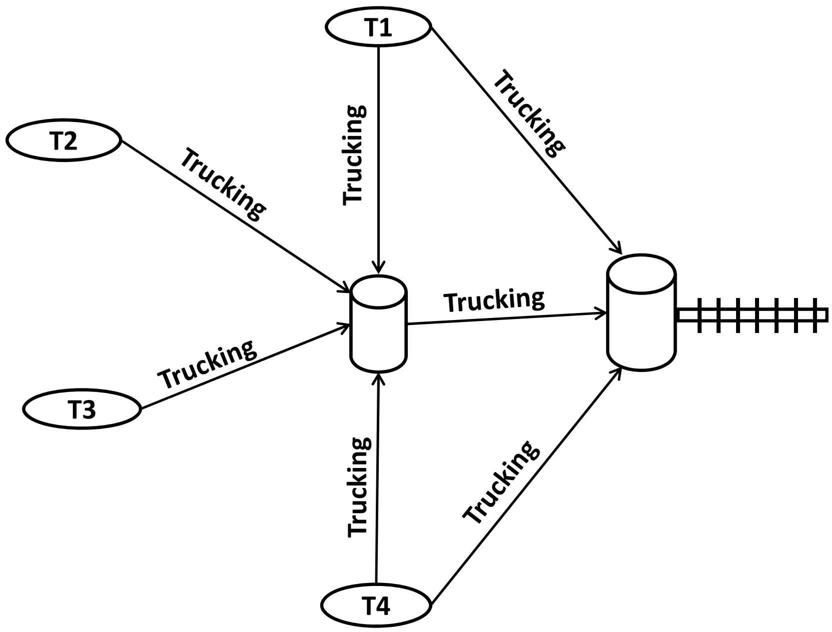

Figure 1: Crop Flows in Elevator Network

3.1.4 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.[5]

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 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.

[5] The shortest-path algorithm yields slightly shorter trip distances than the fastest-path algorithm—i.e., less than 2% on average. Thus, the selection of one method over the other does not significantly affect the results.

3.1.4.1 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.[6]

3.1.4.2 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 ships the commodity out of state.

3.1.4.3 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 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.

3.1.4.4 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

[6] 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.

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.

3.2 Oil Model Group

The oil model utilizes three main models (1) an oil forecasting and location model; (2) an oil-related trip distribution model, in which movements or flows are predicted from input sources to spacing units, and from spacing units to oil collection and saltwater disposal sites; and (3) a traffic model in which predicted flows are assigned to individual road segments. The results of these models are combined with the results of the agricultural model to estimate truck trips generated on individual segments of county and local roadways for use in the investment analysis.

3.2.1 Oil Forecasting and Location Model

Forecasts of future oil development were obtained from the Oil & Gas Division. Over the long term, the total number of wells in the forecast is expected to grow to roughly 46,000, which represents approximately 32,000 additional wells at the time of this writing. However, forecasts do not include future well locations. To forecast future well locations, a probabilistic method (a maximum likelihood algorithm) was developed. This allocation model integrates spatial and non-spatial factors to predict likely drilling locations for each spacing unit. The maximum likelihood estimate for each spacing unit considers factors such as the number of existing wells within the spacing unit, the age of the lease in the spacing unit, proximity to existing wells, proximity to input sources, and proximity to destinations. For each year of the analysis, the maximum likelihood was calculated for each spacing unit, and then sorted in descending order. For each year, the spacing units with the maximum likelihood were selected as the next drilling sites subject to the upper bound constraint of new wells per year as provided by the Oil & Gas Division. In subsequent years, the well numbers and likelihood factors were updated, new ratios calculated, and wells distributed.

3.2.2 Network Routing Algorithm

Route generation provides the links between all possible origins and all possible destinations. Each spacing unit was connected to each of the origin and destination locations for future use in the network optimization models. Connection of each potential origin and destination is done for two reasons. The first is to avoid arbitrarily designating the maximum distance which shipments may travel. Secondly, due to the capacity limitations placed on freshwater and oil collection facilities in the optimization models, complete connectivity of origins and demands are critical.

The ESRI ArcMap Network Analyst software is used to generate the optimal routes between origins and potential destinations[7]. In this study, the purpose of routing is to identify the least cost routes between an origin and multiple destinations for use as arc costs in a distribution optimization model.

Using this method, each origin will be connected to each potential destination. The set of origins and destinations are not fixed throughout the entire analysis, as drilling locations will change from year to year, and additional locations will be added to the network as time progresses. For example, the base set of oil collection facilities is expected to expand between 2012 and 2015 as additional capacity is introduced. Moreover, as additional freshwater depots in the Western Area Water Authority enter into operation, they are included as potential input sources during the year they are projected to open through subsequent analysis years.

3.2.3 Trip Distribution Model

The trip distribution model utilized a mathematical programming model to minimize the travel time for the distribution of oil-related inputs and production. Individual trip classes are shown in Figure 2. Inputs to the drilling process include sand, freshwater, gravel, supply, equipment, and pipe movements from their respective origins to each spacing unit in the state. Outbound flows consist of crude oil movements to collection facilities and movements of saltwater to disposal sites.

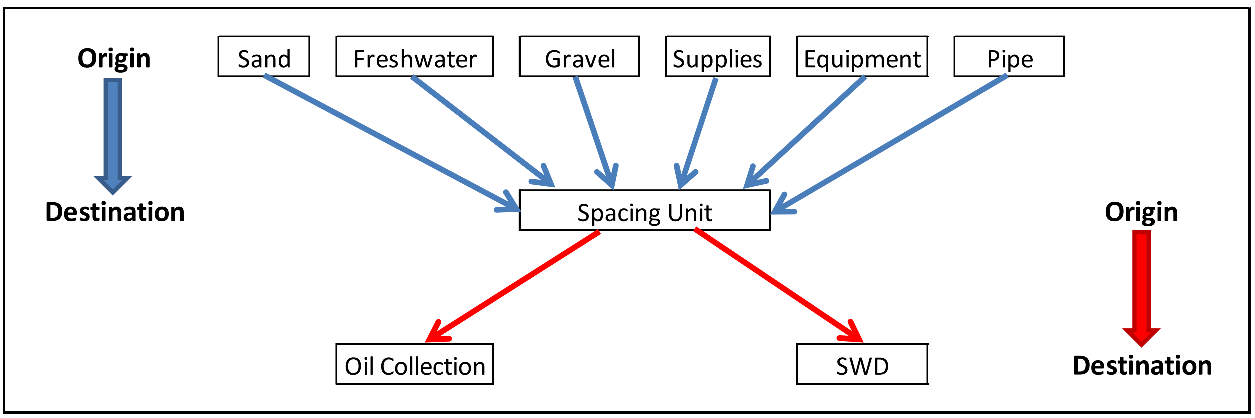

Figure 2. Trip classes included in distribution model

Assignment of routes for individual truck movements was completed using a constrained optimization model. Each spacing unit has multiple origins from which inputs may be sourced, yet only one will be chosen. Assignment of origin-destination pairs assumes that the source movement is an all-or-nothing assignment.

The objective of the oil development distribution model is to minimize the total cost of moving six inputs and two outputs from input origins and output destinations, subject to the following constraints: the demands at the township well sites, the supply capacities at input origin locations, handling capacities at destination locations, and the number of trucks on a route must be greater than or equal to zero. The model is estimated 21 times in total to optimize distribution from years 2011 through 2032.

[7] Network Analyst utilizes Dijkstra's algorithm to select the least cost path between an origin and multiple destinations.

The distribution model assigns truck movements to individual routes. An individual segment of the state highway system may theoretically be included in each route that was chosen. For this reason, the selected routes must be disaggregated to component highway segments in order to assign the traffic flows to individual segments. Traffic flows from the agricultural and oil models were combined and then aggregated to the segment level, thus producing a segment level estimate of traffic volumes.

4. County and Township Road Investment Analysis

This section of the report outlines the methods used to quantify road investment needs and presents the results of the study. It is divided into two main sections, corresponding to paved and unpaved roads.

4.1 Paved Road Analysis

The paved road analysis follows the approach used in the 2010 studies. For the most part, the same methods and models used to analyze state highways are applied to county and local roads. However, the inputs and assumptions reflect the unique characteristics of these roads.

More than 5,600 miles of paved county and local roads (exclusive of city streets) are traveled by agricultural and oil related traffic and other highway users. Some of these roads are under the jurisdiction of governments or agencies other than counties, such as townships, municipal governments, the Bureau of Indian Affairs (BIA), and the Forest Service. City streets and Forest Service roads are excluded from the study.[8] BIA and tribal roads are included, but the results are presented separately from county and township roads.

In addition to miles of road and forecasted traffic levels, the key factors that influence paved road investments are: the number of trucks that travel the road, the types of trucks and axle configurations used to haul inputs and products, the structural characteristics of the road, the width of the road, and the current surface condition. The primary indicator of a truck's impact is its composite axle load—which, in turn, is a function of the number of axles, the type of axle (e.g., single, double, or triple), and the weight distribution to the axle units.

4.1.1 Trucks Axle Weights

The pavement design equations of the American Association of State Highway and Transportation Officials (AASHTO) are used to analyze paved road 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.

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. For example, a 16,000-pound single axle followed by a

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[8] Investments in city streets primarily reflect access to commercial and residential properties and include the costs of parking and traffic control devices. This does not mean that city streets are unaffected by truck traffic. However, the specific focus of this study is county and township roads.

20,000-pound single axle generates a total of 2.19 ESALs, as compared to 2.0 ESALs for the passage of two 18,000-pound single axles.[9] 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.

4.1.2 Trucks Used to Haul Oil Products and Inputs

The forecasted trips for each type of load moving to and from well sites were shown earlier in Table 3. The characteristics of these trips are depicted in Table 4. Specifically, the number of axles in the truck, the weight per axle group (in kilopounds or kips), and the ESALs are shown.

For example, the truck used to transport a derrick has six axles positioned in three distinct groups, plus a single steering axle, for a total of seven axles. The first axle group (other than the steering axle) is a tandem set weighing 45,000 pounds. The second group is a three-axle set weighing 60,000 pounds. The third group is a tandem axle weighing 42,000 pounds. The ESAL factors for the three axle groups are 3.58, 2.48, and 2.49, respectively. The ESAL factor of the steering axle (which weighs 12,000 pounds) is 0.23. In total, the truck weighs 159,000 pounds with an ESAL factor of 8.78.

The heaviest weights and highest ESAL factors are generated by the indivisible loads listed in the first part of Table 4. These vehicles (which exceed the maximum vehicle weight limit) travel under special permits. In comparison, a truck used to transport sand while complying with Bridge Formula B weighs 76,000 pounds and generates an ESAL factor of 2.24. Nevertheless, based on enforcement data from the North Dakota Highway Patrol and the results of special studies at truck weigh stations, it has been estimated that 25% of these trucks are overloaded. The typical overloaded vehicle weighs 90,000 pounds with an ESAL factor of 3.78 (instead of 2.24).

In the analysis, 75% of the trips for this type of truck are assumed to be legally loaded and 25% are assumed to be overloaded. A similar assumption is made for movements of fresh water. The estimated ESAL factor for movements of crude oil in 5-axle tanker trucks is 2.42. These tank trailers are designed for transporting oil at the 80,000 pound weight limit.

4.1.3 Trucks Used to Haul Grains and Farm Products

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 5, approximately 56% of the inbound volume is transported to elevators in five-axle tractor-semitrailer trucks. Another 4% arrives in double trailer trucks—e.g., Rocky Mountain Doubles. Another 12% to 13% arrives in four-axle trucks equipped with triple or tridem rear axles.

[9] These calculations reflect a light pavement section with a structural number of 2.0 and a terminal serviceability (PSR) of 2.0.

