NDSU UPPER GREAT PLAINS TRANSPORTATION INSTITUTE

Final Report

Infrastructure Needs: North Dakota's County, Township and Tribal Roads and Bridges: 2017-2036

Report Requested by North Dakota Legislative Assembly
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Summary of Study

This report the response 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 inventory and condition data available. Agricultural and oil-related traffic are 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 significant data collection effort was undertaken to provide the most complete and current data on the condition of the county and township roadway system in the state. Condition information was collected in conjunction with the North Dakota Department of Transportation (NDDOT) using its Pathways van, which utilizes instrumentation and software to provide objective assessments. Falling weight deflectometer and ground penetrating radar analyses were conducted to develop a clear picture of the existing pavement and subgrade structure. In addition, more than 1,000 traffic counts were collected on the county and township road system to develop the data needed to calibrate a statewide travel demand model, which was used to forecast future traffic levels. And new for this study was the development of GRIT (Geographic Roadway Inventory Tool) which was used to gather and verify county roadway inventory information such as pavement age, thickness, etc… directly from local road authorities.

An enhanced county level survey was developed to assess component costs, blading, graveling, and maintenance costs for each of the 53 counties in North Dakota. Survey instrument training was provided to the counties via recorded webinar. A secondary analysis of survey results was performed to identify significant variations from county to county by region within the state.

For traffic forecasting, a travel demand model (TDM) has been developed by the Upper Great Plains Transportation Institute (UGPTI) for the entire state using the Citilabs Cube suite of software. The TDM network 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. Due to uncertainty in crude oil pricing and the resulting drilling activity, three scenarios were estimated based on possible drilling rig counts within the state: 30, 60, and 90 rigs. Throughout the study, the 60-rig scenario is referred to as the "likely scenario."

Using the TDM, inputs and products are routed to and from wells to minimize time and/or cost, subject to available supplies and capacities. A comparable 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 the calibration tools available in the Cube software package.

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 increases as traffic volumes grow. For example, a non-impacted road has an expected gravel cycle of five years and a blading interval of once per month, while an impacted section has an expected gravel cycle of two to five years and a blading interval of twice per month. This is a doubling of the gravel maintenance costs over the same time period.

As shown in Tables A-C, the predicted statewide unpaved infrastructure needs range from $5.86 billion to $6.21 billion for the next 20 years. Approximately 43% of these needs can be traced to the 17 oil and gas producing counties.

Table A: Summary of Unpaved Road Investment and Maintenance Needs for Counties and Townships in North Dakota- 30 Rigs (Millions of 2016 Dollars)

Period	Statewide	Oil Patch	Rest of State
2017-18	$ 600.05	$ 248.47	$ 351.58
2019-20	$ 590.00	$ 237.84	$ 352.16
2021-22	$ 601.62	$ 248.57	$ 353.05
2023-24	$ 597.85	$ 244.43	$ 353.42
2025-26	$ 583.02	$ 229.07	$ 353.96
2027-36	$ 2,887.13	$ 1,130.88	$ 1,756.25
2017-36	**$ 5,859.67**	**$ 2,339.26**	**$ 3,520.41**

Table B: Summary of Unpaved Road Investment and Maintenance Needs for Counties and Townships in North Dakota- 60 Rigs (Millions of 2016 Dollars) (Likely Scenario)

Period	Statewide	Oil Patch	Rest of State
2017-18	$ 644.65	$ 293.04	$ 351.61
2019-20	$ 606.97	$ 254.84	$ 352.14
2021-22	$ 659.80	$ 306.77	$ 353.03
2023-24	$ 660.86	$ 307.47	$ 353.40
2025-26	$ 602.62	$ 248.61	$ 354.01
2027-36	$ 2,915.81	$ 1,159.72	$ 1,756.09
2017-36	**$ 6,090.72**	**$ 2,570.44**	**$ 3,520.27**

Table C: Summary of Unpaved Road Investment and Maintenance Needs for Counties and Townships in North Dakota- 90 Rigs (Millions of 2016 Dollars)

Period	Statewide	Oil Patch	Rest of State
2017-18	$ 670.42	$ 318.79	$ 351.63
2019-20	$ 626.93	$ 274.77	$ 352.17
2021-22	$ 668.08	$ 314.98	$ 353.10
2023-24	$ 658.79	$ 305.38	$ 353.41
2025-26	$ 619.96	$ 265.95	$ 354.01
2027-36	$ 2,961.71	$ 1,205.62	$ 1,756.09
2017-36	**$ 6,205.89**	**$ 2,685.48**	**$ 3,520.40**

Paved Road Needs

As shown in Tables D-F, $2.19 to 2.27 billion in paved road investment and maintenance expenditures will be needed during the next 20 years. Roughly 38% of these expenditures will be needed in the oil and gas producing counties of western North Dakota. Much of the investment will be needed during the first few bienniums as a result of backlogs in road improvements, especially on the eastern half of the state.

Table D: Summary of Paved Road Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2016 Dollars) – 30 Rig Scenario

Period	Statewide	Oil Patch	Rest of State
2017-18	$291.0	$81.1	$209.9
2019-20	$293.5	$90.9	$202.5
2021-22	$256.4	$100.7	$155.6
2023-24	$206.6	$70.3	$136.3
2025-26	$233.1	$75.6	$157.5
2027-36	$922.4	$391.6	$530.8
2017-36	**$2,203.0**	**$810.2**	**$1,392.8**

Table E: Summary of Paved Road Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2016 Dollars) – 60 Rig Scenario (Likely Scenario)

Period	Statewide	Oil Patch	Rest of State
2017-18	$296.1	$85.6	$210.5
2019-20	$299.3	$96.8	$202.5
2021-22	$278.1	$121.7	$156.4
2023-24	$236.8	$100.5	$136.3
2025-26	$233.4	$75.9	$157.5
2027-36	$920.8	$390.8	$530.1
2017-36	**$2,264.5**	**$871.1**	**$1,393.4**

Table F: Summary of Paved Road Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2016 Dollars) – 90 Rig Scenario

Period	Statewide	Oil Patch	Rest of State
2017-18	$302.1	$91.6	$210.5
2019-20	$308.1	$105.6	$202.5
2021-22	$280.3	$123.9	$156.4
2023-24	$240.5	$104.2	$136.3
2025-26	$230.8	$73.3	$157.5
2027-36	$916.8	$386.6	$530.1
2017-36	**$2,278.5**	**$885.1**	**$1,393.4**

Bridge Needs

Table G shows the estimated bridge investment and maintenance needs for county and township bridges from 2016-2036. Most of the improvement needs are determined by the study's improvement model to be backlog needs, occurring during the first study biennium. Based upon discussion with NDDOT Bridge and Local Government Divisions, these needs have been distributed evenly over the first five biennia of the study period.

Table G: Summary of Bridge Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2016 Dollars)

Period	Statewide	Oil Patch	Rest of State
2017-18	$87.0	$20	$67
2019-20	$87.0	$21	$66
2021-22	$87.1	$20	$67
2023-24	$87.0	$21	$66
2025-26	$90.0	$23	$67
2027-36	$11.3	$3	$8
2017-36	**$449.4**	**$108**	**$341**

Total Statewide Needs

As shown in Table H, the combined estimate of infrastructure needs for all county and township roads is $8.8 billion over the next 20 years. Forty percent of this estimate relates to projected needs in the oil and gas producing counties of western North Dakota. Unpaved road funding needs comprise approximately 67% of the total. If averaged over the next 20 years, the annualized infrastructure need is equivalent to $440 million per year.

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

Table H: Summary of All Road and Bridge Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2016 Dollars) (Likely Scenario)

Period	Statewide	Oil Patch	Rest of State
2017-18	$1,028.7	$399.6	$629.1
2019-20	$994.2	$372.6	$621.6
2021-22	$1,025.9	$449.5	$576.4
2023-24	$985.7	$429.0	$556.7
2025-26	$924.0	$345.5	$578.5
2027-36	$3,848.7	$1,553.5	$2,295.2
2017-36	**$8,804.2**	**$3,549.5**	**$5,254.7**

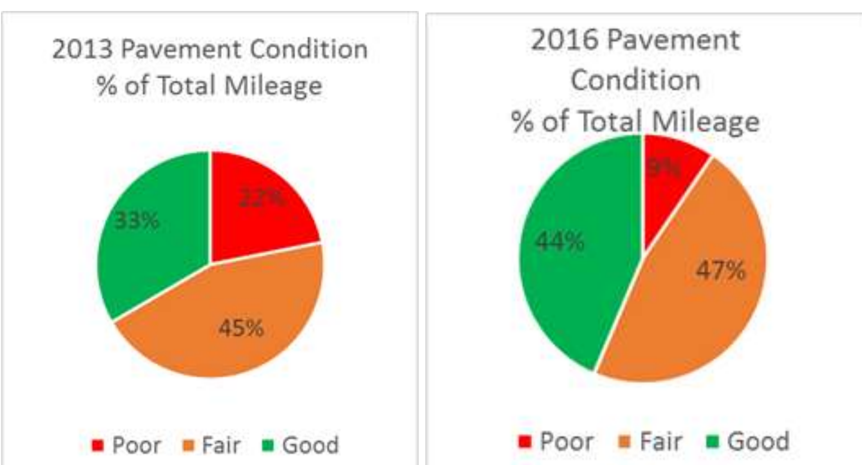
Table I: Summary of All Road and Bridge Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2016 Dollars) (Likely Scenario)

Period	Unpaved	Paved	Bridges	Total
2017-18	$644.7	$296.1	$87.0	$1,027.8
2019-20	$607.0	$299.3	$87.0	$993.3
2021-22	$659.8	$278.1	$87.1	$1,025.0
2023-24	$660.9	$236.8	$87.0	$984.7
2025-26	$602.6	$233.4	$90.0	$926.0
2027-36	$2,915.8	$920.8	$11.3	$3,847.9
2017-36	**$6,090.7**	**$2,264.5**	**$449.4**	**$8,804.7**

General Comparison with 2014 Study

Investments in pavement over the current and previous bienniums have reduced the 20 year costs for pavements and improved overall pavement condition. The charts below in Figure A show how the percentage of poor miles of pavement have decreased and the good miles of pavement have increased between 2013 and 2016.

Figure A. Pavement Condition Change from 2013 to 2016



This study also shows a reduction of approximately $660 million in 20-year pavement needs when compared to the 2014 study. Much of the reduction is due to lower unit costs for pavement materials. Additional reductions are due to the number of miles of newer pavement constructed in the current and previous biennium. Better pavement structure information obtained through non-destructive testing and the asset management system/geographic roadway inventory tool (GRIT) has also improved the costing information as county-supplied data indicates that some pavements are thicker and wider than originally thought. This enhanced county-supplied data will continue to improve paved, unpaved, and structural forecasts in future studies.

The costs for unpaved roads/gravel have increased about 6% (approximately $360 million) over the 20-year period. Much of this increase is due to more uniform reporting by counties as a result of a revised survey instrument and related webinar training provided to counties during this study. Unit prices for gravel have not changed significantly.

Projections of bridge funding needs have stayed close to the previous study because of the large backlog of bridges needing improvements or replacement. Bridge inspections are performed every 2 years and during that time, a few bridges have deteriorated enough to enter the scoring area where improvement would be suggested. Unit prices for bridges have reduced slightly as the pricing differential between east and west has disappeared. Unit prices statewide now reflect the pricing used in the 2014 study for eastern North Dakota.

Contents

1. Introduction

In response to a request from the North Dakota Legislature, NDSU's Upper Great Plains Transportation Institute (UGPTI) estimated county, township, and tribal road and bridge investment needs across the state. This report is the third in a series of studies. 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. The oil study was quickly followed by an analysis of the roadway investments needed to facilitate agricultural logistics. Results of both studies were presented to the Legislature in January 2011.

The 2010 study was based on forecasts of increased agricultural production and the addition of 21,500 oil wells over the study time frame. These forecasts were quickly outdated, necessitating a second statewide study in 2012. The results of this second study were presented to interim legislative committees in advance of the 2013 session. The 2012 study reflected higher agricultural and energy production forecasts, including the addition of 46,000 new oil wells. At the request of the Legislature, county and township bridge investment needs were included in the 2012 study.

The current (2016) study is based on the latest forecasts of agricultural and energy production and road construction prices. Specifically, it reflects the addition of 60,000 new wells, higher input and construction costs, and the latest traffic and roadway condition data available. All data used in this study have been collected during the past year. Investment needs are forecast for a 20-year time period, starting with the 2016-2017 biennium.

This report focuses on county, township, and tribal roads and bridges. State highway and city needs are not considered. Those needs will be presented by the North Dakota Department of Transportation in a separate report. In this report, investment needs are estimated for three classes of road systems: county, township, and tribal – referred to collectively as local roads. In some cases, distinctions are made between county major collector and county local roads. In these instances, "local" refers to a subclassification within a county.

The material presented in this report is organized under the following headings:

- Key economic and industry trends that affect the demand for traffic on local roads
- Key assumptions and methods related to agricultural and energy production and traffic forecasts
- The Geographic Information System and road network model used in this study
- The statewide traffic data collection and analysis plan
- The traffic prediction model used to forecast truck trips on individual road segments
- Methods of analyzing unpaved roads and forecasts of unpaved road funding needs
- Methods of analyzing paved roads and forecasts of paved road funding needs
- Methods of analyzing bridges and forecasts of bridge investment needs

2. Background Trends in Agriculture and Oil Development Impacting Traffic Levels on Local Roads

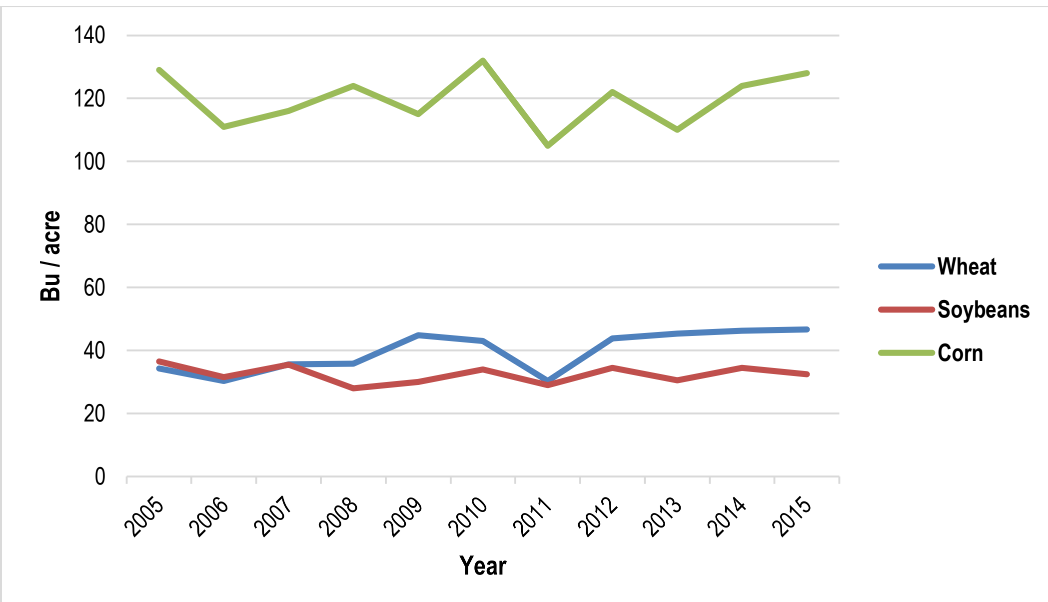
Over the last decade, North Dakota's, local road systems have seen significant changes in traffic patterns, not only in terms of volumes, but also in terms of clustering due to changing land use and the consolidation of transload locations. This section describes major trends in agriculture and oil development over the past 10 years which have had an impact on the number, type, and pattern of truck movements within the state.

2.1. Agricultural Trends

2.1.1. Yield

Per acre yields for major crops in North Dakota have increased over the past 10 years because of increases in technology, genetically modified varieties, improved farming practices, and other factors. Figure 1 shows yield trends for the three major crops in North Dakota: corn, wheat and soybeans.

Figure 1. Average Yield for Corn, Soybeans and Wheat in North Dakota (2005-2015)



There are significant year-to-year yield variations primarily due to changes in weather, but the overall trend is an increase in yield for wheat and a stable trend for corn and soybeans. For all of the crops, yield increased during the last few years since the weather-related decline observed in 2010-11.

If the acreage of each of these crops is held constant, these yield increases will lead to a slightly greater than 2% growth rate in the number of truck trips generated as a result of agricultural production in North Dakota. However, changes in the number of acres, or the crop mix, over the last decade have also contributed to increased truck volumes.

2.1.2. Crop Mix

Crop mix refers to the percentage of land being used to produce each commodity. As shown in Figure 1, the three major commodities have different yield rates. In 2015, the average statewide yield for wheat was roughly 45 bushels/acre. For soybeans, the average yield was 30 bushels/acre. Corn yield was 130 bushels/acre. Any shift in wheat acreage to corn would represent a 188% increase in yield on average. A shift in soybean acreage to corn would represent a 333% increase in yield on average. These increases directly correspond to increases in truck traffic. Moreover, the fertilizer requirements for corn production versus wheat production are nearly double, so an increase in inbound input movements is expected as well.

Again, using the largest three commodities by acreage for comparative purposes, Figure 2 shows the number of acres by year planted of corn, soybeans and wheat in North Dakota from 2005 to 2015. This chart is a stacked line chart, so the difference between the top and the bottom of each of the commodity ranges is the value of the number of acres. The summation of these ranges is the total number of acres that these three commodities comprise.

Figure 2. Planted Acres of Corn, Soybeans and Wheat in North Dakota (2005-2015)

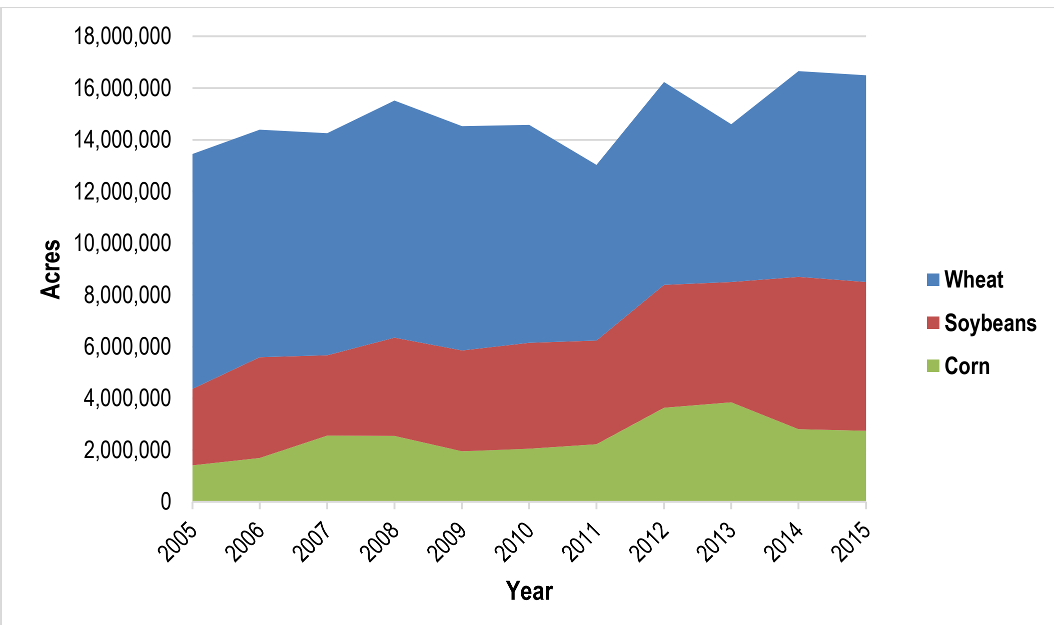
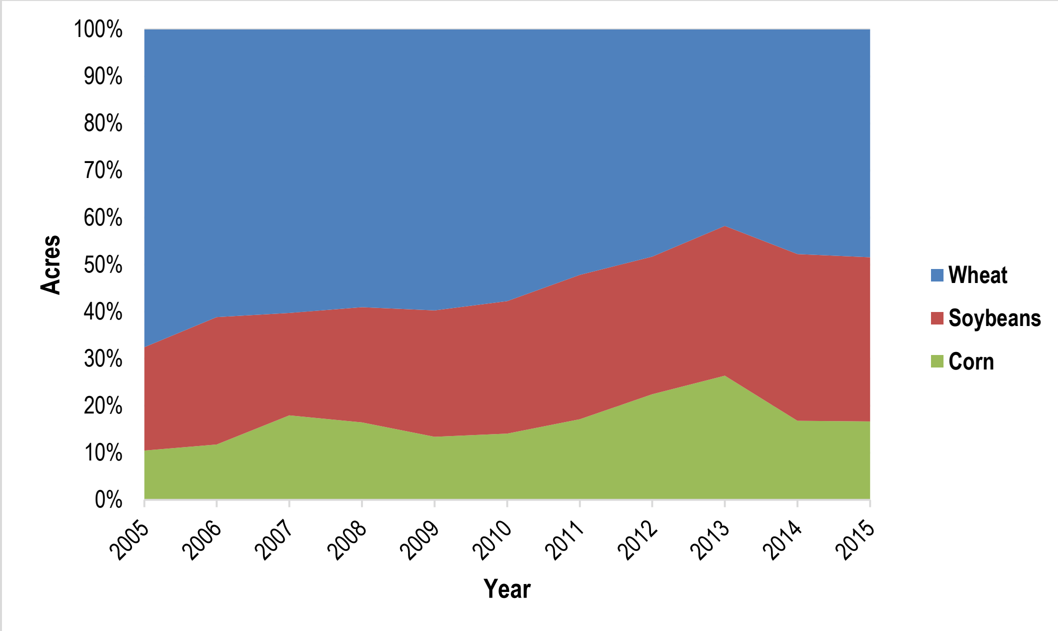


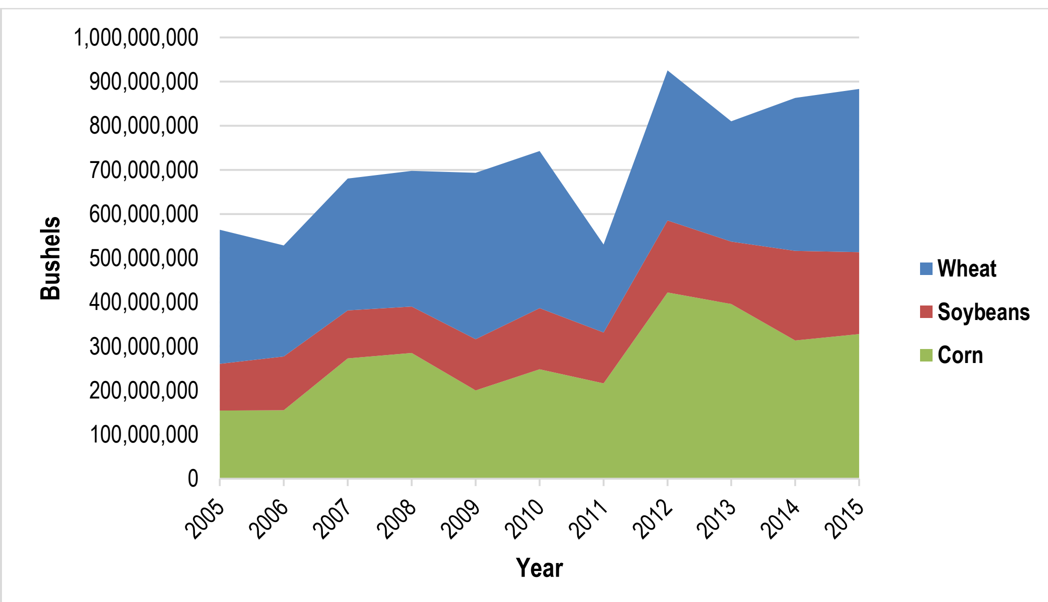
Figure 3 breaks the acreages down by percentage. At the beginning of the period, wheat was planted on nearly 68% of the corn, wheat and soybean acres, soybeans on 22%, and corn on 10%. In 2015, wheat was planted on 48%, soybeans on 35% and corn on 17% of these acres. For reference, in 2015, corn, wheat, and soybeans were planted on 16.5 million acres in North Dakota, which is 70% of all acres planted in North Dakota. **Figure 3. Percent Acres of Corn, Soybeans and Wheat in North Dakota (2005-2015)**



2.1.3. Total Production

Due to the combination of increased yields and changing crop mix, total production has increased over the past decade. As shown in Figure 4, total production has increased from roughly 565 million bushels of corn, wheat and soybeans in 2005 to 880 million bushels in 2015. Excluding 2011's weather related decrease, there is a readily observable upward trend in overall production.

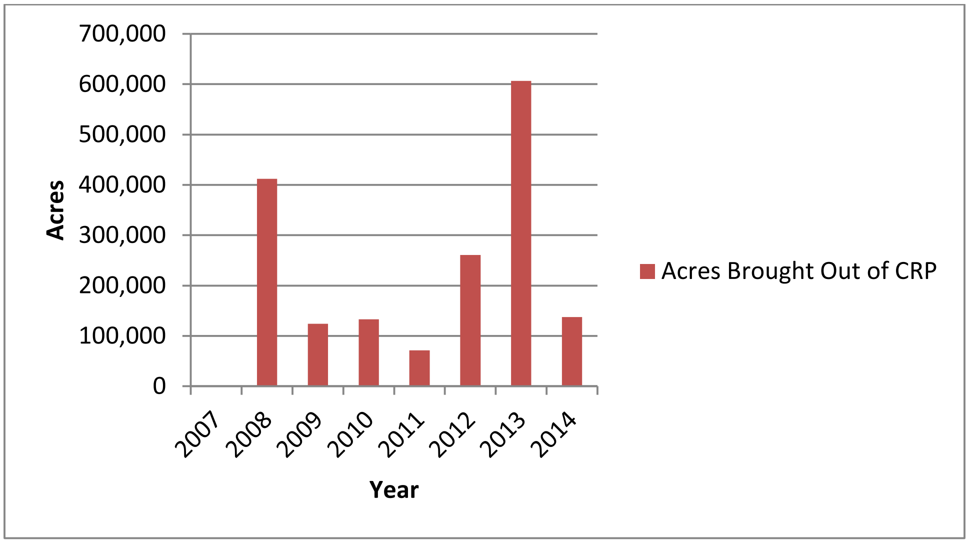
Figure 4. Total Production of Corn, Wheat and Soybeans in North Dakota 2005-2015



2.1.4. Conservation Reserve Program

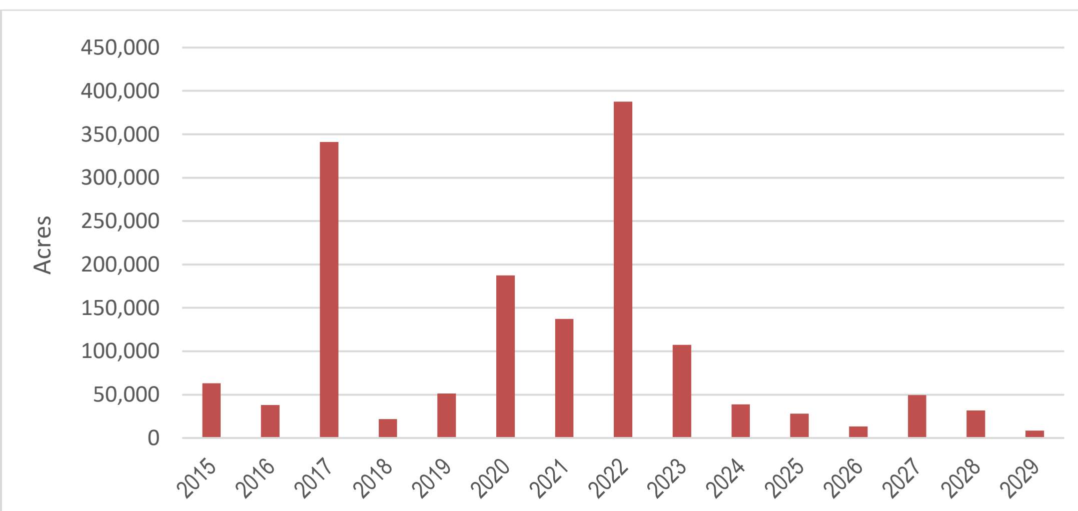
As the farm economy has been positive recently, many North Dakota producers have chosen not to re-enroll acres in the Conservation Reserve Program (CRP). As a result, previously enrolled acres went back into production, increasing truck traffic in areas which, for the recent past, had seen virtually no trip generation. Figure 5 shows the number of acres in North Dakota by year since 2007 that have been brought out of the CRP and put back into production.

Figure 5. CRP Acres in North Dakota Not Renewed: 2007-2014



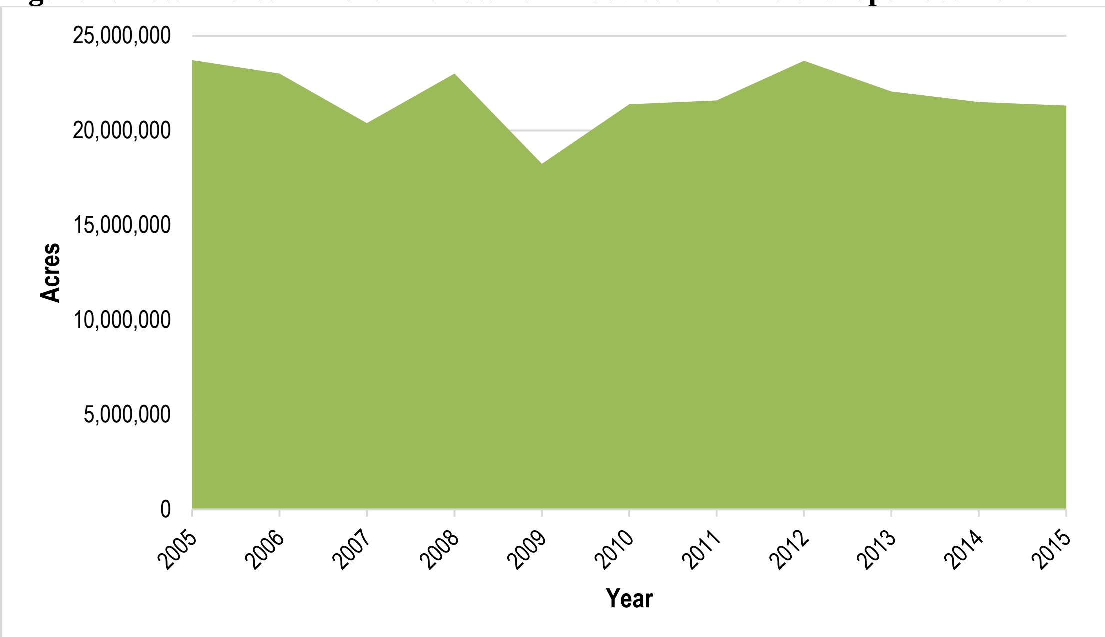
According to the Farm Service Agency, from 2007 to 2014, 1.74 million acres have come out of the CRP in North Dakota (the figure for 2015 has not been published yet). Over the next 10 years, contracts on an additional 1.6 million acres are set to expire. Figure 6 shows the expirations by year through 2029.

Figure 6. CRP Acres Set to Expire in North Dakota: 2015-2029



The true impact of acres being brought back into production on traffic volumes is unclear at this time. For a comparison of the impact of the acres brought out of CRP since 2007, Figure 7 shows the total number of acres of land in North Dakota used for production of field crops. If additional data regarding the timing and location of the contract expirations were available, the changes could be estimated. However, any impacts are not expected to be significant in comparison to total traffic volumes. Thus, the additional shifting of acres into or out of production will not have a dramatic effect on the results presented in this report and will not appreciably affect the near-term forecasts of road investment needs.

Figure 7. Total Acres in North Dakota for Production of Field Crops 2005-2015



2.1.5. Elevator Throughput

Since the mid 1990s there has been an increase in the number of grain elevators that can handle and load 100 or more rail cars. These shuttle elevators receive a discounted rail rate in exchange for guaranteed volumes and service times. Discounted transportation rates allow shuttle elevators to expand their draw areas through higher spot prices, thereby increasing the total volume of grain marketed at their facilities. In 2002, there were 15 shuttle car elevators in North Dakota. By 2015, there were. A comparison of the numbers of elevators by shipment categories is shown in Table 1.

Table 1. Elevator Types in North Dakota, 2005 and 2015

Elevator Type	2005	2015	Change
No Rail (0 Car)	32	12	-20
Single (1-25 Cars)	123	106	-17
Multi Car (25-52 Cars)	71	56	-15

Unit (52-100 Cars)	75	53	-22
Shuttle (100+ Cars)	24	59	35
All Types	**325**	**286**	**39**

Over the last decade there has been a decline in the numbers of all types of elevators, with the exception of shuttle elevators. Shuttle elevators experienced a 2.5-fold increase. The number of elevators by type tells only part of the story with regard to changes in agricultural marketing in North Dakota. The Annual Elevator Marketing Report compiled by UGPTI provides total throughput by elevators in each class. Figures 8 and 9 show the total throughput by elevator class in 2005 and 2015 respectively, and is taken directly from the Annual Elevator Marketing Report for the corresponding years.

Figure 8. Elevator Throughput by Elevator Class: 2005

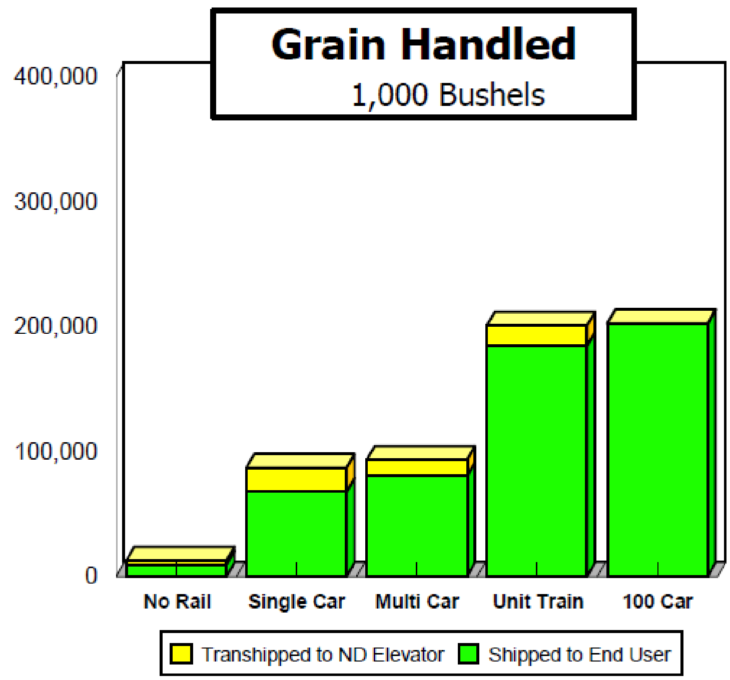
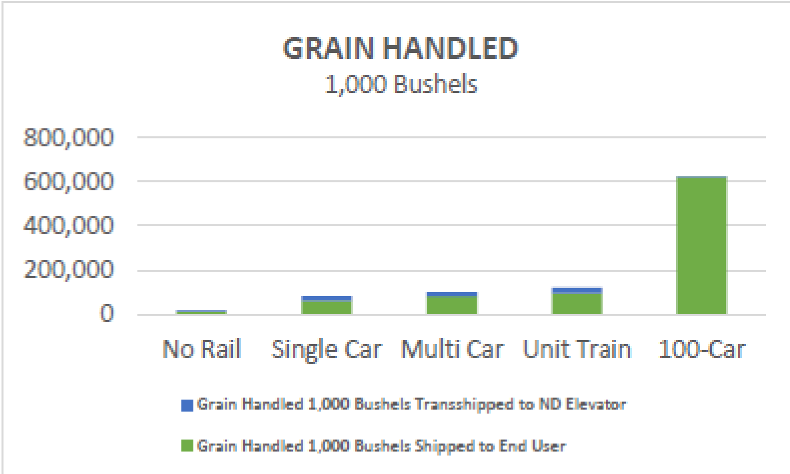


Figure 9. Elevator Throughput by Elevator Class: 2015



As these figures show, a substantially larger percentage of grain was marketed through shuttle elevators in 2015 than in 2005, a change that has an impact on the local road system throughout the state. For example, in 2005, unit and shuttle train elevators marketed roughly 400 million bushels of grain. At that time the combined number of facilities in those two classes was 99 elevators. In 2015, roughly 600 million bushels of grain were marketed through shuttle elevators which represent just 59 facilities statewide. The result of this change is consolidation of higher levels of truck traffic at fewer destination points. Often these shuttle elevators are located on or near state highways, but the county major collector (CMC) and other county routes where traffic is consolidated also may see increased truck traffic, depending on the location and network density near these facilities.

2.1.6. Combined Impact of Factors

As discussed in the previous sections, a variety of factors are changing in the agricultural industry within North Dakota, all of which may result in increased truck traffic related to agricultural production and marketing. Increased yield for nearly every crop produced in the state, a changing crop mix favoring the highest productivity, and higher consolidation of grain volumes at elevators and ethanol facilities each contribute to increased traffic. The combination of these factors, whether total acreage increases or not, trend toward higher traffic volumes, particularly on CMC routes and state highways.