Table 4:Axle and Vehicle Weights and Equivalent Single Axle Loads for Drilling Related Truck Movements to and From Oil Wells

	Steering Axle			Axle Group 1			Axle Group 2			Axle Group 3			Axle Group 4			Vehicle Total	
Load Type	**Axles**	**Kips**	**ESALs**	**Axles**	**Kips**	**ESALs**	**Axles**	**Kips**	**ESALs**	**Axles**	**Kips**	**ESALs**	**Axles**	**Kips**	**ESALs**	**Kips**	**ESALs**
Generator House	1	12.7	0.40	3	54.7	1.90	4	59.4	6.08	2	33.4	1.11				160.2	9.49
Crown Section	1	15.0	0.65	2	45.0	3.58	2	45.0	3.58	2	35.0	1.38				140.0	9.19
Shaker Tank/Pit	1	14.1	0.65	3	51.6	1.44	4	54.0	4.00	2	23.0	0.32				142.7	6.40
Derrick	1	12.0	0.23	2	45.0	3.58	3	60.0	2.48	2	42.0	2.49				159.0	8.78
Suction Tank	1	11.8	0.23	3	42.1	0.78	3	49.6	1.24	1	17.1	1.00				120.6	3.25
VFD House	1	13.9	0.40	3	54.7	1.90	3	45.8	0.92	2	27.8	0.55	1	12.7	0.40	154.9	4.16
Mud Pump	1	12.9	0.40	3	54.3	1.90	3	56.5	2.17	2	37.2	1.69	1	5.0	0.02	165.9	6.18
Mud Boat	1	16.0	0.65	2	40.0	2.06	3	60.0	2.48	0	0.0					116.0	5.19
Shaker Skid	1	12.0	0.23	2	45.0	3.58	3	54.8	1.90	0	0.0					111.8	5.71
Substructure, Centerpiece, etc.	1	14.0	0.40	3	43.4	0.78	2	45.3	3.58	2	32.6	1.11	1	25.3	4.31	160.6	10.18
Draw Works	1	14.4	0.40	3	58.0	2.17	3	59.0	2.48	2	36.0	1.38				167.4	6.43
Hydraulic Unit	1	16.0	0.65	2	28.0	0.55	2	26.0	0.42	3	60.0	2.48				130.0	4.09
Choke Manifold	1	14.0	0.40	2	41.8	2.49	2	39.5	2.06	1	19.8	1.49	1	4.0	0.00	119.1	6.44
MCC House	1	18.0	1.00	3	58.5	2.48	3	58.5	2.48	2	39.0	2.06				174.0	8.02
Tool Room, Junk Box, etc.	1	12.0	0.23	2	45.0	3.58	3	60.0	2.48	0	0.0					117.0	6.29
Screen House	1	13.0	0.40	4	56.0	4.98	4	56.5	4.98	2	33.0	1.11				158.5	11.46
Light Plant	1	14.0	0.40	4	58.0	6.08	4	66.0	8.83	2	32.0	0.89				170.0	16.20
Mud Tank	1	13.0	0.40	3	47.5	1.07	4	58.8	6.08	1	19.5	1.49				138.8	9.04
Workover Rigs	2	45.0	3.58	3	60.0	2.48										105.0	6.06
Fresh Water Unpermitted Overloads[1]	1	14.0	0.40	3	38.0	0.46	2	19.0	0.16	2	19.0	0.16				90.0	1.18
Fresh Water Legal Loads [2]	1	10.0	0.12	3	33.0	0.31	2	16.5	0.11	2	16.5	0.11				76.0	0.64
Fresh Water Empty Return Loads	1	6.0	0.02	3	14.0	0.01	2	9.0	0.01	2	9.0	0.01				38.0	0.05
Sand Unpermitted Overloads[1]	1	14.0	0.40	2	38.0	1.69	2	38.0	1.69							90.0	3.78
Sand Legal Loads[2]	1	10.0	0.02	2	33.0	1.11	2	33.0	1.11							76.0	2.24
Sand Empty Return Loads	1	6.0	0.00	2	16.0	0.07	2	16.0	0.07							38.0	0.14

1. 25% of Loads @ 90 kips
2. 75% of Loads @ 76 kips

Table 5: 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%

After considering entries in the "other" category, the following assumptions have been made. Sixty-two percent of the grains and oilseeds delivered to elevators in North Dakota are expected to arrive in combination trucks, as typified by the five-axle tractor-semitrailer. The remaining 38% is expected to arrive in single-unit trucks, typified by the three-axle truck. The impact factor for grain movements in tractor-semitrailers is 2.7 ESAL per *front-haul* mile, which includes the loaded and empty trips. In comparison, the impact factor for a single-unit truck is 1.5 ESALs per mile. Nevertheless, the ESAL factors per ton-mile are roughly the same for both trucks, given the differences in payload.

4.1.4 Surface Conditions

As noted earlier, the road condition information used in this study was derived from field data and surveys. The conditions of more than 1,000 miles of paved CMC routes in western North Dakota were assessed using a 0 to 100 distress scale developed by the North Dakota Department of Transportation (NDDOT).[10] The field distress scores were converted to the Present Serviceability Rating (PSR), a 0 to 5 scale used in the pavement model. In other counties, road supervisors or engineers rated surface conditions using an ordinal scale ranging from 1 to 5. These scores were subsequently converted to PSR values. The end result is a comprehensive dataset of paved county road conditions in North Dakota with every mile of road rated according to condition.

The results of the condition assessment are summarized in Table 6, which shows that 14% of paved county and township road miles are in excellent condition, meaning they have recently been improved.[11] This group includes 244 miles of improvements in western North Dakota funded by a 2011 appropriation from the North Dakota legislature. As shown in Table 6, another 47% of paved road miles are in good condition; 30% are in fair condition. Only 8% of paved road miles are rated as poor. Road condition ratings for each county are shown in Appendix C.

Table 6: Conditions of Paved County and Township Roads in North Dakota in 2012

Condition	Miles	Percent
Very Good	732	14%
Good	2,512	47%
Fair	1,634	31%
Poor	436	8%
All	5,314	100%

[10] Cass County also provided a shapefile with similar condition assessments for each road segment.
[11] Segments with improvements scheduled for completion in 2012 are coded as excellent, even if the improvements are still in progress.

4.1.5 Structural Conditions

The capability of a pavement 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 and material composition of the surface, base, and sub-base layers. The surface (top) layer is typically composed of asphalt while the sub-base (bottom) layer is comprised of aggregate material. The base (intermediate) layers consist of the original or older surface layers that have been overlain or resurfaced. Roads that have not yet been resurfaced or have recently been reconstructed may have only surface and aggregate sub-base layers.

In this study, structural numbers are used to estimate (1) the contributions of existing pavements at the time a road is resurfaced, and (2) the overlay thickness required for a new structural number that will allow the road to last for 20 years. The deterioration of the existing pavement is reflected in this calculation. For example, the average in-service structural number of a county road with a 6-inch aggregate sub-base and a 5-inch asphalt surface layer in fair condition at the time it is resurfaced is computed as $6 \times 0.08 + 5 \times 0.25 = 1.7$. In this equation, 0.08 and 0.25 are the structural coefficients of the sub-base and surface layers, respectively. These coefficients vary with age and the condition of the pavement.[12]

Typical layer thicknesses have been derived from an earlier survey of county and local roads.[13] Statewide values are shown in Table 7. For the most part, county roads in North Dakota reflect traditional designs for low-volume roads, with aggregate sub-base layers of less than 6 inches, thin intermediate or base layers (which are the original surface layers), and thin asphalt layers that have been placed on top of the original surfaces. These roads were originally designed for much lighter traffic than they are experiencing today. Their structures reflect budgetary limitations that have largely resulted in thin overlays as a means of improving the most miles of road with a limited amount of funds

Table 7: Typical Structure of County Roads in North Dakota*

	Layer Thickness (Inches)			
Layer	**Minimum**	**Average**	**Maximum**	**Standard Deviation**
Top (Surface)	1.75	2.69	4.50	0.62
Intermediate (Base)	0.00	2.45	3.50	0.58
Bottom (Sub-base)	2.00	4.44	9.00	1.41

* Mean values are weighted by miles of paved road in county.

[12] 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 less than 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 0.40. For aggregate base layers, the AASHTO guide suggests using coefficients of 0.0 to 0.11, depending upon the extent of degradation and contamination of aggregates with fine soil particles or abrasions.

[13] For a discussion of the survey see: Tolliver, D. and A. Dybing. "Additional Road Investments Needed to Support Oil and Gas Production and Distribution in North Dakota," Upper Great Plains Transportation Institute, Dec. 2010; http://www.ugpti.org/resources/reports/details.php?id=o6.

4.1.6 Types of Improvements

Three types of road improvements are analyzed in this study: (1) reconstruction, (2) resurfacing, and (3) resurfacing with widening. If a pavement is not too badly deteriorated, normal resurfacing is a cost-effective method of restoring structural capacity. 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 5 to 6 inches. Without extensive truck traffic, a relatively thin overlay (e.g., 2 to 3 inches) may be effective.

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 subgrade preparation, drainage work, and shoulder improvements, as well as the widening of substandard lanes. A road may be reconstructed for several reasons. (1) The pavement is too deteriorated to resurface. (2) The road has a degraded base that will provide little structural contribution to a resurfaced pavement. (3) The road is too narrow to accommodate thick overlays without widening. The graded width determines whether a thick asphalt layer can be placed on top of the existing pavement without compromising capacity.

As a road's surface is elevated due to overlays, a cross-sectional slope must be maintained. As a result, the useable width may decline. For narrower roads, this may result in reduced lane and shoulder widths and/or the elimination of shoulders.[14] In such cases, a combination of resurfacing and widening within the existing right-of-way may be feasible if the road is not too badly deteriorated. This improvement does not necessarily result in wider lanes or shoulders. However, it prevents further reductions in lane and shoulder widths.

4.1.7 Improvement Logic

The forecasting procedure used in this study considers the current condition of the road, whether its width is deficient, and the overlay needed in light of the forecasted traffic.[15] The PSR of each road segment is predicted year by year, starting from its current value, using the projected traffic load and characteristics of the pavement. When the PSR is projected to drop below the terminal serviceability level, an improvement is selected.

If (as shown in Table 8) a road segment has deteriorated to a condition where resurfacing is no longer feasible it is marked for reconstruction, regardless of width. If the width is also deficient, the road will be widened and built to new design standards to accommodate the projected traffic.

[14] 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 may have to be eliminated and lanes narrowed.

[15] The improvement logic used in this study is based upon general approaches that are widely followed in practice. However, individual counties may adopt different approaches based on local conditions and insights.

Table 8: Decision Logic of Paved Road Model

Current PSR	Current Width Status	Required Overlay Thickness	Selected Improvement
< Reconstruction PSR	N/A	N/A	Reconstruct
≥ Reconstruction PSR	Deficient	< 3 inches	Resurface
≥ Reconstruction PSR	Deficient	≥ 3 inches	Resurface and widen
≥ Reconstruction PSR	Sufficient	N/A	Resurface

If a pavement is in fair or better condition or has not yet dropped below the reconstruction PSR, it is slated for resurfacing and/or widening. If the width is sufficient, the segment is resurfaced to the required thickness based on the following formula:

$$I = \frac{SN_{New} - SN_{Old}}{0.40}$$

Where:

SN_{New}	=	Estimated structural number of section corresponding to a 20 year design life, based on projected traffic
SN_{Old}	=	Estimated structural contribution of existing layers, based on projected condition at the time of improvement
I	=	Inches of new asphalt surface layer required for new structural number
0.40	=	Structural coefficient of asphalt surface layer

If the width is deficient and the projected overlay thickness is ≥ 3 inches, the road is resurfaced and widened within the existing right of way—a technique referred to as "sliver widening." However, if the width is deficient and the required overlay thickness is less than 3 inches, the road is assumed to be resurfaced (for perhaps the last time) without sliver widening.[16] Note that sliver widening may not result in wider lanes or shoulders and added capacity. However, it prevents the further loss of lane or shoulder width and (for these reasons) is beneficial to capacity and safety.

4.1.8 Preservation Maintenance

Preservation 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 9 have been derived from a South Dakota Department of Transportation study, with the original cost factors updated to 2012 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. The paved road model and additional details regarding the analysis process are presented in Appendix D.

[16] A 3-inch overlay would result in the need for an additional foot of width on either side without reducing the finished width.

Table 9: 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
	99	$627	$2,717	$88	$1045
100	199	$627	$2,717	$131	$1045
200	299	$836	$3,658	$146	$1045
300	399	$836	$3,658	$146	$1045
400		$836	$3,814	$162	$1045

4.1.9 Forecast of Improvement Needs

4.1.9.1 Required Overlay Thicknesses

As noted earlier, the projected thickness of an overlay is a function of the truck traffic and the existing pavement structure and condition. 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 layers at the time of resurfacing.[17]

Overlay thicknesses may be classified as thin (≤ 2 inches), moderate (between 2 and 3 inches), and thick (≥ 3 inches). As shown in Figure 3, roughly 29% of the paved road miles in oil and gas producing counties are expected to need thick overlays. Another 23% will require moderate overlays. Thin overlays will suffice for 48% of the miles in these counties. Roughly 7% of the miles in the remainder of the state will require thick overlays. An additional 22% will require overlays of more than 2 inches.

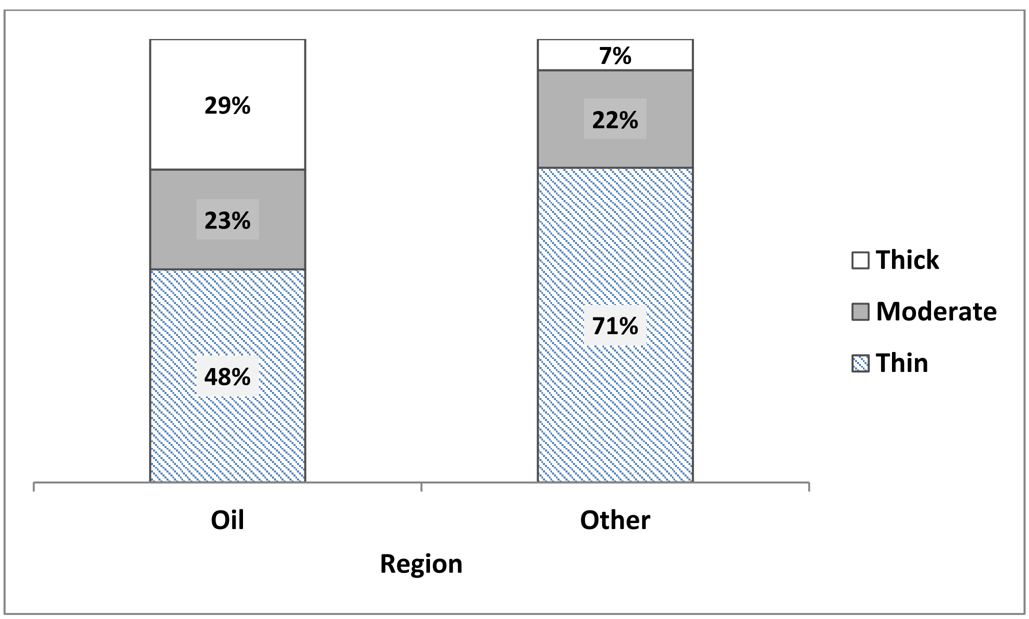

Figure 3: Projected Overlay Thickness of County and Townships Roads, by Region

[17] The assumed structural coefficient of a deteriorated surface layer (that now serves as a base layer) is 0.25 (unless it is already in poor condition), while the assumed structural coefficient of the original base layer is 0.7.

4.1.9.2 Miles Improved

As shown in Figure 4, approximately 2% of the miles of county and township paved roads in the state must be reconstructed because of poor condition and heavy traffic that will cause existing pavements to deteriorate very quickly. Another 9% of road miles must be widened when they are resurfaced.

Overall, the analysis shows that most of the miles of paved county and township roads in the state can be resurfaced without being reconstructed or widened. However, many of the road segments that can be improved in the near term using thin overlays must be widened in the future, beyond the time frame of this study.

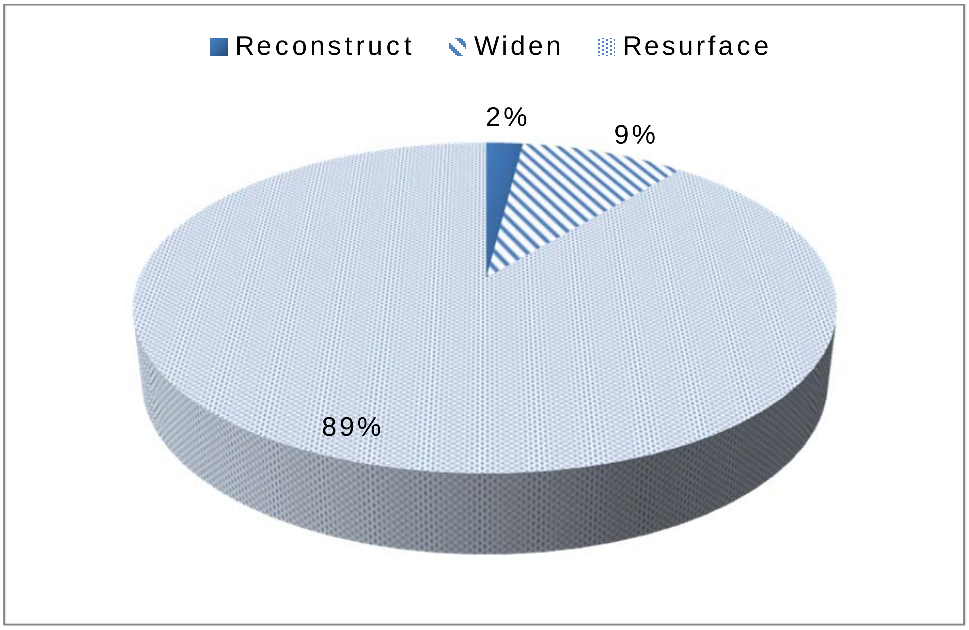

Figure 4: Percent of County and Township Paved Road Miles Reconstructed or Widened

4.1.9.3 Estimated Improvement Costs

The resurfacing cost of each segment is estimated from the inches of overlay needed and a unit cost of $3,545 per inch of pavement per foot of surface area. With this unit cost, a two-inch overlay costs roughly $184,000 per mile for a 24-foot roadway (Figure 5). A three-inch overlay costs roughly $277,000 per mile, while a five-inch overlay results in a cost of $461,000 per mile.[18]

[18] As noted earlier, all of the improvement costs utilized in this study include allowances for preliminary and construction engineering costs.

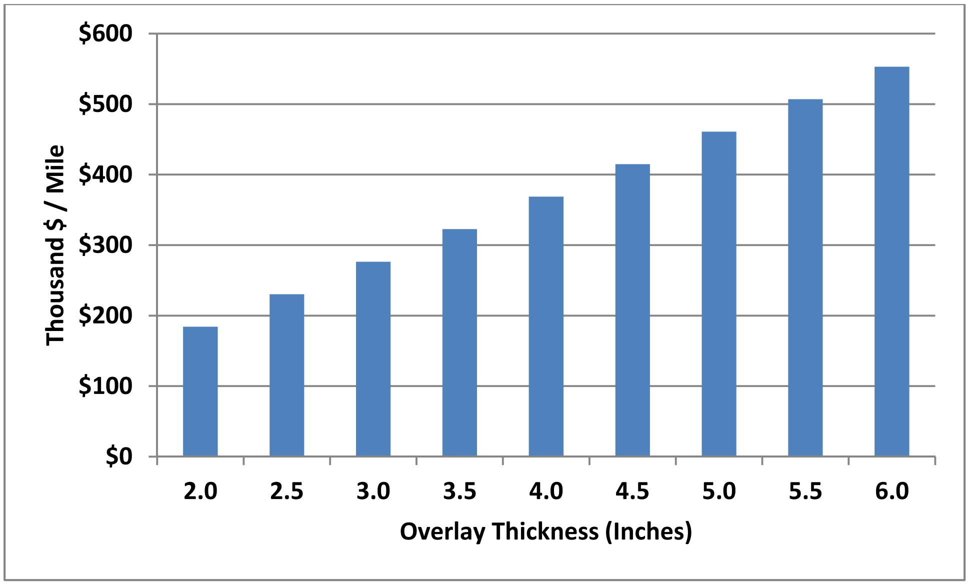

Figure 5: Average Resurfacing Cost per Mile as a Function of Overlay Thickness

The results of the analysis are summarized in Tables 10 and 11. Table 10 shows the projected improvements and costs for each biennium during the next 10 years, a projected subtotal for the 2013-2022 period, and a grand total for 2013-2032. Analogous information is shown in Table 11 for oil and gas producing counties. The values in Table 11 are included in Table 10.

A total of 92 miles of paved county and township roads in North Dakota must be reconstructed because of poor condition (Table 10). Another 414 miles are candidates for widening. The remaining 4,805 miles will need resurfacing during the next 20 years. Each mile of paved road is selected for only one of type of improvement (e.g., reconstruction, resurfacing with widening, or simple resurfacing). In addition, routine maintenance costs are estimated for each mile of road based on traffic level.

The estimated cost for all county and township roads is approximately $1,946 million or $97 million per year. Roughly 7% of the expected cost is due to reconstruction. Sixteen percent is attributable to widening. Resurfacing accounts for 47%. Another 30% is linked to routine maintenance. Approximately 87% of all investment needs can be traced to CMC routes (Figure 6).

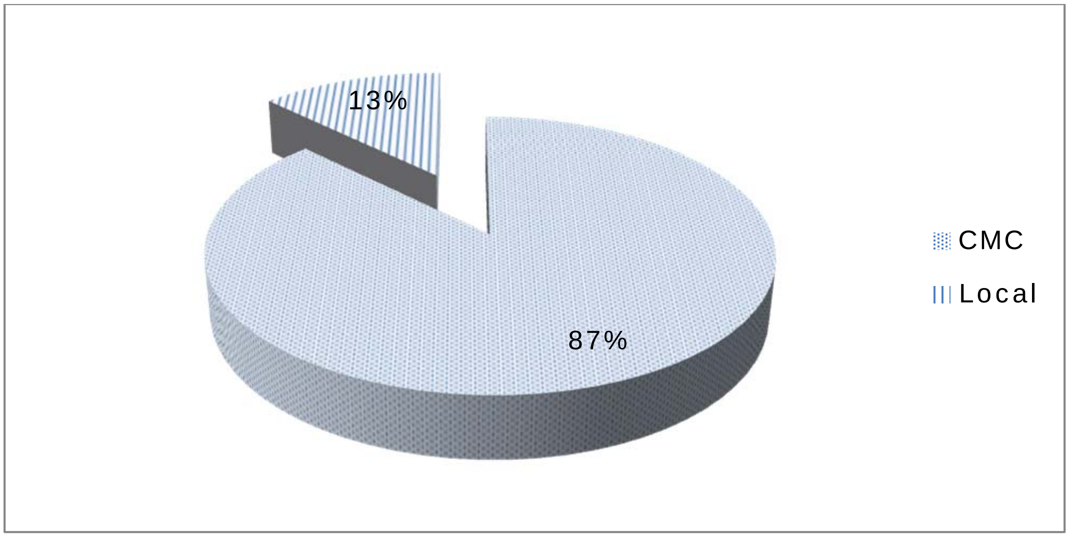

Figure 6: Projected County and Township Paved Road Investments by Functional Class

Approximately $832 million (or 43%) of the projected statewide need can be traced to oil and gas producing counties (Table 11). Eighty-one percent of the widening cost and all of the reconstruction costs are attributable to this region. Moreover, as shown in Tables 10 and 11, the improvement needs are bunched during the early years of the analysis period, with most of the reconstruction and roughly one-third of the widening costs needed during the first biennium. Forty-four percent of the projected investments over the next 10 years in the oil patch are needed during the first biennium, as a result of the upfront reconstruction and widening improvements shown in Table 11.

The weighted-average cost for the predicted resurfacing improvements is roughly $191,000 per mile. The average routine maintenance cost is $5,450 per mile per year. For roads that do not need to be reconstructed or widened, the annualized cost per mile is roughly $15,000 per year. Once deferred investment needs have been taken care of and regular preservation maintenance is practiced on all segments, annualized costs should stabilize near this level. However, as noted earlier, most of the roads with potential width issues have not been addressed in this analysis if the projected overlay thickness is less than 3 inches. These costs have been not eliminated. Instead, they have been deferred to a future funding period.