2.2. Oil Production Trends

2.2.1. Technology

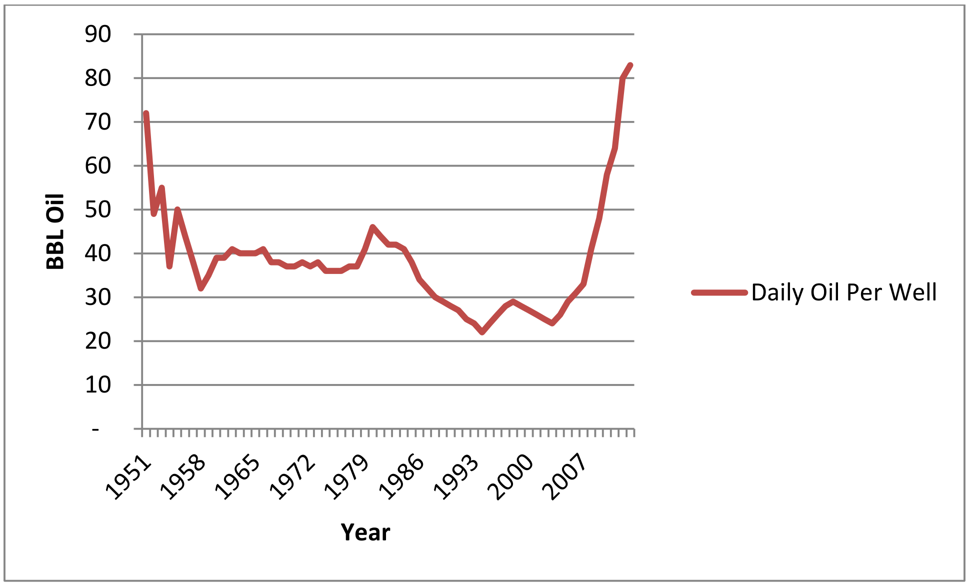
The current oil boom in North Dakota came about as a result of improved technology in oil exploration and extraction. Two primary technological advances have led to increased productivity within the Bakken/Three Forks formations: horizontal drilling and hydraulic fracturing.

Horizontal drilling consists of an initial vertical wellbore which, at a specified depth, is deviated at an angle that is adjusted until the final wellbore is a horizontal lateral wellbore. Because the shale formations being explored are relatively narrow, this allows for a much larger contact area between the wellbore and the formation, which is greatly enhanced through hydraulic fracturing. Hydraulic fracturing results in multiple longitudinal fractures along the horizontal lateral. Multiple fracturing stages ensure that fractures occur along the entire horizontal alignment thereby optimizing the oil recovery potential.

2.2.2. Well Productivity

As a result of the improved extraction technology, the average productivity of a North Dakota oil well has dramatically increased. From 2005-2012 average oil well production increased from 25 BBL oil/day to 82 BBL oil/day. Figure 10 shows the daily average statewide oil production by year in North Dakota since the first well was drilled in 1951.

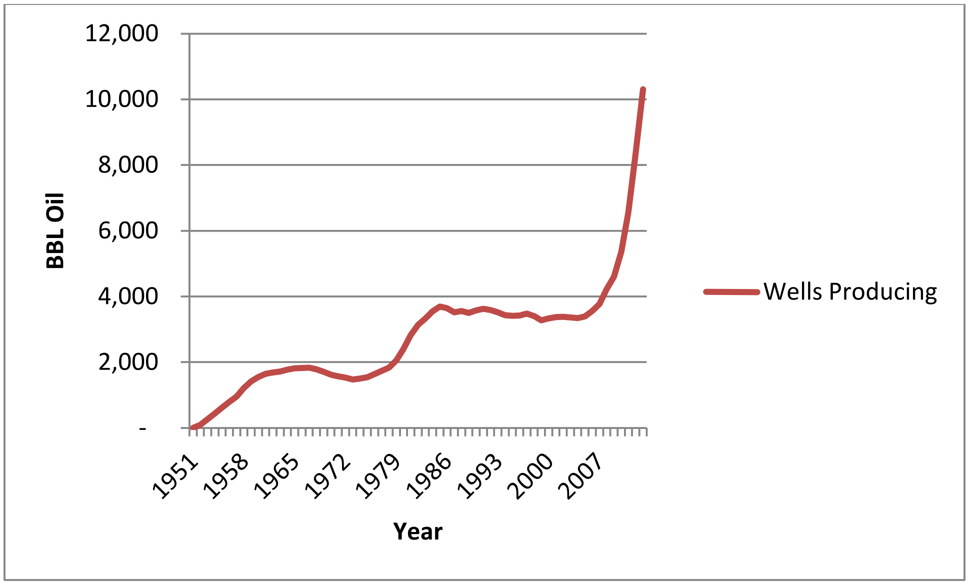
Figure 10. Daily Oil Produced Per Well in North Dakota 1951-2012



2.2.3. Total Number of Wells

Improved extraction technology has not only increased the productivity of wells in North Dakota, but effectively expanded the geographic area where oil could be profitably extracted. As a result, expanded drilling has occurred throughout the play, encompassing 17 counties in western North Dakota with the heaviest activity occurring in Dunn, McKenzie, Mountrail, and Williams counties. The total number of producing wells per year is shown in Figure 11. From the late 1970s until mid-2000s the number of producing wells remained relatively constant. With the technological advances in exploration and extraction, the number of producing wells has increased exponentially.

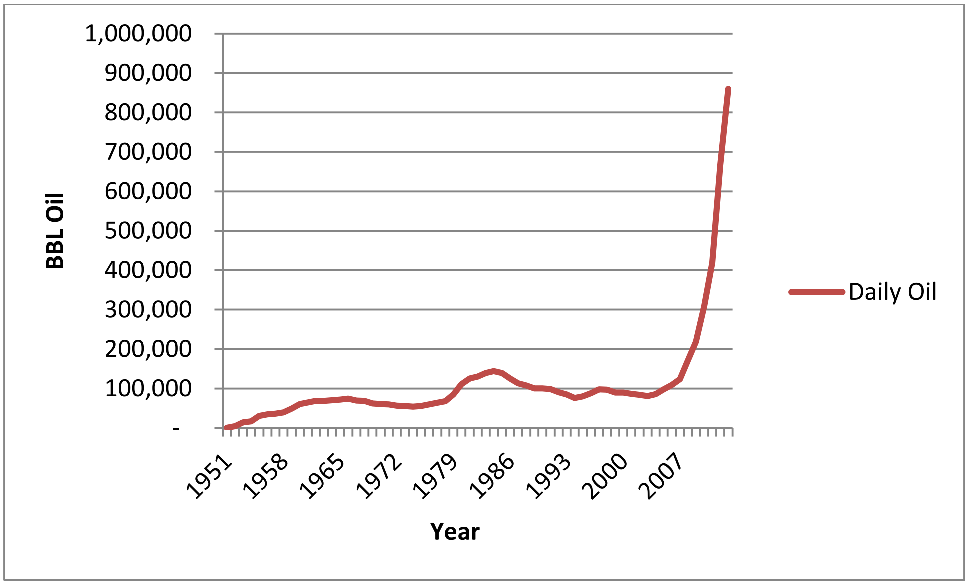
Figure 11. Total Producing Oil Wells in North Dakota (1951-2012)



2.2.4. Total Production

As outlined previously, productivity per well has increased while the total number of wells has increased as well. The combination of these two trends has resulted in a significant surge in the total statewide production of oil. Figure 12 shows the historical daily oil production from 1951 to 2013.

Figure 12. Historical Daily Oil Production in North Dakota



2.2.5. Changes in Forecasted Development

Throughout the initial development of the Bakken and Three Forks formations, there was a degree of uncertainty about the extent and duration of the potential development of the play. In 2010, at the request of the North Dakota Department of Commerce and the North Dakota Oil and

Gas Producing Counties Association, UGPTI conducted a study to estimate the additional road needs due to oil development impacts on county and township roads. At that time, the estimated scope and duration of the play was a total of 21,250 new wells over a 20-year timeframe.

Beginning in 2011, UGPTI conducted a study at the direction of the North Dakota Legislature to estimate statewide needs for county and township roads. This study updates that effort. At the conclusion of that study, the estimated number of new wells was 45,000. The current forecast for total new wells is 65,000, with 45,000 to 75,000 as the outer ranges. It is expected that as more is known about the development of the play, the forecasts will become more consistent.

3. Model Methods and Assumptions

This section of the report describes the key assumptions related to agricultural and energy production and movement patterns, including: (1) primary sources of production and travel demand data, (2) the geographic basis for production forecasts, and (3) land use patterns (such as crop and well densities) that give rise to truck trips.

3.1. Agriculture

3.1.1. Transportation Analysis Zones

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.

3.1.2. Crop Mix and Production

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 2012. 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 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, 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. For use in traffic forecasting, township crop production estimates are converted to truck trips, based on each commodity's weight and density.

3.1.3. Total Acres

As presented in the previous section, annual acreage is relatively unchanged over the past 10 years despite 1.7 million additional acres resuming production with the expiration of CRP contracts. With the estimated 1.6 million acres of CRP set to expire within the next 15 years, an increase in total acres is expected. However, spatial data is currently unavailable for the location of the acres set to expire by year. Consequently, the assumption made for the purpose of this study is that acres in production will remain at 2012 levels, which is the highest on record for the past 10 years.

3.1.4. Yield Trends

Following comparisons of NASS yield data trends for each of the eight crops specifically modeled in the rural road traffic model, there were variations from commodity to commodity in terms of growth. For the three major commodities, corn, soybeans, and wheat, there were 2%, 2%, and 4% growth rates respectively. Over the same time period, wheat acres decreased in favor of corn, so the effective level of wheat production is constant. For the purpose of forecasting increased tonnage and truck generation, a 2% growth rate was applied to all commodities for future year forecasting purposes. This is consistent with the yield growth rate for five of the eight modeled commodities.

3.1.5. Elevator and Processor 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 (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.

Ethanol facility demands were estimating by obtaining the output capacity of ethanol for each facility and dividing the capacity by the conversion rate of 2.78 gallons of ethanol per bushel of corn. For processing facilities, annual capacities were obtained through news releases, website publications, or phone surveys of the facilities. Individual elevator and plant demands are based upon actual data in the base year of 2013. Because there is forecasted growth in each commodity's yield over the 20-year analysis period, in order to balance the model, an equal increase in the plant and elevator demand for the commodities was implemented for future year analysis.

3.2. Oil and Gas

3.2.1. Transportation Analysis Zones

The zone representing the geographic unit of production in this study is the spacing unit. The spacing unit defined in this study is a 1,280-acre (2-square mile) polygon that is the basis of oil development within the Bakken formation. The initial spacing unit shapefiles were obtained from the Oil & Gas Division website. For areas within the study area that were not divided into spacing units, the fishnet procedure in ArcMap was used to construct new spacing units for the purpose of spatial forecasting of the future locations of new wells.

3.2.2. Wells per Rig per Year

As a result of discussions with the Oil & Gas Division, the total number of wells per spacing unit is assumed to be 20-24. This is an increase in rig productivity from the previous study, which assumed 10-12 wells per rig per year.

3.2.3. Well Forecasts

Because of uncertainty in present and future crude petroleum markets, three scenarios were estimated. Each of the scenarios forecast the number of new wells drilled as a function of the number of active drilling rigs within the state. The scenarios estimated were: 30, 60 and 90 rigs. As stated above, it is assumed that each rig can drill 20-24 new wells per year.

3.2.4. Spatial Forecasts

The annual forecasts and county-level forecasts provide the total number of wells expected within the oil patch and within each individual county. They do not, however, provide the locations of the wells within each county. To distribute the new wells within spacing units, a geopspatial forecasting method called Hot Spot analysis was used. Hot Spot analysis identifies geographic clustering of activities within a specified region. Hot Spot analysis is also known as Heat Mapping, where the reference to heat refers to the concentration of the activity within any given area.

Figures 13-18 shows the clustering of existing wells in the base year and 20 year forecast under each rig scenario. Lighter spacing units represent undrilled units, and darker units represent units that have completed drilling. The intermediate shades represent spacing units at various stages of development.

By identifying the degree of clustering of existing wells, one can forecast the location of future wells in areas where existing development has already occurred, subject to the constraint of 8-20 wells per spacing unit. Once that constraint has been reached, no additional wells may be added.

Figure 13. Hot Spot Map of Oilfield Spacing Units, 30 Rig Scenario 2015

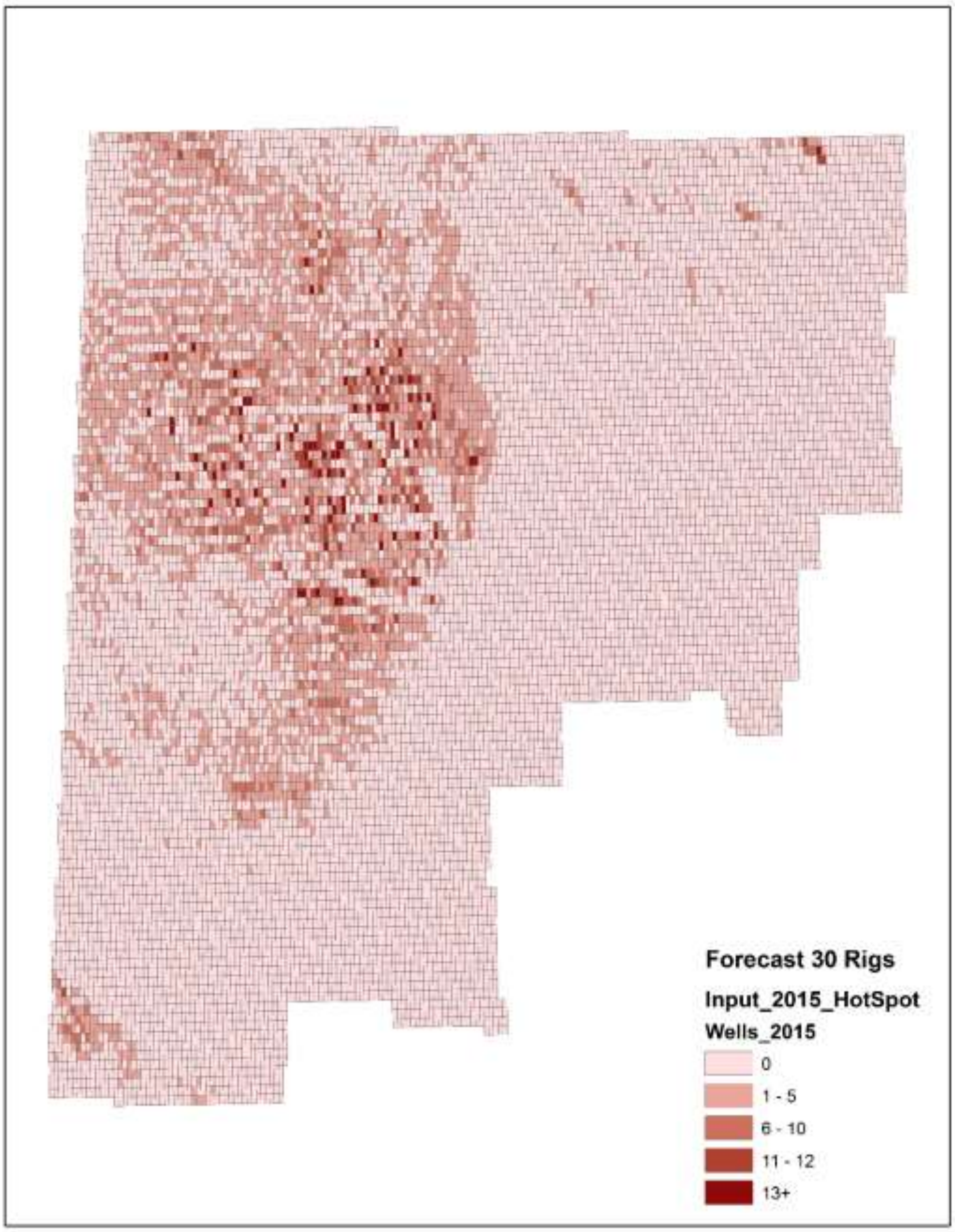


Figure 14. Hot Spot Map of Oilfield Spacing Units, 30 Rig Scenario 2035

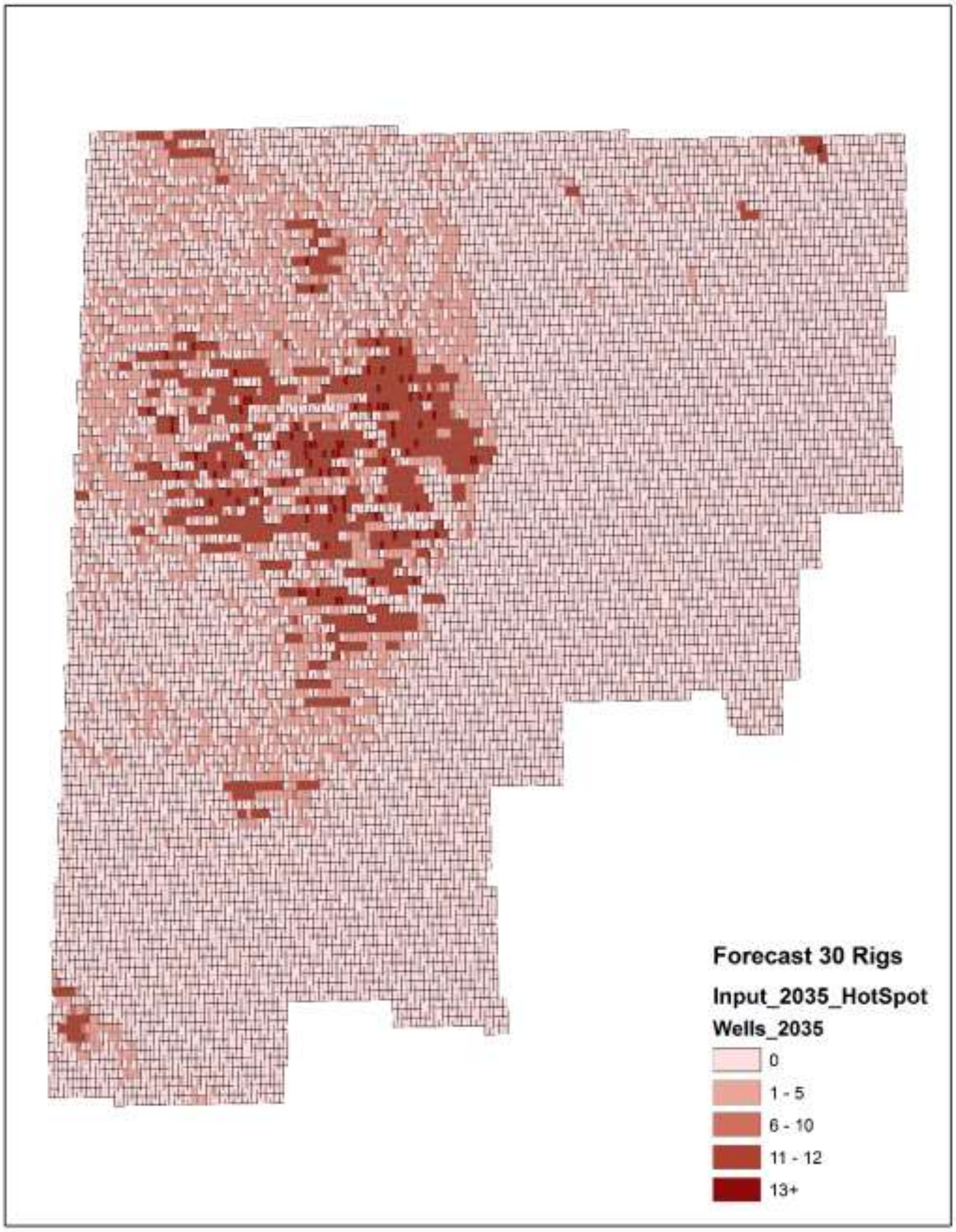


Figure 15. Hot Spot Map of Oilfield Spacing Units, 60 Rig Scenario 2015

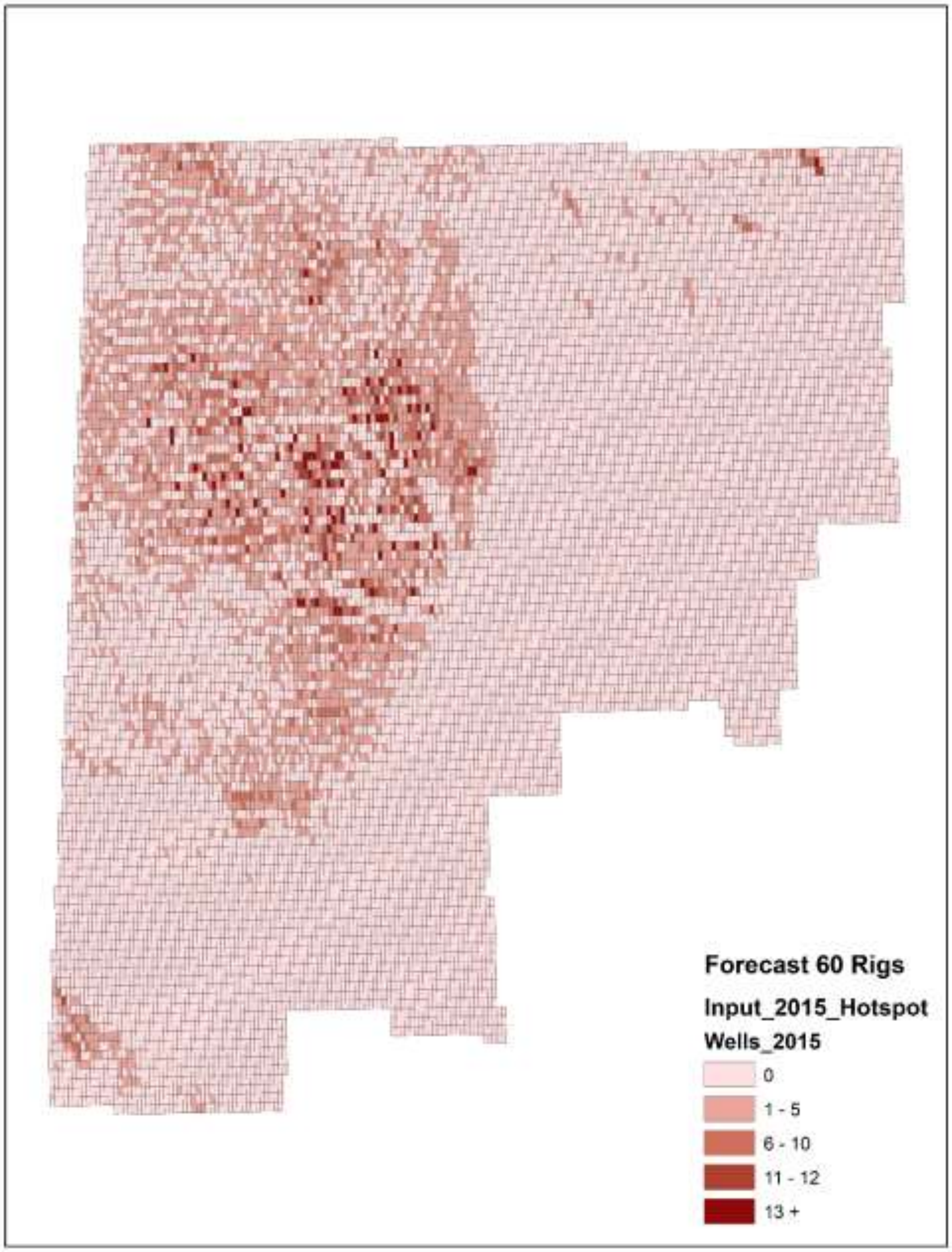


Figure 16. Hot Spot Map of Oilfield Spacing Units, 60 Rig Scenario 2035

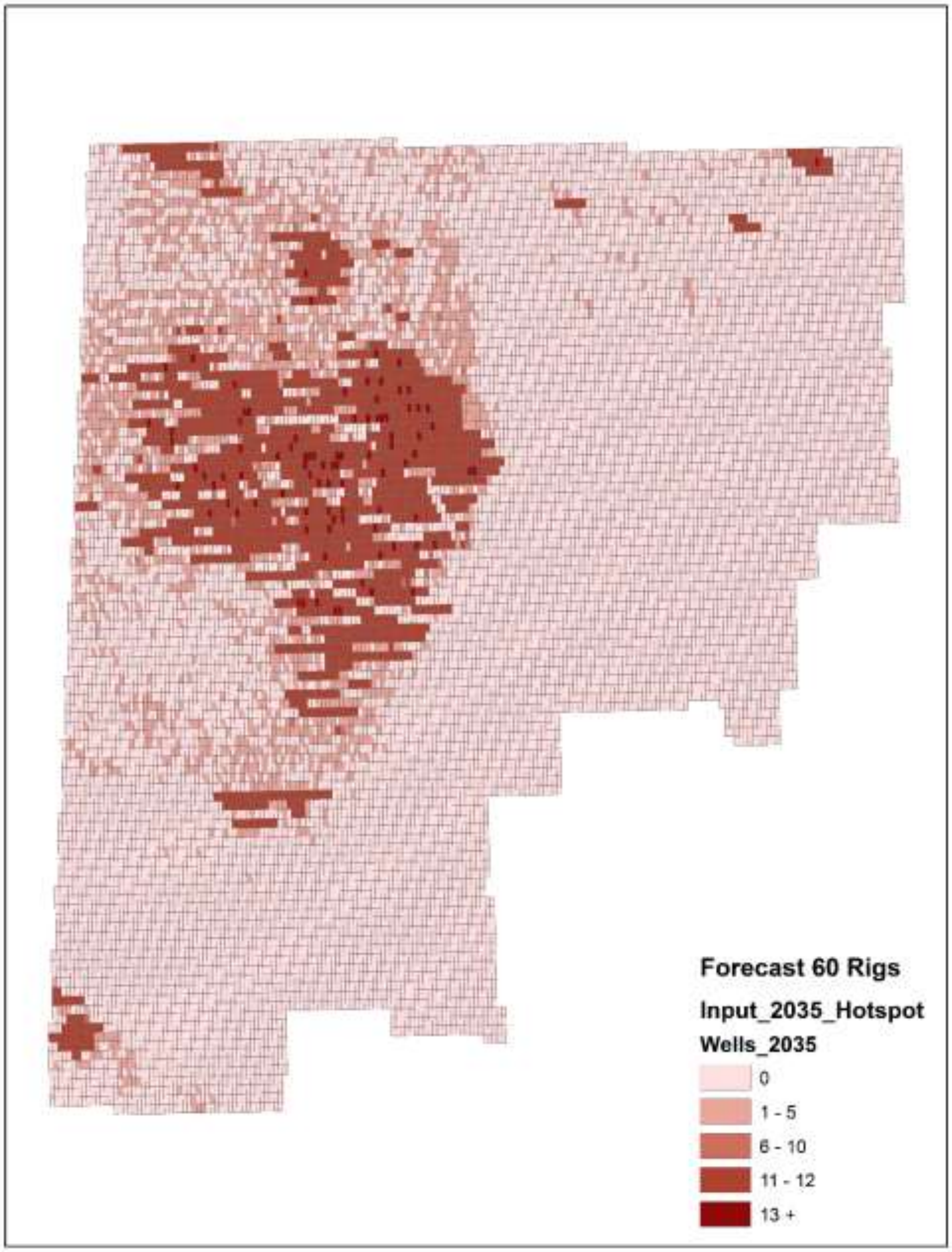


Figure 17. Hot Spot Map of Oilfield Spacing Units, 90 Rig Scenario 2015

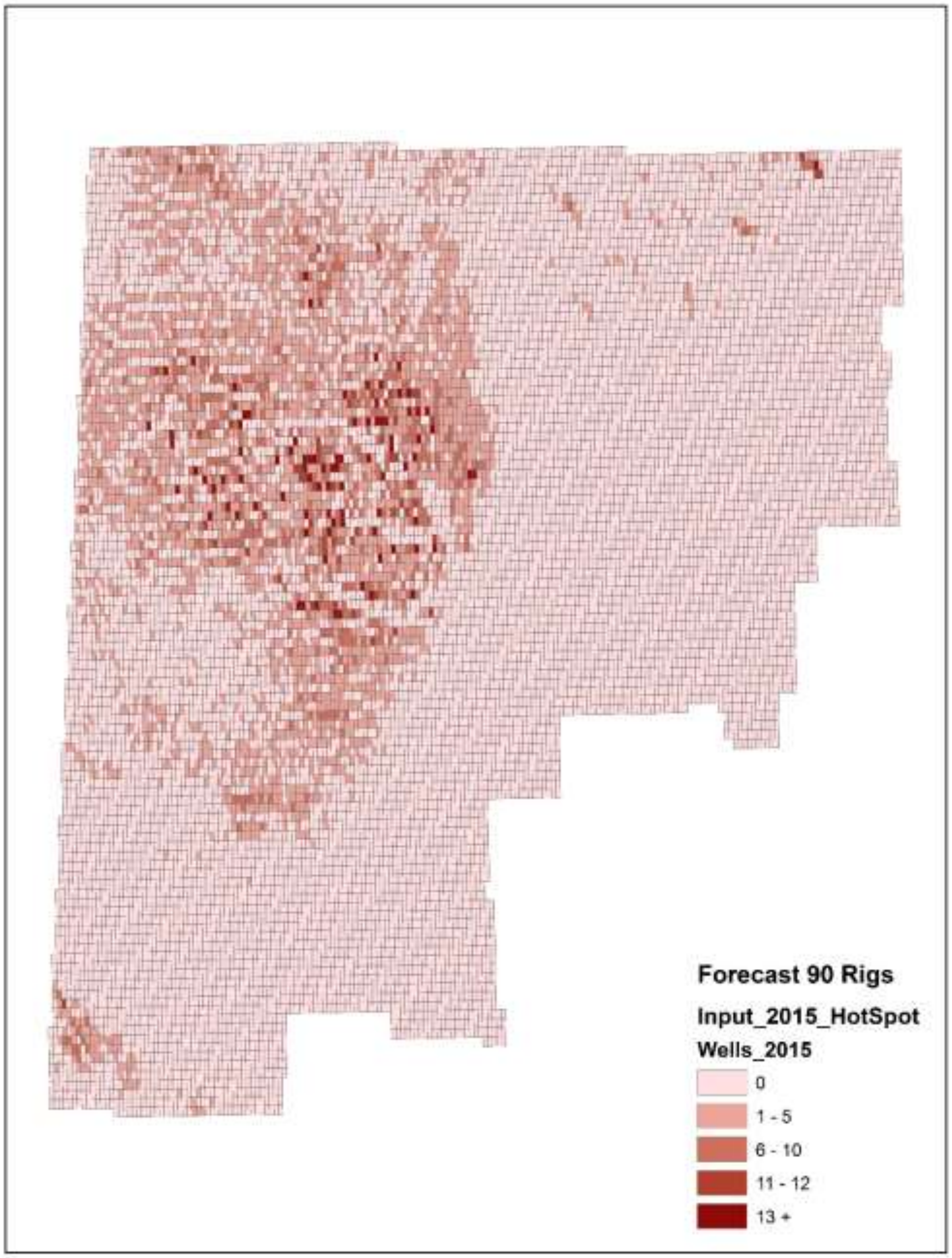
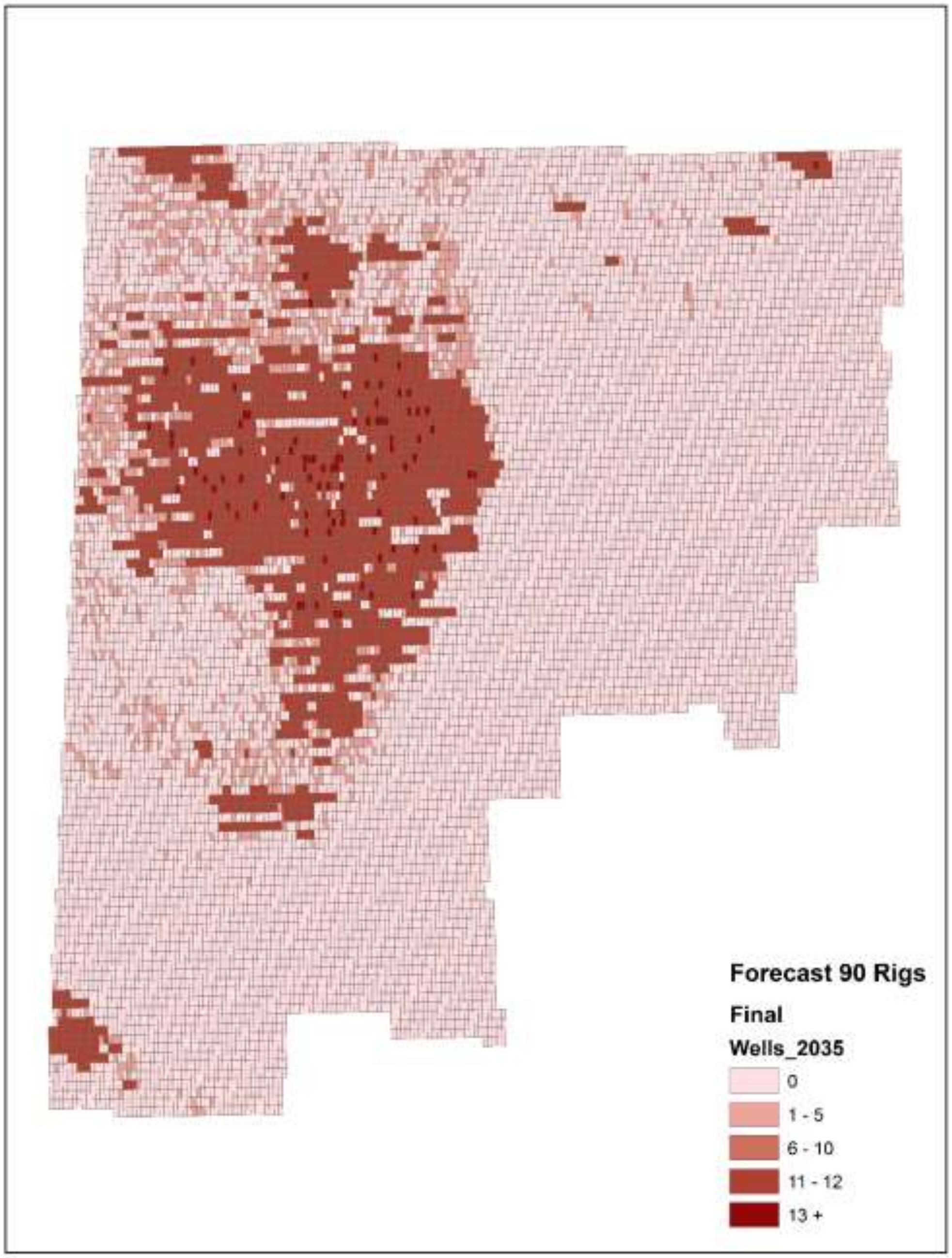


Figure 18. Hot Spot Map of Oilfield Spacing Units, 90 Rig Scenario 2035



All annual location forecasts are doubly constrained. That is, they are constrained by the statewide forecast of new wells and the county-level forecast of new wells per year provided by the Oil and Gas Division. These constraints ensure that within the modeling framework the forecasted truck trips generated cannot exceed the forecasted exploration and production limits.

3.2.5. Initial Production Rates

Once the wells have been drilled, an initial production rate must be applied to represent the starting point of production for an individual well. The Oil and Gas Division provided county average initial production rates for each of the oil producing counties. In addition, the Bakken well production curve is applied to this initial production rate to estimate future year production levels. Because of the steep decline in production over the first three years of the life of a Bakken well, inclusion of this production curve is critical to avoid overestimating crude oil production, and the number of truck trips generated by oil production in North Dakota.

3.2.6. Truck Volumes

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

Table 2. 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 rig	3	Both

Total – Single Direction	1,150	
Total Truck Trips	2,300	

3.2.7. Mode Splits

At the time this report was written, roughly 60% of outbound crude oil from well sites to either rail or pipeline transload locations is transported via truck, with the remaining 40% transported by gathering pipelines. Based on discussions with the Oil and Gas Division and the ND Pipeline Authority, forecast assumptions with regard to changes in the mode for outbound crude were made. The underlying assumption is that 2,400 miles of gathering pipeline will be built per year for the next 10 years. As a result, by 2024, 80% of outbound crude oil from well sites will be transported to transload locations via gathering pipelines and the remaining 20% will be transported via truck. It is assumed that this shift will occur in a linear fashion. The mode split by year is shown in Table 3.

Table 3. Mode Split for Outbound Oil from Well Site to Transload Locations

Year	Percent Truck	Percent Pipeline
2015	62%	38%
2016	58%	42%
2017	53%	47%
2018	48%	52%
2019	44%	57%
2020	39%	61%
2021	34%	66%
2022	29%	71%
2023	25%	75%
2024-2035	20%	80%

4. Road Network

4.1. Data Sources

The primary GIS network used for this study was obtained from the ND GIS Hub Explorer at https://apps.nd.gov/hubdataportal/srv/en/main.home. Two individual shapefiles were utilized in the creation of the network: State and Federal Roads and County and City Roads. Both of these shapefiles are maintained by NDDOT. For each of the lines representing a road, a variety of attributes, or data about the roadway, are provided.

Table 4. Miles Analyzed by Surface Type

Surface Type	Miles
Graded & Drained	8,189
Gravel	57,438
Paved	6,038
Trail	16,943
Unimproved	4,854
Total	**93,462**

4.2. Network Connectivity

Network connectivity is required to have a routable network for use in the travel demand modeling component of this study. Initially, both the State and Federal and County and City roads presented multiple widespread connectivity errors which were repaired prior to conducting the routing analysis. In addition, certain attributes were found to be in error, particularly in areas of significant growth. These errors will likely be corrected as the network is continually updated.

4.3. Jurisdiction

The GIS Hub files contain an attribute named RTE_SIN which represents the jurisdiction of the roads. This attribute provides accurate data on the state and federal systems as well as the federal aid system. However, below the CMC system there is no distinction between county-owned non-CMC routes and township roads. To identify township roads apart from county non-CMCs, UGPTI and ND-LTAP conducted surveys of all 53 counties in North Dakota. The results were then attributed to the original network for identification purposes. In addition to non-CMC identification, UGPTI and ND-LTAP staff asked for information about other jurisdictional categories, but responses were not consistent on a statewide basis aside from the non-CMC designation.

Table 5 presents the total miles by initial "RTE_SIN" designation–the base designation on the GIS Hub shapefile. These numbers represent the data that was available prior to the survey of the counties by UGPTI and ND-LTAP. The area most in question is the second category "Township and County Non-CMC," primarily because this category combined two jurisdictions, county and township. Because two jurisdictions were combined within a single category, separating needs by jurisdiction proved difficult without additional information.

Table 5. Initial Jurisdictional Information Using Provided RTE_SIN Designation (Surfaced Roads Only)

Jurisdiction	Miles
Forest Service	344

Township and County Non-CMC	60,245
CMC (Federal Aid)	10,525
Tribal	488
Total	**71,602**

Table 6 presents the updated jurisdictional information based upon the ND-LTAP/UGPTI survey of counties. There were minor reductions to the forest service roads because some in western North Dakota have been transferred to county jurisdiction. The largest change is in the township and county non-CMC categories. Within the township category, only organized townships are included. In the county non-CMC, county routes and unorganized townships are included. The instruction in the survey was to determine ownership of the road, not only who provides for maintenance on the road surfaces.

Table 6. Updated Jurisdictional Information Based Upon Survey Results (Surfaced Roads Only)

Jurisdiction	**Miles**
Forest Service	289
Township	46,993
CMC (Federal Aid)	10,525
County Non-CMC	13,307
Tribal	488
Total	**71,602**

3

5. Traffic Data and Model

The primary objective of the traffic study was to collect traffic volume and classification data on county and township roads throughout the state. Traffic data was collected for two primary reasons: (1) to gain a better understanding of current traffic flows, and (2) enable the calibration of the traffic forecasting model used in the study.

The traffic collection plan provided for geographic coverage of the entire state, focusing on county major collector routes, higher volume routes, and paved roads. Based on road mileage and other factors, it was determined that approximately 15 to 25 classification counts per county would provide adequate information to calibrate the traffic model.

At locations where traffic counts were taken, the raw information was turned into an estimate of the average number of vehicles traveling the road segment each day. At locations, where vehicles were classified, the raw information was used to estimate the daily trips of each type of vehicle, including single-unit, combination, and double-trailer trucks.

5.1. Traffic Data Collection

A cooperative plan was developed with NDDOT to change volume counts to classification studies in certain instances and add counts to adequately cover the counties during the NDDOT's 2015 counting cycle. This left the middle one-third of the state as the only area without planned data collection activities in 2015. However, UGPTI students and staff collected classification data at approximately 160 locations in this central one-third of the state. In addition, 2014 NDDOT counts in this part of the state were also used as there were no significant changes.

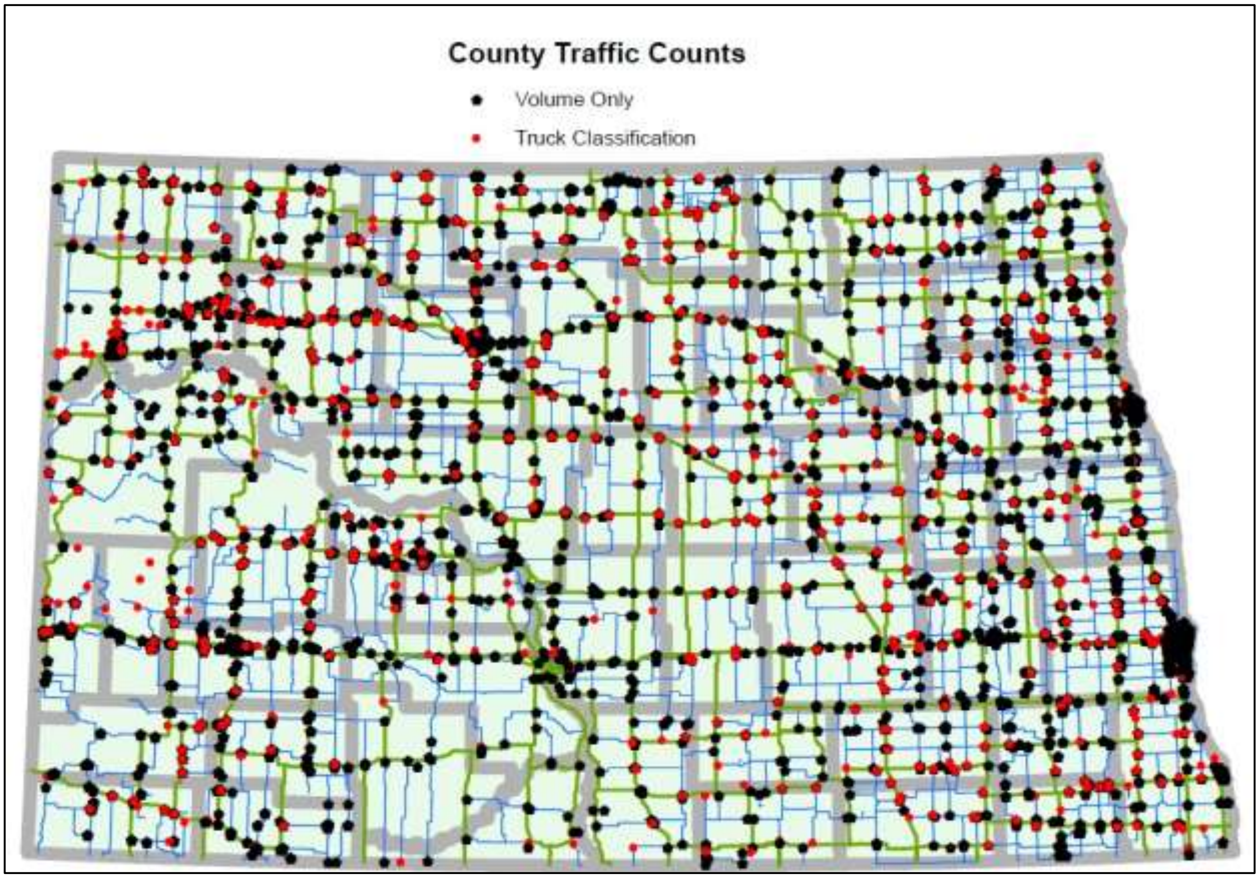
Between NDDOT and UGPTI staff, approximately 410 vehicle classification counts were taken across the state on county and township roads. More than 1,200 additional volume counts were also taken. In addition, 2014 counts conducted by the NDDOT in certain parts of the state were used to provide supplemental traffic information. Figure 19 depicts the locations of county and township traffic data collection.

5.2. Traffic Data Processing

All traffic counts were checked for quality control and processed using standard processes and procedures recommended by Federal Highway Administration. This detailed process entails the application of seasonal adjustment factors to the raw 48-hour counts to annualize them to an average annual daily traffic (AADT) volume. The seasonal adjustment factors used in the study were developed from annual traffic recorders (ATR's) located throughout the state on various functional road systems. For count locations involving volumes only, a seasonal axle factor was also applied to the raw counts.

All traffic data collected by UGPTI was verified and sent to NDDOT for final processing, using the same standard processes and procedures recommended by Federal Highway Administration. The joint processing of data by NDDOT and UGPTI assures consistency among the various traffic counts taken around the state.

Figure 19. Traffic Data Collection Sites



5.3. Traffic Model Development

To forecast future traffic volumes on county and township roads, an effective base year traffic model must be constructed that accurately reflects existing truck traffic movements. The data collection described above provides direct observations against which the traffic model results can be compared. Only when the baseline traffic model has been shown to sufficiently model existing traffic can it be used to predict future traffic levels.

5.3.1. Movement Types

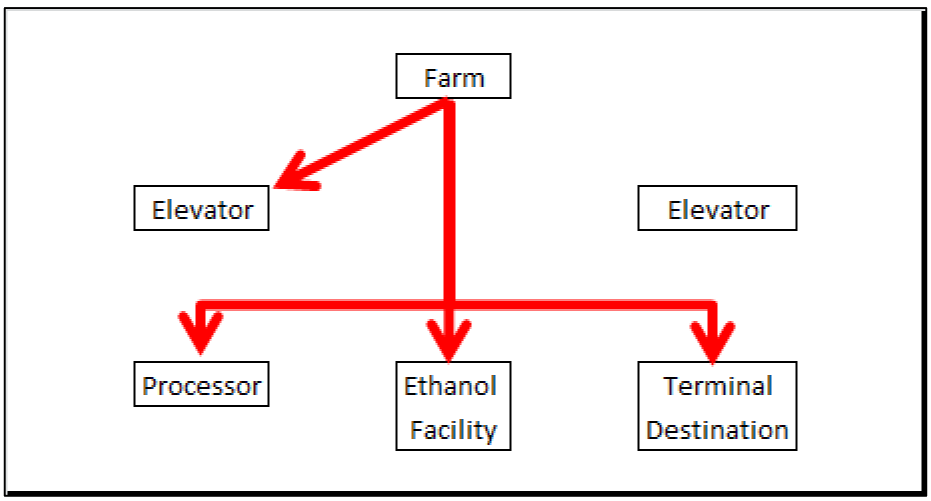
The travel demand model developed for this study consists of 18 individual submodels: eleven for agricultural movements and seven for oil-related movements. Nine of the eleven agricultural submodels represent individual commodities, with the remaining representing fertilizer and transshipment movements. Five of the seven oil related submodels relate to inputs to the drilling process and the remaining two represent the movement of outbound crude oil and salt water.

5.3.2. Distribution Networks - Agriculture

For the two major submodel classes: (agriculture and oil), two different distribution networks are modeled. The traditional farm-to-market, and market-to-terminal destination network has changed significantly within the state over the past decade, primarily because of the increase in shuttle elevators, processors and ethanol facilities.

Figure 20 provides an overview of the movements from the farm to a variety of destinations. In this simplified diagram, the farm-to-elevator movement is shown, as well as farm-to-final destinations such as processors, ethanol facilities, or terminal destinations such as Minneapolis or Duluth. Each of these movements is effectively a truck movement because there is no rail access from individual farms.

Figure 20. Agricultural Distribution Network without Transshipments



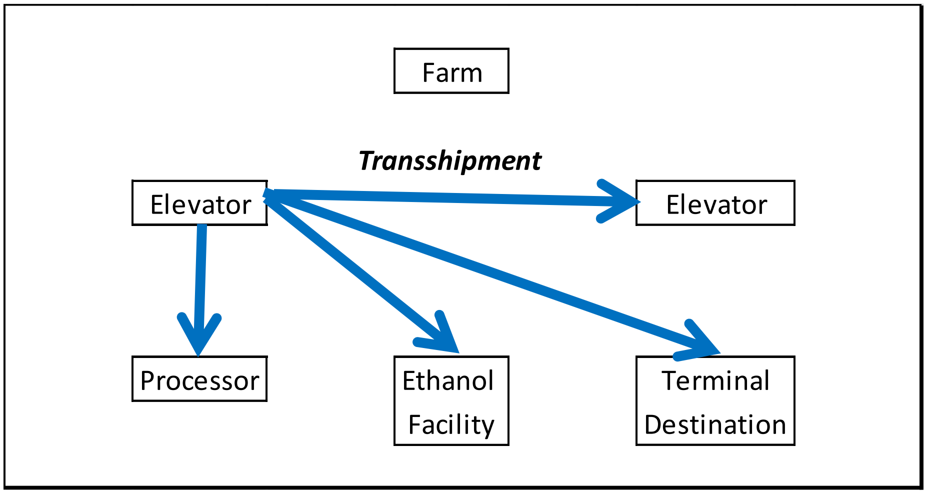
To take advantage of lower shipping rates at higher volumes, grain is commonly shipped between elevators for consolidation. Depending on the final destination of the grain from the elevator, the mode split between truck and rail varies. But as a general rule, as distance increases, truck transportation is less favored. However, almost all transshipment movements are performed via truck within the state, adding truck trips to the roadway networks.

Figure 21shows potential movements from the elevator once the grain has been delivered from the farm. The elevator may transport grain to a processor, ethanol plant, terminal facility, or another elevator. The receiving elevator would then also have the same options as the prior elevator. As mentioned above, outbound movements from elevators have a mode choice option, as most grain elevators within the state have rail access. Numerous variables factor into mode choice at this point, but for the purposes of this study, sufficient data as to the actual mode split by elevator is available so actual observed data was used to model mode split for outbound movements.

5.3.3. Distribution Networks – Oil Related Movements

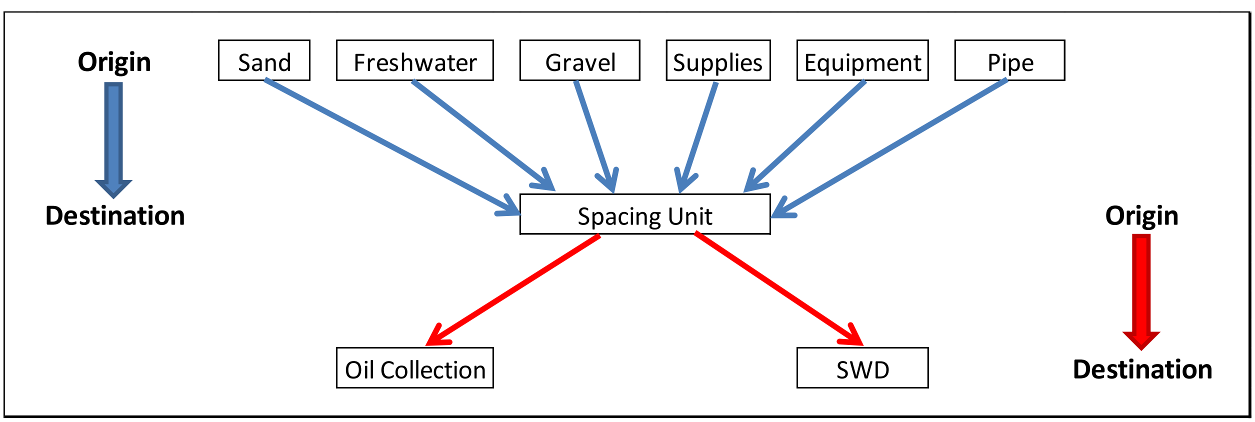
In contrast to the agricultural model where the base unit of production and related origin is the township, the oil model’s base unit of production is the spacing unit, which functions as both an origin and destination as time progresses. Figure 22 provides a simplified diagram of the modeled oil-related movements. The blue arrows represent inbound drilling related movements to the spacing unit, and the red arrows represent outbound produced oil and water from the spacing unit to transload or injection destinations.

Figure 21. Transshipment Movements within an Agricultural Network



Within the model framework both inbound and outbound movements were individually modeled. For example, frac sand, freshwater, gravel, supplies, equipment, and pipe movements were separately estimated and the results aggregated to the segment level. Similarly, both the movements from the well site to the oil collection sites and saltwater disposal locations were specifically modeled.

Figure 22. Oil Related Movement Network



5.3.4. Cube Modeling Framework

Conventional transportation modeling utilizes the Four Step Model (FSM). The components of the FSM are 1) trip generation, 2) trip distribution, 3) mode split, and 4) traffic assignment. The first step in the development of a transportation model is identification of the origins and destinations of the trips to be modeled. Trip generation forecasting identifies the type and scope of movements between traffic analysis zones (TAZ). As discussed above, the TAZ for the agricultural model is a township equivalent, and the TAZ for the oil model is the spacing unit.

Trip generation focuses on trips originating as a result of activities present within some zones, and trips attracted by activities present within other zones. Once the origins, potential destinations, and number of trips have been identified, movements between productions (origins), and attractions (destinations) are estimated. Distribution refers to the selection of flows between origins and destinations, and is generally made using a gravity model or linear programming model. Traffic assignment occurs once movements between origins and destinations have been selected, and the minimum-cost route between them is selected. The distinction between distribution and assignment is that distribution selects the origin and destination for individual trips generated, and assignment selects the method of connecting them. This is generally the final step in the FSM, but in the case of optimization models, traffic assignment for all possible destinations from origins is completed to generate arc cost data for the model.

Trip generation is the first of the four steps, and as the name indicates, generates trips and the origin and destination points. Using the agriculture model as an example, each township represents an area of production. Each grain elevator or processor represents an area of attraction. Based on known production at the township and known throughput at the elevator, researchers can estimate the trips generated at each. For the oil submodels, a similar approach is used, but the focus is the spacing unit, rather than the township.

Trip Distribution effectively pairs the origins and destination based upon production and attraction volumes and the effective cost between them. The gravity model for trip distribution contains three primary components: zones where trips originate, zones where trips terminate, and a measure of separation between the zones. The measure of separation between the zones is a key factor, as it represents the level of attraction between the zones or repulsion between zones. In many cases, a generalized cost of traveling between the zones, often a combination of travel time, distance travelled, and actual costs, is used (S. P. Evans 1972). "It is assumed that the number of trips per unit time between pairs of zones for a particular purpose is proportional to a decreasing cost function of the cost of traveling between them" (E. Evans 1970). The use of the gravity model for trip distribution is widespread. The end result of this type of analysis is the number of trips between each origin and each destination (trip assignment).

Mode choice is the third step in the four-step model. This step was not directly included in the travel demand model for two reasons. First, the movements modeled were specifically truck-related movements. Second, the primary factor where mode split would have a significant impact on traffic volumes relates to gathering pipelines between well sites and oil transload facilities. Because assumptions were specified by Oil and Gas and the ND Pipeline Authority, they were implicitly utilized in the study.

Trip assignment is the final step in the four-step model. Trip generation estimated the total number of trips generated and attracted. Trip distribution organized them into origin-destination pairs. Trip assignment selects the optimal (least cost) route between the origin and destination for each of the individual O-D pairs. This is where the individual roadway segments are selected. The precise method for selecting the paths between origin and destination is minimization of cost using Djikstra's algorithm within Cube Voyager. The cost selected for the purpose of routing is time. Each individual segment was assigned a travel speed based on posted speed or roadway class., Based on this speed, the individual travel time was calculated for each segment. Cube Voyager then selects the least-cost path between the origin and destination for each pair, aggregating the movements at the segment level.

5.3.5. Calibration Procedures

The traffic data collection effort described previously was a significant effort undertaken in conjunction with NDDOT to provide an accurate, objective and detailed estimate of traffic volumes for multiple classes of roadways throughout the state. For the purposes of the travel demand model, these counts are used for calibration purposes. As discussed previously, for a travel demand model to predict future traffic flows with confidence, it must sufficiently predict existing traffic flows. Comparing modeled traffic flows to observed counts determines whether the model sufficiently predicts existing traffic flows.

As part of the travel demand model development, a critical component of the four-step model is the trip distribution step. The gravity model described above uses friction factors between zones. These friction factors encourage or penalize movements within certain specified time thresholds. In the absence of trip length distribution data for individual commodity and input movements, scenario analysis was performed on the individual submodels for calibration of the traffic model.

The final step in the calibration process was to utilize Cube Analyst Drive. Cube Analyst Drive compares actual counts on segments to the predicted assigned traffic. Initially, the software provides detailed statistical measurements as to the quality of the fit. Then, utilizing the matrix estimation procedure, the software re-estimates the trip distribution matrix in an iterative fashion to improve the statistical comparisons. The resulting matrix was then compared to the initial unadjusted matrix to identify any significant variations. Where significant variations were identified, the trip generation volume estimates at the TAZ in question and related assumptions were reevaluated and altered if deemed appropriate.

6. Unpaved Road Analysis

6.1. Gravel Roads

Assessment of the funding needs to maintain and preserve 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. During the input process from the 2014 study, concern was expressed by policy-makers and county officials as to the homogeneity of costs and practices within regions, as well as the varied utilization of contractors for work within the counties. The survey was enhanced to collect additional information as to graveling practices, aggregate type, use of contractors, and reported traffic levels by county. This provided additional information as to the reason for regional discrepancies and allowed for consistency within regions where costs and practices are similar.

6.1.1. Traffic Classification

Within each county, unpaved roads were classified by daily truck estimates. Classification ranges are shown in Table 7. 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. Traffic counts taken across the state for the purpose of this study indicate that these estimates have increased slightly statewide, and greatly in areas of oil development or in proximity to new shuttle train facilities. In the UGPTI conditions and practices questionnaire, counties were asked to provide maintenance practices on an average mile of gravel road classified by three traffic ranges (low, medium, high). Counties were asked to define their own range thresholds for these classifications. The surveys are presented in Appendix A and the spatial distribution of county traffic volume thresholds is shown in Appendix D, Fig. D.7 and D.8.

Table 7: 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

6.1.2. Improvement Types

Survey questions asked county and township officials to provide the improvement and maintenance cycles for gravel roads within their jurisdictions. The county surveys asked officials to provide these cycles separately for each of the three traffic volume categories. Improvement types considered included 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 with regard to performance under the freeze/thaw cycle in North Dakota.

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 $4,500-12,000 per mile, Permazyme treatments at $12,000-$15,000 per mile, and concrete stabilization ranging from $108,000 to $220,000 per mile. As mentioned previously, 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. Compared 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 where direct observations were not provided.

Maintenance types by traffic category are shown in Table 8. The spatial distribution of maintenance cost components and improvement habits is presented in Appendix D. The consensus from the survey responses was that on roads with higher traffic volumes, the gravel interval decreases and the number of bladings per month increases. For example, a road considered in the medium category has a gravel cycle of three to five years and a blading interval of once per month. A a high-traffic road has a gravel cycle of one to three years and a blading interval of three-four times per month. The difference is a doubling of the gravel maintenance costs over the same time period. The other important takeaway is that counties located in the oil patch tend to have shorter improvement cycles and higher standards for overlay thickness than the rest of the state. Most of these counties use advanced stabilization methods. The unit costs of gravel supply and transportation are generally higher in the western part of the state.

Table 8: Improvement Types for Unpaved Roads by Traffic Category

Traffic Category	Improvement
Low	Low Volume Average
Baseline	County Average
Elevated	County Reported
Moderate-High	County Reported and Indexed

It is entirely possible that at the very high and potentially high categories of traffic on gravel roads, counties may choose to convert the surfaces to an asphalt surface. This study does not explicitly model upgrading gravel pavements on a statewide basis, as it is expected that the decision to convert surface type is part of a county-level planning program. The estimates of maintenance costs in the very high and the potentially high categories may equal or exceed the annual equivalent improvement and maintenance costs for an asphalt surface, depending on an individual county's cost characteristics. .

6.1.3. Projected Investment Needs

The projected costs by time period, region, and functional class for the three oil drilling scenarios (30, 60, 90 rigs) are summarized in Tables 9-11. The total projected statewide need during the 20-year analysis period ranges from $5.83 billion to $6.21 billion. Approximately 40% to 43% of these needs can be traced to the 17 oil and gas producing counties of western North Dakota.

Table 9: Summary of Unpaved Road Investment and Maintenance Needs for Counties and Townships in North Dakota- 30 Rigs (Millions of 2016 Dollars)

Period	Statewide	Oil Patch	Rest of State
2017-18	$ 600.05	$ 248.47	$ 351.58
2019-20	$ 590.00	$ 237.84	$ 352.16
2021-22	$ 601.62	$ 248.57	$ 353.05
2023-24	$ 597.85	$ 244.43	$ 353.42
2025-26	$ 583.02	$ 229.07	$ 353.96
2027-36	$ 2,887.13	$ 1,130.88	$ 1,756.25
2017-36	**$ 5,859.67**	**$ 2,339.26**	**$ 3,520.41**

Table 10: Summary of Unpaved Road Investment and Maintenance Needs for Counties and Townships in North Dakota- 60 Rigs (Millions of 2016 Dollars)

Period	Statewide	Oil Patch	Rest of State
2017-18	$ 644.65	$ 293.04	$ 351.61
2019-20	$ 606.97	$ 254.84	$ 352.14
2021-22	$ 659.80	$ 306.77	$ 353.03
2023-24	$ 660.86	$ 307.47	$ 353.40
2025-26	$ 602.62	$ 248.61	$ 354.01
2027-36	$ 2,915.81	$ 1,159.72	$ 1,756.09

2017-36	$ 6,090.72	$ 2,570.44	$ 3,520.27

Table 11: Summary of Unpaved Road Investment and Maintenance Needs for Counties and Townships in North Dakota- 90 Rigs (Millions of 2016 Dollars)

Period	Statewide	Oil Patch	Rest of State
2017-18	$ 670.42	$ 318.79	$ 351.63
2019-20	$ 626.93	$ 274.77	$ 352.17
2021-22	$ 668.08	$ 314.98	$ 353.10
2023-24	$ 658.79	$ 305.38	$ 353.41
2025-26	$ 619.96	$ 265.95	$ 354.01
2027-36	$ 2,961.71	$ 1,205.62	$ 1,756.09
2017-36	**$ 6,205.89**	**$ 2,685.48**	**$ 3,520.40**

The estimated needs are shown by jurisdiction for the 2017-2018 biennium in Table 12. For further clarification of roads, both county and township roads are included in the county jurisdiction row entitled Non-CMC/Twp. This category combines both roads in unorganized townships and township roads for which the county assumes maintenance responsibility. Per the survey of townships, an estimated 453 roads in organized townships are maintained by the counties in which they are located. Similarly, the investment needs are shown by jurisdiction for the entire analysis period in Table 13.

Table 12: Unpaved Road Investments Needs, by Jurisdiction (2017-2018)

	30 Rigs		60 Rigs		90 Rigs	
Jurisdiction and/or Maintenance Resp.	Needs (Millions)	Percent of Needs	Needs (Millions)	Percent of Needs	Needs (Millions)	Percent of Needs
County	$ 386.6	64%	$ 421.5	65%	$ 441.6	66%
Township	$ 202.9	34%	$ 210.6	33%	$ 215.9	32%
Tribal	$ 10.5	2%	$ 12.5	2%	$ 13.0	2%
Total	$ 600.0	100%	$ 644.7	100%	$ 670.4	100%

Table 13: Unpaved Road Investment Needs, by Jurisdiction (2017-2036)

	30 Rigs		60 Rigs		90 Rigs	
Jurisdiction and/or Maintenance Resp.	Needs (Millions)	Percent of Needs	Needs (Millions)	Percent of Needs	Needs (Millions)	Percent of Needs
County	$3,753.5	64%	$3,932.0	65%	$4,014.1	65%
Township	$2,012.1	34%	$2,050.5	34%	$2,077.3	33%

Tribal	$ 94.1	2%	$ 108.2	2%	$ 114.5	2%
Total	**$5,859.7**	**100%**	**$6,090.7**	**100%**	**$6,205.9**	**100%**

Table 14 presents the unpaved road needs by county for the 2017-2018 biennium, as well as for the total study period.

Table 14: Unpaved Road Needs by County

	30 Rigs		**60 Rigs**		**90 Rigs**	
County	**2017-18**	**2017-36**	**2017-18**	**2017-36**	**2017-18**	**2017-36**
Adams	$ 5.8	$ 58.2	$ 5.8	$ 58.2	$ 5.8	$ 58.2
Barnes	$ 13.2	$ 132.1	$ 13.2	$ 132.1	$ 13.2	$ 132.1
Benson	$ 7.6	$ 75.7	$ 7.6	$ 75.7	$ 7.6	$ 75.7
Billings	$ 8.5	$ 83.6	$ 10.1	$ 90.4	$ 11.7	$ 90.1
Bottineau	$ 10.6	$ 106.0	$ 10.7	$ 106.2	$ 10.8	$ 106.8
Bowman	$ 8.4	$ 84.3	$ 8.7	$ 84.7	$ 8.7	$ 85.8
Burke	$ 14.1	$ 140.3	$ 14.8	$ 141.2	$ 14.9	$ 141.9
Burleigh	$ 15.2	$ 151.1	$ 15.2	$ 151.1	$ 15.2	$ 151.1
Cass	$ 28.5	$ 286.9	$ 28.5	$ 286.9	$ 28.5	$ 286.9
Cavalier	$ 9.3	$ 93.3	$ 9.3	$ 93.3	$ 9.3	$ 93.3
Dickey	$ 7.2	$ 72.4	$ 7.2	$ 72.4	$ 7.2	$ 72.4
Divide	$ 17.3	$ 173.2	$ 18.2	$ 180.6	$ 19.2	$ 189.7
Dunn	$ 30.1	$ 263.1	$ 38.7	$ 316.9	$ 45.4	$ 326.2
Eddy	$ 3.0	$ 30.1	$ 3.0	$ 30.1	$ 3.0	$ 30.1
Emmons	$ 7.7	$ 76.6	$ 7.7	$ 76.6	$ 7.7	$ 76.6
Foster	$ 3.3	$ 33.3	$ 3.3	$ 33.3	$ 3.3	$ 33.3
Golden Valley	$ 8.5	$ 84.6	$ 8.8	$ 87.0	$ 9.3	$ 89.9
Grand Forks	$ 20.4	$ 203.8	$ 20.4	$ 203.8	$ 20.4	$ 203.8
Grant	$ 12.4	$ 124.5	$ 12.4	$ 124.5	$ 12.4	$ 124.5
Griggs	$ 3.4	$ 34.1	$ 3.4	$ 34.1	$ 3.4	$ 34.1
Hettinger	$ 6.6	$ 66.5	$ 6.6	$ 66.5	$ 6.6	$ 66.5
Kidder	$ 5.3	$ 55.0	$ 5.3	$ 55.0	$ 5.3	$ 55.0
LaMoure	$ 7.7	$ 76.7	$ 7.7	$ 76.7	$ 7.7	$ 76.7
Logan	$ 4.9	$ 48.9	$ 4.9	$ 48.9	$ 4.9	$ 48.9
McHenry	$ 20.4	$ 204.3	$ 20.4	$ 204.3	$ 20.4	$ 204.3
McIntosh	$ 4.7	$ 47.3	$ 4.7	$ 47.3	$ 4.7	$ 47.3

	30 Rigs		60 Rigs		90 Rigs	
County	**2017-18**	**2017-36**	**2017-18**	**2017-36**	**2017-18**	**2017-36**
McKenzie	$ 39.0	$ 313.2	$ 57.2	$ 404.8	$ 63.4	$ 463.9
McLean	$ 15.5	$ 154.9	$ 15.5	$ 154.9	$ 15.5	$ 154.9
Mercer	$ 9.1	$ 90.6	$ 9.1	$ 90.7	$ 9.1	$ 90.7
Morton	$ 12.5	$ 125.3	$ 12.5	$ 125.3	$ 12.5	$ 125.3
Mountrail	$ 22.4	$ 203.4	$ 28.4	$ 234.9	$ 33.1	$ 240.8
Nelson	$ 5.8	$ 57.6	$ 5.8	$ 57.6	$ 5.8	$ 57.6
Oliver	$ 3.5	$ 34.8	$ 3.5	$ 34.6	$ 3.5	$ 34.7
Pembina	$ 8.5	$ 85.2	$ 8.5	$ 85.2	$ 8.5	$ 85.2
Pierce	$ 10.8	$ 108.1	$ 10.8	$ 108.1	$ 10.8	$ 108.1
Ramsey	$ 6.2	$ 62.2	$ 6.2	$ 62.2	$ 6.2	$ 62.2
Ransom	$ 5.6	$ 56.4	$ 5.6	$ 56.4	$ 5.6	$ 56.4
Renville	$ 6.0	$ 59.5	$ 6.0	$ 59.5	$ 6.0	$ 59.5
Richland	$ 16.8	$ 167.8	$ 16.8	$ 167.8	$ 16.8	$ 167.8
Rolette	$ 5.9	$ 59.2	$ 5.9	$ 59.2	$ 5.9	$ 59.2
Sargent	$ 4.4	$ 44.5	$ 4.4	$ 44.5	$ 4.4	$ 44.5
Sheridan	$ 5.4	$ 53.7	$ 5.4	$ 53.8	$ 5.4	$ 53.8
Sioux	$ 5.8	$ 57.9	$ 5.8	$ 57.9	$ 5.8	$ 57.9
Slope	$ 6.4	$ 63.8	$ 6.4	$ 63.0	$ 6.4	$ 64.3
Stark	$ 18.1	$ 181.9	$ 18.4	$ 184.3	$ 19.1	$ 185.6
Steele	$ 5.1	$ 51.2	$ 5.1	$ 51.2	$ 5.1	$ 51.2
Stutsman	$ 11.2	$ 112.1	$ 11.2	$ 112.1	$ 11.2	$ 112.1
Towner	$ 7.2	$ 72.2	$ 7.2	$ 72.2	$ 7.2	$ 72.2
Traill	$ 7.2	$ 71.9	$ 7.2	$ 71.9	$ 7.2	$ 71.9
Walsh	$ 18.9	$ 190.6	$ 18.9	$ 190.6	$ 18.9	$ 190.6
Ward	$ 23.3	$ 233.5	$ 23.3	$ 233.9	$ 23.4	$ 233.7
Wells	$ 8.4	$ 83.9	$ 8.4	$ 83.9	$ 8.4	$ 83.9
Williams	$ 26.8	$ 258.0	$ 34.2	$ 292.2	$ 38.3	$ 316.6
Total	$ 600.0	$ 5,859.7	$ 644.7	$ 6,090.7	$ 670.4	$ 6,205.9

7. Pavement Structural Data

7.1. Introduction

The accuracy of this study's road needs forecasts is closely tied to the accuracy of the input data. For paved roads, this data includes pavement layer thicknesses and structural information.

Nondestructive test data provide layer type, thickness, and elastic modulus for input into the AASHTO-based (American Association of State Highway and Transportation Officials) Structural Number (SN) equation. This equation describes the capability of the existing epavement to support traffic loads. Analysis results were also used to directly identify road segments requiring improvement based on structural deficiency. Segments with weak subgrade or thin or deteriorated asphalt and base layers can indicate a need for reconstruction.

Nondestructive testing used for this study included ground penetrating radar (GPR) and falling weight deflectometer (FWD). These tests allow rapid, accurate, and cost-effective collection of the data for this study's pavement analysis. Note that this study represents a network-level analysis and the findings herein are neither intended nor suitable to be a replacement for a project-level engineering study.

7.2. Methodology

7.2.1. Sampling Method

Testing and analysis of every mile of paved county and local road in North Dakota would be cost- and time-prohibitive. Therefore, this study continued to build upon the previous study by adding an additional 2,000 miles of GPR data and approximately 380 2-mile-long FWD test segments within the GPR collection area. Sampling segments were selected from GIS data from the ND GIS Hub. With the previous study and the additional miles collected for this study, all county paved roadways over 2 miles in length will have testing data for this study.

Before beginning testing, counties were notified of the schedule and purpose of data collection to allow any questions or concerns related to NDT to be addressed.

7.2.2. Ground Penetrating Radar (GPR)

Ground Penetrating Radar (GPR) is a method of collecting pavement layer thickness data by sending radio waves through a pavement structure. A calibrated GPR system can collect accurate network-level structural data with minimal safety risk and traffic disruption. GPR offers significant time and cost savings over a traditional core sampling process.

Infrasense, Inc. (Infrasense) was contracted to perform GPR testing and analysis on the selected test segments. Testing involved a vehicle-based GPR system traveling at highway speed. Test segments were located using GPS coordinates and scanned at continuous one-foot intervals.

While GPR data was collected continuously for the full length of each county roadway, layer analysis focused on the 50 feet on either side of each FWD test location. Infrasense's proprietary winDECAR software was used to determine layer type and thickness for each test location. These results were ultimately averaged for the segment as a whole.

GPR data analysis was conducted at the network level. However, the continuously-collected raw data is maintained by Infrasense, Inc. and can be analyzed at a higher (i.e. project-level) resolution or provided in raw form upon request to the consultant.

7.2.3. Falling Weight Deflectometer (FWD)

A falling weight deflectometer (FWD) simulates the deflection of a pavement surface caused by a fast-moving truck. The FWD generates a load pulse by dropping a weight. This load pulse is transmitted to the pavement through a circular load plate. The load pulse generated by the FWD momentarily deforms the pavement under the load plate into a dish or bowl shape. From a side view, the shape of the deformed pavement surface is a deflection basin.

Based on the force imparted to the pavement and the shape of the deflection basin, it is possible to estimate the stiffness of the pavement. If the thickness of the individual layers is also known, the stiffness of those layers can also be calculated.

Dynatest Consulting, Inc. (Dynatest) was contracted to conduct FWD testing and analysis on selected segments. Testing for the previous study was conducted in August and September 2013 and additional testing was completed October 2015. Two different load levels (9,000 and 12,000 lbs.) were applied, with two replicates for each load. Tests were spaced at 0.25-mile intervals, resulting in over 35,000 deflection basins over the two separate testing sessions. Full test specifications are shown in Table 16.

Table 16. Falling Weight Deflectometer Test Specifications

Maximum Test Spacing	0.25 mi (1,320 ft)
Test Lane	Outer lane
Test Location	Outside wheel path
Direction	Single direction
Geophone Spacing (in)	0, 8, 12, 24, 36, and 60
Test Load Weights (lb)	9,000 and 12,000
Acceptable Range	±10 percent of specified load level
Number of Drops per Test	2 seating drops (unrecorded); 2 drops per weight

Air and pavement surface temperature data were measured at each drop to allow normalization of backcalculated layer elastic moduli to a reference temperature (77°F). Each test location was tagged with GPS coordinates which were used to coordinate FWD and GPR analysis locations. Each measured deflection basin was analyzed using Dynatest ELMOD software to backcalculate elastic moduli for each layer. The backcalculation process involved a cooperative, iterative effort by GPR and FWD consultants. Initially, GPR layer thicknesses at FWD test locations were used as inputs for backcalculation of layer moduli. Results were verified for reasonableness and accuracy. Unreasonable layer moduli were identified and corrective actions taken in the form of GPR layer thickness reexamination, revised backcalculation, or both. This cooperative quality control process improved the accuracy of the layer type and thickness identified by GPR data as well as the accuracy of the backcalculated layer moduli. A detailed description of the FWD testing and analysis process is included in Appendix B.