Table 10: Statewide Summary of Forecasted Improvements and Costs for Paved County and Township Roads

Period	Resurfacing		Widening		Reconstruction		Maintenance Cost ($000)	Total Cost ($000)
	Miles	Cost ($000)	Miles	Cost ($000)	Miles	Cost ($000)		
2013-2014	249	$76	135	$131	66	$98	$57	$363
2015-2016	497	$105	177	$114	17	$25	$57	$301
2017-2018	768	$160	96	$59	0	$0	$57	$277
2019-2020	734	$138	5	$3	0	$0	$57	$199
2021-2022	499	$88	0	$0	0	$0	$58	$146
2013-2022	**2,747**	**$567**	**413**	**$307**	**83**	**$123**	**$286**	**$1,286**
2023-2032	2,058	$351	0	$0	10	$14	$295	$660
2013-2032	**4,805**	**$918**	**414**	**$308**	**92**	**$138**	**$581**	**$1,946**

Table 11: Summary of Forecasted Improvements and Costs for Paved County and Township Roads in Oil and Gas Producing Counties

Period	Resurfacing		Widening		Reconstruction		Maintenance Cost ($000)	Total Cost ($000)
	Miles	Cost ($000)	Miles	Cost ($000)	Miles	Cost ($000)		
2013-2014	103	$42	116	$120	66	$98	$18	$278
2015-2016	81	$21	121	$82	17	$25	$18	$146
2017-2018	217	$48	68	$44	0	$0	$18	$111
2019-2020	175	$33	4	$3	0	$0	$18	$54
2021-2022	141	$25	0	$0	0	$0	$18	$43
2013-2022	**717**	**$169**	**309**	**$249**	**83**	**$123**	**$90**	**$632**
2023-2032	544	$93	0	$0	10	$14	$93	$200
2013-2032	**1,262**	**$262**	**309**	**$249**	**92**	**$138**	**$183**	**$832**

4.2 Gravel Roads

Assessment of the funding needs to maintain and preserve the unpaved county and local roads focuses on traffic levels, and existing practices as reported by counties and townships in survey responses. Each county was analyzed separately, which allows the study to focus on county level needs based upon existing practices and expectations.

4.2.1 Traffic Classification

Within each county, unpaved roads were classified by daily truck estimates. Classification ranges are shown in Table 12. Each category represents a differing traffic level leading to differing maintenance needs. Note that the 25-50 range represents the baseline traffic level. A 2007 survey prior to significant oil development reported an average of 20 trucks per day on local roads and 22 on County Major Collector (CMC) routes. It is assumed that traffic levels have increased marginally since the survey was conducted, and greatly in areas of oil development or in proximity to new shuttle train facilities. In the conditions and practices questionnaire, counties were asked to provide maintenance practices on an average mile of gravel road, which is consistent with traffic levels previously reported.

Table 12: Unpaved Road Classification Scheme

Traffic Range (Truck ADT)	Category
0-25	Low
25-50	Baseline
50-100	Elevated
100-150	Moderate
150-200	High
200+	Very High

4.2.2 Improvement Types

Survey questions asked county and township officials to provide the gravel and blading cycles on gravel roads within their jurisdiction. If the county was located within the oil patch, gravel and blading cycles on gravel roads were asked for both non-impacted gravel roads and impacted gravel roads. The consensus from the survey responses was that on impacted roads, the gravel interval decreases and the number of bladings per month increase. For example, a non-impacted road has a gravel cycle of 5 years and a blade interval of once per month, while an impacted section has a gravel cycle of 2 to 3 years and a blade interval of twice per month. The effective difference is a doubling of the gravel maintenance costs over the same time period. On the low impact road sections, increased blading activity is implemented to maintain roadway surface condition. For roads outside the oil patch, a similar response to higher traffic levels is expected, and there will be an increase in gravel application and blading frequency to maintain the roadway surface.

Improvement types considered include the following: increased regraveling frequency, intermediate improvements, and asphalt surfacing. The first and the last improvement types are the most straightforward; as traffic increases, the application of gravel increases. Once traffic reaches a very high level, life cycle costs deem an asphalt surface to be the more cost-effective improvement type. The intermediate category of improvements includes base stabilization and armor coat treatments.

There is no single intermediate improvement which can be applied to each county in North Dakota for this category because of differing soil types, moisture levels, and skill and equipment availability. Types of intermediate improvements include the use of stabilizers such as Base 1 from Team Labs, Permazyme from Pacific Enzymes, and asphalt and cement stabilization. Stabilization has had limited use on county roads in North Dakota according to interviews with county road supervisors. Recent trials have yielded mixed results, with some positive cases resulting in reduced maintenance costs. However, the longevity of these types of treatments are unknown, particularly performance under the freeze/thaw cycle in North Dakota. Many counties responded that they are on the first or second year of these treatments, and the longevity is unknown.

The goal of stabilization is to add structure, minimize use of new aggregate or preserve existing aggregate, reduce susceptibility to moisture and provide a base upon which to apply an armor coat. Cost estimates reported in the county surveys list Base One treatments at $5,000-$7,000 per mile, Permazyme treatments averaging $12,000 per mile, and concrete stabilization ranging from $60,000-$100,000 per mile. As mentioned above, the life of these treatments are unknown, as historical performance data is unavailable. If Base One application would occur annually, Permazyme biennially, and concrete stabilization once per decade, the cost per year would be equal. In comparison to a statewide annual average regraveling cost of roughly $5,000 for average roads, the cost of stabilization is approximately equivalent to doubling the graveling and blading frequency. For this reason, the cost of increased gravel application and blading frequency is used as a proxy for these intermediate improvements.

Maintenance types by traffic category are shown in Table 13. The low impact category receives a low volume average maintenance type, as reported by county representatives. In the county survey, county representatives were asked about the maintenance practices on an average non-impacted roadway, and the responses are used to calculate the county average cost used for baseline traffic levels. As traffic increases beyond baseline numbers, survey responses indicate that the intervals of gravel overlays and blading decrease, with a corresponding increase in annualized cost represented in the elevated and moderate categories. The high and very high categories represent an increase of 150-200% over the average maintenance with the addition of a dust suppressant application.

Table 13: Improvement Types for Unpaved Roads by Traffic Category

Traffic Category	Improvement
Low	Low Volume Average
Baseline	County Average
Elevated	County Average Increased by 50%
Moderate	County Average Increased by 100%
High	County Average Increased by 150%, Dust Suppressant
Very High	County Average Increased by 200%, Dust Suppressant

4.2.3 Projected Investment Needs

The projected costs by time period, region, and functional class are summarized in Table 14. The total projected statewide need over the 20-year analysis period is roughly $5 billion. Approximately 53% of these needs can be traced to the 17 oil and gas producing counties of western North Dakota. Roughly 91% of the costs are linked to local roads. Only 9% is related to CMC routes. Both paved and unpaved road needs are shown for each county in the appendix.

Table 14: Unpaved Road Investment Needs (Millions of 2012 Dollars)

Period	Statewide	Region		Functional Class	
		Oil Patch	**Rest of State**	**CMC**	**Local**
2013-2014	$470.53	$243.15	$227.38	$44.20	$426.34
2015-2016	$470.53	$243.15	$227.38	$44.20	$426.34
2017-2018	$485.88	$255.12	$230.76	$46.17	$439.71
2019-2020	$501.23	$267.09	$234.14	$48.14	$453.09
2021-2022	$501.23	$267.09	$234.14	$48.14	$453.09
2023-2032	$2,604.09	$1,376.05	$1,228.05	$247.16	$2,356.93
2013-2032	$5,033.49	$2,651.66	$2,381.83	$477.99	$4,555.49

4.3 County and Township Funding Levels

In assessing road investment needs, it is useful to relate projections to current funding levels. The North Dakota Transportation Funding Report (which is a survey of counties and townships that provides data on the sources and amounts of funding used to maintain and improve county roads) is used for this purpose. Data from 2009-2011 have been obtained from the North Dakota Tax Department.

In an effort to derive an estimate for a typical funding period, absent special appropriations, 2010 was selected as the most representative year. The 2009 data are known to include substantial revenues from 2008 and 2009 weather related appropriations, while the 2011 estimates reflect revenues from the 2011 oil and agricultural road impact appropriations.

The funding report classifies revenues according to four major categories: local, state, federal and private. Based on this report, local government revenue totals increased from $58.8 million in 2009 to $67 million in 2010 and to $84.2 million in 2011. Private contributions totaled $6.8 million in 2009, $4.5 million in 2010, and $15.4 million in 2011. Federal government revenue was relatively consistent over the same period: $47.6 million in 2009, $35.4 million in 2010, and $41.4 million in 2011.

State funding sources varied significantly over the 2009-2011 period. Highway tax disbursements totaled $58.5 million in 2009, $47.6 million in 2010, and $61.5 million in 2011. General fund disbursements increased from $3.6 million in 2010 to $12.1 million in 2011. Similarly, revenues categorized as “Other State Funds” increased from $3.0 million in 2010 to $14.2 million in 2011. Miscellaneous State Receipts have remained relatively constant during the 2009-2011 period, ranging from $2.3 to $3.1 million. Finally, revenues categorized as “State Government – Specify” ranged from $4.6 million in 2010 to $15.4 million in 2011.

It is unclear which categories of special appropriations have been reported to the North Dakota Tax Department. Moreover, county receipts from the Gross Production Tax that are used for transportation purposes are not differentiated from other state funding categories. For these reasons, a typical baseline funding estimate is difficult to discern.

The average funding level during the 2009-2011 period was $199.6 million. The average from 2009-2010 was $180 million, which omits the impacts of the agricultural and oil impact appropriations in 2011. It may be assumed that 2010 is a representative financial year because one-time funding sources were minimal and traditional funding sources totaled $167 million.

Reported township funding levels also vary by year. One of the reasons is that the number of respondents varies by year, thus impacting the accuracy of the overall numbers. Statewide total reported revenue in 2009 was $43.9 million for townships. In 2010, this total decreased to $31.7 million, and in 2011 to $27 million. However, due to variations in the survey response rate, it is likely that certain township revenues are not included in these figures. Given these considerations, a working estimate of $208 million in annual county and township revenue is utilized for transportation purposes.

As noted earlier, the average annual funding need for paved county and township roads during the 20-year analysis period is $97 million per year. Unpaved road needs average $252 million per year. Collectively, the annualized roadway investment and maintenance needs of $350 million for county and township roads exceed traditional revenue sources by $142 million. However, when the additional appropriations from the 2011 legislature are considered (i.e., the $142 million of special appropriations for oil impacted counties and the $76 million for agricultural haul roads), the potential revenues seem to compensate counties and townships for the annualized costs identified in this study. However, the estimates presented in this study do not reflect extreme events or weather-related disasters. Rather, the routine maintenance costs listed in Tables 10 and 11 reflect only normal and traffic-related expenses. Furthermore, the timing of the investment needs creates challenges in matching revenues with costs. As noted earlier, catch up costs in the oil patch exceed revenues for the first biennium.

5. Indian Reservation Roads

Thus far, only county and township roads have been analyzed, following the directive from Senate Bill 2325. However, some of the roads utilized by agricultural and oil-related traffic are under the jurisdiction of the Bureau of Indian Affairs (BIA) and Native American tribal governments. These roads are included in the GIS network model and traffic predictions and investment forecasts are developed for them. However, the results are presented separately and are not compared to revenue sources, since funding for Indian reservation roads is appropriated and distributed differently than funding for county and township roads. Only those roads predicted to have oil-related and agricultural traffic are included in the analysis. As a result, some BIA or tribal roads may not be reflected in the study.

The same methods and assumptions are used to analyze county, township, and tribal roads. The results of the paved road analysis are summarized in Table 15, which shows the forecasted improvements and costs for all tribal road segments and specifically for those routes in oil producing regions. The values in column 2 of Table 15 are included in the values in column 3. Altogether, 217 miles of paved Indian Reservation Roads are captured in the analysis. Roughly two-thirds of these miles are in poor condition. Based on field distress scores, 24% percent of these miles may need reconstruction due to poor condition. However, detailed judgments cannot be made regarding the remaining miles that are in poor condition. It is assumed that these segments can still be effectively resurfaced. The forecasted improvements are shown by funding period for paved and unpaved roads in Table 16.

Table 15: Summary of Indian Reservation Paved Road Investment Analysis*

Projected Improvement or Cost	Oil Impacted Regions	Total: North Dakota
Miles Resurfaced	13	163
Resurfacing Cost (Million$)	$2.8	$28.3
Miles Widened	3	3
Widening Cost (Million$)	$1.2	$1.2
Miles Reconstructed	51	51
Reconstruction Cost (Million$)	$76.9	$76.9
Maintenance Cost (Million$)	$6.7	$21.5
Total Cost (Million$)	$87.6	$127.9

Table 16: Summary of Projected Investment Needs for Impacted Indian Reservation Roads*

Period	Paved	Unpaved	Total
2013-2014	$77.87	$2.32	$80.19
2015-2016	$3.58	$2.32	$5.90
2017-2018	$2.61	$2.49	$5.10
2019-2020	$3.09	$2.65	$5.74
2021-2022	$6.53	$2.65	$9.18
2023-2032	$34.20	$15.44	$49.64
2013-2032	$127.88	$27.86	$155.74

*Results include only those roads projected to have oil-related or agricultural traffic.

6. Major Areas of Uncertainty

The analysis is based on the best and latest information available, including 2012 traffic and condition assessments and 2012 county survey data. The unpaved road analysis reflects current practices used for low-volume roads and materials and acquisition costs specific to different regions of the state. The paved road model is the same one used to analyze state and federal highways and reflects the same parameters used in the design of pavements.

As with any study, there are uncertainties regarding the inputs and models used to estimate county and local road costs. As detailed in Appendix D, the uncertainties in the paved road analysis are addressed (to some extent) through the use of statistical reliability factors. While uncertainties are inherent in the predicted truck traffic levels, this study utilizes one of the most specific traffic forecasting models of any study thus far.

The major areas of uncertainty that characterize this study are summarized in Table 17. The levels of confidence placed in the data, inputs, and/or procedures are broadly assessed through an ordinal scale:

1. Relatively Low (i.e., there is some confidence but considerable uncertainty exists)
2. Moderate
3. Moderately High
4. High

5. Very High (e.g., controlled factors and processes)

Very high confidence levels would be very unusual in any transportation study or component. High levels of confidence can rarely be placed in subjective and/or survey data or highly variable processes. Moderate and moderately high confidence levels are most typical.

Table 17: Summary of Uncertainties Underlying the County and Local Road Investment Analysis

Sources of Uncertainty	Confidence Level	Possible Effects on Results
Oil production forecast	4	Signifantly affects truck traffic levels and investment needs in western North Dakota, but has little or no impact in the rest of the state
Timing and phasing of drilling in specific locations	3	Affects truck traffic levels on specific routes and the timing of investment needs in western North Dakota, but has little or no impact in the rest of the state
Sources, supplies, capacities, and locations of inputs used in oil production	3	Affects truck traffic levels on specific routes and the timing of investment needs in western North Dakota, but has little or no impact in the rest of the state
Crop yields, land allocation, and agricultural production forecasts	4	Affects truck traffic levels and investment needs, primarily in central and eastern North Dakota
Roadway distress data collected through field assessments	4	Affects the predicted timing of investment needs, the miles of road reconstructed, the estimated structural contributions of existing pavements, and the structural number needed for future traffic
Roadway condition data collected through surveys	3	Affects the predicted timing of investment needs, the miles of road reconstructed, the estimated structural contributions of existing pavements, and the structural number needed for future traffic
Road improvement costs per mile, inch-mile, or other unit	4	Affects the improvement costs arising from forecasted improvements during the analysis period
Truck types used, the proportion of traffic moved in each type of truck, and load factors	3	Affects the predicted structural numbers of paved roads and the investment needs of paved and unpaved roads
Truck routing and spatial analysis procedures (which predict trips based on driver behavior, distance, and cost)	2	Affects the specific road segments impacted and predictions of traffic levels on specific routes, but has less impact on overall forecasts of county and regional investment needs
Gravel road improvement model (which reflects uncertainties in practices and timing)	3	Affects the frequencies of graveling and blading and the timing and estimated costs of unpaved roads

Table 17: Summary of Uncertainties Underlying the County and Local Road Investment Analysis		
Sources of Uncertainty	**Confidence Level**	**Possible Effects on Results**
Pavement structural model, which predicts SN values and reflects uncertainties in materials performance, traffic, and other inputs	4	Affects predicted levels of paved road improvement costs throughout the state, but addresses uncertainty through a statistical reliability procedure that simulates the effects of higher than predicted traffic loads
Paved road improvement model, which selects the improvement and predicts the year of improvement	3	Affects predicted levels of paved road improvement costs throughout the state and the timing of improvements—e.g., how much investment is needed in near-term funding periods versus later years
County and township revenues	2	Revenues do not directly affect the investment analysis, but affect estimates of funding gaps

The improvements quantified in this study are intended to provide acceptable service for a target period of 20 years. However, many unknown and localized conditions may affect the outcomes or change the scope and costs of the improvements required. While it cannot be guaranteed that the improvements will eliminate or mitigate issues such as spring load restrictions, these benefits are expected to result from reconstruction projects and thick (structural) overlays in many cases.

The mitigating effects of thin overlays are more difficult to project and cannot be counted upon to solve load restriction problems in many areas. The results will depend largely upon the qualities of the underlying soils and pavement layers, which can only be completely ascertained from core samples. Moreover, it must be noted that spring load restrictions are not simple structural decisions, but are partly administrative in nature. At times, spring load restrictions may be placed in effect to protect thin pavements from rapid deterioration that could result in expensive reconstruction projects in the future. However, load restrictions may also be put in place to divert truck traffic to alternate routes that have more substantial pavement sections or are simply in better condition. For these reasons, predicting the impacts of road improvements on load restrictions at the local level involves a great deal of uncertainty.

Appendix A: Flexible Pavement Condition Rating Scoring Sheet

CONDITION	EXTENT				SEVERITY	Score
CODE	NONE	<10%	10-	>30%	LENGTH	
ALLIGATOR	0	2	4	6	HAIRLINE	
CRACKING		8	10	12	SPALLED & TIGHT	
AC		14	16	18	SPALLED & LOOSE	
	NONE	<10%	10-	>30%	LENGTH	
BLEEDING	0	1	2	3	OCCASIONAL SMALL PATCHES	
		4	5	6	WHEEL TRACKS SMOOTH	
BLD		7	8	9	LITTLE VISIBLE AGGREGATE	
	NONE	<100'	100'-	>200'	L.F. in 100'	
LONGITUDINAL	0	1	2	3	<1/4" WIDTH	
CRACKING		4	5	6	1/4-1"	
LC		7	8	9	>1" AND/OR SPALLED	
	NONE	<100'	100'-	>200'	L.F. in 100'	
TRANSVERSE	0	1	2	3	<1/4" WIDTH	
CRACKING		4	5	6	1/4-1"	
TC		7	8	9	>1" OR SPALLED OR DEPRESSED	
	NONE	<10%	10-	>30%	LENGTH	
BLOCK	0	1	2	3	<1/4" WIDTH	
CRACKING		4	5	6	1/4-1"	
BC		7	8	9	>1" AND/OR SPALLED	
	NONE	<10%	10-	>30%	AREA OF SAMPLE	
RAVELING	0	1	2	3	MINOR LOSS	
WEATHERING		4	5	6	SOME SMALL HOLES / PITS	
RW		7	8	9	HIGHLY PITTED / ROUGH	
	NONE	< 5%	5-15%	>15%	AREA OF SAMPLE	
BITUMINOUS	0	2	4	6	GOOD CONDITION	
PATCHING		8	10	12	FAIR CONDITION	
BP		14	16	18	POOR CONDITION	
	< 1/4 "	1/4-3/8"	3/8-1/2"	>1/2"	DEPTH SEVERITY CATEGORY	
RUTTING **RT**	0	4	9	18	WITH 20% TRIGGER	
					Total Score (99- individual scores)	

County _______

Route __________

Miles from Start of Route_________ (Rate first 500 Ft of each mile)

Appendix B: County Road Survey

County: ______________________________
Contact: ______________________ ________________ __________________
Name Phone Email

Preparer: ______________________ Date Prepared: ______________________

Gravel Road Costs
Please report costs for gravel for county roads in the table below. The table asks for unit costs for graveling, maintaining, and operating gravel roads.

Gravel/Scoria Cost		
Average Gravel/Scoria Cost (crushing & royalties)		Per cubic yd.
Trucking Cost from Gravel Origin		Per loaded mile/Cu. Yard
Placement Costs		Per mile
Blading Cost		Per mile
Dust Suppressant Costs		Per mile
Snow Removal Cost		Per mile

Average Regraveling Thickness (Scoria/Gravel) ________________ Cubic yd/mile or Inches
(Please circle one)

Road Maintenance and Practices

Gravel Road Practices

Please report blading and graveling frequency for county gravel roads.

Blading Frequency

- ❑ 1 per week
- ❑ 1 per month
- ❑ 2 per month
- ❑ other (please explain) ____________________

Regraveling Frequency

- ❑ Every year
- ❑ Every 2-3 years
- ❑ Every 3-4 years
- ❑ 5 or more years
- ❑ other (please explain) ____________________

Stabilization

- ❑ Currently use (if this is selected, please comment on success rate)
- ❑ Exploring usage
- ❑ Do not plan to use

If currently used please specify type of stabilization, cost per application, and application frequency

How would you classify the average gravel road condition in your county?

❑Very Good ❑Good ❑Fair ❑Poor

Paved Road Practices

Please report typical paved road maintenance practices used in your county.
Typical overlay frequency: _______________
Typical overlay thickness: ________________

Is roadway width due to repeated overlay treatment an issue in your county?
❑Yes ❑No

If so – what is the estimated number of miles affected?

Aside from routine maintenance and improvements, what other challenges are facing roadway maintenance in your county? (flooding, high traffic generators, etc.)

____

____

Comments or Suggestions (please attach additional sheets if needed):

Appendix C: Paved Road Conditions, by County

Table C.1: Paved Road Conditions, by County			
County	**Condition**	**Miles**	**Percent**
Adams	Good	1.1	5%
Adams	Fair	21.2	95%
Barnes	Very Good	24.3	10%
Barnes	Good	75.6	31%
Barnes	Fair	120.3	50%
Barnes	Poor	22.2	9%
Benson	Very Good	2.9	3%
Benson	Good	30.5	34%
Benson	Fair	41.3	46%
Benson	Poor	15.7	17%
Billings	Very Good	22.2	55%
Billings	Good	13.5	33%
Billings	Fair	4.7	12%
Bottineau	Very Good	24.8	12%
Bottineau	Good	174.6	88%
Bowman	Very Good	4.8	4%
Bowman	Good	88.9	67%
Bowman	Fair	38.2	29%
Burke	Very Good	14.1	28%
Burke	Good	30.5	60%
Burke	Fair	6.2	12%
Burleigh	Very Good	11.9	7%
Burleigh	Good	90.1	50%
Burleigh	Fair	46.3	26%
Burleigh	Poor	30.5	17%
Cass	Very Good	184.5	59%
Cass	Good	116.1	37%
Cass	Fair	12.5	4%
Cass	Poor	1.0	0%
Cavalier	Very Good	4.0	6%
Cavalier	Good	21.9	35%
Cavalier	Fair	26.8	42%
Cavalier	Poor	10.6	17%
Dickey	Very Good	20.2	24%
Dickey	Good	39.9	47%
Dickey	Fair	24.6	29%
Divide	Very Good	5.2	18%
Divide	Good	10.9	39%
Divide	Fair	11.8	42%
Dunn	Very Good	10.0	67%