Infrasense and Dynatest used an iterative FWD/GPR calibration process which eliminated the need for pavement coring in GPR calibration. Initial backcalculated layer moduli were verified for reasonableness and accuracy. Unreasonable moduli were identified and corrective actions were taken on these sections, including reexamination of GPR layer thicknesses, revised backcalculation, or both. The result of this process was a database in which more than 89 percent of backcalculated moduli fell within reasonable range.

7.3. Results

The inter-system quality control process described previously resulted in a database in which more than 89% of backcalculated layer moduli fell within defined reasonable ranges as described in Table 17. The remaining unreasonable deflection basins were removed from the results database.

Table 17. Reasonable Layer Moduli Ranges

Layer Type	Minimum (ksi)	Maximum (ksi)
Asphalt Concrete	50	750
Granular Base	1	100
Subgrade	1	30

Even as this testing effort included a large sample of paved county and local roads throughout the state, some assumptions had to be made about pavement structure on non-tested roads. Region-wide averages for layer type, thickness and moduli were applied to paved road segments without any test data.

Tables 18, 19, 20, and 21 describe countywide, regional, and statewide pavement layer and moduli results. County averages are displayed for the 51 counties and all tribal areas with a tested roadway. A more detailed summary of nondestructive test results is available in Appendix B.

Table 18. Nondestructive Test Results, Aggregated by Jurisdiction

County	Asphalt Concrete Thickness (in)	Granular Base Thickness (in)	Asphalt Concrete Modulus at 77°F (ksi)	Unbound Base Modulus (ksi)	Subgrade Modulus (ksi)
Adams	3.6	5.4	91.0	64.0	4.0
Barnes	7.2	4.5	315.2	34.5	7.4
Benson	5.5	4.0	223.4	67.1	8.4
Billings	10.4	8.7	411.0	90.0	8.0
Bottineau	7.1	3.5	270.0	44.3	8.3
Bowman	2.9	6.2	148.6	63.4	8.5
Burke	5.6	7.4	298.5	61.5	13.2

Burleigh	7.3	4.6	339.5	38.8	9.1
Cass	8.6	4.5	360.8	49.4	9.0
Cavalier	5.5	4.8	213.9	29.7	7.8
Dickey	5.9	4.8	272.3	47.6	6.2
Divide	4.9	6.5	338.0	63.5	8.7
Dunn	5.9	12.7	306.1	76.7	11.7
Eddy	6.5	4.7	230.1	50.0	12.0
Emmons	4.2	3.8	436.6	45.5	12.0
Fort Berthold	5.5	1.9	170.7	32.6	8.6
Foster	5.0	3.3	122.9	42.7	7.0
Golden Valley	7.1	5.1	103.0	27.0	7.0
Grand Forks	7.6	4.5	353.3	40.2	7.6
Griggs	7.1	3.5	285.9	76.3	7.6
Hettinger	7.9	0.7	411.0	35.0	8.0
Kidder	6.8	3.6	312.0	91.2	10.0
LaMoure	5.7	2.8	528.2	32.7	8.7
Logan	9.4	0.0	N/A	N/A	N/A
McHenry	6.6	3.1	249.7	33.5	9.0
McIntosh	4.0	1.2	665.0	39.0	14.0
McKenzie	6.1	10.7	335.5	48.7	11.3
McLean	6.1	3.4	265.5	40.0	6.0
Mercer	6.7	4.4	185.4	24.3	7.0
Morton	8.0	7.0	578.0	62.1	10.7
Mountrail	6.5	12.3	329.9	43.1	12.3
Nelson	6.7	5.6	287.6	37.0	9.4
Oliver	5.7	8.0	316.1	32.5	8.0
Pembina	6.7	5.7	211.6	31.8	7.9
Pierce	7.6	4.7	244.4	40.5	9.5
Ramsey	5.9	5.2	265.6	67.8	7.9
Ransom	5.9	5.0	320.2	45.8	9.2
Renville	7.2	3.2	236.3	41.0	7.9
Richland	5.7	4.9	221.0	29.6	7.2
Rolette	8.7	1.9	293.8	49.4	8.3
Sargent	6.7	3.6	333.5	84.8	7.9
Sheridan	6.5	2.7	180.0	40.0	7.0
Spirit Lake	7.1	5.3	197.2	30.2	8.2
Standing Rock	4.0	3.2	235.0	55.0	7.0
Stark	4.2	6.3	263.3	29.4	8.9
Steele	7.0	5.0	280.6	38.3	8.3

Stutsman	5.7	5.8	190.4	37.0	8.3
Traill	7.1	4.7	203.1	38.1	6.8
Turtle Mountain	8.8	0.0	N/A	N/A	N/A
Walsh	5.8	6.2	199.5	30.0	7.2
Ward	6.6	4.8	339.1	42.5	7.3
Wells	5.4	4.0	434.2	39.6	10.0
Williams	6.5	5.0	325.7	71.3	9.2

Table 19. Nondestructive Test Results by Region

Region	Asphalt Concrete Thickness (in)	Granular Base Thickness (in)	Asphalt Concrete Modulus at 77°F (ksi)	Unbound Base Modulus (ksi)	Subgrade Modulus (ksi)
Oil Impacted	6.21	5.95	291.06	46.84	8.82
Non-Impacted	6.52	4.59	293.83	42.47	8.11
Statewide	6.42	5.05	292.84	44.03	8.36

Table 20. Typical Structure of County and Local Roads in North Dakota

Layer	Layer Thickness (Inches)			
	Minimum	Average	Maximum	Standard Deviation
Asphalt Concrete (surface)	1.25	6.42	20.00	2.23
Granular Base	0.00	5.05	26.00	3.62

Table 21. Typical Layer Strengths of County and Local Roads in North Dakota

Layer	Layer Modulus (ksi)			
	Minimum	Average	Maximum	Standard Deviation
Asphalt Concrete (surface) at 77°F	27.00	292.84	1,531.00	183.56
Granular Base	6.00	44.03	193.00	28.52
Subgrade	3.00	8.36	28.00	2.99

Note that this study's GPR analysis did not delineate between multiple asphalt layers. As a result, all existing asphalt layers are represented in this study as a combined layer with an overall modulus. This has no impact on this study's subsequent pavement analysis, which considers only the total structural contribution of the combined layers.

The results suggest a general trend in North Dakota's county and township roads of a thick combined asphalt layer, possibly the result of multiple thin-lift overlays over the course of a long service life, with a relatively thin unbound base layer. The absence of base layer in some cases can indicate that granular material has been subsumed into a poor subgrade. 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.

8. Paved Road Analysis

The paved road analysis follows a similar approach to the one used in the 2014 study. For the most part, the same methods and models have been used, but expanded data collection has reduced uncertainty and improved the accuracy of this study's county and township paved roads needs forecasts.

A major part of the expanded data collection includes the use of the UGPTI/DOTSC developed asset inventory tool. This online tool has allowed county roadway managers to input roadway data based on past improvement projects. This gives us a practical view of the age and past construction practices of the counties. For the study, construction project data was taken from the inventory and input into the model to forecast future projects.

More than 5,500 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.[1] 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.

8.1. Truck Axle Weights

AASHTO pavement design equations were used to analyze paved road impacts. These same equations are used by most state transportation departments. The equations are expressed in equivalent single axle loads (ESALs). In this form of measurement, 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 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.[2] 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

[1] 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.

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

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.

8.2. Trucks Used to Haul Oil Products and Inputs

The forecasted trips for each type of load moving to and from well sites were shown in Table 3. The characteristics of these trips are depicted in Table 22. 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 22. 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 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.

Table 22: 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

8.3. 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 23, 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.

Table 23: 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. 62% 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% are 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.

8.4. Surface Conditions

Paved road condition data for this study was based on a collaborative effort with NDDOT using the Pathway pavement data collection vehicle to collect approximately 4,500 miles of paved roads. The Pathway data collection vehicle is a state-of-the-art van equipped with the computer, sensor, and video equipment designed to collect data and video images of the roadway and pavement surface. The inertial road profiler installed in the vehicle is a South Dakota design manufactured according to ASTM E950 specifications and meeting class 1 requirements. This device collects the longitudinal profile of the pavement surface for both wheel paths. These longitudinal profiles are used to calculate pavement IRI (International Roughness Index) value using quarter car simulation and half car simulation. Additional sensors, lasers, video, and a 3D subsystem installed on the van are used to collect and measure rut information and automatically determine pavement distress scores. The use of this equipment helped to ensure a standardized and consistent method of pavement data collection across the state.

The pavement data collection took place in late summer and fall of 2015. Road condition data was not collected on approximately 1,000 miles. These miles included short segments in cities and sub-divisions, roads not identified as paved on the county base maps, and roads under construction. Of these 1000 miles, the GRIT pavement age information entered by local agencies was used to estimate the pavement condition based on standard low volume pavement performance measures. Construction projects or proposed 2016 projects were projected to a new score. The remaining miles were calculated as the average of pavement scores in each county.

The pavement data was processed and provided with GPS coordinates representing the average score of every 528' of all paved roads collected. Each of these points representing 528' was then averaged and attached to each of the project segments as entered into GRIT by the local road authority. The data obtained included an IRI value which represents the roughness (how it rides) expressed in inches per mile and PCI which represents the distresses such as cracking and rutting and provided in the NDDOT format on a 0 to 100 scale. These two values were then converted into a PSR (0 to 5) for use with the AASTHO 93 pavement design equation. The following formulas were used for this conversion:

• IRI converted to 0 – 5 Score using Minnesota Survey Panel equation:

$$PSR_{Ride} = 5.697 - (0.264 * \sqrt{IRI})$$

• ND PCI (0 -100) score converted to 0 – 5 score using straight line equation of NDDOT verbal ratings for condition:

$$PSR_{distress} = 0.1667 * (PCI_{ND}) - 11.667$$

• Combined ride and condition with following equation:

$$PSR_{combined} = \sqrt{PSR_{ride} * PSR_{distress}}$$

This $PSR_{combined}$ score was then used for the analysis. See maps for results.

In addition to pavement data collection the video images from the van were used to scale pavement and shoulder width information for approximately 4.500 miles of roadway. The video was also used to help verify surface type for roadways with out of date information.

The results of the condition assessment are summarized in Table 24, which shows that over 23% of paved county and township road miles are in very good condition, meaning they have recently been improved. As shown in Table 24, another 54% of paved road miles are in good condition; 20% are in fair condition. Only 3% of paved road miles are rated as poor. Road condition ratings for each county are shown in Appendix C.

Table 24: Conditions of Paved County and Township Roads in North Dakota in 2016

Condition	Miles - 2015	Percent - 2015	Percent - 2013
Very Good	1,301.6	23%	9%
Good	2,962.5	53%	62%
Fair	1,118.1	20%	20%
Poor	174.4	3%	6%
Very Poor	0.5	<0.1%	3%
	5,557.1	100%	100%

8.5. 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 overlaid 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.

Layer thicknesses and strengths have been measured using the nondestructive testing and back-calculation process described elsewhere. Statewide values are shown in Tables 25 and 26.

Table 25. Typical Structure of County and Local Roads in North Dakota

Layer	Layer Thickness (Inches)			
	Minimum	**Average**	**Maximum**	**Standard Deviation**
Asphalt Concrete (surface)	1.25	6.4	20.0	2.23
Granular Base	0	5.1	26.0	3.62

Table 26. Typical Layer Strengths of County and Local Roads in North Dakota

Layer	Layer Modulus (ksi)			
	Minimum	**Average**	**Maximum**	**Standard Deviation**
Asphalt Concrete (surface) at 77°F	27.0	253.0	1,531.0	183.56
Granular Base	6.0	44.0	193.0	28.52
Subgrade	3.0	8.4	28.0	2.99

Backcalculated moduli are converted to layer coefficients (a_1, a_2, and a_3) using the relationships described in the AASHTO Guide for Design of Flexible Pavement Structures, the source of the pavement analysis method used in this study. The combined asphalt surface layer determined through the combined GPR/FWD analysis was assumed in most cases to consist of a medium (2.5 inch) thickness new overlay with the remainder of surface layer material considered older asphalt base. This acknowledges the limitations of the AASHTO process in converting asphalt dynamic modulus to layer coefficients a_1 and a_2, which use separate regression equations which generate different coefficients for a common asphalt dynamic modulus.

8.6. Types of Improvement

Five types of road improvements are analyzed in this study: (1) reconstruction, (2) mine and blend, (3) resurfacing, (4) resurfacing with widening, and (5) breaking and seating concrete pavements with an asphalt overlay. 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 six to seven inches. Without extensive truck traffic, a relatively thin overlay (e.g. two to three 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 or subgrade that will provide little structural contribution to a resurfaced pavement, or (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.

On low-volume roads, the high cost of full-depth pavement reconstruction may not justify the benefits in terms of pavement serviceability. In this case, existing aggregate base and hot bituminous pavement can be salvaged as base material for a new pavement in a "mine and blend" process. This treatment allows reduced cost major rehabilitation of low volume roads where subgrade strength is not a problem.

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.[3] 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.

There are several concrete pavements that were built during the oil embargo crisis of the 1970s still remain on roads within North Dakota. These roadways cannot have a simple asphalt overlay to repair them. The existing concrete pavement must be cracked and re-seated and can then be overlaid. This is a lower cost option to improve ride quality and structure of the existing concrete pavement than a full reconstruction project.

[3] 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.

8.7. Improvement Logic

The forecasting procedure used in this study considers the current serviceability of the road, condition of the subgrade, condition and thickness of the unbound base, lane and shoulder width deficiency, maximum daily truck traffic during the analysis period, and the overlay needed in light of the forecasted traffic.[4] 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 a road segment shows evidence of subgrade failure through poor back-calculated modulus (less than 5000psi), the segment is selected for reconstruction regardless of other criteria.

If subgrade is adequate but the road segment has deteriorated to a condition at which resurfacing is no longer feasible, the segment will be selected for major rehabilitation (e.g. reconstruction or mine and blend). Low volume roads are selected for a more inexpensive mine and blend treatment. Otherwise the road segment will be selected for full reconstruction.

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 forecasted 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 greater than 2 inches, treatment is determined based on the condition of the pavement's unbound base layer. If base layer has inadequate strength or depth to support a thick overlay and high traffic loading, the segment is assigned major rehabilitation in the form of mine and blend treatment. Otherwise 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 2 inches or less, the road is assumed to be resurfaced (for perhaps the last time) without sliver widening. 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.

Maximum sliver widening widths are defined regionally based on feedback on current practice from NDDOT Local Government Division. The four major oil-producing counties (Dunn,

[4] This improvement logic expands upon the logic used in previous UGPTI needs studies and is based upon general approaches that are widely followed in practice. However, individual counties may adopt different approaches based on local conditions and insights.

McKenzie, Mountrail, and Williams) currently allow a maximum sliver widening width of 2 feet per side. Other oil- and gas-producing counties may add up to 4 feet per side in a sliver widening treatment, while the rest of the state may extend paved width up to 5 feet per side.

8.8. Preservation Maintenance

Preservation maintenance costs on paved roads include activities performed periodically (such as crack sealing, chip seals, and striping), as well as annual activities (such as patching). The cost relationships in Table 27 have been derived from a South Dakota Department of Transportation study and unpublished UGPTI research. Costs have been updated to 2014 levels and annualized. For example, the annualized seal coat cost would allow for at least two applications during a typical 20-year lifecycle for roads with maximum daily truck volume greater than 500. Maintenance costs are derived separately for high-traffic segments in oil- and gas-producing counties because of the increased cost of microsurfacing treatments in those counties.

Table 27: Routine Maintenance Cost Factors for Paved Roads by Traffic Level

AADT Traffic Range	Region	Annualized Cost of Road Maintenance Activities				
		Chip Seal	Crack Sealing	Contract Patching	Microsurfacing	Total
0-500	All	$5,000	$1,071	$2,857	-	**$8,929**
>500	All	$3,333	$1,429	$5,714	$11,429	**$21,905**

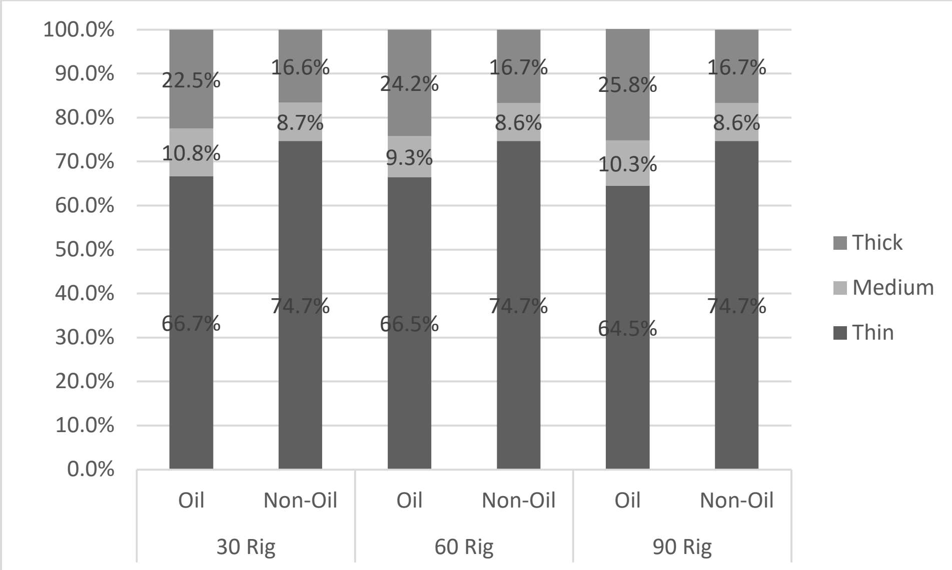
8.9. Forecasted Improvement Needs

8.9.1. Required Overlay Thickness

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.

Overlay thicknesses may be classified as thin (≤ 2 inches), moderate (between 2 and 3 inches), and thick (≥ 3 inches). As shown in Figure 23, roughly 22-26% of the paved road miles in oil- and gas-producing counties are expected to need thick overlays or major rehabilitation. Another 9-11% will require moderate overlays. Thin overlays will suffice for 64-66% of the miles in these counties. Roughly 16% of the miles in the remainder of the state will require thick overlays or major rehabilitation. An additional 9% will require overlays of 2-3 inches.

Figure 23: Projected Overlay Thickness of County and Township Roads, by Region

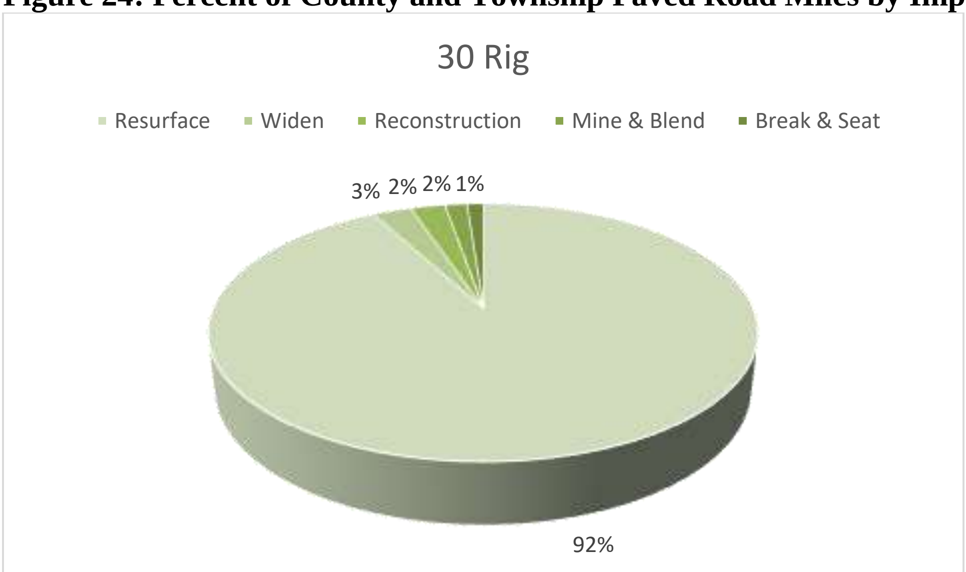


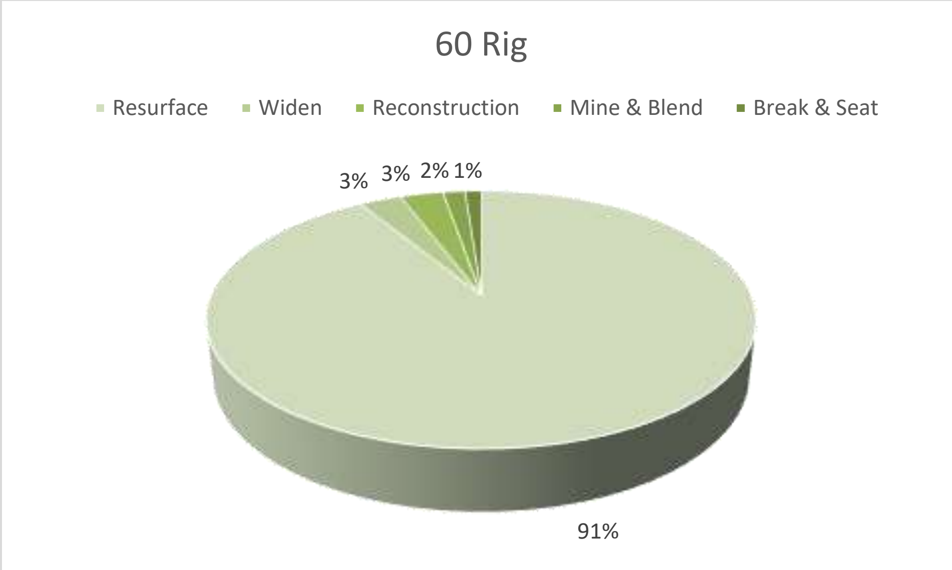
8.9.2. Miles Improved

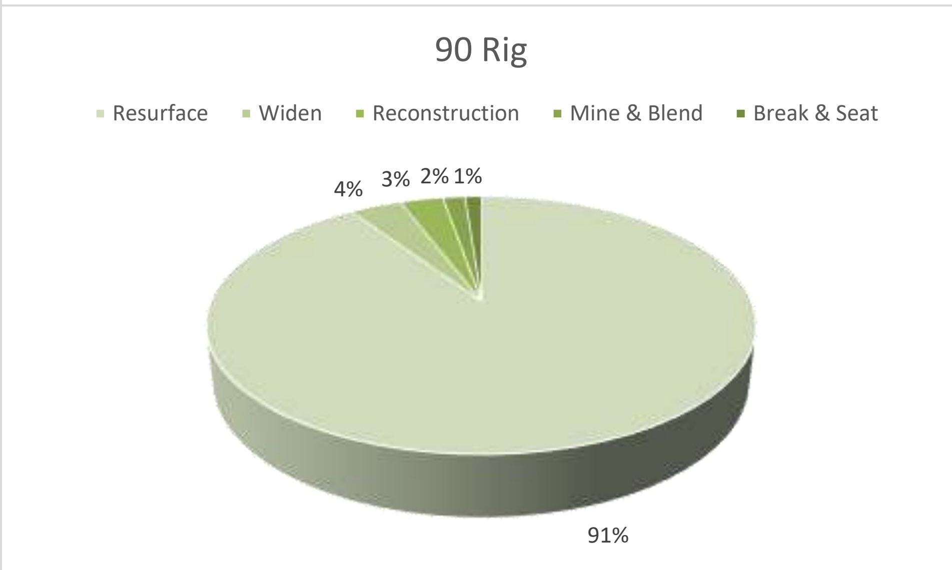
As shown in Figure 24, approximately 5% of the miles of county and township paved roads in the state must receive major rehabilitation (reconstruction or mine and blend treatment) because of poor condition and heavy traffic that will cause existing pavements to deteriorate very quickly. Another 3% of 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 major rehabilitation or widening. 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 24: Percent of County and Township Paved Road Miles by Improvement Type



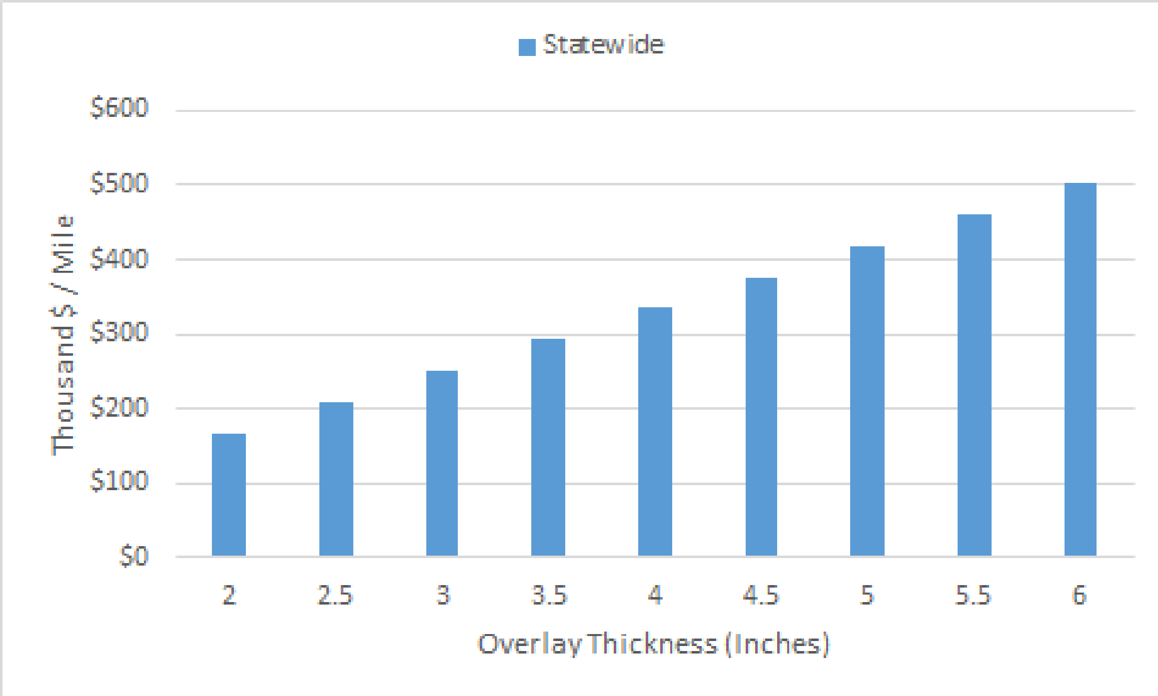




8.9.3. Improvement Costs per Mile

With the fall in oil prices, construction costs have declined and evened out within the state. In the previous study, all construction types had individual prices based on two regions: oil-producing and non-oil counties. For this study, NDDOT bid information and plan documents were gathered to determine a more current cost climate for the state. With this information, the resurfacing cost of each project was determined to be $3,489 per inch foot width statewide. This is a decrease over both the oil producing county and non-oil county costs of the previous study. With these unit costs, a two-inch overlay costs roughly $167,500 per mile for a 24-foot roadway (Figure 25). A three-inch overlay costs roughly $251,000 per mile, while a five-inch overlay results in a cost of $419,000 per mile[5].

Figure 25. Average Resurfacing Cost per Mile as a Function of Overlay Thickness



Major rehabilitation costs are estimated using NDDOT unit cost data have also been normalized statewide. Reconstruction cost is estimated at $1,250,000 per mile statewide. Mine and blend treatment is expected to cost roughly $600,000 per mile. Break and seat treatments are expected to cost approximately $400,000 per mile. Segments selected for sliver widening are assigned a widening cost of $77,500 per added foot width (in addition to overlay cost).

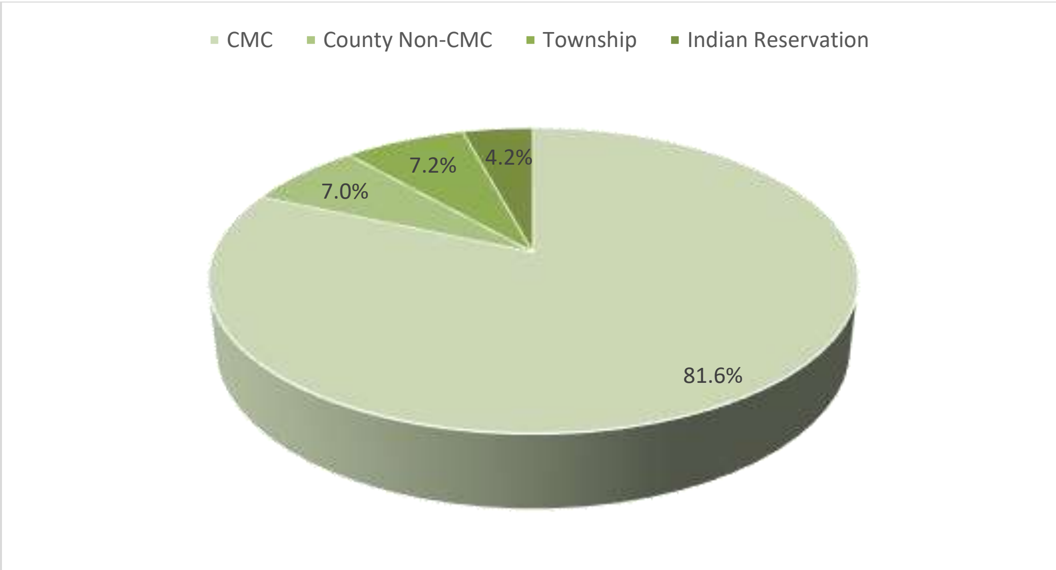
The results of the analysis are summarized in Tables 28-33. These tables show the projected improvements and costs for each biennium during the next 10 years, a projected subtotal for the 2017-2026 period, and a grand total for 2017-2036. Similar information is shown for oil- and gas-producing counties. The values in oil and gas tables are included in the statewide tables. Appendix D describes total paved road needs by county.

Approximately 135-168 miles (depending on rig count traffic model) of paved county and township roads in North Dakota must be reconstructed or reclaimed because of poor condition, high traffic loads, or deficient width (Tables 28, 30 & 32). Another 155-205 miles are candidates for widening. The remaining miles will need resurfacing during the next 20 years. Each mile of paved road is selected for only one type of improvement (e.g. reconstruction, mine and blend, resurfacing with sliver widening, or simple resurfacing). In addition, routine maintenance costs are estimated for each mile of road based on traffic level.

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

The estimated cost for all county and township roads ranges from approximately $2,203 to $2,279 million or $110 to $113 million per year. Roughly 10% of the expected cost is due to major rehabilitation. Five percent is attributable to widening. Resurfacing accounts for 39%-41% based on traffic. The remaining costs are linked to routine maintenance. Approximately 82% of all investment needs can be traced to CMC routes (Figure 26).

Figure 26: Projected County and Township Paved Road Investments by Functional Class



Depending on the oil rig scenario used, $810 million to $885 million (36%-39%) of the projected statewide need can be traced to oil- and gas-producing counties (Table 27). Fifty to fifty-nine percent of the widening cost and 50% to 58% of the major rehabilitation costs are attributable to this region. Moreover, as shown in Tables 26 and 27, the improvement needs are greater during the early years of the analysis period, with more than 20% of the reconstruction and 75% of the widening costs needed during the first two biennia. Nineteen to twenty-one percent of the projected investments over the next 10 years in the oil patch are needed during the first biennium. A majority of this initial need is a result of the upfront rehabilitation and widening improvements shown in Table 27.

The weighted-average cost for the predicted resurfacing improvements is roughly $180,000 per mile. The average routine maintenance cost is approximately $9,300 per mile per year. For roads that do not require major rehabilitation or widening, the annualized cost per mile is roughly $18,600 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.

Table 28: Summary Statewide of Forecasted Improvements and Costs for Paved County and Township Roads ($Millions) – 30 Rig Scenario

Period	Resurfacing		Widening		Reconstruction		Mine & Blend		Break & Seat		Maintenance Cost	Total Cost
	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost		
2017-2018	514.2	$122.0	56.6	$26.4	11.2	$14.0	27.5	$16.5	29.8	$11.9	$100.3	$291.0
2019-2020	615.9	$116.6	61.6	$29.9	16.7	$20.9	44.3	$22.0	9.6	$3.8	$100.3	$293.5
2021-2022	399	$69.1	13.6	$6.5	64.6	$79.9	0.3	$0.2	0.0	$0.0	$100.7	$256.4
2023-2024	400.9	$67.5	0.5	$0.7	23.4	$29.3	5.1	$3.1	11.4	$4.6	$101.5	$206.6
2025-2026	647.7	$108.7	0.0	$0.0	16.8	$21.0	0.4	$0.2	1.8	$0.7	$102.5	$233.1
2017-2026	**2,577.7**	**$483.9**	**132.3**	**$63.5**	**132.7**	**$165.1**	**77.6**	**$42.0**	**52.6**	**$21.0**	**$505.3**	**$1,280.6**
2027-2031	1,026.5	$176.8	8.9	$4.3	1.0	$1.2	6.5	$3.9	4.9	$2.0	$261.0	$449.2
2032-2036	1,515.5	$253.6	10.6	$4.1	0.8	$1.0	2	$1.2	7.3	$2.2	$211.2	$473.2
2015-2036	**5,119.7**	**$914.3**	**151.8**	**$71.9**	**134.5**	**$167.3**	**86.1**	**$47.1**	**64.8**	**$25.2**	**$977.5**	**$2,203.0**

Table 29: Summary of Forecasted Improvements and Costs for Paved County and Township Roads in Oil and Gas Producing Counties ($Millions) – 30 Rig Scenario

Period	Resurfacing		Widening		Reconstruction		Mine & Blend		Break & Seat		Maintenance Cost	Total Cost
	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost		
2017-2018	105.8	$26.4	13.1	$8.0	0.7	$0.9	17.8	$10.7	0.0	$0.0	$35.1	$81.1
2019-2020	151.3	$34.4	34.8	$19.5	1.5	$1.9	0.0	$0.0	0.0	$0.0	$35.2	$90.9
2021-2022	100.9	$20.8	1.6	$0.8	35.1	$43.8	0.0	$0.0	0.0	$0.0	$35.3	$100.7
2023-2024	58.2	$10.8	0.5	$0.7	18.4	$23.0	0.0	$0.0	0.0	$0.0	$35.7	$70.3
2025-2026	167.2	$30.2	0	$0.0	7.6	$9.4	0.0	$0.0	0.0	$0.0	$35.9	$75.6
2017-2026	**583.4**	**$122.6**	**50.0**	**$29.0**	**63.3**	**$79.0**	**17.8**	**$10.7**	**0.0**	**$0.0**	**$177.2**	**$418.6**
2027-2031	530.1	$94.7	8.9	$4.3	0.0	$0.0	6.5	$3.9	0.0	$0.0	$91.6	$194.6
2032-2036	679.0	$118.4	2.5	$1.4	0.3	$0.4	2	$1.2	4.9	$1.2	$74.4	$197.0
2015-2036	**1,792.5**	**$335.7**	**61.4**	**$34.7**	**63.6**	**$79.4**	**26.3**	**$15.8**	**4.9**	**$1.2**	**$343.2**	**$810.2**

Table 30: Summary Statewide of Forecasted Improvements and Costs for Paved County and Township Roads ($Millions) – 60 Rig Scenario (Likely Scenario)

Period	Resurfacing		Widening		Reconstruction		Mine & Blend		Break & Seat		Maintenance Cost	Total Cost
	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost		
2017-2018	508.6	$122.5	64.2	$29.3	11.2	$14.0	27.5	$16.5	29.8	$11.9	$101.9	$296.1
2019-2020	637.8	$120.0	61.6	$29.9	16.7	$20.9	44.3	$22.0	9.6	$3.8	$102.7	$299.3
2021-2022	387.3	$67.9	13.9	$6.9	80.3	$99.5	0.3	$0.2	0.0	$0.0	$103.6	$278.1
2023-2024	420.8	$70.0	13.4	$4.8	40.1	$50.1	5.1	$3.1	11.4	$4.6	$104.3	$236.8
2025-2026	643.5	$106.0	0.0	$0.0	16.8	$21.0	0.4	$0.2	1.8	$0.7	$105.4	$233.4
2017-2026	**2,598.0**	**$486.4**	**153.1**	**$70.9**	**165.1**	**$205.5**	**77.6**	**$42.0**	**52.6**	**$21.0**	**$517.9**	**$1,343.7**
2027-2031	979.9	$169.1	0.9	$0.8	1.0	$1.2	6.5	$3.9	4.9	$2.0	$267.6	$444.5
2032-2036	1,496.3	$250.5	10.6	$4.3	0.8	$1.0	2.4	$1.4	7.3	$2.2	$216.9	$476.3
2015-2036	**5,074.2**	**$906.0**	**164.6**	**$76.0**	**166.9**	**$207.7**	**86.5**	**$47.3**	**64.8**	**$25.2**	**$1,002.4**	**$2,264.5**

Table 31: Summary of Forecasted Improvements and Costs for Paved County and Township Roads in Oil and Gas Producing Counties ($Millions) – 60 Rig Scenario (Likely Scenario)

Period	Resurfacing		Widening		Reconstruction		Mine & Blend		Break & Seat		Maintenance Cost	Total Cost
	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost		
2017-2018	105.8	$28.2	15.1	$9.1	0.7	$0.9	17.8	$10.7	0.0	$0.0	$36.7	$85.6
2019-2020	173.2	$37.8	34.8	$19.5	1.5	$1.9	0.0	$0.0	0.0	$0.0	$37.5	$96.8
2021-2022	84.2	$18.9	1.9	$1.2	50.8	$63.4	0.0	$0.0	0.0	$0.0	$38.2	$121.7
2023-2024	78.2	$13.3	13.4	$4.8	35.1	$43.9	0.0	$0.0	0.0	$0.0	$38.5	$100.5
2025-2026	163	$27.6	0	$0.0	7.6	$9.4	0.0	$0.0	0.0	$0.0	$38.8	$75.9
2017-2026	**604.4**	**$125.8**	**65.2**	**$34.6**	**95.7**	**$119.5**	**17.8**	**$10.7**	**0.0**	**$0.0**	**$189.7**	**$480.5**
2027-2031	488.5	$87.8	0.9	$0.8	0.0	$0.0	6.5	$3.9	0.0	$0.0	$98.2	$190.7
2032-2036	659.9	$115.3	2.5	$1.6	0.3	$0.4	2.4	$1.4	4.9	$1.2	$80.1	$200.1
2015-2036	**1,752.8**	**$328.9**	**68.6**	**$37.0**	**96.0**	**$119.9**	**26.7**	**$16.0**	**4.9**	**$1.2**	**$368.0**	**$871.3**

Table 32: Summary Statewide of Forecasted Improvements and Costs for Paved County and Township Roads ($Millions) – 90 Rig Scenario

	Resurfacing		Widening		Reconstruction		Mine & Blend		Break & Seat		Maintenance	Total
Period	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost	Cost	Cost
2017-2018	483.8	$115.0	89.0	$40.5	11.2	$14.0	27.5	$16.5	30.7	$12.3	$103.8	$302.1
2019-2020	643.5	$121.3	77.0	$36.3	16.7	$20.9	44.3	$22.0	9.6	$3.8	$103.9	$308.1
2021-2022	395.5	$69.4	13.9	$6.9	80.3	$99.5	0.3	$0.2	0.0	$0.0	$104.3	$280.3
2023-2024	437	$72.5	13.4	$5.4	40.1	$50.1	5.1	$3.1	11.4	$4.6	$104.8	$240.5
2025-2026	621.3	$102.5	0.0	$0.0	16.8	$21.0	0.7	$0.4	4.8	$1.1	$105.7	$230.8
2017-2026	**2,581.1**	**$480.7**	**193.3**	**$89.1**	**165.1**	**$205.5**	**77.9**	**$42.2**	**56.5**	**$21.8**	**$522.5**	**$1,361.8**
2027-2031	975.3	$168.3	0.9	$0.8	1	$1.2	6.5	$3.9	4.9	$2.0	$268.4	$444.6
2032-2036	1,479.7	$247.9	8.5	$3.1	0.8	$1.0	2	$1.2	3.5	$1.4	$217.5	$472.2
2015-2036	**5,036.1**	**$896.9**	**202.7**	**$93.0**	**166.9**	**$207.7**	**86.4**	**$47.3**	**64.9**	**$25.2**	**$1,008.4**	**$2,278.6**

Table 33: Summary of Forecasted Improvements and Costs for Paved County and Township Roads in Oil and Gas Producing Counties ($Millions) – 90 Rig Scenario

	Resurfacing		Widening		Reconstruction		Mine & Blend		Break & Seat		Maintenance	Total
Period	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost	Cost	Cost
2017-2018	81.0	$20.8	39.9	$20.2	0.7	$0.9	17.8	$10.7	0.9	$0.4	$38.7	$91.6
2019-2020	178.9	$39.1	50.2	$25.8	1.5	$1.9	0.0	$0.0	0.0	$0.0	$38.7	$105.6
2021-2022	92.4	$20.3	1.9	$1.2	50.8	$63.4	0.0	$0.0	0.0	$0.0	$38.9	$123.9
2023-2024	94.3	$15.8	13.4	$5.4	35.1	$43.9	0.0	$0.0	0.0	$0.0	$39.1	$104.2
2025-2026	140.8	$24.1	0.0	$0.0	7.6	$9.4	0.3	$0.2	3.0	$0.4	$39.1	$73.3
2017-2026	**587.4**	**$120.1**	**105.4**	**$52.6**	**95.7**	**$119.5**	**18.1**	**$10.9**	**3.9**	**$0.8**	**$194.5**	**$498.6**
2027-2031	483.9	$87.0	0.9	$0.8	0	$0.0	6.5	$3.9	0	$0.0	$99.1	$190.7
2032-2036	643.3	$112.7	0.4	$0.4	0.3	$0.4	2	$1.2	1	$0.4	$80.8	$195.9
2015-2036	**1,714.6**	**$319.8**	**106.7**	**$53.8**	**96.0**	**$119.9**	**26.6**	**$16.0**	**4.9**	**$1.2**	**$374.4**	**$885.2**

Table 34: Summary of Projected Investment Needs for County and Township Roads – 30 Rig Scenario

Period	Paved	Unpaved	Total
2017-2018	$291.0	$589.5	$880.5
2019-2020	$293.5	$581.0	$874.5
2021-2022	$256.4	$591.9	$848.3
2023-2024	$206.6	$588.3	$794.9
2025-2026	$233.1	$574.0	$807.1
2027-2031	$449.2	$1,147.8	$1,597.0
2032-2036	$473.2	$1,136.3	$1,609.5

Table 35: Summary of Projected Investment Needs for County and Township Roads – 60 Rig Scenario (Likely Scenario)

Period	Paved	Unpaved	Total
2017-2018	$296.1	$632.1	$928.2
2019-2020	$299.3	$597.6	$896.9
2021-2022	$278.1	$647.6	$925.7
2023-2024	$236.8	$649.7	$886.5
2025-2026	$233.4	$593.5	$826.9
2027-2031	$444.5	$1,164.2	$1,608.7
2032-2036	$476.3	$1,144.8	$1,621.1

Table 36: Summary of Projected Investment Needs for County and Township Roads – 90 Rig Scenario

Period	Paved	Unpaved	Total
2017-2018	$302.1	$657.5	$959.6
2019-2020	$308.1	$616.4	$924.5
2021-2022	$280.3	$656.1	$936.4
2023-2024	$240.5	$647.1	$887.6
2025-2026	$230.8	$610.8	$841.6
2027-2031	$444.6	$1,208.6	$1,653.2
2032-2036	$472.2	$1,161.4	$1,633.6

8.9.4. Indian Reservation Roads

Thus far, only county and township roads, excluding Indian Reservation Roads, have been presented. 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 travel demand network and traffic predictions and investment forecasts are developed for them. However, the results are presented separately here, because funding for Indian Reservation Roads is appropriated and distributed differently than funding for county and township roads.

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 37, which shows the forecasted improvements and costs for all tribal road segments and specifically for those routes in oil-producing regions. The values in columns 2 and 4 of Table 37 are included in the values of columns 3 and 5, respectively. Altogether, 181.8 miles of paved IRR (Indian Reservation Roads) are captured in the analysis. Roughly 35% to 50% of these miles may need reconstruction due to poor condition, poor subgrade, or inadequate width. It is assumed that the remaining 95-120 miles can still be effectively resurfaced. The forecasted improvements are shown by funding period for paved and unpaved roads in Tables 38-40.

Table 37: Summary of Indian Reservation Paved Road Investment Analysis

Projected Improvement or Cost	Oil Impacted Region – 30 Rigs	Total: North Dakota – 30 Rigs	Oil Impacted Region – 60 Rigs	Total: North Dakota – 60 Rigs	Oil Impacted Region – 90 Rigs	Total: North Dakota – 90 Rigs
Miles Resurfaced	39.2	126.3	39.2	126.3	20.9	108.0
Resurfacing Cost (Million$)	$8.6	$23.7	$10.1	$25.2	$4.5	$19.6
Miles Widened	0.0	0.0	0.0	0.0	18.3	18.3
Widening Cost (Million$)	$0.0	$0.0	$0.0	$0.0	$7.8	$7.8
Miles Reconstructed	11.8	11.8	11.8	11.8	11.8	11.8
Reconstruction Cost (Million$)	$14.8	$14.8	$14.8	$14.8	$14.8	$14.8
Miles Reclaimed	0.0	23.1	0.0	23.1	0.0	23.1
Mine & Blend Cost (Million$)	$0.0	$9.2	$0.0	$9.2	$0.0	$9.2
Miles Break & Seat	0	28.2	0.0	28.2	0.0	28.2
Break & Seat Cost (Million$)	$0.0	$11.3	$0.0	$11.3	$0.0	$11.3
Maintenance Cost (Million$)	$8.7	$32.1	$8.7	$32.1	$8.7	$32.1
Total Cost (Million$)	$32.0	$91.1	$33.6	$92.7	$35.8	$94.9

Table 38: Summary of Projected Investment Needs for Impacted Indian Reservation Roads – 30 Rig Scenario

Period	Paved	Unpaved	Total
2017-2018	$23.4	$10.5	$33.9
2019-2020	$20.5	$9.0	$29.5
2021-2022	$14.4	$9.7	$24.1
2023-2024	$8.1	$ 9.6	$17.7
2025-2026	$7.7	$9.0	$16.7
2027-2031	$10.1	$17.9	$28.0
2032-2036	$6.8	$18.5	$25.3

Table 39: Summary of Projected Investment Needs for Impacted Indian Reservation Roads – 60 Rig Scenario (Likely Scenario)

Period	Paved	Unpaved	Total
2017-2018	$25.0	$12.5	$37.5
2019-2020	$20.5	$9.4	$29.9
2021-2022	$14.5	$12.2	$26.7
2023-2024	$8.1	$11.2	$19.3
2025-2026	$7.7	$9.1	$16.8
2027-2031	$10.1	$17.8	$27.9
2032-2036	$6.8	$21.5	$28.3

Table 40: Summary of Projected Investment Needs for Impacted Indian Reservation Roads – 90 Rig Scenario

Period	Paved	Unpaved	Total
2017-2018	$27.1	$13.0	$40.1
2019-2020	$20.5	$10.5	$31.0
2021-2022	$14.4	$12.0	$26.4
2023-2024	$8.1	$11.7	$19.8
2025-2026	$7.7	$9.2	$16.9
2027-2031	$10.1	$18.3	$28.4
2032-2036	$6.8	$23.2	$30.0

9. Bridge Analysis

9.1. Introduction

Ideally, bridges allow the highway network to meet the needs of the travelling public. However, bridge inadequacies can restrict the capacity of the transportation system in two ways. First, if the width of a bridge is insufficient to carry a modern truck fleet and serve current traffic demand, the bridge will restrict traffic flow and trucks may need to be rerouted. Second, if the strength of a bridge is deficient and unable to carry heavy trucks, then load limits must be posted and truck traffic again must be rerouted. These detours mean lost time and money for road users, including the agricultural and energy-related traffic which is a key driver of the North Dakota economy. A network of modern and structurally adequate bridges, therefore, serves a critical role in the state's transportation network.

This study expands and improves upon the bridge needs forecasting methodology used in the previous UGPTI needs study. The forecast is based upon the goal of maintaining a bridge network which serves modern traffic demand.

9.2. Data Collection

Bridge inventory, condition, and appraisal data were collected from two resources: the National Bridge Inventory (NBI) database (comma delimited file) and the NDDOT's bridge inventory database (shapefile of county/urban bridge). These databases were combined and spatially merged with a shapefile of the county and local road centerlines which are the focus of this study. Each bridge was individually calibrated with regard to their spatial location and relationship to road segment.

The combined and spatially-located data set includes a total of 2,420 NBI (2015) rural non-culvert structures which are county- or township-owned and currently open to traffic. This dataset represents the basis for this study's needs analysis.

Bridges with total span length less than 20 feet and culverts are not included in the NBI database and are not considered in this study's needs forecasts.

To support statistical significance, a complete NBI (2015) North Dakota bridge population dataset was used to develop the bridge condition forecasting models which will be explained in greater detail later. This dataset contains a total of 2,420 bridges in the state.

9.2.1. Condition of County and Township Bridges

Table 41 summarizes the age distribution of county- and township-owned bridges in North Dakota based on the 2015 NBI, which was the most recent data available at the time of this report. Forty-five percent of bridges in the data set are older than 50 years. Another 35% are between 30 and 50 years of age. A total of 371 bridges (15%) were built more than 75 years ago. Although 50 years was historically considered the design life of many bridges, service lives can be extended through diligent maintenance and rehabilitation.

Table 41: Age distribution of county, township, and city owned bridges in ND

Age (Years)	Frequency of Bridges	Percent	Cumulative Frequency	Cumulative Percent
≤ 20	261	10.79%	261	10.79%
> 20 and ≤ 30	293	12.11%	554	22.89%
> 30 and ≤ 40	469	19.38%	1,023	42.27%
> 40 and ≤ 50	451	18.64%	1,474	60.91%
> 50 and ≤ 75	606	25.04%	2,080	85.95%
> 75	340	14.05%	2,420	100%
Age is the elapsed time since original construction or reconstruction.				

The condition assessment scale used in the National Bridge Inventory is shown in Table 42. In this scale, a brand-new bridge component deteriorates from excellent condition to failure via eight interim steps or levels. Independent ratings are developed for each of the three major components which comprise a bridge structure – deck, superstructure and substructure. The latest recorded component ratings are shown in Table 43, and in an alternative format in Table 44.

Table 42: Component Rating Scales

Code	Meaning	Description
9	Excellent	
8	Very Good	No problems noted
7	Good	Some minor problems
6	Satisfactory	Structural elements show some minor deterioration
5	Fair	All primary structural elements are sound but may have minor section loss, cracking, spalling or scour
4	Poor	Advanced section loss, deterioration, spalling or scour
3	Serious	Loss of section, deterioration, spalling or scour has seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.
2	Critical	Advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.
1	Imminent Failure	Major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service.
0	Failed	Out of service – beyond corrective action.

Table 43: Deck, Superstructure and Substructure Component Condition Ratings of County and Township Bridges in North Dakota

Component Rating	Deck		Superstructure		Substructure	
	Bridges	Percent	Bridges	Percent	Bridges	Percent
9	79	3.26%	118	4.88%	110	4.55%
8	342	14.13%	640	26.45%	506	20.91%
7	547	22.60%	695	28.72%	582	24.05%
6	440	18.18%	498	26.45%	472	19.50%
5	241	9.96%	319	13.18%	458	18.93%
4	68	2.81%	123	5.08%	216	8.93%
3	7	0.29%	24	0.99%	66	2.73%
2	2	0.08%	2	0.08%	8	0.33%
1	1	0.04%	0	0.0%	1	0.04%
NA	693	28.64%	1	0.04%	1	0.04%

Table 44: Component Ratings [alternative format]

Component Ratings	Deck		Superstructure		Substructure	
	Bridges	Percent	Bridges	Percent	Bridges	Percent
Good (7-9)	968	56%	1453	60%	1198	50%
Fair (5-6)	681	39%	817	34%	930	38%
Poor (3-4)	75	4%	147	6%	282	12%
Critical (0-2)	3	0%	2	0%	9	0%

Component ratings are important but are not the only factors which define a bridge's overall adequacy in supporting traffic loads. This overall sufficiency can be expressed as a sufficiency rating (SR), a single value calculated from four separate factors which represent structural adequacy and safety, serviceability and functional obsolescence, essentiality to the public, and other considerations. The formula is detailed in the document "Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges" (FHWA 1995), commonly referred to as the NBI coding guide. Sufficiency rating is expressed as a percentage, in which 100% would represent an entirely sufficient bridge and 0% would represent an entirely insufficient or deficient bridge. Approximately 51 percent of bridges in North Dakota have a sufficiency rating greater than 85%. Twenty-six percent of the bridges have sufficiency rating less than 60%.

Each bridge in the NBI is also assigned a status which indicates whether the bridge is functionally obsolete, structurally deficient, or non-deficient. This value depends on component ratings and other appraisal ratings. More than 28% of North Dakota's local bridges are marked either structurally deficient or functionally obsolete.

Functional obsolescence occurs when a bridge's design no longer allows it to adequately serve present-day traffic demands. This can include bridges which are too narrow or provide too little clearance for a modern truck fleet. Note that a status of functionally obsolete does not indicate structural deficiency.

Structurally deficient is a status which indicates a bridge has one or more structural defects that warrant attention. The status does not indicate the severity of defect and indeed a structurally deficient bridge can still be safe for traffic, but bridges with this status are typically monitored more closely and may be scheduled for rehabilitation or replacement.

It can be helpful to consider a bridge's status in terms of its impact on the roadway network. If the width of a bridge is insufficient to carry modern traffic volume and truck fleet, the bridge will constrict traffic flow and trucks may need to be rerouted. If the strength of a bridge is deficient and unable to carry heavy trucks, then load limits must be posted and truck traffic must be rerouted. In either case, a bridge with an NBI status flag can negatively impact the volume and weight of traffic supported by the highway system.

9.2.2. Minimum Maintenance Bridges

Many of the state's county- and township-owned bridges exist on low- or minimum-maintenance roads. These bridges may be located on closed or unimproved roads and serve very low traffic demand. The user cost-benefits ratios of replacement typically do not justify the high investment cost. Based on discussion with NDDOT's Bridge and Local Government Divisions, this study assumes that structures on low maintenance roads will not receive maintenance, rehabilitation or replacement. The study's road network data did not include a designation for minimum maintenance roads, so an effort had to be made to identify these roads based on existing road data and recent satellite photography.

First, North Dakota road centerline data from the Cube HERE base network was used to identify bridges carried by roads with surface type "Gravel or "Dirt" This captured 1,090 of the study's total database of 2,420bridges. This effort identified 169 bridges as existing on minimum maintenance roads.

Bridges identified using the above criteria were assigned no preventive maintenance or improvement needs. Bridges flagged with maintenance status will later be validated through county surveys, but this step was not possible within the timeframe of this study.

9.3. Methodology

9.3.1. Deterioration Model

In 2009, UGPTI developed a set of empirical models to forecast component (deck, superstructure and substructure) deterioration rates for bridges nationwide. UGPTI has since developed regional empirical regression models with a focus on North Dakota. These updated models are based on the 3,492 North Dakota bridges in the 2015 NBI database. They were validated using the updated 2015 NBI database.

The multivariate component deterioration models include four effects: bridge type, reconstruction history, and bridge jurisdiction or location.

The effects are categorized as indicator or dummy variables. The indicator variables shift the intercept of the regression, thereby creating many unique levels or categories that will provide their own unique intercepts. However, slope (rate of change in component rating with age) is the same after controlling for all effects. Bridge deck, superstructure and substructure condition (the dependent variables of the models) are treated as integer-scaled variables using the scale range from 0 to 9 (where 0 indicates failure and 9 means excellent condition).

Bridge age is the independent variable used in the models and is calculated as 2016 minus the year of original construction or reconstruction year. A polynomial function between bridge rating and age was adopted. The hypothesis is based on two suppositions. First, the rate of loss may be modest and nearly linear until a bridge's condition deteriorates to fair, at which point more maintenance and repairs must be implemented to keep the bridge in acceptable condition. These improvements may slow down the deterioration rate with time. Second, once the bridge is in serious condition it may continue in light service for some time under close scrutiny via posting (e.g., limiting the traffic loads). Age and age-squared are the quantitative independent continuous variables in this study.

All models must be tested empirically and validated by the data. In this analysis, culverts are eliminated from the dataset; the remaining bridges consist of four material types (concrete, pre-stressed concrete, steel, and timber). The regional transportation district variable includes eight classes and captures differences attributable to the bridges' geographic and jurisdictional location.

The detailed model statistics are attached in Appendix E.

Forecasted component ratings were used to calculate bridge sufficiency rating. The sufficiency rating equation, however, includes several other elements in addition to deck, superstructure and substructure condition. The detailed sufficiency rating formula is documented in NBI coding guide Appendix F. These are shown in Table 45.

Table 45: Other factors that affect sufficiency rating

NBI Item	Description	NBI Item	Description
19	Detour Length	62	Culverts
28	Lanes on Structure	66	Inventory Rating
29	Average Daily Traffic	67	Structural Evaluation
32	Approach Roadway Width	68	Deck Geometry
36	Traffic Safety Features	69	Underclearances
43	Structure Type	71	Waterway Adequacy
51	Bridge Roadway Width	72	Approach Roadway Alignment
53	Vert. Clearance over Deck	100	STRAHNET Highway Designation

The prediction of these factors over time was outside the scope of this study but it was determined that they could reasonably be held constant until major treatment (i.e. rehabilitation or replacement) selection. This allowed the study to use a calculated sufficiency rating for the purpose of treatment selection. The use of sufficiency rating rather than component score allows the forecasting model to consider not only structural adequacy but also safety, obsolescence, and essentiality to the public. This better reflects the state of bridge improvement planning and improves the accuracy of this study's forecasted improvements.

Note that the assumptions made for sufficiency rating calculation do not necessarily hold true for bridges which undergo major improvements (rehabilitation or replacement), because these treatments typically address not only component structural deficiencies but also any other elements which contribute to a bridge's deficiency or obsolescence (e.g. traffic safety features). The component ratings and age of a replaced or rehabilitated bridge can be assumed to be reset based on knowledge of construction practice. Updated bridge age is reset to zero for newly replaced bridges and reset to 10 for rehabilitated bridges (this results in a component rating of seven). Similar assumptions cannot be made about the other factors of the sufficiency rating formula. A sufficiency rating cannot, therefore, be reasonably forecasted for bridges which have received major improvement. For this reason, a sufficiency rating was calculated for each bridge only until the year of major treatment selection or the end of the analysis period, whichever occurred first.

Similarly, the forecasted component ratings are also used to update the NBI status condition based on NBI status definitions. The updated status is, in turn, used as an input for the improvement selection model, described below.

9.3.2. Improvement Selection Model

The analysis considered four possible treatment types for each bridge during each year of the analysis period: preventive maintenance, rehabilitation, replacement, and no action. Bridge rehabilitation is further separated into widening and deck maintenance. Bridge replacement is separated into three subcategories based the type of structure which will replace the existing bridge:

1. New bridge with 32-foot width
2. Single barrel reinforced concrete box culvert
3. Multiple barrel reinforced concrete box culvert

An improvement selection model was developed based on current practice and discussions with NDDOT personnel. The decision criteria include, but are not limited to, bridge status, sufficiency rating, operating rating, bridge geometry, and component condition ratings. The full improvement selection model is detailed in Appendix G.

The AASHTO and Federal Highway Administration (FHWA) have defined bridge preventive maintenance as "a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without substantially increasing structural capacity)" (FHWA 2011). This can include cyclical activities such as deck washing or condition-based activities such as scour mitigation or concrete patching. FHWA notes that effective bridge preventive maintenance activities can extend the useful life of bridges and reduce lifetime cost.

Preventive maintenance can encompass a wide variety of activities, but this study's improvement model was limited to the selection of a generalized annual "preventive maintenance" treatment category. It is assumed that each bridge owner will determine the maintenance treatments and intervals most appropriate for their bridges.

An additional forecasted preventive maintenance need was included for deck washing on maintenance-eligible bridges within five miles of municipalities with population greater than 5,000. While county and township roads are not generally subject to deicing treatment, bridges near towns may be exposed to deicing chemicals tracked from nearby municipal roads. This deck washing allocation recognizes the need for maintenance to combat chloride-induced corrosion of reinforcement (and resulting loss of service life) for concrete bridge decks.

Effective preventive maintenance can be described as the right treatment to the right bridge at the right time. Accordingly, bridges were considered eligible for preventive maintenance until deteriorating to a point at which preventive maintenance would provide limited effectiveness at arresting deterioration – for example, painting a steel bridge which has already experienced major corrosion and section loss. Bridges with very narrow (i.e. less than 20-foot width) decks were considered ineligible for preventive maintenance. Maintenance-ineligible bridges were allowed to proceed to rehabilitation or replacement state.

Bridge rehabilitation is defined by FHWA as "major work required to restore the structural integrity of a bridge as well as work necessary to correct major safety defects." It represents an improvement which generally exceeds the scope of preventive maintenance but does not involve complete replacement of the structure. In this study, bridges were generally considered eligible for rehabilitation if their condition had deteriorated beyond preventive maintenance state but did not yet warrant total replacement. A number of exclusionary factors were applied to bridges for which it was determined that rehabilitation would be either undesirable or impossible. These included unknown foundation, poor substructure condition, and timber superstructure. Finally, to facilitate the movement of modern commercial traffic, bridges on the federal aid highway network were assigned rehabilitative deck widening treatment if their deck width was less than 28 feet. This study recognizes that, in general, county and local agencies do not currently practice rehabilitation. However, bridge forecasts include rehabilitation to demonstrate the possibility of reduced lifecycle cost if effective treatment plans were to be adopted.

Bridge replacement represents the final and most cost-intensive type of bridge treatment. It involves a complete replacement of the existing structure, either with a new bridge or another structure. This study assumes short span bridges will be replaced by reinforced concrete box culverts (RCBC), per current state of practice. Structures less than 40 feet in length will be replaced by a single-barrel RCBC, while structures between 40 and 50 feet in length will be replaced by multiple-barrel RCBC. Structures with total length greater than 50 feet are replaced by new bridges.

Typically when older substandard bridges are replaced by modern ones, the lengths and widths of the structures increase. Based on recent North Dakota bridge replacement project data, a new structure is roughly 70% longer than the original one. Replacement widths of 32 feet are used for bridges on and off the CMC system, respectively, to allow clearance for a modern truck fleet.

Several criteria were used to qualify bridges for replacement. These are described in detail in Appendix G. In general, bridges qualified for replacement if their status was functionally obsolete (FO) or structurally deficient (SD), if they had low sufficiency rating (<60), or if they included a narrow deck (≤24 feet). Removal of load postings was a priority, so bridges on CMC routes with operating rating less than a standard HS-20 load were sent to replacement state regardless of other condition criteria.

For the purpose of this study's 20-year analysis period it is assumed that a bridge which receives a major improvement (rehabilitation or replacement) will not be considered for another major improvement for the remainder of the study period and will instead be assigned preventive maintenance. This is a reasonable assumption considering the length of the study and the unlikelihood of a bridge requiring multiple major treatments in a 20-year period. Culvert structures require comparatively little preventive maintenance and are not considered eligible for preventive maintenance treatment in this study.

9.3.3. Cost Model

Preventive maintenance cost estimates used an annual unit cost of $0.24 per square foot of deck area. This value represents a typical annualized cost of maintenance as derived from other state DOT preventive maintenance expenditures outlined in individual state needs studies and in NCHRP 20-68A Scan 07-05 Best Practices In Bridge Management Decision-Making (2009). An additional $0.05 per square foot for annual deck washing was allowed for deck washing on bridges within five miles of municipalities greater than 5,000 residents, as described in the previous section.

Deck replacement cost is based on a model developed by Sinha et al. in "Procedures for the Estimation of Pavement and Bridge Preservation Costs for Fiscal Planning and Programming" (2005). This model expresses rehabilitation cost as percentages of total replacement cost. Deck replacement is expected to consist of 45% of equivalent bridge replacement cost.

Bridge widening cost was estimated as 50% of potential replacement cost. This figure was based upon discussion with NDDOT Local Government and Bridge Division personnel.

Replacement costs were estimated by developing unit costs from recent (2009-2015) NDDOT bid reports and plan documents. Unit costs reflect 2015 dollars, and the final costs estimated were adjusted to reflect 2016 dollars. The type of replacement structure was based on the criteria described in the Improvement Selection Model section of this chapter.

A deficient bridge less than 40 feet long is assumed to be replaced by a culvert structure costing $400,000. A deficient bridge between 40 and 50 feet in length is assumed to be replaced by a culvert structure costing $600,000. Costs for bridges longer than 50 feet are calculated using the square footage of the deck and an average replacement unit cost. Unit replacement costs were $275 per square foot of deck area. All costs include preliminary engineering and construction engineering costs. Preliminary engineering costs are assumed to add an additional 10% to the bid price, while construction engineering adds approximately 15% of the bid price.

9.4. Results

9.4.1. Estimated Needs by County

Estimated statewide improvement and preventive maintenance needs for the study period, 2016-2036, are $449 million in 2016 dollars. Total forecasted needs by district are displayed in Table 35. Most of the improvement needs are determined by the study's improvement model to be backlog needs, occurring during the first study biennium. Based upon discussion with NDDOT Bridge and Local Government Divisions, these needs have been distributed evenly over the first five biennia of the study period. These forecasts are shown in Table 46.

9.4.2. Summary of Bridge Study Component

In this study, inventory and condition data from the 2015 National Bridge Inventory were used to identify county and township bridges on maintained roads that require maintenance, rehabilitation or replacement in years 2016 through 2036. The study's methodology has been expanded significantly from a similar UGPTI study in 2012. Cost inflation and a more thorough improvement model contributed to an increase in forecasted needs.

While this study has utilized the data available in the National Bridge Inventory, a more detailed study is needed to examine the conditions of specific structural elements (e.g. trusses, girders, abutments, etc.). Element-level bridge inspection data will begin to be phased into the federal bridge database starting in 2014. This data will make possible a more detailed needs assessment.

Further refinement of this study's prioritization scheme will require more detailed traffic counts at each bridge location to validate the travel demand model at the necessary resolution. Verification of the NBI-coded detour distance for each field must also be verified using a detailed road centerline GIS network in future studies. While this bridge analysis involved some integration of the study's detailed statewide travel demand model, manual verification was not possible within the given timeframe and must be implemented in future efforts. This will not only guarantee the validity of the study's prioritization scheme but also provide a tool for NDDOT to improve existing NBI-coded detour distance.

Table 46: Total County and Township Bridge Needs by County, in Thousands of 2016 Dollars

County	Rehabilitation and Replacement		Preventive Maintenance Cost	Total Cost
	Bridges	Cost		
Adams	4	$2,598,162.73	$247,036.50	$2,845,199.23
Barnes	1	$454,724.41	$365,670.45	$820,394.86
Benson	3	$1,154,101.05	$71,281.28	$1,225,382.33

County	Rehabilitation and Replacement		Preventive Maintenance Cost	Total Cost
	Bridges	Cost		
Billings	2	$997,572.18	$209,659.93	$1,207,232.11
Bottineau	44	$26,818,044.62	$461,378.63	$27,279,423.25
Bowman	4	$723,818.90	$149,629.39	$873,448.29
Burke	4	$1,600,000.00	$37,504.73	$1,637,504.73
Burleigh	6	$1,830,577.43	$341,766.62	$2,172,344.05
Cass	49	$31,682,611.55	$2,503,739.89	$34,186,351.44
Cavalier	6	$2,600,000.00	$79,199.73	$2,679,199.73
Dickey	0	$0.00	$428,072.42	$428,072.42
Divide	3	$1,200,000.00	$49,784.78	$1,249,784.78
Dunn	4	$2,321,522.31	$290,878.86	$2,612,401.17
Eddy	1	$829,921.26	$209,578.08	$1,039,499.34
Emmons	4	$2,535,662.73	$277,098.46	$2,812,761.19
Foster	3	$1,403,873.85	$68,814.25	$1,472,688.09
Golden Valley	6	$3,527,296.59	$119,554.08	$3,646,850.67
Grand Forks	57	$26,236,125.50	$1,310,888.39	$27,547,013.89
Grant	20	$18,492,191.60	$543,975.11	$19,036,166.71
Griggs	3	$3,853,543.31	$225,315.64	$4,078,858.95
Hettinger	30	$18,573,129.92	$423,150.21	$18,996,280.13
LaMoure	11	$8,756,496.06	$411,141.46	$9,167,637.53
Logan	3	$634,251.97	$64,237.01	$698,488.98
McHenry	27	$16,047,408.14	$417,923.98	$16,465,332.12
McIntosh	1	$600,000.00	$15,525.30	$615,525.30
McKenzie	10	$3,713,812.34	$467,686.28	$4,181,498.61
McLean	3	$1,611,301.85	$295,730.06	$1,907,031.91
Mercer	3	$1,143,536.75	$448,466.12	$1,592,002.86
Morton	84	$44,974,639.11	$1,048,940.50	$46,023,579.61
Mountrail	3	$2,294,750.66	$179,567.68	$2,474,318.34
Nelson	2	$1,465,257.91	$208,636.08	$1,673,893.99
Oliver	0	$0.00	$147,237.51	$147,237.51
Pembina	18	$13,461,187.66	$717,144.38	$14,178,332.04
Pierce	1	$1,673,228.35	$35,300.70	$1,708,529.05
Ramsey	7	$3,875,328.08	$163,156.99	$4,038,485.08
Ransom	5	$8,705,249.34	$449,601.03	$9,154,850.37
Renville	3	$3,608,136.48	$195,614.60	$3,803,751.09
Richland	43	$27,914,074.80	$1,107,339.82	$29,021,414.62
Rolette	1	$400,000.00	$35,524.60	$435,524.60

County	Rehabilitation and Replacement		Preventive Maintenance Cost	Total Cost
	Bridges	Cost		
Sargent	6	$2,816,535.43	$27,477.42	$2,844,012.85
Sheridan	1	$1,467,979.00	$113,992.59	$1,581,971.60
Sioux	1	$186,023.62	$162,038.22	$348,061.84
Slope	2	$497,604.99	$184,516.01	$682,121.00
Stark	31	$17,429,954.07	$609,035.84	$18,038,989.91
Steele	21	$10,811,548.56	$437,465.53	$11,249,014.08
Stutsman	5	$2,071,653.54	$335,675.24	$2,407,328.78
Towner	8	$3,087,270.34	$63,084.74	$3,150,355.08
Traill	53	$45,719,521.00	$1,179,343.01	$46,898,864.01
Walsh	63	$35,900,032.81	$1,060,619.29	$36,960,652.09
Ward	13	$8,528,477.69	$373,593.50	$8,902,071.19
Wells	2	$1,323,622.05	$259,430.25	$1,583,052.30
Williams	18	$9,428,477.69	$203,711.91	$9,632,189.60
Statewide	**703**	**$429,580,240.21**	**$19,832,735.11**	**$449,412,975.32**

Table 47: Statewide Summary of Forecasted Needs for County and Township Bridges ($000)

Period	Rehabilitation		Replacement		Improved Bridges	Maintenance Cost	Total Cost
	Bridges	Cost	Bridges	Cost			
Backlog	95	$27,527	604	$400,649	699	$9,312	$437,488
2016-2017	19	$5,505	120	$79,599	139	$1,862	$86,967
2018-2019	19	$5,505	120	$79,599	139	$1,862	$86,967
2020-2021	20	$5,709	120	$79,599	140	$1,862	$87,170
2022-2023	19	$5,505	120	$79,599	139	$1,862	$86,967
2024-2025	20	$5,905	124	$82,252	144	$1,862	$90,020
2026-2036	0	$0	2	$800	2	$10,520	$11,320
2016-2036	97	$28,130	606	$401,449	703	$19,832	$449,412

10. Summary and Conclusions

This report outlines the study to estimate the needs for maintaining and improving North Dakota's network of county and township roads and bridges over the next 20 years. The needs estimates presented in this report have been developed at a network planning level. Project specific costs may vary either above or below the estimated cost of a specific road segment for a number of reasons. Factors such as wetlands mitigation, geometric corrections, and high right-of-way acquisition costs, among others may influence the actual project specific costs. In addition, because this is a network planning study, project-specific enhancements such as turning lanes and climbing lanes were not modeled. These enhancements are typically included in a project as a result of a project-specific analysis.

The combined needs estimates by biennium are presented in Table 48.

Table 48: Statewide Summary of Forecasted Needs for County and Township Roads and Bridges

Period	Unpaved	Paved	Bridges	Total
2017-18	$645	$292	$88	$1,025
2019-20	$607	$302	$88	$997
2021-22	$660	$277	$88	$1,025
2023-24	$661	$235	$88	$984
2025-26	$603	$234	$88	$925
2027-36	$2,915	$913	$12	$3,840
2017-36	**$6,090**	**$2,254**	**$449**	**$8,796**

All estimates presented in this report are based upon the best data available at the time of the writing of the report, and assumptions used to arrive at these estimates are based upon the most recent forecasts of oil development within North Dakota. Any significant changes in costs, forecasts, practices, or highway technology may require re-estimation of the needs for county and township roads.

For additional information regarding the data collected for this study, presentations, and other assumptions, please visit: http://www.ugpti.org/downloads/road_needs/.

11. Appendix A: Cost and Practices Surveys

County Road Needs Study

County: ______________________________

Contact: ______________________ ________________ __________________
Name Phone Email

Preparer: ______________________ Date Prepared: ______________________

Aggregate Description

To determine the type and quality of aggregate used in your county, please check all boxes that apply. For example, if your county uses crushed, spec gravel – select crushed material and specifications.

- Gravel ❑
- Scoria ❑
- Pit Run ❑
- Crushed Material ❑
- Specifications ❑
- Tested ❑
- Other__________________ ❑

Placement Practices

When aggregate overlays are placed in your county, please select the typical practice that is used to apply an aggregate overlay.

- Truck Drop and Blade ❑
- Windrow/Equalize ❑
- Water/Rolling/Compaction ❑
- Other__________________ ❑

Operational Tasks

In this section, please provide a percentage of tasks that are done using county resources versus the percentage of work done by a contractor. For example, if your county owns the pit and does all of the crushing using county labor, 100% would be entered into the first column, and 0% in the second column.

	Performed by:	
Task	County	Contractor
Crushing		
Hauling		
Placement		
Blading		
Dust Control		
Base Stabilization		

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. If you are quoting contractor prices, please circle "yes" in the right hand column.