Table C.1: Paved Road Conditions, by County			
County	**Condition**	**Miles**	**Percent**
Dunn	Good	0.3	2%
Dunn	Fair	0.2	1%
Dunn	Poor	4.5	30%
Eddy	Good	38.9	58%
Eddy	Fair	14.3	21%
Eddy	Poor	14.1	21%
Emmons	Good	14.4	90%
Emmons	Fair	0.5	3%
Emmons	Poor	1.1	7%
Foster	Good	19.3	22%
Foster	Fair	70.4	78%
Golden Valley	Very Good	10.4	44%
Golden Valley	Good	13.5	56%
Grand Forks	Good	92.1	32%
Grand Forks	Fair	185.2	64%
Grand Forks	Poor	11.3	4%
Grant	Poor	3.4	100%
Griggs	Good	12.1	30%
Griggs	Fair	23.0	57%
Griggs	Poor	5.3	13%
Hettinger	Very Good	8.3	47%
Hettinger	Good	5.4	30%
Hettinger	Fair	4.0	23%
Kidder	Good	29.4	43%
Kidder	Fair	20.4	30%
Kidder	Poor	18.7	27%
LaMoure	Very Good	6.2	4%
LaMoure	Good	52.4	33%
LaMoure	Fair	66.2	42%
LaMoure	Poor	33.9	21%
Logan	Good	11.0	100%
McHenry	Good	93.5	100%
McIntosh	Good	28.6	34%
McIntosh	Fair	28.4	33%
McIntosh	Poor	28.1	33%
McKenzie	Very Good	19.8	17%
McKenzie	Good	40.0	34%
McKenzie	Fair	57.4	49%
McLean	Good	6.3	4%
McLean	Fair	135.5	96%
Mercer	Very Good	3.7	3%
Mercer	Good	85.8	82%

Table C.1: Paved Road Conditions, by County			
County	**Condition**	**Miles**	**Percent**
Mercer	Fair	15.1	14%
Morton	Good	48.9	50%
Morton	Fair	30.5	31%
Morton	Poor	18.0	18%
Mountrail	Very Good	24.8	24%
Mountrail	Good	23.7	23%
Mountrail	Fair	13.8	14%
Mountrail	Poor	40.1	39%
Nelson	Good	66.6	80%
Nelson	Fair	17.0	20%
Oliver	Very Good	2.9	11%
Oliver	Good	23.4	86%
Oliver	Poor	1.0	4%
Pembina	Very Good	42.3	21%
Pembina	Good	84.5	42%
Pembina	Fair	72.3	36%
Pierce	Good	3.6	31%
Pierce	Fair	8.0	69%
Ramsey	Very Good	6.9	5%
Ramsey	Good	76.8	58%
Ramsey	Fair	46.8	36%
Ramsey	Poor	1.0	1%
Ransom	Good	11.7	20%
Ransom	Fair	48.0	80%
Renville	Very Good	13.1	16%
Renville	Good	49.8	60%
Renville	Fair	20.0	24%
Richland	Very Good	24.8	10%
Richland	Good	122.0	48%
Richland	Fair	75.6	30%
Richland	Poor	32.5	13%
Rolette	Very Good	18.4	32%
Rolette	Good	14.8	26%
Rolette	Fair	15.3	27%
Rolette	Poor	8.6	15%
Sargent	Very Good	60.6	61%
Sargent	Good	36.4	37%
Sargent	Poor	2.8	3%
Sheridan	Fair	20.9	100%
Sioux	Poor	0.4	100%
Slope	Good	3.8	100%
Stark	Very Good	22.7	25%

Table C.1: Paved Road Conditions, by County			
County	**Condition**	**Miles**	**Percent**
Stark	Good	63.4	69%
Stark	Fair	6.1	7%
Steele	Good	0.3	0%
Steele	Fair	50.3	61%
Steele	Poor	32.2	39%
Stutsman	Good	169.0	71%
Stutsman	Fair	42.6	18%
Stutsman	Poor	27.0	11%
Towner	Fair	1.2	68%
Towner	Poor	0.5	32%
Traill	Very Good	25.9	18%
Traill	Good	49.7	35%
Traill	Fair	53.5	37%
Traill	Poor	14.8	10%
Walsh	Very Good	9.1	5%
Walsh	Good	103.5	55%
Walsh	Fair	59.4	32%
Walsh	Poor	14.6	8%
Ward	Very Good	18.4	7%
Ward	Good	210.5	77%
Ward	Fair	37.9	14%
Ward	Poor	6.5	2%
Wells	Very Good	23.0	21%
Wells	Good	41.8	38%
Wells	Fair	10.9	10%
Wells	Poor	35.3	32%
Williams	Very Good	62.3	38%
Williams	Good	70.5	44%
Williams	Fair	29.1	18%

Appendix D: Pavement Modeling Process

Pavement Performance

The performance of a pavement is measured through its serviceability (or condition) and the number of axle loads it can sustain before being resurfaced or improved. The condition at which a pavement must be resurfaced or rehabilitated is called "terminal serviceability" (t), which effectively marks the end of a pavement's useful life. Below this level, user and maintenance costs increase rapidly.

A pavement is designed for a performance period (T) based on a projected traffic load and environmental factors. Twenty years is often cited as the design-performance period for asphalt or flexible pavements. However, the period can be shorter or longer depending upon budgetary constraints, maintenance, and environmental factors.

The actual traffic load that will be experienced during the design period is unknown at the time the pavement is built and must be projected from historical data or traffic forecasting models. The traffic measure of greatest interest is the accumulated equivalent single-axle loads or ESALs. In particular, the total ESAL load that a pavement can endure before reaching terminal serviceability ($ESAL_t$) and the ESAL load accumulated during the design-performance period ($ESAL_T$) are of special interest. The design process is intended to ensure (with a high degree of probability) that the traffic actually experienced during the design-performance period is less than or equal to the traffic that would cause the pavement to deteriorate to its terminal serviceability level—i.e., the design period ESALs are less than or equal to the ESAL life of the pavement.

Predictive Equation

An equation for predicting the cumulative ESALs (or ESAL life) of a flexible pavement as a function of its structural number (SN), resilient modulus (MR), initial PSR (PSR_I), terminal PSR (PSR_t), and design reliability (R) is shown below.

$$(1) \quad \log_{10}(W_{18}) = R + A + \frac{G}{B} + M$$

Where:

$\log_{10}(W_{18})$ = The service life of the pavement in equivalent 18,000-lb single axle loads

$R = Z_R S_0$

Z_R = A standard normal deviate

S_0 = Standard deviation

$A = 9.36 \log_{10}\left(SN + \sqrt{6/SN}\right) - 0.2$

$G = \log_{10}\left(\frac{\Delta PSR_S}{\Delta PSR_L}\right)$

$$B = 0.4 + \frac{1094}{\left(SN + \sqrt{6/SN}\right)^{5.19}}$$

$$M = 2.32 \log_{10}(MR) - 8.07$$

$$\Delta PSR_S = PSR_i - PSR_t$$

PSR_i = Initial serviceability rating of the pavement

PSR_t = Terminal serviceability rating (e.g. when the pavement should be resurfaced)

$$\Delta PSR_L = 2.7$$

In Equation (1), ΔPSR_S denotes the decline in PSR from its initial or design value (e.g., 4.5) to its terminal level (e.g., 2.5), while ΔPSR_L represents the total decline in PSR until ultimate failure (2.7) as used during the AASHTO road test. In this study, $\Delta PSR_S = 2.0$.

Reliability

There are many sources of uncertainty in pavement deign and performance. If a sample of pavements is designed using the same materials and thicknesses, many of these sections will reach terminal serviceability at different times because of variations in traffic, materials properties, and environmental and climatic conditions. The major sources of variation that affect pavement design and performance include:[19]

1. Construction factors—e.g., layer thicknesses, material strengths, etc.
2. Environmental factors (e.g., soils and climate)
3. Traffic forecasts and projections
4. Prediction error: i.e., errors in performance prediction internal to Equation 1

The reliability of the predicted performance may be expressed as $Prob(ESAL_t \geq ESAL_T)$. In actuality, the logs of the two ESAL terms are used, since the log ratio or difference is expected to be normally distributed. Nevertheless, the difference between the accumulated ESALs at terminal serviceability and the accumulated ESALs during the design period is the basis for the measurement.

Algebraically, the deviation between the design period ESALs and ESAL life is expressed as $\log_{10}(ESAL_t/ESAL_T)$ or equivalently $\log_{10}(ESAL_t) - \log_{10}(ESAL_T)$. These deviations are assumed to be normally distributed with a known variance and standard deviation. Z_R is a critical value or location in the standard normal distribution that corresponds to $Prob(\log_{10}(ESAL_t) - \log_{10}(ESAL_T) < 0)$ — i.e., the probability that the design period traffic ($ESAL_T$) turns out to be greater that the ESAL life of the pavement ($ESAL_t$). The reliability factor is computed as $Z_R \times S_0$, where S_0 is the standard deviation of a theoretical distribution of deviations or differences between $\log_{10}(ESAL_t)$ and $\log_{10}(ESAL_T)$.

The reliability factor may be expressed as a percentage. For example, a reliability factor of 75% (which is used in this study) indicates a 75% likelihood that the pavement section will survive the design-performance period. This value lies within the range of factors typically used for collector

[19] Washington State Department of Transportation. "WSDOT Pavement Guide, Volume 2: Pavement Notes for Design, Evaluation and Rehabilitation," Olympia, WA, February, 1995.

roads. The use of a 75% reliability factor essentially doubles the ESAL forecast used in the pavement prediction model. Much higher reliability factors (e.g., 90%) are often used for interstate and principal arterial highways. However, in most cases, traffic is projected from historical trends, which leads to great uncertainty in rapidly growing or changing regions when economic or industry factors are considered directly in the forecasts. In comparison, truck traffic levels in this study are forecast directly from the locations and intensities of oil and agricultural production. Because the external or exogenous forces that give rise to traffic demand are internalized in the forecasts, greater confidence may be placed in the traffic forecasts than if they were derived solely from historical traffic counts and trend lines.

The selection of a reliability factor involves several tradeoffs. The use of a higher reliability factor would increase the likelihood that the pavements would survive the predicted performance period. However, the use of higher reliability factors result in thicker pavements and significantly higher investment costs. Given the time variability of oil traffic, higher reliability factors could result in the overbuilding of roads and investment forecasts during the early phase of oil development than might be needed in the long run. Given the pros and cons, the 75% reliability factor is felt to be the most appropriate one for this study.

Pavement Deterioration Model

With some extensions, the predictive model shown in Equation 1 can be used to predict the condition of a pavement each year of an analysis period using the cumulative ESAL load. In order to do so, Equation 1 must be solved for G (Equation 2).

(2) $G = B(\log_{10}(W_{18}) - R - A - M)$

Substituting for G yields:

(3) $\log_{10}\left(\frac{\Delta PSR_S}{\Delta PSR_L}\right) = B(\log_{10}(W_{18}) - R - A - M)$

An equivalent form of Equation 3 is:

(4) $\frac{\Delta PSR_S}{\Delta PSR_L} = 10^{B(\log_{10}(W_{18}) - R - A - M)}$

Solving for ΔPSR_S and substituting yields:

(5) $PSR_i - PSR_t = \Delta PSR_L \times 10^{B(\log_{10}(W_{18}) - R - A - M)}$

Instead of the terminal PSR (PSR_t), the model is used to predict the PSR at the end of each year (n) of the analysis period. Instead of using the ESAL load for the entire design period, the accumulated load at the end of each year ($\log_{10}(W_{18n})$) is forecast and used in the model. With these revisions, the pavement deterioration model is shown in Equation 6.

(6) $PSR_n = PSR_i - 2.7 \times 10^{B(\log_{10}(W_{18n}) - R - A - M)}$

Figure D.1 shows the deterioration of a hypothetical pavement from a PSR of 4.5 to 1.8 (the reconstruction level) using Equation 6, juxtaposed against a dashed linear trend line. The total PSR is 2.7. As the chart shows, the new pavement deteriorates relatively slowly at first. However the rate of deterioration increases with time. In this example, the pavement loses 23% of its total PSR loss during the first five years of existence. In comparison, the pavement loses 38% during the last five years. It does not survive the performance period, deteriorating below the resurfacing PSR within 11 years, indicating a mismatch between structural number and traffic.