Gravel/Scoria Cost			
- Average Gravel/Scoria Cost (crushing & royalties at the pit)		Per cubic yd.	Is this Contractor Price? (yes/no)
- Trucking Cost from Gravel Origin		Per loaded mile/Cu. Yard	Is this Contractor Price? (yes/no)
- Average trucking distance for aggregate		Miles	
- Placement Costs		Per mile	Is this Contractor Price? (yes/no)
- Blading Cost		Per mile	Is this Contractor Price? (yes/no)
- Dust Suppressant Costs		Per mile	Is this Contractor Price? (yes/no)
- Base Stabilization Cost		Per mile	Is this Contractor Price? (yes/no)
- Snow Removal Cost		Per mile	Is this Contractor Price? (yes/no)

Gravel Road Practices

This section asks for information regarding gravel road practices based upon differing traffic levels. Under the "Daily Traffic" row, please enter what you would consider low, medium and high traffic levels on gravel roads within your county. In the example below, low is categorized as less than 50 vehicles, medium 50-150 vehicles and high 150-350. This is expected to vary significantly from county to county, so please use your own estimates of traffic levels. Following the traffic entry, please enter the regraveling thickness, blading frequency, regraveling frequency, and whether dust suppressant or base stabilization are used at each of these traffic categories.

EXAMPLE	***Traffic Levels***		
	Low	***Medium***	***High***
Daily Traffic	***>50***	***50-150***	***150-350***
Average Regraveling Thickness	***3 in***	***4 in***	***5 in***
Blading Frequency (# per year)	***8***	***12***	***16***
Regraveling Frequency (years between regraveling)	***7***	***5***	***3***
Dust Suppressant (yes/no)	***no***	***no***	***Yes***
Base Stabilization (yes/no)	***no***	***no***	***Yes***

County Entry	Traffic Levels		
	Low	Medium	High
Daily Traffic			
Average Regraveling Thickness			
Blading Frequency (# per month)			
Regraveling Frequency (years between regraveling)			
Dust Suppressant (yes/no)			
Base Stabilization (yes/no)			

If you answered yes for Dust Suppressant – which type do you use?____

If you answered yes for Base Stabilization – which type do you use?____

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

❑ Very Good ❑ Good ❑ Fair ❑ Poor

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

Please return this survey in the enclosed envelope by **October 15, 2015**. Please direct any questions to Alan Dybing at 701.231.5988 or alan.dybing@ndsu.edu.

"North Dakota State University does not discriminate on the basis of race, color, national origin, religion, sex, disability, age, Vietnam Era Veteran's status, sexual orientation, marital status, or public assistance status. Direct inquiries to the Vice President of Equity, Diversity, and Global Outreach, 205 Old Main, Fargo, ND 58108, (701) 231-7708."

Township Road Needs Study

Township: ____________________ County: ______________________

Contact: ____________________ ______________ ________________
Name Phone Email

Preparer: ____________________ Date Prepared: ____________________

Component Costs

Please report costs for gravel for township 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
- Placement Costs		Per mile
- Blading Cost		Per Mile
- Dust Suppressant Costs (If applicable)		Per mile

Average Gravel/Scoria Overlay Thickness ____________________ Cubic yd/mile or Inches
(Please circle one)

Road Maintenance Practices

Gravel Road Practices

Please report blading and graveling frequency for gravel roads.

Blading Frequency

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

Graveling Frequency

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

Does your township contract directly for maintenance activities, or does your county provide for maintenance?

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

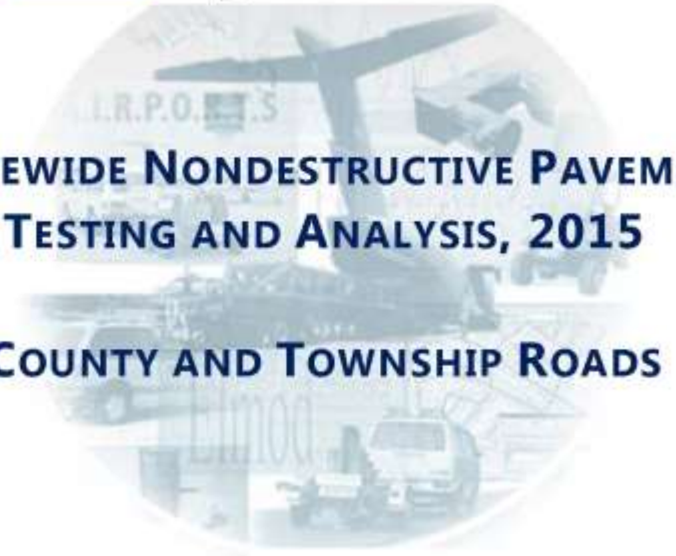
Comments or Suggestions:

Please complete this survey by November 1 and return to:
Alan Dybing
Upper Great Plains Transportation Institute
NDSU Dept 2880
P.O. Box 6050
Fargo, ND 58108-6050

Please direct any questions to Alan Dybing at 701.231.5988 or alan.dybing@ndsu.edu.

12. Appendix B: Falling Weight Deflectometer Results

Dynatest®



STATEWIDE NONDESTRUCTIVE PAVEMENT TESTING AND ANALYSIS, 2015

COUNTY AND TOWNSHIP ROADS

Submitted to

NDSU NORTH DAKOTA STATE UNIVERSITY

North Dakota State University
NDSU Dept. 2880
PO Box 6050
Fargo, ND 58108-6050

March, 2016

PROJECT REPORT

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EXECUTIVE SUMMARY

The North Dakota State University's Upper Great Plains Transportation Institute (UGPTI) is conducting a state wide research to develop regional traffic models and infrastructure needs for counties and townships in North Dakota. As part of the network-level model requirements, pavement layer thickness and structural assessment is needed. This project was the second cycle of this work and consisted of collecting non-destructive pavement deflection data on approximately 760 miles of county and township roads, in approximately 380 locations, across North Dakota, covering 47 counties. The list of segments was provided by UGPTI. The deflection testing was performed using a Dynatest Falling Weight Deflectometer (FWD). In addition to deflection testing, Ground Penetrating Radar (GPR) was collected by Infrasense, Inc. The two tests were combined to evaluate the structural condition of the layers in each pavement section. The *in situ* elastic layer moduli were determined through backcalculation. This report provided the results of the FWD data collection and the backcalculation of layer moduli.

The FWD tests were conducted during the period of 09/21 through 10/28/2015 in approximately 380 locations. Two different load levels were applied (9,000 and 12,000 lbs.) and two replicates for each load. The backcalculation of layer moduli was performed for each one of the 14,800 deflection basins collected. The software package employed was the Dynatest ELMOD computer program. ELMOD is used to backcalculate the mechanistic layer properties of an axial-symmetric, semi-infinite pavement system (i.e. the elastic moduli or E-values of each structural layer in the pavement).

The combined FWD/GPR approach used in this project eliminated the need for pavement coring for GPR calibration. This approach consisted of an inter-procedural optimization technique that eliminated the need of coring by using the quality checks on backcalculation data as means to identify adjustments in the thickness analysis of the GPR data. The goal of the inter-procedural optimization technique was to improve the overall quality and accuracy of both analyzes (backcalculation and GPR), and ultimately enhancing reasonableness in the structural condition assessment.

The great majority of surface layer backcalculated moduli values were between 50 and 650 ksi, which is very reasonable for hot mix asphalt layers at various deterioration phases. For base layer backcalculated moduli, the majority of values were between 15 and 60 ksi, which is also very reasonable for granular base layers. And finally the subgrade layer backcalculated moduli varied between 6 and 15 ksi.

Since the amount of data analyzed was very large, a practical database compiling all the data was created in Microsoft Excel™ during the first edition of this project. A simple form was

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prepared to help visualize the raw data (deflections) and the backcalculation results. The upgraded version of this tool, called Pavement Analysis Tool, will be provided as part of this project final deliverables, along with the Final Report.

This project was part of a broader study in which traffic models and infrastructure needs will be assessed for county and township roads across the state of North Dakota. It is possible that a few segments may require refinement in the backcalculation during the next phases of this study. As additional information about each segment becomes available, the backcalculation process may be refined, especially for the deflection basins in which less desirable results were obtained.

This project has the following deliverables:

1. Draft and Final Reports
    a. Electronic submission in pdf format
    b. Hard copies may be provided upon request
2. Electronic files:
    a. FWD data files (mdb files)
    b. KML files with geo-coordinates of test locations
    c. ELMOD files (mde files)
    d. Pavement Analysis Tool (Excel file)

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TABLE OF CONTENTS

1. INTRODUCTION

The North Dakota State University's Upper Great Plains Transportation Institute (UGPTI) is conducting a state wide research project to develop regional traffic models and infrastructure needs for the counties and townships in North Dakota. As part of the network-level model requirements, pavement layer thickness and structural assessment is needed.

Non-destructive deflection testing was performed on 760 miles of paved county and township roads across 47 counties. The segment selection was created by UGPTI. The deflection testing was performed using a Dynatest Falling Weight Deflectometer (FWD). In addition to deflection testing, Ground Penetrating Radar (GPR) was collected by Infrasense, Inc. The two tests were combined to evaluate the structural condition of the layers in each pavement section. The *in situ* elastic layer moduli were determined through backcalculation.

The FWD tests were conducted during the period of 09/21 through 10/28/2015 in 380 locations throughout North Dakota. Two different load levels were applied in two replicates of each. The backcalculation of layer moduli was performed for each one of the 14,800 deflection basins collected. A total of 181 basins were not good enough for backcalculation (1.2% of the total collected). This result is remarkably good, given the magnitude of the project and uncertainties experienced in the field.

This report provides the results of the non-destructive deflection testing and the backcalculation of layer moduli of all pavement sections tested.

2. PROJECT LOCATIONS

The pavement segments selected for this study are indicated in the general map in Figure 1. All locations were georeferenced by UGPTI and provided to Dynatest. Within each pavement segment a 2-mile long pavement section was tested near the middle of the provided pavement segment. A set of maps was created and the list of segments was imported into a geodatabase for accurate identification in the field.

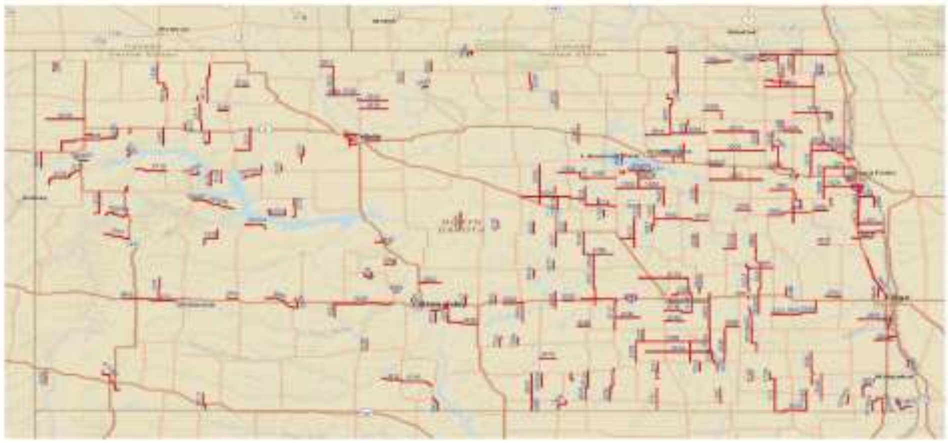

Figure 1. General overview of site locations.

3. NONDESTRUCTIVE PAVEMENT TESTING

3.1 The Dynatest FWD Test System

The Dynatest Model 8002 FWD Test System was used to generate the requisite non-destructive testing (NDT) load-deflection data analyzed in this report. The Dynatest FWD generates a transient, impulse-type load of 25-30 msec duration, at any desired (peak) load level between 1,500 and 27,000-lbf. The load frequency is designed to approximate the effect of a 30-50 mph moving wheel load. Figure 2 shows the FWD test system. A detailed description of the equipment is provided in Appendix A.

Figure 2. Dynatest 8002 FWD Test System.

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The FWD is used in pavement structural analysis. A body of mass (shown in yellow in the back of the trailer - Figure 2) is dropped from various heights onto a circular load plate, which generates vertical pressure applied on the surface of the pavement. Geophones spaced in the longitudinal direction (traffic direction) within the area of the load influence measure the velocity of the load pulse as it travels through the layered pavement. The load pulse velocity is integrated resulting in the surface deflection as shown schematically in Figure 3. The load magnitude is measured using a load cell located at the load plate. The measurements of load and deflections were used to calculate *in situ* stiffness (layer moduli) of each layer in the pavement structure.

Figure 3. Schematic representation of FWD testing.

3.2 Tested Features and Procedures

All deflection testing was performed according to the specifications requested by NDSU as shown in Table 1.

Table 1 . Falling Weight Deflectometer Testing Specifications.

Maximum test spacing	0.189 mi (1000 ft)
Test lane	Outer lane
Test location	Outside wheel path
Direction	Single direction
Geophone Spacing (in)	0, 8, 12, 18, 24, 36, 48, 60, and 72
Test load weights (lbs.)	9,000 and 12,000
Acceptable range	± 10% of specified load level
Number of drops per test	2 seating drops (unrecorded) 2 drops per weight

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3.2.1 Test Spacing and location with cross section

The test spacing was 0.189 mi (1000 ft.) between test points. It was defined that any segment would have at least 9 test locations. The test space was reduced from 0.189 mi to a smaller value whenever the segment was shorter than 1 mile. Most segments were tested in one direction only. If a segment was less than 1 mile long, or the length of asphalt paved road was less than 1 mile, the segment was tested in both directions. There was no preference for which direction to test – it depended on route the crew were traveling. Tests were performed at the outer wheel path.

3.2.2 Load Levels

Two unrecorded seating drops were applied at 6,000 lbs., before the application of the recorded drops. Testing was conducted at two load levels: 9,000 and 12,000 lbs., with two recorded drops at each load level and time history recorded at the second drop of each load level. The data was stored in US customary units in MDB files (output directly from the testing equipment). The sequence of drops and data recorded is summarized in Table 2.

Table 2. Test Sequence.

Drop Sequence	Drop Load (lbs.)	Recorded (Y/N)	Time History (Y/N)
Non-a	6,000	N	N
Non-b	6,000	N	N
1	9,000	Y	N
2	9,000	Y	Y
3	12,000	Y	N
4	12,000	Y	Y

3.2.3 Sensor Spacing

Nine deflection sensors were used and the sensor spacing from the center of the load plate is shown in Table 3.

Table 3. Sensor Spacing.

Sensor Number	Distance from center of the load plate	
	in	mm
1	0	0
2	8	203
3	12	305
4	18	457
5	24	610
6	36	914
7	48	1,219
8	60	1,524
9	72	1,829

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3.2.4 Plate Diameter

The diameter of the load plate used was 5.92 inches (300 mm).

3.2.5 Video or Digital Photographs

Although not solicited in the RFP, photographs were taken during the testing performed from 9/21 to 10/22 with a digital camera mounted on the vehicle at regular intervals of 1000 ft. The camera malfunctioned on 10/22 and no images were collected after this point since it was not a project requirement. This data is available and can be provided upon request.

3.2.6 GPS

All test locations were georeferenced.

3.2.7 Traffic Control

Traffic control was provided throughout the duration of the data collection by Swanston Equipment - Pavement Marking, based in Fargo, ND. The traffic control consisted of one attenuator truck stationed behind the FWD unit. The FWD also had flashing lights to alert live traffic and increase safety.

3.2.8 Untested Segments

During the field data collection 10 of the identified segments were found to have either a PCC surface, gravel surface, or be under construction. FWD testing was not performed on these sections. Table 4 contains the 10 sections for which FWD data was not collected.

Table 4 Untested Segments

Object ID	Segment	Reason
221	0945	PCC Surface
298	5212	Under Construction
50	3133	Under Construction
52	3104	Gravel Surface
40	105001	Under Construction
41	105002	Gravel Surface
275	011002	Gravel Surface
374	011004	Gravel Surface
268	2314	Gravel Surface
370	4124	Gravel Surface

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4. LAYER MODULI BACKCALCULATION

4.1 The ELMOD Computer Program

The FWD-generated load-deflection data were analyzed using a mechanistic method. A specially developed method was implemented in a software package designed to do the task in the best and most efficacious manner possible. Mechanistic *in situ* layer properties and wheel load responses are derived through a reverse, layered analysis technique, known as backcalculation.

The software package employed was the Dynatest ELMOD computer program. ELMOD is an acronym for Evaluation of Layer Moduli and Overlay Design, and the program is used to backcalculate the mechanistic layer properties of an axial-symmetric, semi-infinite pavement system (i.e. the elastic moduli or E-values of each structural layer in the pavement). Version 6.1 was used in this analysis. Figure 4 provides a screenshot of the software main form for illustration purposes.

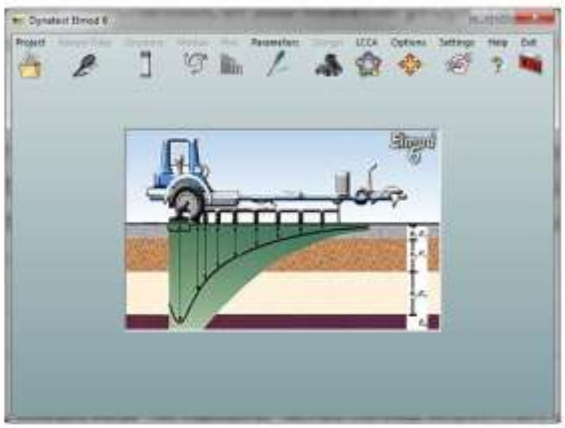

Figure 4. ELMOD 6.1 opening screen.

Backcalculation is an optimization analysis. The search for *in situ* layer elastic properties is driven by the goal of minimizing the error between calculated and measured deflection. In each iteration a set of layer elastic moduli is assigned to the pavement layers. The peak surface displacements induced by the FWD circular load are calculated using theory of elasticity for multilayer finite structures. There are many variations of multilayer linear elastic solutions, varying mainly on the choice of the numerical method in the algorithm. These solutions are based on Burmister's 1943 differential solution. ELMOD is capable of providing solutions based on Burmister's generalized solution as well as a transform Odemark-Boussinesq solution.

It should be noted that, in general, most of the measured magnitudes of deflection are due to the response of the subgrade. It is therefore very important that the subgrade modulus is accurately determined. A small error in the subgrade modulus will lead to large errors in the overlying layers. Subgrade soils, especially fine grained types, typically exhibit non-linear behavior in relation to loading. They can be either stress-hardening or strain-softening depending on gradation and degree of compaction. For this reason, it is important to consider any load-related non-linearity of the subgrade. The Odemark-Boussinesq solution implemented in ELMOD is capable of performing this type of calculation. The subgrade stiffness is calculated at various depths using the deflection data. The results are fitted into a non-linear stress-dependent stiffness model and used throughout the backcalculation process.

Due to the large influence of the subgrade on the measured deflections, it is important that the deflections are measured at a load level similar to that resulting from wheel loading, and that the deflections, especially those measured at large distances from the loading center (≥ ~3 ft), are measured very accurately. The equipment used in this project provides accuracy of 2% ± 2 microns (0.08 mils) and a typical absolute accuracy of 1% ± 1 micron (0.04 mils).

4.2 Analysis Approach

Backcalculation requires non-destructive deflection testing and the pavement layer thicknesses. In this study, Dynatest collected the deflection data and Infrasense collected the thickness data. Infrasense suggested an approach to analyze GPR data in which no pavement coring would be necessary. The verification and quality checks of the GPR results would be based on the backcalculation results. Therefore, Dynatest and Infrasense worked closely together during the analysis period and developed an inter-procedural optimization technique.

This approach consisted of a first assessment of the layer thicknesses, followed by the backcalculation of layer moduli. At the end of this first iteration, the layer moduli were verified for reasonableness and consistency within a segment. Unrealistic results were flagged and two possible actions were taken: (1) the backcalculation was repeated with different assumptions for these test points, or (2) the GPR results were reevaluated. Sometimes both actions were taken to effectively improve final results. Dynatest was responsible for all backcalculation and verification, while Infrasense was responsible for the GPR analysis.

The goal of the inter-procedural optimization technique was to improve the overall quality and accuracy of both analyzes (backcalculation and GPR), and ultimately enhancing reasonableness in the structural condition assessment. Figure 5 schematically describes the inter-procedural optimization.

Figure 5. Inter-procedural optimization flowchart.

After the first round of GPR analyzed data was provided, the backcalculation was performed in all feasible deflection basins. A total of 14,658 sets of pavement layer moduli were calculated. In this first round, the recommended deflection basin fit was the backcalculation option used in ELMOD. The moduli seeds were automatically determined by the radius of curvature method. This option was chosen to ensure all calculations were executed in the same way, without any interference from the analyst. The surface layer was always assumed to be asphaltic material (e.g., hot mix asphalt, emulsion-based surface treatments, etc.); the base layer, when present, and the subgrade were of granular material.

The presence, or not, of a base layer was determined during the analysis of the GPR data. Only a maximum of a three-layer system was considered to minimize convergence problems during the backcalculation that may arise when 4- or more-layer systems are analyzed. The maximum three-layer system assumption provided a more stable analysis, which was more effective for the overall quality of results, especially in this case of a network level type of analysis. Multiple layers of asphaltic materials were grouped into one surface layer; multiple intermediate layers of granular material (e.g., base and subbase) were grouped into one base layer. Very thin base layers (less than 3 inches) were grouped as part of the subgrade.

The behavior of asphaltic materials depends on load frequency and temperature. All tests were done at the same load pulse duration (inverse of frequency), but the temperature during the test varied continuously during the day and through the test period. The backcalculation provides the layer moduli at the temperature at the time of testing. Therefore, the layer moduli calculated at a reference temperature is required for a uniform comparison and verification of reasonableness and accuracy of results across the entire segment and the network. The reference temperature selected was 77 °F. Bells equation was used to estimate the mid-depth temperature of the asphaltic layer, based on the surface temperature measured at the time of testing and the previous day average temperature. Data from ten weather stations across North Dakota were used to determine the latter parameter. The location of these weather stations is provided in Table 5. The website http://www.wunderground.com/ (Weather Underground) was used.

Table 5. Weather Station Approximate Locations.

Location	Latitude	Longitude
Devils Lake	48.1	98.9
Bismarck	46.8	100.8
Dickinson	46.9	102.8
Fargo	46.9	96.8
Garrison	47.7	101.4
Grand Forks	47.9	97.1
Hettinger	46	102.6
Jamestown	46.9	98.7
Minot	48.2	101.3
Williston	48.3	103.7

The quality control check was defined in terms of reasonableness of backcalculated layer moduli. A range of values was defined for each layer type. The backcalculated layer modulus was defined as unreasonable and flagged for verification if its value was outside the reasonable range of values for that layer type. The entire dataset was verified after the first round of backcalculation was completed. The reasonable range of values used is provided in Table 6. The minimum and maximum values were defined based on initial observations of the dataset and the expected magnitudes for each material type. For instance, it was found that there was a significant variation in the surface layer moduli due mainly to: (1) variation in material type (e.g., dense graded asphalt concrete mixtures, surface treatments), and (2) age and level of deterioration. Therefore, a wider range of possible values was selected.

Table 6. Reasonable Range of Values for Backcalculated Layer Moduli.

Layer Type	Minimum (ksi)	Maximum (ksi)
Asphalt Concrete	30	2000
Granular Base	10	200
Granular Subgrade	1	30

In addition to verifying magnitude of backcalculated layer moduli, the layer thicknesses obtained from the GPR analysis was also checked. Unreasonably thin layers were identified. It is difficult to backcalculate moduli of thin layers (i.e., less than 3 inches). Whenever an unreasonable layer moduli value was found, the layer thickness was verified. This process

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ensured both set of unknowns (thicknesses and layer moduli) were being checked, and alternatives to proceed with the calculation were found in order to minimize unrealistic results at the end of the analysis.

After the first iteration, there were 3,018 deflection basins with unreasonable results out of 14,658 in the entire dataset. These deflection basins were reevaluated with manually input seed values and rearranged layer definitions. All layer rearrangements were sent to Infrasense for input and comments. The layer rearrangements defined as acceptable by Infrasense based on the GPR data were maintained. The others were flagged for further detailed analysis. After the second iteration, 1,977 remained with unreasonable results. This is a remarkably good achievement for mostly automated backcalculation. Figure 6 shows the percentage of all segments with reasonable results. After a purely automated process, 79% of the deflection basins yielded reasonable backcalculated layer moduli values with the structure input provided by the GPR analysis. The effort of manually performing backcalculation of the deflection data and modifying some of the pavement structure assumptions improved the quality of the data to 86% of the total collected. One additional final iteration was performed and the deflection basins which yielded acceptable results increased to close to 89%.

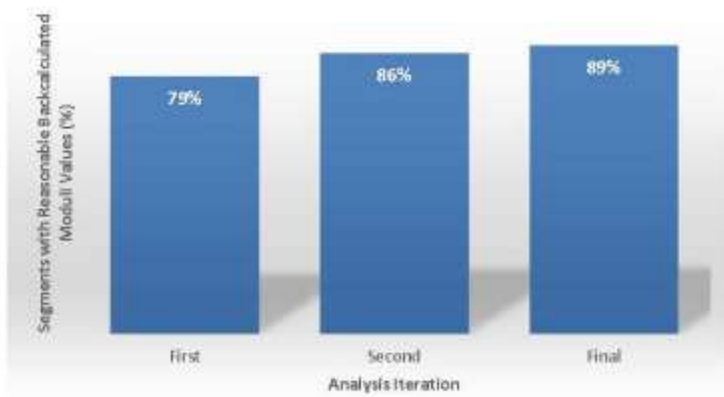

Figure 6. Deflection basins with reasonable results by analysis iteration.

Typical backcalculation analysis yields 80 to 90% reasonable and accurate results when project level data is used. The number may raise to above 90% after improvement techniques are used (e.g., seeding values, increasing range of solution domain, grouping layers, etc.) The results obtained are very satisfactory, especially for an analysis done over sample segments of a large network.

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4.3 Results

The results obtained in this analysis are expected to be used in following projects to identify infrastructure needs for counties and townships in North Dakota. Limited statistical compilation of the data is provided here; mostly for showing the reasonableness of the data. The purpose is to provide a snapshot of the backcalculated layer moduli variation across all segments. It is expected that additional data manipulation will be required to fulfill needs of other projects. The results summarized here correspond to the final iteration between GPR and FWD analysis.

The distribution of all surface layer moduli backcalculated at reference temperature (77°F) is provided in Figure 7. The average modulus was 313 ksi. The great majority of values fell between 50 and 650 ksi, which is very reasonable for hot mix asphalt layers at various deterioration phases. Only 6.4% of the data values were higher than 750 ksi, which was defined as a high boundary, and 3.9% were lower than 50 ksi. The lower boundary may represent segments with a thin asphalt layer (e.g., surface treatments); in these cases, the top layer consisted of the surface treatment plus granular material (backcalculation assumption to avoid convergences issues due to thin layer).

The results obtained in this project are very consistent with the results obtained in the previous project (dated 2013). Considering that both projects were good size samples of the entire network of township and county roads in North Dakota, the similarities in the processed data is not a surprise. It indicates the consistency and quality of data analysis and representation of field conditions.

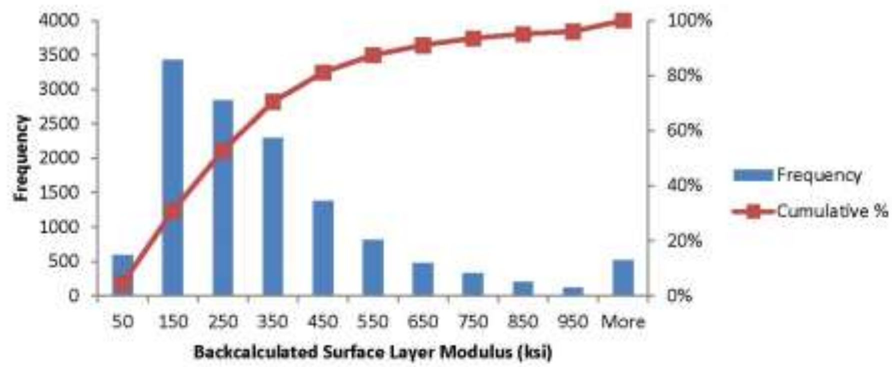

Figure 7. Backcalculated surface layer moduli distribution at reference temperature (77°F).

The distribution of backcalculated base layer moduli is shown in Figure 8. The average value for the entire project was 56.5 ksi. The majority of values fell between 15 and 90 ksi, which is

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reasonable for granular base layers. Values unexpectedly higher than 90 ksi were observed in 16.6% of the deflection basins analyzed.

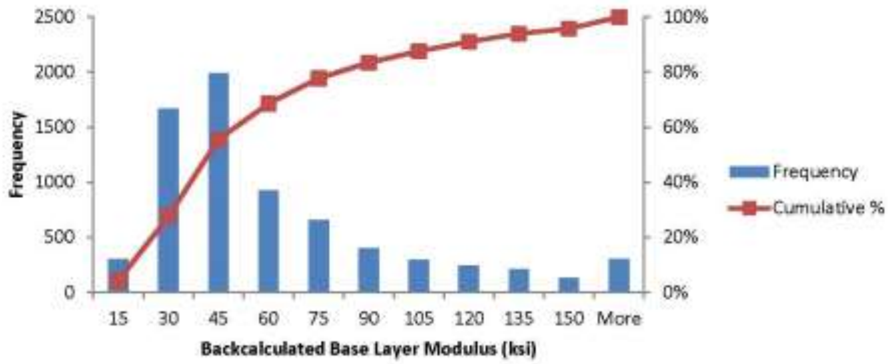

Figure 8. Backcalculated base layer moduli distribution.

The distribution of subgrade layer moduli is provided in Figure 9. Few data points (98) were found at unrealistic high values above 30 ksi (0.66%). After removal of surface- and base-related outliers, there was none left to be cut out from the subgrade outlier analysis. This is the reason why Figure 9 does not show values above 30 ksi. The average for the entire dataset was 8.7 ksi, and the great majority within 6 and 15 ksi. Similar to the result with the surface layer, the subgrade analysis provided results very similar to what was found in the first edition of this project (2013).

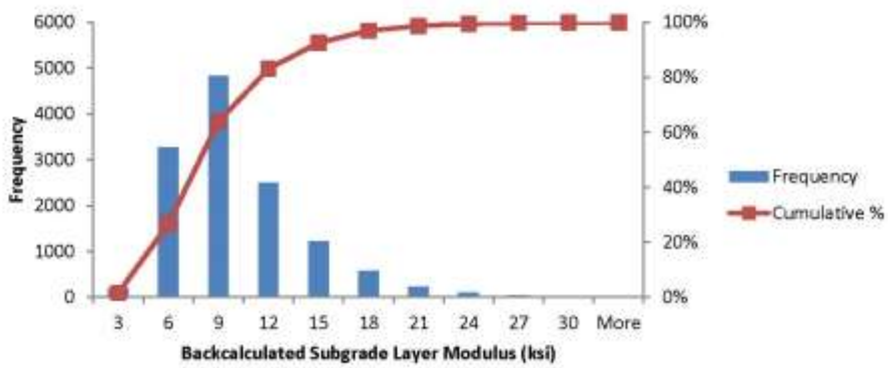

Figure 9. Backcalculated subgrade layer moduli distribution.

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4.4 Pavement Analysis Tool

The dataset analyzed contained over 14,500 deflection basins in more than 3,600 locations. A database compiling all the data was created in Microsoft Excel™ during the last edition of this project. A simple form was prepared to help visualize the raw data (deflections) and the backcalculation results. For this current edition, an updated version of this database and tool was created. Figure 10 provides a screen shot of the main table (Summary). The data can be queried by segment, drop number, and layer moduli. Plots of deflection and backcalculated layer moduli are provided, as shown in Figure 11, along with simple statistics (sample in Figure 12). The location of the segment is provided in the map on the right side of the screen.

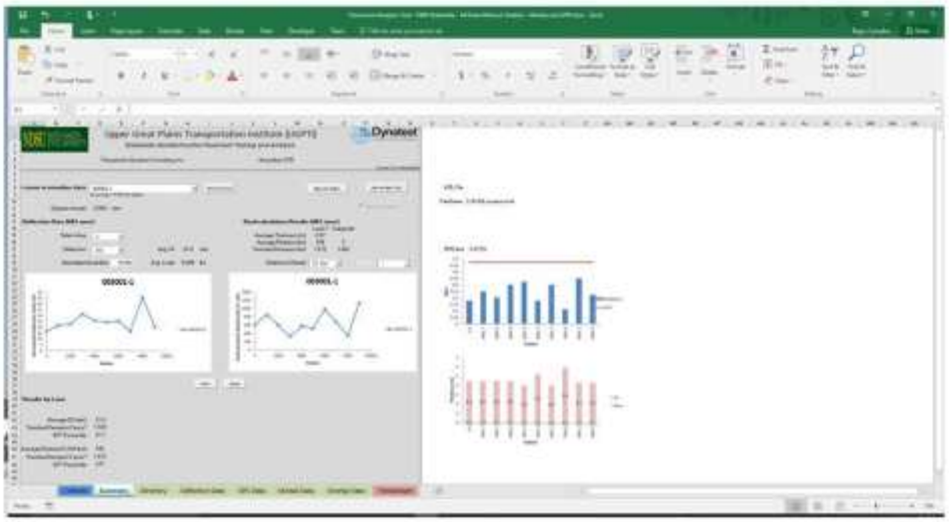

Figure 10. Overview of the summary screen of the Pavement Analysis Tool.

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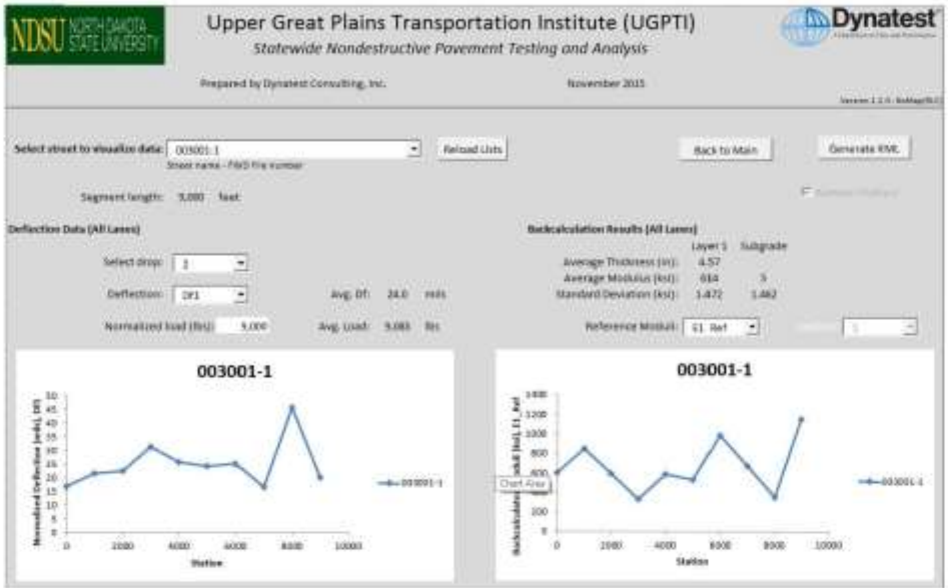

Figure 11. Example of deflection and backcalculated layer moduli plots.

Results by Lane	
Average Df1 (mils):	23.9
Standard Deviation Factor[1]:	1.329
84[th] Percentile:	31.7
Average Modulus E1_Ref (ksi):	634
Standard Deviation Factor[2]:	1.472
84[th] Percentile:	417

Figure 12. Example of statistics shown by segment.

The data was grouped in separate tables in the spreadsheet to facilitate manipulation. The tables and contents are as follows:

- Directory
  - FWD File Name
  - Date of Testing
  - From and To Station (feet)
- Deflection Data
  - FWD File Name
  - Station (feet)
  - Drop Number (see Table 2)

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- Force (lbs.)
- Stress (psi)
- Deflection Basin (mils)

- GPS Data
  - FWD File Name
  - Station (feet)
  - Latitude (degrees)
  - Longitude (degrees)
  - Height (feet)
- Moduli Data
  - FWD File Name
  - Section (not applicable)
  - Drop Number (see Table 2)
  - Thickness:
    - H1: surface layer
    - H2 base layer, when applicable
    - H3 and H4: not applicable
  - Test temperature (°F)
  - Backcalculated Moduli
    - E1_Ref: Surface layer at reference temperature (77°F)
    - E2_Ref: Base layer
    - E3_Ref and E4_Ref: not applicable
    - E-Subgrade: Subgrade layer

The Overlay table is not applicable to this project. The TempGraph table is used to create the plots shown in the summary and should not be deleted or altered.

5. DELIVERABLES

This project has the following deliverables:

3. Draft and Final Reports
   a. Electronic submission in pdf format
   b. Hard copies may be provided upon request
4. Electronic files (with Final Report Delivery):
   a. FWD data files (mdb files)
   b. KML files with geo-coordinates of test locations
   c. ELMOD files (mde files)
   d. Pavement Analysis Tool (Excel file)

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6. CONCLUSIONS

This project consisted of collecting non-destructive pavement deflection data on approximately 760 miles of county and township roads across North Dakota, covering 47 counties. The list of segments was provided by UGPTI. The deflection testing was performed using a Dynatest Falling Weight Deflectometer (FWD). In addition to deflection testing, Ground Penetrating Radar (GPR) was collected by Infrasense, Inc. The two tests were combined to evaluate the structural condition of the layers in each pavement section. The *in situ* elastic layer moduli were determined through backcalculation. This report provided the results of the FWD data collection and the backcalculation of layer moduli.