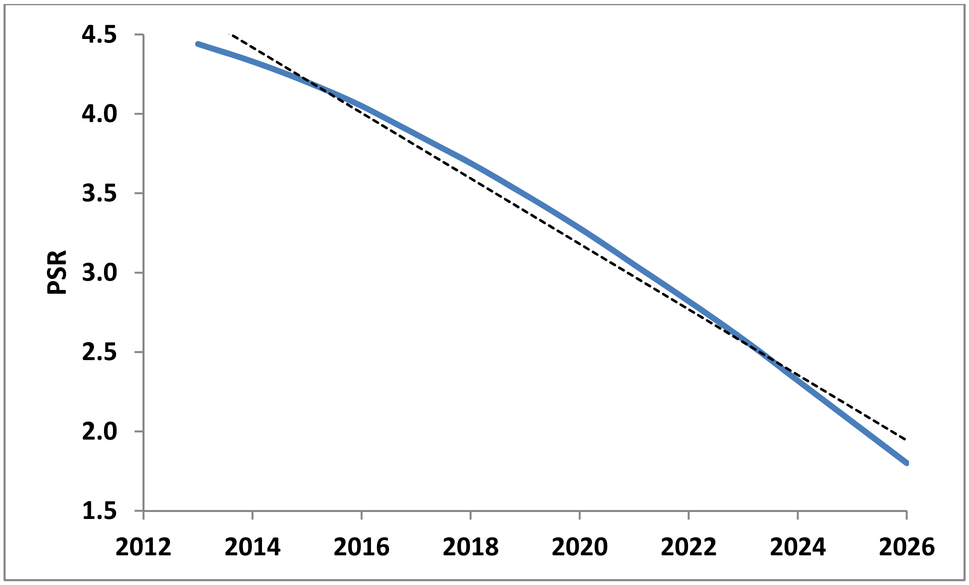

Figure D.:1 Deterioration of Hypothetical Pavement with Traffic

Environmental-Related Deterioration

The predicted deterioration in Figure D.1 is solely the result of traffic. The effects of environmental deterioration are simulated in the model by assuming an exponential rate of deterioration over the life of a pavement (the maximum feasible pavement life without truck traffic, but with regular routine maintenance). A maximum life of 30 years is used in this study, which is the time frame over which climatic and environmental forces would cause a new pavement to deteriorate to its reconstruction level.

As shown in Figure D.2, the environmental deterioration function is used to enforce a minimum rate of PSR loss per year, regardless of the level of traffic. Therefore, pavements with little or no truck traffic are still projected to deteriorate, but at a much slower rate than sections with heavy traffic. The primary factors that influence the design and longevity of pavements are summarized in Table D.1.

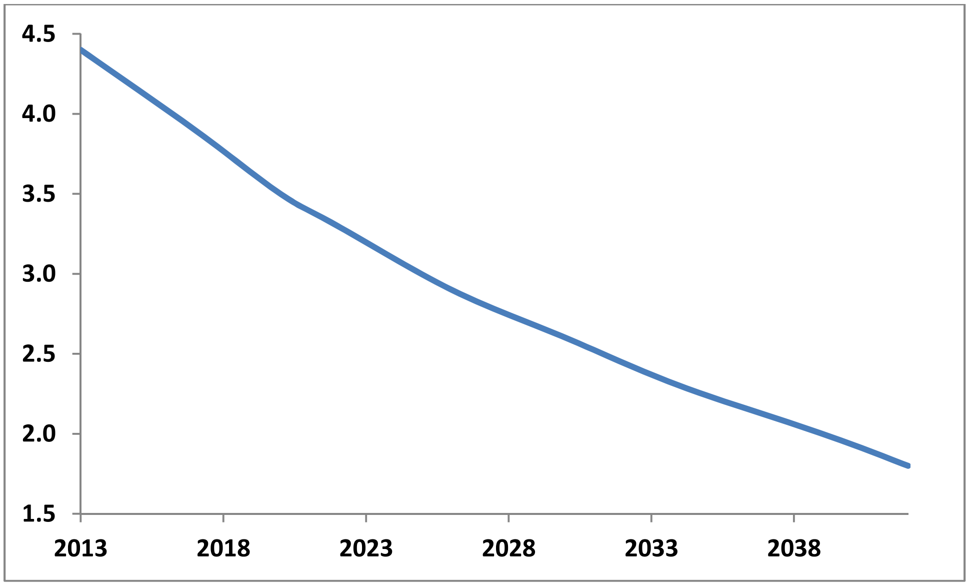

Figure D.2: Depiction of Environmental-Related Pavement Deterioration

Table D.1: Primary Factors Affecting Paved Road Analysis

Factor	Effects on Analysis
Average Daily Trips (ADT)	The average number of vehicles per day influences the geometric design (e.g., number of lanes, lane width, and shoulder type and width) and annual road maintenance.
Average Daily Truck Trips (ADTT)	The average number of trucks per day influences the geometric and structural design.
Truck Type and Axle Configuration	The number of axles in a truck, the types of axles, and the axle weights determine the equivalent single axle load (ESAL) factor and the pavement impact of a truck.
Structural Number (SN)	The structural number is a reflection of the strength and longevity of a pavement, derived from the composition and thickness of the surface, base, and subbase layers, using structural coefficients that vary with the type of material and layer position.
Cumulative ESALs	The forecasted ADTT and ESAL factors determine the cumulative traffic load for the design period and the structural number that is needed.
Existing Pavement Structure	The composition and thickness of existing pavement layers determine the structural contributions of these layers when the pavement is resurfaced or overlaid in the future.

Table D.1: Primary Factors Affecting Paved Road Analysis

Factor	Effects on Analysis
Present Serviceability Rating (PSR)	The PSR is a reflection of the serviceability or condition of a pavement, expressed as a score ranging from 0 to 5, with 4 and higher representing "excellent," 3 to 4 "good," 2 to 3 "fair," 1 to 2 "poor," and 0 to 1 "very poor." Because the PSR it is heavily influenced by pavement roughness and ride quality, it is a proxy for service level.
Initial PSR (PSR_i)	The initial PSR is the serviceability or condition rating assigned to a newly resurfaced or reconstructed pavement. In this study, it is assumed to be 4.5.
Terminal PSR (PSR_t)	The terminal PSR is the serviceability or condition rating that triggers a resurfacing improvement. If the road is not resurfaced before or when terminal serviceability is reached, user costs and the rate of deterioration will increase greatly. A terminal serviceability rating of 2.5 is used in this study.
Current PSR	The current PSR, SN, and ESAL load determine when a pavement will need resurfacing.
Reconstruction PSR	The reconstruction PSR is the lowest serviceability or condition rating at which a pavement can be resurfaced. Once the condition drops below this level, the road must be fully reconstructed, because of extensive damage to the surface and base layers. A reconstruction PSR of 1.8 is used in this study.
Soil Modulus (MR)	MR is a measure of the effective soil support beneath the pavement. It is a site specific value that influences the structural number needed, given the expected traffic load. In the absence of detailed soil samples, a value of 5,000 PSI is used in this study.
Maximum Feasible Life	The maximum feasible life of a pavement with no truck traffic (but with regular routine maintenance) is used to simulate environmental deterioration over time. A value of 30 years is used, which is the time frame over which climatic and environmental forces will cause a new pavement to deteriorate to the reconstruction level.
Graded width	The graded roadway width determines whether a thick overlay can be applied without widening the road.

Appendix E: Detailed Results by County and Funding Period

Table E.1: County and Township Unpaved Road Funding Needs, by County and Time Period (Millions of 2012 Dollars)

County	2013-2014	2015-2016	2017-2018	2019-2020	2021-2022	2023-2032	2013-2032
Adams	$4.26	$4.26	$4.40	$4.55	$4.55	$23.97	$45.98
Barnes	$11.52	$11.52	$11.66	$11.80	$11.80	$62.43	$120.72
Benson	$6.97	$6.97	$7.02	$7.07	$7.07	$36.62	$71.72
Billings	$13.02	$13.02	$14.41	$15.80	$15.80	$86.03	$158.08
Bottineau	$9.70	$9.70	$9.92	$10.13	$10.13	$54.45	$104.03
Bowman	$6.78	$6.78	$6.93	$7.07	$7.07	$36.97	$71.59
Burke	$13.31	$13.31	$13.67	$14.03	$14.03	$74.19	$142.55
Burleigh	$6.87	$6.87	$6.88	$6.89	$6.89	$34.63	$69.02
Cass	$18.31	$18.31	$18.55	$18.78	$18.78	$98.82	$191.56
Cavalier	$5.25	$5.25	$5.27	$5.29	$5.29	$27.13	$53.47
Dickey	$3.98	$3.98	$4.03	$4.07	$4.07	$20.82	$40.95
Divide	$20.09	$20.09	$21.32	$22.56	$22.56	$93.78	$200.39
Dunn	$12.97	$12.97	$14.17	$15.37	$15.37	$82.79	$153.63
Eddy	$1.67	$1.67	$1.68	$1.69	$1.69	$8.60	$16.98
Emmons	$6.24	$6.24	$6.34	$6.45	$6.45	$33.25	$64.96
Foster	$2.30	$2.30	$2.34	$2.37	$2.37	$12.96	$24.64
Golden Valley	$4.22	$4.22	$4.84	$5.46	$5.46	$26.31	$50.52
Grand Forks	$12.42	$12.42	$12.52	$12.62	$12.62	$66.57	$129.18
Grant	$6.95	$6.95	$7.00	$7.06	$7.06	$35.85	$70.87
Griggs	$2.51	$2.51	$2.56	$2.61	$2.61	$13.33	$26.14
Hettinger	$6.79	$6.79	$7.03	$7.27	$7.27	$37.93	$73.08
Kidder	$2.90	$2.90	$2.92	$2.94	$2.94	$14.81	$29.40
LaMoure	$4.27	$4.27	$4.34	$4.40	$4.40	$22.39	$44.08
Logan	$3.40	$3.40	$3.40	$3.41	$3.41	$17.19	$34.21
McHenry	$15.45	$15.45	$15.55	$15.65	$15.65	$80.81	$158.55
McIntosh	$1.15	$1.15	$1.15	$1.15	$1.15	$5.73	$11.46
McKenzie	$32.27	$32.27	$34.47	$36.68	$36.68	$179.67	$352.04

Table E.1: County and Township Unpaved Road Funding Needs, by County and Time Period (Millions of 2012 Dollars)

County	2013-2014	2015-2016	2017-2018	2019-2020	2021-2022	2023-2032	2013-2032
McLean	$16.38	$16.38	$16.69	$17.01	$17.01	$92.16	$175.63
Mercer	$7.26	$7.26	$7.53	$7.80	$7.80	$41.89	$79.53
Morton	$7.61	$7.61	$7.69	$7.76	$7.76	$40.87	$79.31
Mountrail	$22.96	$22.96	$23.75	$24.54	$24.54	$121.80	$240.57
Nelson	$3.18	$3.18	$3.18	$3.19	$3.19	$16.39	$32.31
Oliver	$2.50	$2.50	$2.55	$2.59	$2.59	$13.70	$26.43
Pembina	$7.21	$7.21	$7.24	$7.28	$7.28	$37.34	$73.55
Pierce	$9.62	$9.62	$9.87	$10.11	$10.11	$53.30	$102.63
Ramsey	$5.25	$5.25	$5.30	$5.36	$5.36	$27.60	$54.11
Ransom	$2.99	$2.99	$3.02	$3.05	$3.05	$15.84	$30.94
Renville	$6.22	$6.22	$6.36	$6.51	$6.51	$34.33	$66.15
Richland	$6.36	$6.36	$6.44	$6.52	$6.52	$34.12	$66.32
Rolette	$2.90	$2.90	$2.96	$3.01	$3.01	$15.54	$30.33
Sargent	$8.78	$8.78	$9.04	$9.30	$9.30	$51.86	$97.07
Sheridan	$7.78	$7.78	$7.99	$8.21	$8.21	$42.74	$82.72
Sioux	$1.26	$1.26	$1.31	$1.36	$1.36	$7.02	$13.56
Slope	$4.14	$4.14	$4.22	$4.30	$4.30	$22.10	$43.18
Stark	$11.40	$11.40	$12.71	$14.01	$14.01	$61.60	$125.13
Steele	$7.50	$7.50	$7.62	$7.73	$7.73	$41.87	$79.95
Stutsman	$15.04	$15.04	$15.32	$15.61	$15.61	$85.02	$161.65
Towner	$3.63	$3.63	$3.64	$3.65	$3.65	$18.64	$36.83
Traill	$5.98	$5.98	$6.00	$6.03	$6.03	$31.19	$61.21
Walsh	$11.72	$11.72	$11.85	$11.99	$11.99	$61.48	$120.73
Ward	$12.57	$12.57	$12.86	$13.15	$13.15	$69.71	$134.02
Wells	$10.32	$10.32	$10.65	$10.99	$10.99	$60.51	$113.78
Williams	$34.41	$34.41	$35.72	$37.03	$37.03	$217.44	$396.04
Total	$470.53	$470.53	$485.88	$501.23	$501.23	$2,604.09	$5,033.49

All paved road costs presented in this study include preliminary and construction engineering for overlays and reconstruction improvements.

Table E2:Estimated County and Township Paved Road Improvements and Investment Needs, by County: 2013-2032						
County	Miles Resurfaced	Miles Widened	Miles Reconstructed	Total Miles Improved	Total Cost (Million$)	Annual Cost per Mile
Adams	22.3	0.0	0.0	22.3	$5.820	$13,025
Barnes	235.4	7.0	0.0	242.4	$74.867	$15,443
Benson	90.3	0.0	0.0	90.3	$26.298	$14,555
Billings	36.0	4.5	0.0	40.4	$13.661	$16,899
Bottineau	147.9	51.5	0.0	199.5	$83.890	$21,030
Bowman	130.0	0.0	1.9	131.9	$41.159	$15,603
Burke	42.1	8.7	0.0	50.8	$17.875	$17,592
Burleigh	178.8	0.0	0.0	178.8	$50.666	$14,168
Cass	312.2	1.9	0.0	314.1	$92.831	$14,778
Cavalier	55.5	7.9	0.0	63.4	$23.756	$18,735
Dickey	84.7	0.0	0.0	84.7	$26.956	$15,917
Divide	20.6	7.3	0.0	27.8	$13.032	$23,398
Dunn	10.4	0.0	4.5	15.0	$11.884	$39,713
Eddy	67.2	0.0	0.0	67.2	$22.385	$16,657
Emmons	16.0	0.0	0.0	16.0	$4.182	$13,045
Foster	87.8	1.9	0.0	89.7	$26.721	$14,890
Golden Valley	23.1	0.8	0.0	23.9	$6.677	$13,960
Grand Forks	285.9	0.0	0.0	285.9	$81.681	$14,284
Grant	2.4	1.0	0.0	3.4	$1.460	$21,341
Griggs	40.3	0.2	0.0	40.4	$13.068	$16,154
Hettinger	17.7	0.0	0.0	17.7	$4.750	$13,392
Kidder	68.6	0.0	0.0	68.6	$17.971	$13,104
LaMoure	148.0	10.7	0.0	158.7	$49.712	$15,659
Logan	11.0	0.0	0.0	11.0	$3.104	$14,097
McHenry	93.5	0.0	0.0	93.5	$27.661	$14,786
McIntosh	85.1	0.0	0.0	85.1	$24.536	$14,418
McKenzie	78.9	25.1	13.4	117.3	$84.407	$35,987

Table E2:Estimated County and Township Paved Road Improvements and Investment Needs, by County: 2013-2032						
County	**Miles Resurfaced**	**Miles Widened**	**Miles Reconstructed**	**Total Miles Improved**	**Total Cost (Million$)**	**Annual Cost per Mile**
McLean	126.4	13.2	2.2	141.9	$49.748	$17,535
Mercer	103.3	0.0	1.3	104.6	$32.504	$15,543
Morton	97.4	0.0	0.0	97.4	$26.075	$13,388
Mountrail	1.9	50.4	50.0	102.3	$140.493	$68,638
Nelson	83.7	0.0	0.0	83.7	$23.896	$14,278
Oliver	27.3	0.0	0.0	27.3	$7.711	$14,098
Pembina	197.1	2.0	0.0	199.1	$62.669	$15,741
Pierce	11.6	0.0	0.0	11.6	$3.326	$14,323
Ramsey	131.4	0.0	0.0	131.4	$37.316	$14,205
Ransom	59.7	0.0	0.0	59.7	$17.210	$14,417
Renville	82.9	0.0	0.0	82.9	$24.602	$14,834
Richland	218.6	36.3	0.0	255.0	$94.788	$18,586
Rolette	57.1	0.0	0.0	57.1	$16.613	$14,557
Sargent	96.0	3.7	0.0	99.8	$29.578	$14,825
Sheridan	20.9	0.0	0.0	20.9	$6.077	$14,539
Sioux	0.4	0.0	0.0	0.4	$0.106	$12,985
Slope	3.8	0.0	0.0	3.8	$1.036	$13,467
Stark	50.4	36.6	5.2	92.2	$53.767	$29,163
Steele	73.0	9.9	0.0	82.9	$26.864	$16,209
Stutsman	235.2	3.4	0.0	238.6	$72.715	$15,239
Towner	1.7	0.0	0.0	1.7	$0.457	$13,328
Traill	130.4	13.5	0.0	143.8	$46.319	$16,103
Walsh	181.6	5.0	0.0	186.6	$58.558	$15,691
Ward	261.5	1.3	10.5	273.3	$96.360	$17,626
Wells	111.2	0.0	0.0	111.2	$32.123	$14,446
Williams	49.0	110.0	3.0	162.0	$133.659	$41,257

Table E.3: County and Township Paved Road Investment Needs by County and Period (Thousands of 2012 Dollars)						
County	**2013_2014**	**2015_2016**	**2017_2018**	**2019_2020**	**2021_2022**	**2023_2032**
Adams	$202	$621	$651	$552	$902	$2,892
Barnes	$6,426	$15,319	$11,138	$8,800	$7,008	$26,176
Benson	$1,471	$3,313	$6,529	$2,145	$3,565	$9,276
Billings	$2,550	$1,571	$383	$698	$389	$8,070
Bottineau	$2,231	$20,752	$27,181	$8,474	$4,583	$20,669
Bowman	$5,938	$5,355	$2,340	$2,232	$2,554	$22,740
Burke	$1,477	$4,233	$3,177	$1,002	$1,234	$6,753
Burleigh	$2,852	$5,770	$4,365	$4,582	$3,448	$29,648
Cass	$5,427	$4,731	$4,984	$12,086	$6,153	$59,451
Cavalier	$2,197	$8,162	$3,752	$1,913	$1,065	$6,667
Dickey	$3,786	$2,978	$4,105	$1,652	$2,487	$11,949
Divide	$3,658	$4,353	$823	$760	$553	$2,886
Dunn	$7,016	$1,106	$2,133	$512	$173	$944
Eddy	$1,090	$1,890	$3,888	$5,701	$4,212	$5,603
Emmons	$144	$144	$217	$232	$195	$3,251
Foster	$2,699	$7,017	$5,826	$4,467	$1,844	$4,868
Golden Valley	$218	$636	$218	$243	$440	$4,922
Grand Forks	$5,426	$8,033	$10,736	$9,071	$8,390	$40,025
Grant	$31	$31	$602	$521	$64	$212
Griggs	$1,344	$2,496	$3,641	$1,013	$459	$4,116
Hettinger	$431	$331	$405	$203	$735	$2,647
Kidder	$614	$2,107	$1,643	$4,142	$1,361	$8,104
LaMoure	$3,574	$6,149	$12,391	$8,375	$4,940	$14,283
Logan	$115	$115	$115	$400	$305	$2,055
McHenry	$1,060	$1,060	$3,783	$5,218	$6,886	$9,655
McIntosh	$1,336	$3,431	$3,086	$4,726	$1,471	$10,486
McKenzie	$62,586	$8,197	$1,897	$1,942	$1,326	$8,460
McLean	$6,804	$11,375	$9,923	$5,364	$5,783	$10,498

Table E.3: County and Township Paved Road Investment Needs by County and Period (Thousands of 2012 Dollars)						
County	**2013_2014**	**2015_2016**	**2017_2018**	**2019_2020**	**2021_2022**	**2023_2032**
Mercer	$3,021	$2,378	$4,371	$3,968	$2,683	$16,084
Morton	$879	$2,558	$2,455	$3,402	$2,839	$13,941
Mountrail	$82,984	$27,422	$5,959	$3,080	$1,084	$19,965
Nelson	$997	$1,291	$2,353	$4,798	$5,049	$9,409
Oliver	$304	$304	$304	$304	$729	$5,766
Pembina	$5,264	$9,333	$9,789	$6,896	$5,734	$25,654
Pierce	$198	$584	$1,133	$179	$170	$1,062
Ramsey	$2,074	$3,470	$4,781	$5,023	$4,753	$17,215
Ransom	$1,475	$2,750	$3,568	$3,045	$1,879	$4,492
Renville	$1,010	$2,354	$5,079	$3,528	$3,773	$8,859
Richland	$14,489	$22,059	$18,580	$8,994	$4,297	$26,368
Rolette	$1,427	$1,461	$2,754	$963	$761	$9,247
Sargent	$902	$2,299	$1,915	$4,043	$2,824	$17,594
Sheridan	$358	$1,406	$749	$1,189	$997	$1,379
Sioux	$4	$4	$4	$4	$4	$87
Slope	$38	$38	$38	$38	$38	$846
Stark	$17,086	$13,967	$7,614	$1,741	$2,496	$10,862
Steele	$1,714	$8,944	$6,634	$3,558	$839	$5,176
Stutsman	$7,261	$5,560	$8,499	$11,548	$10,170	$29,677
Towner	$15	$15	$15	$260	$67	$83
Traill	$2,649	$8,176	$12,521	$5,398	$2,504	$15,072
Walsh	$3,635	$10,062	$9,649	$9,673	$6,322	$19,217
Ward	$10,809	$17,987	$11,562	$13,095	$7,050	$35,856
Wells	$1,679	$2,415	$2,191	$5,199	$3,927	$16,711
Williams	$69,897	$22,987	$24,296	$2,394	$2,080	$12,004

Table E4: Estimated Improvement Needs for Unpaved Indian Reservation Roads, By County (Million 2012 Dollars)							
County	**2013-2014**	**2015-2016**	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2032**	**2013-2032**
Benson	$0.12	$0.12	$0.12	$0.12	$0.12	$0.61	$1.22
Dunn	$0.90	$0.90	$0.95	$1.01	$1.01	$6.59	$11.36
McKenzie	$0.45	$0.45	$0.45	$0.46	$0.46	$2.55	$4.80
McLean	$0.37	$0.37	$0.41	$0.46	$0.46	$2.43	$4.50
Mercer	$0.16	$0.16	$0.17	$0.18	$0.18	$1.00	$1.85
Mountrail	$0.04	$0.04	$0.05	$0.07	$0.07	$0.31	$0.57
Rolette	$0.22	$0.22	$0.22	$0.22	$0.22	$1.16	$2.25
Sioux	$0.07	$0.07	$0.10	$0.14	$0.14	$0.79	$1.31

Table E5: Estimated Improvement Needs for Paved Indian Reservation Roads, , By County ((Thousands of 2012 Dollars)							
County	**2013_2014**	**2015_2016**	**2017_2018**	**2019_2020**	**2021_2022**	**2023_2032**	**2013-2032**
Benson	$270	$270	$271	$271	$1,008	$5,768	$7,858
Dunn	$17,956	$1,448	$153	$159	$162	$916	$20,794
McKenzie	$16,314	$127	$127	$131	$134	$792	$17,625
McLean	$17,699	$189	$643	$189	$531	$1,735	$20,986
Mercer	$10,428	$62	$62	$62	$62	$309	$10,985
Mountrail	$13,837	$121	$155	$120	$123	$2,827	$17,183
Rolette	$883	$880	$713	$939	$2,965	$13,554	$19,934
Sioux	$484	$484	$484	$1,215	$1,545	$8,300	$12,512