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The software package employed was the Dynatest ELMOD computer program. ELMOD is used to backcalculate the mechanistic layer properties of an axial-symmetric, semi-infinite pavement system (i.e. the elastic moduli or E-values of each structural layer in the pavement).

The combined FWD/GPR approach used in this project eliminated the need for pavement coring for GPR calibration. Instead, Dynatest and Infrasense worked closely together during the analysis period and developed an inter-procedural optimization technique that avoided the need of coring. This approach consisted of an iterative process in which backcalculated layer moduli were verified for reasonableness and consistency within a segment. Unrealistic results were flagged and two possible actions were taken: (1) the backcalculation was repeated with different assumptions, and/or (2) the GPR results were reevaluated. This process was repeated a couple of times until a satisfactory number of deflection basins have produced reasonable backcalculated layer moduli.

The goal of the inter-procedural optimization technique was to improve the overall quality and accuracy of both analyzes (backcalculation and GPR), and ultimately enhancing reasonableness in the structural condition assessment. As a result, the final number of deflection basis with reasonable results was 89% of the entire dataset at the second iteration.

The great majority of surface layer backcalculated moduli values were between 50 and 650 ksi, which is very reasonable for hot mix asphalt layers at various deterioration phases. For base layer backcalculated moduli, the majority of values were between 15 and 90 ksi, which is also very reasonable for granular base layers. And finally the subgrade layer backcalculated moduli varied between 6 and 15 ksi.

Since the amount of data analyzed was very large, a practical database compiling all the data was created in Microsoft Excel™ during the execution of the first edition of this project. A simple form was prepared help visualize the raw data (deflections) and the backcalculation results. This tool, called Pavement Analysis Tool, was updated and will be provided as part of the project deliverables along with the Final Report.

This project is part of a broader study in which traffic models and infrastructure needs will be assessed for county and township roads across the state of North Dakota. It is possible that a few segments may require refinement in the backcalculation during the next phases of this study. As additional information about each segment becomes available, the backcalculation process may be refined, especially for the deflection basins in which less desirable results were obtained.

APPENDIX A FWD/HWD DESCRIPTION

A-1

Dynatest FWD/HWD Test Systems

Dynatest, the original commercial developer of the Falling Weight Deflectometer (FWD) technology, is the world's largest supplier of FWD equipment. This highly accurate, well supported, reliable and continuously refined Dynatest product line is a proven load/deflection measurement solution for engineers worldwide.

The Dynatest FWD technology additionally provides a measurement foundation for the proprietary Dynatest "analytical-empirical" pavement engineering methodology, a system of advanced automated pavement measurement, analysis and management engineering services and products available only through Dynatest.

Why a Falling Weight Deflectometer (FWD)?

The **Dynatest Model 8000 FWD** makes it possible to treat pavement structures in the same manner as other civil engineering structures by using mechanistically based design methods.

Selecting the type of rehabilitation to be implemented on a given pavement is of considerable economic significance. To reach that decision without an adequate knowledge of the structural condition of the pavement may have very costly consequences.

The use of a Dynatest FWD enables the engineer to determine a deflection basin caused by a controlled load with accuracy and resolution superior to other existing test methods. The FWD produces a dynamic impulse load that simulates a moving wheel load, rather than a static, semi-static or vibratory load. These developments allow the use of mechanistic approaches to analyse FWD data.

FALLING WEIGHT DEFLECTOMETER

Heavy Weight Deflectometer (HWD)

Dynatest was also the first to introduce a heavier loading FWD, the Dynatest Model 8081 HWD. With an expanded loading range, simulating heavy aircraft such as the Boeing 747 (one wheel), the HWD can properly introduce anticipated load/deflection measurements on even heavy pavements such as airfields and very thick highway pavements. The wider loading range also provides the consultant with a load/ deflection instrument appropriate for both roads and airfields as required.

HEAVY WEIGHT DEFLECTOMETER

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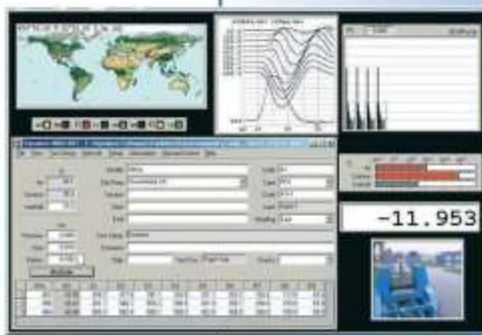
Dynatest FWD/HWD Test Systems

FWD Data Reduction

FWD/HWD generated data, combined with layer thickness, can be confidently used to obtain the "in-situ" resilient E-moduli of a pavement structure. This information can in turn be used in a structural analysis to determine the bearing capacity, estimate expected life, and calculate an overlay requirement, if applicable (over a desired design life).



Software Products for Structural Analysis and Design

For routine analysis purposes,
Dynatest has developed a software system, ELMOD 6, for both flexible and rigid pavements.

This software application allows extremely rapid data reduction and analysis of FWD/HWD measurements, calculating the layer E-moduli for a typical drop sequence in one second or less. Seasonally adjusted E-moduli, residual life, and required overlay (if applicable) are also calculated within seconds.

For analysis of airfield pavements, **Dynatest** offers the PCN module, which calculates PCN-values in accordance with the ACN/PCN method, as described in the ICAO design manuals.

FWDWin for Windows™

Support for multiple languages.

Data Files:

- Data is stored in Access(tm) (.mdb) databases for ease of processing.

The program can simultaneously generate various formats:

- .fwd, *.f20, *.f25, *.PDDX Pavement Deflection Data eXchange (PDDX by AASHTO), *.XML eXtensible Markup Language (XML by W3C)
- 15 Active Sensor Capability (hardware required)
- Surface modulus plots can be graphed real time along road sections under test
- Real Time Backcalculation
- Network Database

Advantages

- A non-destructive test device
- One man operational
- Accurate and fast (up to 60 test points/hr)
- Wide loading range
  FWD: (7-120 kN) or
  (1,500-27,000 lbf)
  HWD: (30-320 kN) or
  (6,500-71,800 lbf)
  Allowing for simulation of new large Aircraft such as A-380 and B-777
- Designed for multi-purpose pavement applications, ranging from unpaved roads to airfields
- Excellent repeatability
- Ideal for mechanistic/analytical design approaches

Requirements

Windows® XP
Windows® 7

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13. Appendix C: Paved Road Conditions, by County

County	Condition	Miles	Percent
Adams	Very Good	7.4	70%
Adams	Poor	3.1	30%
Barnes	Very Good	83.7	38%
Barnes	Good	50.6	23%
Barnes	Fair	85.3	39%
Benson	Very Good	13.6	22%
Benson	Good	33.1	54%
Benson	Fair	15.2	25%
Billings	Very Good	7	44%
Billings	Good	8.9	56%
Bottineau	Very Good	30	15%
Bottineau	Good	147.2	74%
Bottineau	Fair	20.5	10%
Bowman	Very Good	43.2	30%
Bowman	Good	30.3	21%
Bowman	Fair	40.6	28%
Bowman	Poor	30.4	21%
Burke	Very Good	29.6	62%
Burke	Good	18	38%
Burleigh	Very Good	0.7	0%
Burleigh	Good	258.9	92%
Burleigh	Fair	21.6	8%
Cass	Very Good	74.9	24%
Cass	Good	196.4	62%
Cass	Fair	46.3	15%
Cavalier	Very Good	13.9	22%
Cavalier	Good	40.6	64%
Cavalier	Fair	9.1	14%
Dickey	Very Good	8.5	11%
Dickey	Good	11.1	14%
Dickey	Fair	56.5	73%
Dickey	Poor	1.3	2%
Divide	Very Good	17.1	34%
Divide	Good	31.3	63%
Divide	Fair	1.4	3%
Dunn	Very Good	29.3	69%
Dunn	Good	13.1	31%
Eddy	Very Good	18.3	30%
Eddy	Good	27.8	46%

County	Condition	Miles	Percent
Eddy	Good	27.8	46%
Eddy	Fair	6.2	10%
Eddy	Poor	8.5	14%
Emmons	Good	12.4	100%
Fort Berthold	Good	3	7%
Fort Berthold	Fair	38.1	83%
Fort Berthold	Poor	4.9	11%
Foster	Very Good	11.5	12%
Foster	Good	47.3	51%
Foster	Fair	33.8	36%
Golden Valley	Very Good	6.9	30%
Golden Valley	Good	4.1	18%
Golden Valley	Fair	12	52%
Grand Forks	Very Good	111.3	41%
Grand Forks	Good	96.9	35%
Grand Forks	Fair	64.9	24%
Griggs	Very Good	8.4	22%
Griggs	Good	24.3	63%
Griggs	Fair	5.9	15%
Hettinger	Good	15.4	91%
Hettinger	Fair	1.5	9%
Kidder	Very Good	11	22%
Kidder	Good	28.1	57%
Kidder	Fair	5.5	11%
Kidder	Poor	4.6	9%
LaMoure	Very Good	15.5	11%
LaMoure	Good	61.7	42%
LaMoure	Fair	70	48%
Logan	Good	8.4	100%
McHenry	Very Good	16.4	18%
McHenry	Good	61	67%
McHenry	Fair	13.5	15%
McIntosh	Good	57.4	68%
McIntosh	Fair	15.5	18%
McIntosh	Poor	11.2	13%
McIntosh	Very Poor	0.5	1%
McKenzie	Very Good	67.2	44%
McKenzie	Good	86.2	56%
McLean	Very Good	5.3	4%
McLean	Good	93.6	69%

County	Condition	Miles	Percent
McLean	Fair	36.5	27%
Mercer	Very Good	7	7%
Mercer	Good	76.7	79%
Mercer	Fair	11.9	12%
Mercer	Poor	1.3	1%
Morton	Very Good	12.5	15%
Morton	Good	62.3	75%
Morton	Fair	7.8	9%
Mountrail	Very Good	116.6	70%
Mountrail	Good	31.5	19%
Mountrail	Poor	17.8	11%
Nelson	Very Good	25.9	32%
Nelson	Good	40.6	50%
Nelson	Fair	10	12%
Nelson	Poor	5.2	6%
Oliver	Good	8.5	36%
Oliver	Fair	15.5	64%
Pembina	Very Good	54.3	30%
Pembina	Good	74.3	40%
Pembina	Fair	54.9	30%
Pierce	Very Good	3	50%
Pierce	Good	3	50%
Ramsey	Very Good	11.3	10%
Ramsey	Good	88	78%
Ramsey	Fair	12.9	12%
Ransom	Very Good	8.8	16%
Ransom	Good	32.4	58%
Ransom	Fair	14.9	27%
Renville	Very Good	20.9	28%
Renville	Good	44.2	59%
Renville	Fair	10.1	13%
Richland	Very Good	21.3	9%
Richland	Good	140	61%
Richland	Fair	61.7	27%
Richland	Poor	7.8	3%
Rolette	Very Good	6.9	15%
Rolette	Good	28.7	63%
Rolette	Fair	9.8	22%
Sargent	Very Good	13.6	17%
Sargent	Good	49.2	60%
Sargent	Fair	18.8	23%

County	Condition	Miles	Percent
Sheridan	Very Good	4.1	20%
Sheridan	Good	6	29%
Sheridan	Fair	10.2	50%
Sheridan	Poor	0.1	1%
Spirit Lake	Good	16.8	47%
Spirit Lake	Fair	18.7	53%
Standing Rock	Good	9.9	31%
Standing Rock	Fair	21.9	69%
Stark	Very Good	54.8	57%
Stark	Good	41.4	43%
Steele	Very Good	22.9	32%
Steele	Good	25.9	36%
Steele	Fair	23.6	33%
Stutsman	Very Good	52.9	23%
Stutsman	Good	116.8	52%
Stutsman	Fair	37.3	17%
Stutsman	Poor	19.3	9%
Traill	Very Good	47	32%
Traill	Good	56.3	38%
Traill	Fair	40	27%
Traill	Poor	5.5	4%
Turtle Mountain	Good	12	17%
Turtle Mountain	Fair	32.6	46%
Turtle Mountain	Poor	26.6	37%
Walsh	Very Good	14.7	9%
Walsh	Good	91.7	54%
Walsh	Fair	64.3	38%
Ward	Very Good	85.8	27%
Ward	Good	205.7	65%
Ward	Fair	24.6	8%
Ward	Poor	0.7	0%
Wells	Very Good	8	7%
Wells	Good	67.1	60%
Wells	Fair	10.5	9%
Wells	Poor	26	23%
Williams	Very Good	78.4	31%
Williams	Good	166.5	66%
Williams	Fair	6.2	2%

14. Appendix D: Detailed Results by County and Funding Period

Table D.1: County and Township Unpaved Road Investment Needs, by County and Period (Millions of 2016 Dollars) - 30 Rig Scenario							
County	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2024-2026**	**2025-2036**	**2017-2036**
Adams	$5.81	$5.83	$5.83	$5.83	$5.83	$29.84	$58.16
Barnes	$13.20	$13.21	$13.23	$13.24	$13.24	$66.28	$132.13
Benson	$7.57	$7.58	$7.58	$7.58	$7.59	$37.95	$75.71
Billings	$8.53	$8.18	$8.57	$8.76	$8.27	$41.36	$83.63
Bottineau	$10.60	$10.61	$10.61	$10.63	$10.63	$53.13	$106.03
Bowman	$8.41	$8.80	$8.59	$8.54	$8.46	$42.32	$84.34
Burke	$14.12	$14.11	$14.11	$14.11	$14.11	$70.57	$140.35
Burleigh	$15.20	$15.20	$15.20	$15.20	$15.20	$76.02	$151.08
Cass	$28.54	$28.64	$28.89	$29.02	$29.31	$148.01	$286.93
Cavalier	$9.32	$9.36	$9.42	$9.44	$9.44	$47.19	$93.25
Dickey	$7.24	$7.25	$7.26	$7.26	$7.26	$36.30	$72.45
Divide	$17.32	$17.34	$17.32	$17.33	$17.31	$86.56	$173.18
Dunn	$30.13	$26.10	$26.87	$26.19	$25.33	$126.59	$263.12
Eddy	$3.01	$3.02	$3.02	$3.02	$3.02	$15.09	$30.06
Emmons	$7.66	$7.66	$7.66	$7.67	$7.67	$38.35	$76.59
Foster	$3.33	$3.33	$3.33	$3.33	$3.33	$16.64	$33.26
Golden Valley	$8.46	$8.46	$8.49	$8.49	$8.49	$42.44	$84.65
Grand Forks	$20.40	$20.59	$20.59	$20.59	$20.63	$104.13	$203.80
Grant	$12.45	$12.45	$12.45	$12.45	$12.45	$62.24	$124.48
Griggs	$3.40	$3.40	$3.40	$3.41	$3.47	$17.45	$34.10
Hettinger	$6.64	$6.64	$6.64	$6.65	$6.69	$33.44	$66.46
Kidder	$5.32	$5.32	$5.32	$5.32	$5.32	$26.60	$55.03
LaMoure	$7.67	$7.67	$7.67	$7.67	$7.67	$38.33	$76.67
Logan	$4.89	$4.89	$4.89	$4.89	$4.89	$24.46	$48.92
McHenry	$20.43	$20.45	$20.46	$20.46	$20.50	$102.52	$204.35
McIntosh	$4.73	$4.73	$4.73	$4.73	$4.73	$23.63	$47.26
McKenzie	$38.97	$33.48	$43.47	$40.53	$27.63	$132.01	$313.24
McLean	$15.48	$15.48	$15.48	$15.50	$15.51	$77.81	$154.87
Mercer	$9.07	$9.07	$9.07	$9.04	$9.04	$45.21	$90.56
Morton	$12.53	$12.53	$12.53	$12.53	$12.54	$62.68	$125.31
Mountrail	$22.41	$20.52	$20.82	$20.41	$19.95	$99.93	$203.45
Nelson	$5.76	$5.76	$5.76	$5.78	$5.80	$29.04	$57.65
Oliver	$3.53	$3.53	$3.53	$3.53	$3.45	$17.24	$34.83

Pembina	$8.51	$8.53	$8.53	$8.53	$8.55	$42.80	$85.17
Pierce	$10.81	$10.81	$10.81	$10.81	$10.81	$54.10	$108.10
Ramsey	$6.22	$6.24	$6.26	$6.26	$6.26	$31.33	$62.24
Ransom	$5.64	$5.66	$5.66	$5.66	$5.67	$28.42	$56.43
Renville	$5.95	$5.95	$5.95	$5.95	$5.95	$29.76	$59.52
Richland	$16.79	$16.79	$16.80	$16.85	$16.86	$84.85	$167.84
Rolette	$5.92	$5.92	$5.93	$5.93	$5.93	$29.63	$59.23
Sargent	$4.45	$4.45	$4.46	$4.46	$4.46	$22.60	$44.51
Sheridan	$5.37	$5.37	$5.37	$5.37	$5.37	$26.87	$53.74
Sioux	$5.77	$5.77	$5.82	$5.82	$5.82	$29.25	$57.88
Slope	$6.37	$6.41	$6.41	$6.37	$6.37	$31.83	$63.75
Stark	$18.06	$18.10	$18.09	$18.01	$18.03	$90.49	$181.90
Steele	$5.11	$5.12	$5.13	$5.13	$5.13	$25.65	$51.18
Stutsman	$11.20	$11.20	$11.22	$11.23	$11.26	$56.32	$112.14
Towner	$7.22	$7.22	$7.22	$7.22	$7.22	$36.11	$72.23
Traill	$7.16	$7.18	$7.27	$7.29	$7.31	$36.74	$71.90
Walsh	$18.93	$18.98	$19.33	$19.36	$19.37	$97.48	$190.62
Ward	$23.28	$23.73	$23.79	$23.91	$23.92	$119.59	$233.54
Wells	$8.39	$8.39	$8.39	$8.40	$8.40	$42.00	$83.90
Williams	$26.80	$26.99	$26.41	$26.16	$25.57	$127.03	$258.01
Total	$600.05	$590.00	$601.62	$597.85	$583.02	$2,914.22	$5,859.68

Table D.2: County and Township Unpaved Road Investment Needs, by County and Period (Millions of 2016 Dollars) - 60 Rig Scenario

County	2017-2018	2019-2020	2021-2022	2023-2024	2024-2026	2025-2036	2017-2036
Adams	$5.81	$5.83	$5.83	$5.83	$5.83	$29.84	$58.16
Barnes	$13.20	$13.21	$13.23	$13.24	$13.24	$66.28	$132.13
Benson	$7.57	$7.58	$7.58	$7.58	$7.59	$37.95	$75.71
Billings	$10.13	$8.66	$12.08	$10.81	$8.30	$40.55	$90.45
Bottineau	$10.71	$10.60	$10.60	$10.64	$10.63	$53.13	$106.24
Bowman	$8.68	$8.66	$8.77	$8.70	$8.34	$41.70	$84.69
Burke	$14.82	$14.09	$14.27	$14.17	$14.11	$70.57	$141.25
Burleigh	$15.20	$15.20	$15.20	$15.20	$15.20	$76.02	$151.08
Cass	$28.54	$28.64	$28.89	$29.02	$29.31	$148.01	$286.93
Cavalier	$9.32	$9.36	$9.42	$9.44	$9.44	$47.19	$93.25
Dickey	$7.24	$7.25	$7.26	$7.26	$7.26	$36.30	$72.45
Divide	$18.24	$17.99	$18.30	$18.39	$18.09	$90.35	$180.62
Dunn	$38.68	$31.70	$42.33	$45.00	$25.30	$125.31	$316.86

Eddy	$3.01	$3.02	$3.02	$3.02	$3.02	$15.09	$30.06
Emmons	$7.66	$7.66	$7.66	$7.67	$7.67	$38.35	$76.59
Foster	$3.33	$3.33	$3.33	$3.33	$3.33	$16.64	$33.26
Golden Valley	$8.76	$9.96	$9.21	$9.00	$8.44	$42.18	$86.98
Grand Forks	$20.40	$20.59	$20.59	$20.59	$20.63	$104.13	$203.80
Grant	$12.45	$12.45	$12.45	$12.45	$12.45	$62.24	$124.48
Griggs	$3.40	$3.40	$3.40	$3.41	$3.47	$17.45	$34.10
Hettinger	$6.64	$6.64	$6.64	$6.65	$6.69	$33.44	$66.46
Kidder	$5.32	$5.32	$5.32	$5.32	$5.32	$26.60	$55.03
LaMoure	$7.67	$7.67	$7.67	$7.67	$7.67	$38.33	$76.67
Logan	$4.89	$4.89	$4.89	$4.89	$4.89	$24.46	$48.92
McHenry	$20.43	$20.45	$20.46	$20.46	$20.50	$102.52	$204.35
McIntosh	$4.73	$4.73	$4.73	$4.73	$4.73	$23.63	$47.26
McKenzie	$57.18	$39.48	$59.04	$59.24	$44.91	$163.89	$404.76
McLean	$15.49	$15.48	$15.49	$15.51	$15.51	$77.82	$154.91
Mercer	$9.12	$9.12	$9.12	$9.05	$9.05	$45.27	$90.70
Morton	$12.53	$12.53	$12.53	$12.53	$12.54	$62.68	$125.31
Mountrail	$28.42	$21.69	$32.56	$32.33	$20.70	$100.81	$234.88
Nelson	$5.76	$5.76	$5.76	$5.78	$5.80	$29.04	$57.65
Oliver	$3.54	$3.50	$3.50	$3.50	$3.50	$17.07	$34.61
Pembina	$8.51	$8.53	$8.53	$8.53	$8.55	$42.80	$85.17
Pierce	$10.81	$10.81	$10.81	$10.81	$10.81	$54.10	$108.10
Ramsey	$6.22	$6.24	$6.26	$6.26	$6.26	$31.33	$62.24
Ransom	$5.64	$5.66	$5.66	$5.66	$5.67	$28.42	$56.43
Renville	$5.95	$5.95	$5.95	$5.95	$5.95	$29.76	$59.53
Richland	$16.79	$16.79	$16.80	$16.85	$16.86	$84.85	$167.84
Rolette	$5.92	$5.92	$5.93	$5.93	$5.93	$29.63	$59.23
Sargent	$4.45	$4.45	$4.46	$4.46	$4.46	$22.60	$44.51
Sheridan	$5.38	$5.38	$5.38	$5.38	$5.38	$26.87	$53.78
Sioux	$5.77	$5.77	$5.82	$5.82	$5.82	$29.25	$57.88
Slope	$6.44	$6.44	$6.44	$6.30	$6.23	$31.16	$63.02
Stark	$18.41	$18.33	$18.75	$18.30	$17.96	$90.11	$184.35
Steele	$5.11	$5.12	$5.13	$5.13	$5.13	$25.65	$51.18
Stutsman	$11.20	$11.20	$11.22	$11.23	$11.26	$56.32	$112.14
Towner	$7.22	$7.22	$7.22	$7.22	$7.22	$36.11	$72.23
Traill	$7.16	$7.18	$7.27	$7.29	$7.31	$36.74	$71.90
Walsh	$18.93	$18.98	$19.33	$19.36	$19.37	$97.48	$190.62
Ward	$23.31	$23.72	$24.00	$24.11	$23.90	$119.59	$233.91

Wells	$8.39	$8.39	$8.39	$8.40	$8.40	$42.00	$83.90
Williams	$34.17	$28.47	$35.34	$35.46	$26.69	$135.37	$292.21
Total	$644.65	$606.97	$659.80	$660.86	$602.62	$2,954.98	$6,090.71

Table D.3: County and Township Unpaved Road Investment Needs, by County and Period (Millions of 2016 Dollars) - 90 Rig Scenario

County	2017-2018	2019-2020	2021-2022	2023-2024	2024-2026	2025-2036	2017-2036
Adams	$5.81	$5.83	$5.83	$5.83	$5.83	$29.84	$58.16
Barnes	$13.20	$13.21	$13.23	$13.24	$13.24	$66.28	$132.13
Benson	$7.57	$7.58	$7.58	$7.58	$7.59	$37.95	$75.71
Billings	$11.66	$8.68	$11.68	$10.23	$8.36	$40.46	$90.10
Bottineau	$10.75	$10.77	$10.75	$10.75	$10.63	$53.17	$106.80
Bowman	$8.74	$9.56	$8.88	$8.80	$8.30	$41.05	$85.82
Burke	$14.90	$14.62	$14.24	$14.21	$14.12	$70.59	$141.86
Burleigh	$15.20	$15.20	$15.20	$15.20	$15.20	$76.02	$151.08
Cass	$28.54	$28.64	$28.89	$29.02	$29.31	$148.01	$286.93
Cavalier	$9.32	$9.36	$9.42	$9.44	$9.44	$47.19	$93.25
Dickey	$7.24	$7.25	$7.26	$7.26	$7.26	$36.30	$72.45
Divide	$19.22	$18.90	$19.20	$19.20	$18.84	$94.21	$189.72
Dunn	$45.40	$31.11	$43.44	$41.17	$26.93	$127.24	$326.17
Eddy	$3.01	$3.02	$3.02	$3.02	$3.02	$15.09	$30.06
Emmons	$7.66	$7.66	$7.66	$7.67	$7.67	$38.35	$76.59
Foster	$3.33	$3.33	$3.33	$3.33	$3.33	$16.64	$33.26
Golden Valley	$9.33	$10.09	$9.80	$9.08	$8.95	$44.85	$89.85
Grand Forks	$20.40	$20.59	$20.59	$20.59	$20.63	$104.13	$203.80
Grant	$12.45	$12.45	$12.45	$12.45	$12.45	$62.24	$124.48
Griggs	$3.40	$3.40	$3.40	$3.41	$3.47	$17.45	$34.10
Hettinger	$6.64	$6.64	$6.64	$6.65	$6.69	$33.44	$66.46
Kidder	$5.32	$5.32	$5.32	$5.32	$5.32	$26.60	$55.03
LaMoure	$7.67	$7.67	$7.67	$7.67	$7.67	$38.33	$76.67
Logan	$4.89	$4.89	$4.89	$4.89	$4.89	$24.46	$48.92
McHenry	$20.43	$20.45	$20.46	$20.46	$20.50	$102.53	$204.35
McIntosh	$4.73	$4.73	$4.73	$4.73	$4.73	$23.63	$47.26
McKenzie	$63.36	$52.18	$63.62	$60.59	$56.02	$256.10	$463.89
McLean	$15.49	$15.49	$15.50	$15.51	$15.51	$77.82	$154.92
Mercer	$9.12	$9.12	$9.12	$9.05	$9.05	$45.27	$90.72
Morton	$12.53	$12.53	$12.53	$12.53	$12.54	$62.68	$125.31
Mountrail	$33.15	$22.63	$31.74	$31.24	$20.68	$104.14	$240.81

Nelson	$5.76	$5.76	$5.76	$5.78	$5.80	$29.04	$57.65
Oliver	$3.54	$3.50	$3.54	$3.50	$3.50	$17.07	$34.66
Pembina	$8.51	$8.53	$8.53	$8.53	$8.55	$42.80	$85.17
Pierce	$10.81	$10.81	$10.81	$10.81	$10.81	$54.10	$108.10
Ramsey	$6.22	$6.24	$6.26	$6.26	$6.26	$31.33	$62.24
Ransom	$5.64	$5.66	$5.66	$5.66	$5.67	$28.42	$56.43
Renville	$5.96	$5.95	$5.95	$5.95	$5.95	$29.76	$59.53
Richland	$16.79	$16.79	$16.80	$16.85	$16.86	$84.85	$167.84
Rolette	$5.92	$5.92	$5.93	$5.93	$5.93	$29.63	$59.23
Sargent	$4.45	$4.45	$4.46	$4.46	$4.46	$22.60	$44.51
Sheridan	$5.38	$5.38	$5.38	$5.38	$5.38	$26.87	$53.79
Sioux	$5.77	$5.77	$5.82	$5.82	$5.82	$29.25	$57.88
Slope	$6.44	$6.44	$6.75	$6.44	$6.39	$31.96	$64.30
Stark	$19.08	$18.97	$18.75	$18.14	$17.94	$89.93	$185.57
Steele	$5.11	$5.12	$5.13	$5.13	$5.13	$25.65	$51.18
Stutsman	$11.20	$11.20	$11.22	$11.23	$11.26	$56.32	$112.14
Towner	$7.22	$7.22	$7.22	$7.22	$7.22	$36.11	$72.23
Traill	$7.16	$7.18	$7.27	$7.29	$7.31	$36.74	$71.90
Walsh	$18.93	$18.98	$19.33	$19.36	$19.37	$97.48	$190.62
Ward	$23.36	$23.69	$23.86	$23.97	$23.88	$119.40	$233.72
Wells	$8.40	$8.40	$8.40	$8.40	$8.40	$42.00	$83.95
Williams	$38.31	$32.06	$37.20	$36.54	$29.91	$143.66	$316.62
Total	$670.42	$626.93	$668.08	$658.79	$619.96	$3,067.05	$6,205.88

Table D.4: County and Township Paved Road Investment Needs, by County and Period (Millions of 2016 Dollars) – 30 Rig Scenario

County	Miles Resurfaced	Miles Widened	Miles Reclaimed/ Reconstructed	Total Miles Improved	Total Cost (Million$)	Annual Cost per Mile
Adams	7.4	0	3.1	10.6	$6.88	$32,542
Barnes	219.6	0	0	219.6	$73.98	$16,842
Benson	61.9	0	0	61.9	$20.72	$16,742
Billings	15.9	0	0	15.9	$5.21	$16,391
Bottineau	188.2	9.4	0	197.7	$76.75	$19,416
Bowman	142.5	0	0	144.5	$55.12	$19,069
Burke	46.2	1.4	0	47.7	$16.69	$17,507
Burleigh	257.5	10.9	12.7	281.2	$107.43	$19,105
Cass	272.8	14.4	1	317.7	$123.99	$19,516
Cavalier	63.4	0	0	63.6	$21.48	$16,893

Dickey	77.3	0	0	77.3	$28.53	$18,448
Divide	44.1	0	5.7	49.8	$22.87	$22,964
Dunn	42.4	0	0	42.4	$16.49	$19,451
Eddy	53.8	0	0	60.8	$23.66	$19,459
Emmons	12.4	0	0	12.4	$4.24	$17,056
Fort Berthold	34.2	0	11.8	46.1	$29.68	$32,210
Foster	87	0	5.6	92.6	$45.61	$24,629
Golden Valley	23.1	0	0	23.1	$7.69	$16,666
Grand Forks	264.9	4.2	3.9	273.1	$96.64	$17,695
Griggs	38.5	0	0	38.5	$13.44	$17,434
Hettinger	16.9	0	0	16.9	$5.53	$16,391
Kidder	49	0.3	0	49.2	$16.95	$17,214
LaMoure	142.1	0	5.2	147.3	$57.72	$19,598
Logan	8.4	0	0	8.4	$2.56	$15,283
McHenry	76.7	14.2	0	90.9	$38.80	$21,339
McIntosh	78.8	5	0	84.6	$38.20	$22,578
McKenzie	153.3	0	0	153.3	$54.75	$17,854
McLean	107.4	0.6	27.4	135.4	$81.19	$29,973
Mercer	85.3	11.6	0	96.8	$41.95	$21,662
Morton	82.6	0	0	82.6	$27.78	$16,825
Mountrail	148.1	0	0	165.9	$63.73	$19,207
Nelson	76.5	0	0	81.7	$29.69	$18,174
Oliver	24	0	0	24	$8.24	$17,157
Pembina	182.5	1	0	183.5	$63.92	$17,418
Pierce	6	0	0	6	$2.46	$20,601
Ramsey	112.3	0	0	112.3	$38.94	$17,335
Ransom	56.1	0	0	56.1	$18.73	$16,677
Renville	69.1	0	6.1	75.2	$31.83	$21,169
Richland	180	26.6	13.6	230.8	$108.65	$23,535
Rolette	45.3	0	0	45.3	$16.14	$17,820
Sargent	75.5	0	6	81.6	$33.62	$20,606
Sheridan	20.5	0	0	20.5	$7.39	$18,076
Spirit Lake	35.5	0	0	35.5	$12.10	$17,036
Standing Rock	31.7	0	0	31.7	$11.45	$18,041
Stark	84.1	2	3.7	96.3	$45.60	$23,685
Steele	65.5	7	0	72.5	$25.50	$17,594
Stutsman	194.3	21	0	226.3	$87.43	$19,314
Traill	140.9	0	7.7	148.8	$58.86	$19,777
Turtle Mountain	19.8	0	0	71.2	$35.55	$24,981

Walsh	160.5	0	6	170.7	$71.02	$20,798
Ward	308.4	7.3	0.3	316.9	$120.34	$18,989
Wells	105.6	0	6	111.7	$47.74	$21,379
Williams	223.6	14.9	8.6	251.1	$101.54	$20,221
Total	5,119.4	151.8	134.4	5,557.5	$2,202.97	$19,780

Table D.5: County and Township Paved Road Investment Needs, by County and Period (Millions of 2016 Dollars) – 60 Rig Scenario

County	Miles Resurfaced	Miles Widened	Miles Reclaimed/ Reconstructed	Total Miles Improved	Total Cost (Million$)	Annual Cost per Mile
Adams	7.4	0	3.1	10.6	$6.88	$32,542
Barnes	219.6	0	0	219.6	$73.98	$16,842
Benson	61.9	0	0	61.9	$20.72	$16,742
Billings	15.9	0	0	15.9	$5.21	$16,404
Bottineau	175.3	22.3	0	197.7	$78.30	$19,808
Bowman	142.5	0	0	144.5	$55.15	$19,079
Burke	46.2	1.4	0	47.7	$16.69	$17,507
Burleigh	257.5	10.9	12.7	281.2	$107.43	$19,105
Cass	272.8	14.4	1	317.7	$123.99	$19,516
Cavalier	63.4	0	0	63.6	$21.48	$16,893
Dickey	77.3	0	0	77.3	$28.53	$18,448
Divide	44.1	0	5.7	49.8	$23.31	$23,410
Dunn	42.4	0	0	42.4	$14.96	$17,651
Eddy	53.8	0	0	60.8	$23.66	$19,459
Emmons	12.4	0	0	12.4	$4.24	$17,056
Fort Berthold	34.2	0	11.8	46.1	$31.21	$33,870
Foster	87	0	5.6	92.6	$45.61	$24,629
Golden Valley	23.1	0	0	23.1	$7.76	$16,803
Grand Forks	264.9	4.2	3.9	273.1	$96.64	$17,695
Griggs	38.5	0	0	38.5	$13.44	$17,434
Hettinger	16.9	0	0	16.9	$5.53	$16,391
Kidder	49	0.3	0	49.2	$16.95	$17,214
LaMoure	142.1	0	5.2	147.3	$57.72	$19,598
Logan	8.4	0	0	8.4	$2.56	$15,283
McHenry	76.7	14.2	0	90.9	$39.00	$21,446
McIntosh	78.8	5	0	84.6	$38.20	$22,578
McKenzie	143.3	2.3	7.7	153.3	$66.22	$21,595
McLean	107.4	0.6	27.4	135.4	$81.19	$29,973
Mercer	85.3	11.6	0	96.8	$42.13	$21,754

Morton	82.6	0	0	82.6	$27.78	$16,825
Mountrail	148.1	0	0	165.9	$69.74	$21,019
Nelson	76.5	0	0	81.7	$29.69	$18,174
Oliver	18.4	5.6	0	24	$8.89	$18,518
Pembina	182.5	1	0	183.5	$63.92	$17,418
Pierce	6	0	0	6	$2.46	$20,601
Ramsey	112.3	0	0	112.3	$38.94	$17,335
Ransom	56.1	0	0	56.1	$18.73	$16,677
Renville	69.1	0	6.1	75.2	$31.92	$21,232
Richland	180	26.6	13.6	230.8	$108.65	$23,535
Rolette	45.3	0	0	45.3	$16.14	$17,820
Sargent	75.5	0	6	81.6	$33.62	$20,606
Sheridan	20.5	0	0	20.5	$7.39	$18,076
Spirit Lake	35.5	0	0	35.5	$12.10	$17,036
Standing Rock	31.7	0	0	31.7	$11.45	$18,041
Stark	83.8	2	3.7	96.3	$46.23	$24,014
Steele	65.5	7	0	72.5	$25.50	$17,594
Stutsman	194.3	21	0	226.3	$87.43	$19,314
Traill	140.9	0	7.7	148.8	$58.86	$19,777
Turtle Mountain	19.8	0	0	71.2	$35.55	$24,981
Walsh	160.5	0	6	170.7	$71.02	$20,798
Ward	308.4	7.3	0.3	316.9	$120.13	$18,956
Wells	105.6	0	6	111.7	$47.74	$21,379
Williams	206.9	6.9	33.2	251.1	$141.97	$28,274
Total	5,073.9	164.6	166.7	5,557.5	$2,264.53	$20,089

Table D.6: County and Township Paved Road Investment Needs, by County and Period (Millions of 2016 Dollars) – 90 Rig Scenario

County	Miles Resurfaced	Miles Widened	Miles Reclaimed/ Reconstructed	Total Miles Improved	Total Cost (Million$)	Annual Cost per Mile
Adams	7.4	0	3.1	10.6	$6.88	$32,542
Barnes	219.6	0	0	219.6	$73.98	$16,842
Benson	61.9	0	0	61.9	$20.72	$16,742
Billings	15.9	0	0	15.9	$5.28	$16,610
Bottineau	175.3	22.3	0	197.7	$78.95	$19,972
Bowman	142.5	0	0	144.5	$55.35	$19,148
Burke	46.2	1.4	0	47.7	$16.69	$17,507
Burleigh	257.5	10.9	12.7	281.2	$107.43	$19,105
Cass	272.8	14.4	1	317.7	$123.99	$19,516

Cavalier	63.4	0	0	63.6	$21.48	$16,893
Dickey	77.3	0	0	77.3	$28.53	$18,448
Divide	44.1	0	5.7	49.8	$22.77	$22,869
Dunn	42.4	0	0	42.4	$14.48	$17,084
Eddy	53.8	0	0	60.8	$23.66	$19,459
Emmons	12.4	0	0	12.4	$4.24	$17,056
Fort Berthold	15.9	18.3	11.8	46.1	$33.40	$36,239
Foster	87	0	5.6	92.6	$45.61	$24,629
Golden Valley	23.1	0	0	23.1	$7.76	$16,803
Grand Forks	264.9	4.2	3.9	273.1	$96.64	$17,695
Griggs	38.5	0	0	38.5	$13.44	$17,434
Hettinger	16.9	0	0	16.9	$5.53	$16,391
Kidder	49	0.3	0	49.2	$16.95	$17,214
LaMoure	142.1	0	5.2	147.3	$57.72	$19,598
Logan	8.4	0	0	8.4	$2.56	$15,283
McHenry	65.1	25.8	0	90.9	$40.75	$22,411
McIntosh	78.8	5	0	84.6	$38.20	$22,578
McKenzie	143.1	2.6	7.7	153.3	$71.07	$23,178
McLean	107.4	0.6	27.4	135.4	$81.19	$29,973
Mercer	85.3	11.6	0	96.8	$42.31	$21,845
Morton	82.6	0	0	82.6	$27.78	$16,825
Mountrail	148.1	0	0	165.9	$67.48	$20,337
Nelson	76.5	0	0	81.7	$29.69	$18,174
Oliver	18.4	5.6	0	24	$8.89	$18,518
Pembina	182.5	1	0	183.5	$63.92	$17,418
Pierce	6	0	0	6	$2.46	$20,601
Ramsey	112.3	0	0	112.3	$38.94	$17,335
Ransom	56.1	0	0	56.1	$18.73	$16,677
Renville	69.1	0	6.1	75.2	$32.42	$21,565
Richland	180	26.6	13.6	230.8	$108.65	$23,535
Rolette	45.3	0	0	45.3	$16.14	$17,820
Sargent	75.5	0	6	81.6	$33.62	$20,606
Sheridan	20.5	0	0	20.5	$7.39	$18,076
Spirit Lake	35.5	0	0	35.5	$12.10	$17,036
Standing Rock	31.7	0	0	31.7	$11.45	$18,041
Stark	83.8	2	3.7	96.3	$46.36	$24,081
Steele	65.5	7	0	72.5	$25.50	$17,594
Stutsman	194.3	21	0	226.3	$87.43	$19,314
Traill	140.9	0	7.7	148.8	$58.86	$19,777

Turtle Mountain	19.8	0	0	71.2	$35.55	$24,981
Walsh	160.5	0	6	170.7	$71.02	$20,798
Ward	308.4	7.3	0.3	316.9	$120.11	$18,953
Wells	105.6	0	6	111.7	$47.74	$21,379
Williams	198.9	14.9	33.2	251.1	$148.77	$29,628
Total	5,035.8	202.8	166.7	5,557.5	$2,278.54	$20,191

Table D.7: County and Township Paved Road Investment Needs by County and Period (Thousands of 2016 Dollars) – 30 Rig Scenario							
County	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2026**	**2027-2036**	**2017-2036**
Adams	$4,097	$189	$189	$189	$189	$2,026	$6,878
Barnes	$6,892	$13,402	$6,133	$7,321	$4,513	$35,720	$73,981
Benson	$1,891	$3,351	$1,105	$1,900	$2,137	$10,336	$20,720
Billings	$284	$284	$567	$368	$1,030	$2,674	$5,206
Bottineau	$6,410	$12,575	$12,097	$8,846	$5,224	$31,602	$76,754
Bowman	$3,055	$2,581	$2,581	$2,581	$3,210	$41,112	$55,121
Burke	$851	$2,905	$932	$851	$2,346	$8,802	$16,688
Burleigh	$5,099	$15,393	$12,346	$7,171	$38,787	$28,634	$107,430
Cass	$15,987	$7,631	$12,132	$17,058	$10,148	$61,031	$123,988
Cavalier	$1,135	$2,578	$2,372	$2,968	$2,936	$9,489	$21,478
Dickey	$11,556	$2,170	$3,758	$1,397	$2,015	$7,633	$28,530
Divide	$889	$3,352	$889	$6,311	$925	$10,500	$22,866
Dunn	$757	$757	$757	$929	$983	$12,305	$16,488
Eddy	$6,171	$3,291	$2,779	$2,404	$1,086	$7,930	$23,661
Emmons	$222	$557	$222	$391	$908	$1,941	$4,240
Fort Berthold	$6,155	$2,562	$11,865	$823	$4,575	$3,703	$29,682
Foster	$13,870	$9,565	$3,682	$4,466	$4,775	$9,257	$45,614
Golden Valley	$412	$553	$412	$412	$695	$5,207	$7,692
Grand Forks	$9,337	$6,993	$16,909	$7,758	$9,477	$46,170	$96,643
Griggs	$688	$3,152	$1,016	$2,861	$688	$5,034	$13,440
Hettinger	$301	$543	$301	$301	$301	$3,785	$5,533
Kidder	$1,644	$1,584	$1,766	$1,277	$1,261	$9,420	$16,951
LaMoure	$6,933	$15,525	$6,649	$5,303	$7,638	$15,668	$57,716
Logan	$150	$150	$150	$423	$1,017	$674	$2,564
McHenry	$10,056	$8,682	$1,830	$1,624	$3,629	$12,980	$38,801
McIntosh	$18,011	$2,313	$1,685	$1,511	$2,855	$11,825	$38,201
McKenzie	$2,738	$3,129	$2,738	$5,002	$7,977	$33,162	$54,746

Table D.7: County and Township Paved Road Investment Needs by County and Period (Thousands of 2016 Dollars) – 30 Rig Scenario							
County	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2026**	**2027-2036**	**2017-2036**
McLean	$10,361	$11,850	$28,498	$6,902	$8,815	$14,762	$81,189
Mercer	$4,804	$14,700	$3,071	$2,029	$3,579	$13,768	$41,952
Morton	$2,706	$3,059	$1,552	$2,117	$4,771	$13,573	$27,778
Mountrail	$13,613	$3,535	$3,287	$2,963	$2,963	$37,368	$63,728
Nelson	$1,459	$4,925	$2,834	$2,674	$4,465	$13,331	$29,687
Oliver	$2,018	$1,653	$429	$429	$429	$3,279	$8,237
Pembina	$7,828	$6,747	$5,517	$5,037	$6,438	$32,353	$63,921
Pierce	$107	$107	$146	$617	$655	$830	$2,461
Ramsey	$2,653	$5,506	$3,498	$7,441	$5,264	$14,574	$38,936
Ransom	$1,003	$2,173	$1,003	$1,772	$5,365	$7,412	$18,727
Renville	$2,359	$1,817	$9,731	$1,738	$2,355	$13,827	$31,827
Richland	$14,079	$20,767	$27,157	$8,077	$5,692	$32,881	$108,653
Rolette	$1,741	$1,565	$898	$987	$2,610	$8,343	$16,144
Sargent	$1,639	$9,779	$1,457	$6,725	$3,355	$10,661	$33,617
Sheridan	$1,513	$2,494	$365	$365	$365	$2,291	$7,393
Spirit Lake	$2,641	$2,221	$634	$2,986	$764	$2,854	$12,100
Standing Rock	$3,832	$567	$567	$1,698	$567	$4,220	$11,450
Stark	$1,828	$3,109	$2,484	$7,084	$1,828	$29,263	$45,596
Steele	$3,986	$3,924	$1,294	$1,294	$3,023	$11,977	$25,498
Stutsman	$16,555	$14,016	$8,758	$6,812	$5,029	$36,259	$87,429
Traill	$7,115	$7,845	$12,992	$5,071	$4,864	$20,970	$58,857
Turtle Mountain	$9,187	$15,079	$1,271	$2,552	$1,744	$5,718	$35,551
Walsh	$10,628	$5,742	$5,010	$12,765	$9,406	$27,467	$71,018
Ward	$9,781	$13,823	$10,312	$6,468	$16,623	$63,329	$120,336
Wells	$15,182	$5,990	$7,068	$2,198	$1,994	$15,312	$47,744
Williams	$6,773	$4,735	$8,664	$15,335	$8,807	$57,222	$101,536

Table D.8: County and Township Paved Road Investment Needs by County and Period (Thousands of 2016 Dollars) – 60 Rig Scenario							
County	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2026**	**2027-2036**	**2017-2036**
Adams	$4,097	$189	$189	$189	$189	$2,026	$6,878
Barnes	$6,892	$13,402	$6,133	$7,321	$4,513	$35,720	$73,981
Benson	$1,891	$3,351	$1,105	$1,900	$2,137	$10,336	$20,720
Billings	$284	$571	$284	$737	$661	$2,674	$5,210
Bottineau	$6,552	$12,575	$12,097	$10,252	$5,224	$31,602	$78,303
Bowman	$3,055	$2,581	$2,581	$2,581	$3,210	$41,141	$55,150
Burke	$851	$2,905	$932	$851	$2,346	$8,802	$16,688
Burleigh	$5,099	$15,393	$12,346	$7,171	$38,787	$28,634	$107,430
Cass	$15,987	$7,631	$12,132	$17,058	$10,148	$61,031	$123,988
Cavalier	$1,135	$2,578	$2,372	$2,968	$2,936	$9,489	$21,478
Dickey	$11,556	$2,170	$3,758	$1,397	$2,015	$7,633	$28,530
Divide	$889	$3,352	$889	$6,311	$1,884	$9,985	$23,310
Dunn	$757	$757	$757	$757	$757	$11,178	$14,962
Eddy	$6,171	$3,291	$2,779	$2,404	$1,086	$7,930	$23,661
Emmons	$222	$557	$222	$391	$908	$1,941	$4,240
Fort Berthold	$7,684	$2,562	$11,865	$823	$4,575	$3,703	$31,212
Foster	$13,870	$9,565	$3,682	$4,466	$4,775	$9,257	$45,614
Golden Valley	$412	$412	$412	$412	$828	$5,279	$7,755
Grand Forks	$9,337	$6,993	$16,909	$7,758	$9,477	$46,170	$96,643
Griggs	$688	$3,152	$1,016	$2,861	$688	$5,034	$13,440
Hettinger	$301	$543	$301	$301	$301	$3,785	$5,533
Kidder	$1,644	$1,584	$1,766	$1,277	$1,261	$9,420	$16,951
LaMoure	$6,933	$15,525	$6,649	$5,303	$7,638	$15,668	$57,716
Logan	$150	$150	$150	$423	$1,017	$674	$2,564
McHenry	$10,161	$8,772	$1,830	$1,624	$4,564	$12,045	$38,995
McIntosh	$18,011	$2,313	$1,685	$1,511	$2,855	$11,825	$38,201
McKenzie	$4,149	$3,093	$13,109	$4,794	$5,552	$35,520	$66,216

Table D.8: County and Township Paved Road Investment Needs by County and Period (Thousands of 2016 Dollars) – 60 Rig Scenario							
County	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2026**	**2027-2036**	**2017-2036**
McLean	$10,361	$11,850	$28,498	$6,902	$8,815	$14,762	$81,189
Mercer	$4,983	$14,700	$3,071	$2,029	$3,579	$13,768	$42,131
Morton	$2,706	$3,059	$1,552	$2,117	$4,771	$13,573	$27,778
Mountrail	$13,849	$3,771	$3,809	$3,607	$3,729	$40,975	$69,740
Nelson	$1,459	$4,925	$2,834	$2,674	$4,465	$13,331	$29,687
Oliver	$2,672	$1,653	$1,217	$429	$429	$2,491	$8,890
Pembina	$7,828	$6,747	$5,517	$5,037	$6,438	$32,353	$63,921
Pierce	$107	$107	$146	$617	$655	$830	$2,461
Ramsey	$2,653	$5,506	$3,498	$7,441	$5,264	$14,574	$38,936
Ransom	$1,003	$2,173	$1,003	$1,772	$5,365	$7,412	$18,727
Renville	$2,359	$2,213	$9,731	$2,347	$2,355	$12,917	$31,922
Richland	$14,079	$20,767	$27,157	$8,077	$5,692	$32,881	$108,653
Rolette	$1,741	$1,565	$898	$987	$2,610	$8,343	$16,144
Sargent	$1,639	$9,779	$1,457	$6,725	$3,355	$10,661	$33,617
Sheridan	$1,513	$2,494	$365	$365	$365	$2,291	$7,393
Spirit Lake	$2,641	$2,221	$634	$2,986	$764	$2,854	$12,100
Standing Rock	$3,832	$567	$567	$1,698	$567	$4,220	$11,450
Stark	$1,828	$3,109	$2,484	$7,099	$1,828	$29,883	$46,230
Steele	$3,986	$3,924	$1,294	$1,294	$3,023	$11,977	$25,498
Stutsman	$16,555	$14,016	$8,758	$6,812	$5,029	$36,259	$87,429
Traill	$7,115	$7,845	$12,992	$5,071	$4,864	$20,970	$58,857
Turtle Mountain	$9,187	$15,079	$1,271	$2,552	$1,744	$5,718	$35,551
Walsh	$10,628	$5,742	$5,010	$12,765	$9,406	$27,467	$71,018
Ward	$9,781	$13,823	$10,312	$8,039	$16,623	$61,547	$120,125
Wells	$15,182	$5,990	$7,068	$2,198	$1,994	$15,312	$47,744
Williams	$7,650	$9,738	$19,032	$41,292	$9,322	$54,936	$141,970

Table D.9: County and Township Paved Road Investment Needs by County and Period (Thousands of 2016 Dollars) – 90 Rig Scenario							
County	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2026**	**2027-2036**	**2017-2036**
Adams	$4,097	$189	$189	$189	$189	$2,026	$6,878
Barnes	$6,892	$13,402	$6,133	$7,321	$4,513	$35,720	$73,981
Benson	$1,891	$3,351	$1,105	$1,900	$2,137	$10,336	$20,720
Billings	$284	$636	$284	$737	$661	$2,674	$5,276
Bottineau	$6,622	$12,575	$12,097	$10,829	$5,224	$31,602	$78,950
Bowman	$3,055	$2,581	$2,581	$2,581	$3,210	$41,338	$55,347
Burke	$851	$2,905	$932	$851	$2,346	$8,802	$16,688
Burleigh	$5,099	$15,393	$12,346	$7,171	$38,787	$28,634	$107,430
Cass	$15,987	$7,631	$12,132	$17,058	$10,148	$61,031	$123,988
Cavalier	$1,135	$2,578	$2,372	$2,968	$2,936	$9,489	$21,478
Dickey	$11,556	$2,170	$3,758	$1,397	$2,015	$7,633	$28,530
Divide	$889	$3,258	$1,848	$6,311	$925	$9,541	$22,772
Dunn	$757	$1,331	$1,541	$757	$757	$9,340	$14,482
Eddy	$6,171	$3,291	$2,779	$2,404	$1,086	$7,930	$23,661
Emmons	$222	$557	$222	$391	$908	$1,941	$4,240
Fort Berthold	$9,868	$2,562	$11,865	$823	$4,575	$3,703	$33,395
Foster	$13,870	$9,565	$3,682	$4,466	$4,775	$9,257	$45,614
Golden Valley	$412	$412	$412	$412	$828	$5,279	$7,755
Grand Forks	$9,337	$6,993	$16,909	$7,758	$9,477	$46,170	$96,643
Griggs	$688	$3,152	$1,016	$2,861	$688	$5,034	$13,440
Hettinger	$301	$543	$301	$301	$301	$3,785	$5,533
Kidder	$1,644	$1,584	$1,766	$1,277	$1,261	$9,420	$16,951
LaMoure	$6,933	$15,525	$6,649	$5,303	$7,638	$15,668	$57,716
Logan	$150	$150	$150	$423	$1,017	$674	$2,564
McHenry	$11,301	$9,389	$1,830	$2,559	$3,629	$12,045	$40,752
McIntosh	$18,011	$2,313	$1,685	$1,511	$2,855	$11,825	$38,201
McKenzie	$4,749	$4,055	$13,644	$5,317	$5,927	$37,382	$71,073

Table D.9: County and Township Paved Road Investment Needs by County and Period (Thousands of 2016 Dollars) – 90 Rig Scenario							
County	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2026**	**2027-2036**	**2017-2036**
McLean	$10,361	$11,850	$28,498	$6,902	$8,815	$14,762	$81,189
Mercer	$5,159	$14,700	$3,071	$2,029	$3,579	$13,768	$42,307
Morton	$2,706	$3,059	$1,552	$2,117	$4,771	$13,573	$27,778
Mountrail	$13,849	$4,096	$3,198	$3,223	$3,262	$39,848	$67,476
Nelson	$1,459	$4,925	$2,834	$2,674	$4,465	$13,331	$29,687
Oliver	$2,672	$1,653	$1,217	$429	$429	$2,491	$8,890
Pembina	$7,828	$6,747	$5,517	$5,037	$6,438	$32,353	$63,921
Pierce	$107	$107	$146	$617	$655	$830	$2,461
Ramsey	$2,653	$5,506	$3,498	$7,441	$5,264	$14,574	$38,936
Ransom	$1,003	$2,173	$1,003	$1,772	$5,365	$7,412	$18,727
Renville	$2,359	$2,257	$9,731	$2,347	$2,355	$13,373	$32,422
Richland	$14,079	$20,767	$27,157	$8,077	$5,692	$32,881	$108,653
Rolette	$1,741	$1,565	$898	$987	$2,610	$8,343	$16,144
Sargent	$1,639	$9,779	$1,457	$6,725	$3,355	$10,661	$33,617
Sheridan	$1,513	$2,494	$365	$365	$365	$2,291	$7,393
Spirit Lake	$2,641	$2,221	$634	$2,986	$764	$2,854	$12,100
Standing Rock	$3,832	$567	$567	$1,698	$567	$4,220	$11,450
Stark	$1,828	$3,109	$2,484	$7,099	$2,024	$29,815	$46,359
Steele	$3,986	$3,924	$1,294	$1,294	$3,023	$11,977	$25,498
Stutsman	$16,555	$14,016	$8,758	$6,812	$5,029	$36,259	$87,429
Traill	$7,115	$7,845	$12,992	$5,071	$4,864	$20,970	$58,857
Turtle Mountain	$9,187	$15,079	$1,271	$2,552	$1,744	$5,718	$35,551
Walsh	$10,628	$5,742	$5,010	$12,765	$9,406	$27,467	$71,018
Ward	$10,193	$13,823	$10,312	$8,039	$16,623	$61,117	$120,107
Wells	$15,182	$5,990	$7,068	$2,198	$1,994	$15,312	$47,744
Williams	$9,062	$16,029	$19,538	$43,354	$8,548	$52,240	$148,771

Table D.10: Estimated Improvement Needs for Unpaved Indian Reservation Roads, by Reservation (Thousands of 2016 Dollars) – 30 Rigs							
County	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2026**	**2027-2031**	**2032-2036**
Fort Berthold	$ 4,971.14	$ 3,478.17	$ 4,182.24	$ 4,038.92	$ 3,417.94	$ 6,808.12	$ 7,431.76
Spirit Lake	$ 159.06	$ 159.06	$ 159.06	$ 159.06	$ 159.06	$ 318.12	$ 318.12
Standing Rock	$ 4,581.64	$ 4,581.64	$ 4,597.72	$ 4,597.72	$ 4,597.72	$ 9,195.44	$ 9,163.28
Turtle Mountain	$ 534.69	$ 534.69	$ 534.69	$ 534.69	$ 534.69	$ 1,069.39	$ 1,069.39

Table D.11: Estimated Improvement Needs for Unpaved Indian Reservation Roads, by Reservation (Thousands of 2016 Dollars) – 60 Rigs							
County	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2026**	**2027-2031**	**2032-2036**
Fort Berthold	$ 6,988.89	$ 3,836.55	$ 6,674.30	$ 5,653.10	$ 3,565.93	$ 6,674.45	$ 10,409.89
Spirit Lake	$ 159.06	$ 159.06	$ 159.06	$ 159.06	$ 159.06	$ 318.12	$ 318.12
Standing Rock	$ 4,581.64	$ 4,581.64	$ 4,597.72	$ 4,597.72	$ 4,597.72	$ 9,195.44	$ 9,163.28
Turtle Mountain	$ 534.69	$ 534.69	$ 534.69	$ 534.69	$ 534.69	$ 1,069.39	$ 1,069.39

Table D.12: Estimated Improvement Needs for Unpaved Indian Reservation Roads, by Reservation (Thousands of 2016 Dollars) – 90 Rigs							
County	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2026**	**2027-2031**	**2032-2036**
Fort Berthold	$ 7,409.01	$ 4,954.60	$ 6,448.58	$ 6,174.78	$ 3,601.07	$ 7,138.22	$ 12,163.23
Spirit Lake	$ 159.06	$ 159.06	$ 159.06	$ 159.06	$ 159.06	$ 318.12	$ 318.12
Standing Rock	$ 4,581.64	$ 4,581.64	$ 4,597.72	$ 4,597.72	$ 4,597.72	$ 9,195.44	$ 9,163.28
Turtle Mountain	$ 534.69	$ 534.69	$ 534.69	$ 534.69	$ 534.69	$ 1,069.39	$ 1,069.39

Table D.13: Estimated Improvement Needs for Paved Indian Reservation Roads, by Reservation (Thousands of 2016 Dollars) - 30 Rig Scenario							
County	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2026**	**2027-2031**	**2032-2036**
Fort Berthold	$6,155	$2,562	$11,865	$823	$4,575	$2,057	$1,646
Spirit Lake	$2,641	$2,221	$634	$2,986	$764	$1,585	$1,268
Standing Rock	$3,832	$567	$567	$1,698	$567	$3,087	$1,133
Turtle Mountain	$9,187	$15,079	$1,271	$2,552	$1,744	$3,177	$2,541

Table D.14: Estimated Improvement Needs for Paved Indian Reservation Roads, by Reservation (Thousands of 2016 Dollars) - 60 Rig Scenario							
County	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2026**	**2027-2031**	**2032-2036**
Fort Berthold	$7,684	$2,562	$11,865	$823	$4,575	$2,057	$1,646
Spirit Lake	$2,641	$2,221	$634	$2,986	$764	$1,585	$1,268
Standing Rock	$3,832	$567	$567	$1,698	$567	$3,087	$1,133
Turtle Mountain	$9,187	$15,079	$1,271	$2,552	$1,744	$3,177	$2,541

Table D.15: Estimated Improvement Needs for Paved Indian Reservation Roads, by Reservation (Thousands of 2016 Dollars) - 90 Rig Scenario							
County	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2026**	**2027-2031**	**2032-2036**
Fort Berthold	$9,868	$2,562	$11,865	$823	$4,575	$2,057	$1,646
Spirit Lake	$2,641	$2,221	$634	$2,986	$764	$1,585	$1,268
Standing Rock	$3,832	$567	$567	$1,698	$567	$3,087	$1,133
Turtle Mountain	$9,187	$15,079	$1,271	$2,552	$1,744	$3,177	$2,541

Table D.16 Estimated Bridge Improvement Needs, by County (Thousands of 2016 Dollars)				
County	Rehabilitation and Replacement		Preventive Maintenance Cost	Total Cost
	Bridges	Cost		
Adams	4	$2,598,162.73	$247,036.50	$2,845,199.23
Barnes	1	$454,724.41	$365,670.45	$820,394.86
Benson	3	$1,154,101.05	$71,281.28	$1,225,382.33
Billings	2	$997,572.18	$209,659.93	$1,207,232.11
Bottineau	44	$26,818,044.62	$461,378.63	$27,279,423.25
Bowman	4	$723,818.90	$149,629.39	$873,448.29
Burke	4	$1,600,000.00	$37,504.73	$1,637,504.73
Burleigh	6	$1,830,577.43	$341,766.62	$2,172,344.05
Cass	49	$31,682,611.55	$2,503,739.89	$34,186,351.44
Cavalier	6	$2,600,000.00	$79,199.73	$2,679,199.73
Dickey	0	$0.00	$428,072.42	$428,072.42
Divide	3	$1,200,000.00	$49,784.78	$1,249,784.78
Dunn	4	$2,321,522.31	$290,878.86	$2,612,401.17
Eddy	1	$829,921.26	$209,578.08	$1,039,499.34
Emmons	4	$2,535,662.73	$277,098.46	$2,812,761.19
Foster	3	$1,403,873.85	$68,814.25	$1,472,688.09
Golden Valley	6	$3,527,296.59	$119,554.08	$3,646,850.67
Grand Forks	57	$26,236,125.50	$1,310,888.39	$27,547,013.89
Grant	20	$18,492,191.60	$543,975.11	$19,036,166.71
Griggs	3	$3,853,543.31	$225,315.64	$4,078,858.95
Hettinger	30	$18,573,129.92	$423,150.21	$18,996,280.13
Kidder	0	$0.00	$0.00	0
LaMoure	11	$8,756,496.06	$411,141.46	$9,167,637.53
Logan	3	$634,251.97	$64,237.01	$698,488.98

Table D.16 Estimated Bridge Improvement Needs, by County (Thousands of 2016 Dollars)				
County	**Rehabilitation and Replacement**		**Preventive Maintenance Cost**	**Total Cost**
	Bridges	**Cost**		
McHenry	27	$16,047,408.14	$417,923.98	$16,465,332.12
McIntosh	1	$600,000.00	$15,525.30	$615,525.30
McKenzie	10	$3,713,812.34	$467,686.28	$4,181,498.61
McLean	3	$1,611,301.85	$295,730.06	$1,907,031.91
Mercer	3	$1,143,536.75	$448,466.12	$1,592,002.86
Morton	84	$44,974,639.11	$1,048,940.50	$46,023,579.61
Mountrail	3	$2,294,750.66	$179,567.68	$2,474,318.34
Nelson	2	$1,465,257.91	$208,636.08	$1,673,893.99
Oliver	0	$0.00	$147,237.51	$147,237.51
Pembina	18	$13,461,187.66	$717,144.38	$14,178,332.04
Pierce	1	$1,673,228.35	$35,300.70	$1,708,529.05
Ramsey	7	$3,875,328.08	$163,156.99	$4,038,485.08
Ransom	5	$8,705,249.34	$449,601.03	$9,154,850.37
Renville	3	$3,608,136.48	$195,614.60	$3,803,751.09
Richland	43	$27,914,074.80	$1,107,339.82	$29,021,414.62
Rolette	1	$400,000.00	$35,524.60	$435,524.60
Sargent	6	$2,816,535.43	$27,477.42	$2,844,012.85
Sheridan	1	$1,467,979.00	$113,992.59	$1,581,971.60
Sioux	1	$186,023.62	$162,038.22	$348,061.84
Slope	2	$497,604.99	$184,516.01	$682,121.00
Stark	31	$17,429,954.07	$609,035.84	$18,038,989.91
Steele	21	$10,811,548.56	$437,465.53	$11,249,014.08
Stutsman	5	$2,071,653.54	$335,675.24	$2,407,328.78
Towner	8	$3,087,270.34	$63,084.74	$3,150,355.08

Table D.16 Estimated Bridge Improvement Needs, by County (Thousands of 2016 Dollars)				
County	**Rehabilitation and Replacement**		**Preventive Maintenance Cost**	**Total Cost**
	Bridges	**Cost**		
Traill	53	$45,719,521.00	$1,179,343.01	$46,898,864.01
Walsh	63	$35,900,032.81	$1,060,619.29	$36,960,652.09
Ward	13	$8,528,477.69	$373,593.50	$8,902,071.19
Wells	2	$1,323,622.05	$259,430.25	$1,583,052.30
Williams	18	$9,428,477.69	$203,711.91	$9,632,189.60
Statewide	703	$429,580,240.21	$19,832,735.11	$449,412,975.32

Table D.15: Total Estimated Road and Bridge Investment Needs, by County (Millions of 2016 Dollars) - 30 Rigs				
County	**Unpaved Road Needs**	**Paved Road Needs**	**Bridge Needs**	**Total Needs**
Adams	$58.16	$6.88	$2.85	$67.89
Barnes	$132.13	$73.98	$0.82	$206.93
Benson	$75.71	$20.72	$1.23	$97.66
Billings	$83.63	$5.21	$1.21	$90.05
Bottineau	$106.03	$76.75	$27.28	$210.06
Bowman	$84.34	$55.12	$0.87	$140.33
Burke	$140.35	$16.69	$1.64	$158.63
Burleigh	$151.08	$107.43	$2.17	$260.68
Cass	$286.93	$123.99	$34.19	$445.11
Cavalier	$93.25	$21.48	$2.68	$117.41
Dickey	$72.45	$28.53	$0.43	$101.41
Divide	$173.18	$22.87	$1.25	$197.3
Dunn	$263.12	$16.49	$2.61	$282.22
Eddy	$30.06	$23.66	$1.04	$54.76
Emmons	$76.59	$4.24	$2.81	$83.64
Foster	$33.26	$45.61	$1.47	$80.34
Golden Valley	$84.65	$7.69	$3.65	$95.99
Grand Forks	$203.80	$96.64	$27.55	$327.99
Grant	$124.48	$0	$19.04	$143.52
Griggs	$34.10	$13.44	$4.08	$51.62
Hettinger	$66.46	$5.53	$19.00	$90.99
Kidder	$55.03	$16.95	$0.00	$71.98
LaMoure	$76.67	$57.72	$9.17	$143.56
Logan	$48.92	$2.56	$0.70	$52.18
McHenry	$204.35	$38.80	$16.47	$259.62
McIntosh	$47.26	$38.20	$0.62	$86.08
McKenzie	$313.24	$54.75	$4.18	$372.17
McLean	$154.87	$81.19	$1.91	$237.97
Mercer	$90.56	$41.95	$1.59	$134.1
Morton	$125.31	$27.78	$46.02	$199.11
Mountrail	$203.45	$63.73	$2.47	$263.47
Nelson	$57.65	$29.69	$1.67	$89.01

Oliver	$34.83	$8.24	$0.15	$43.22
Pembina	$85.17	$63.92	$14.18	$163.27
Pierce	$108.10	$2.46	$1.71	$112.27
Ramsey	$62.24	$38.94	$4.04	$105.22
Ransom	$56.43	$18.73	$9.15	$84.31
Renville	$59.52	$31.83	$3.80	$95.15
Richland	$167.84	$108.65	$29.02	$305.51
Rolette	$59.23	$16.14	$0.44	$75.81
Sargent	$44.51	$33.62	$2.84	$80.97
Sheridan	$53.74	$7.39	$1.58	$62.71
Sioux	$57.88	$0	$0.35	$58.23
Slope	$63.75	$0	$0.68	$64.43
Stark	$181.90	$45.60	$18.04	$247.54
Steele	$51.18	$25.50	$11.25	$87.93
Stutsman	$112.14	$87.43	$2.41	$201.98
Towner	$72.23	$0	$3.15	$75.38
Traill	$71.90	$58.86	$46.90	$177.66
Walsh	$190.62	$71.02	$36.96	$298.6
Ward	$233.54	$120.34	$8.90	$362.78
Wells	$83.90	$47.74	$1.58	$133.22
Williams	$258.01	$101.54	$9.63	$369.18
Total	$5,859.68	$2,202.98	$449.43	$8,512.09

Table D.16: Total Estimated Road and Bridge Investment Needs, by County (Millions of 2016 Dollars) - 60 Rigs

County	Unpaved Road Needs	Paved Road Needs	Bridge Needs	Total Needs
Adams	$58.16	$6.88	$2.85	$67.89
Barnes	$132.13	$73.98	$0.82	$206.93
Benson	$75.71	$20.72	$1.23	$97.66
Billings	$90.45	$5.21	$1.21	$96.87
Bottineau	$106.24	$78.30	$27.28	$211.82

Bowman	$84.69	$55.15	$0.87	$140.71
Burke	$141.25	$16.69	$1.64	$159.58
Burleigh	$151.08	$107.43	$2.17	$260.68
Cass	$286.93	$123.99	$34.19	$445.11
Cavalier	$93.25	$21.48	$2.68	$117.41
Dickey	$72.45	$28.53	$0.43	$101.41
Divide	$180.62	$23.31	$1.25	$205.18
Dunn	$316.86	$14.96	$2.61	$334.43
Eddy	$30.06	$23.66	$1.04	$54.76
Emmons	$76.59	$4.24	$2.81	$83.64
Foster	$33.26	$45.61	$1.47	$80.34
Golden Valley	$86.98	$7.76	$3.65	$98.39
Grand Forks	$203.80	$96.64	$27.55	$327.99
Grant	$124.48	$0	$19.04	$143.52
Griggs	$34.10	$13.44	$4.08	$51.62
Hettinger	$66.46	$5.53	$19.00	$90.99
Kidder	$55.03	$16.95	$0.00	$71.98
LaMoure	$76.67	$57.72	$9.17	$143.56
Logan	$48.92	$2.56	$0.70	$52.18
McHenry	$204.35	$39.00	$16.47	$259.82
McIntosh	$47.26	$38.20	$0.62	$86.08
McKenzie	$404.76	$66.21	$4.18	$475.15
McLean	$154.91	$81.19	$1.91	$238.01
Mercer	$90.70	$42.13	$1.59	$134.42
Morton	$125.31	$27.78	$46.02	$199.11
Mountrail	$234.88	$69.74	$2.47	$307.09
Nelson	$57.65	$29.69	$1.67	$89.01
Oliver	$34.61	$8.89	$0.15	$43.65
Pembina	$85.17	$61.92	$14.18	$161.27
Pierce	$108.10	$2.46	$1.71	$112.27
Ramsey	$62.24	$38.94	$4.04	$105.22
Ransom	$56.43	$18.73	$9.15	$84.31
Renville	$59.53	$31.92	$3.80	$95.25
Richland	$167.84	$108.65	$29.02	$305.51
Rolette	$59.23	$16.14	$0.44	$75.81
Sargent	$44.51	$33.62	$2.84	$80.97
Sheridan	$53.78	$7.39	$1.58	$62.75

Sioux	$57.88	$0	$0.35	$58.23
Slope	$63.02	$0	$0.68	$63.70
Stark	$184.35	$48.23	$18.04	$250.62
Steele	$51.18	$25.50	$11.25	$87.93
Stutsman	$112.14	$87.43	$2.41	$201.98
Towner	$72.23	$0	$3.15	$75.38
Traill	$71.90	$58.78	$46.90	$177.58
Walsh	$190.62	$71.02	$36.96	$298.60
Ward	$233.91	$120.13	$8.90	$362.94
Wells	$83.90	$47.74	$1.58	$133.22
Williams	$292.21	$141.97	$9.63	$443.81
Total	$6,090.71	$2,264.53	$449.43	$8,703.91

Table D.17: Total Estimated Road and Bridge Investment Needs, by County (Millions of 2016 Dollars) - 90 Rigs

County	Unpaved Road Needs	Paved Road Needs	Bridge Needs	Total Needs
Adams	$58.16	$6.88	$2.85	$67.89
Barnes	$132.13	$73.98	$0.82	$206.93
Benson	$75.71	$20.72	$1.23	$97.66
Billings	$90.10	$5.28	$1.21	$96.59
Bottineau	$106.80	$78.95	$27.28	$213.03
Bowman	$85.82	$55.35	$0.87	$142.04
Burke	$141.86	$16.68	$1.64	$160.18
Burleigh	$151.08	$107.43	$2.17	$260.68
Cass	$286.93	$123.99	$34.19	$445.11
Cavalier	$93.25	$21.48	$2.68	$117.41
Dickey	$72.45	$28.53	$0.43	$101.41
Divide	$189.72	$22.77	$1.25	$213.74
Dunn	$326.17	$14.48	$2.61	$343.26
Eddy	$30.06	$23.66	$1.04	$54.76
Emmons	$76.59	$4.24	$2.81	$83.64
Foster	$33.26	$45.61	$1.47	$80.34
Golden Valley	$89.85	$7.76	$3.65	$101.26
Grand Forks	$203.80	$96.64	$27.55	$327.99

Grant	$124.48	$0	$19.04	$143.52
Griggs	$34.10	$13.44	$4.08	$51.62
Hettinger	$66.46	$5.53	$19.00	$90.99
Kidder	$55.03	$16.95	$0.00	$71.98
LaMoure	$76.67	$57.72	$9.17	$143.56
Logan	$48.92	$2.56	$0.70	$52.18
McHenry	$204.35	$40.75	$16.47	$261.57
McIntosh	$47.26	$38.20	$0.62	$86.08
McKenzie	$463.89	$71.07	$4.18	$539.14
McLean	$154.92	$81.19	$1.91	$238.02
Mercer	$90.72	$42.31	$1.59	$134.62
Morton	$125.31	$27.78	$46.02	$199.11
Mountrail	$240.81	$67.48	$2.47	$310.76
Nelson	$57.65	$29.69	$1.67	$89.01
Oliver	$34.66	$8.89	$0.15	$43.70
Pembina	$85.17	$61.92	$14.18	$161.27
Pierce	$108.10	$2.46	$1.71	$112.27
Ramsey	$62.24	$38.94	$4.04	$105.22
Ransom	$56.43	$18.73	$9.15	$84.31
Renville	$59.53	$32.42	$3.80	$95.75
Richland	$167.84	$108.65	$29.02	$305.51
Rolette	$59.23	$16.14	$0.44	$75.81
Sargent	$44.51	$33.62	$2.84	$80.97
Sheridan	$53.79	$7.39	$1.58	$62.76
Sioux	$57.88	$0	$0.35	$58.23
Slope	$64.30	$0	$0.68	$64.98
Stark	$185.57	$48.36	$18.04	$251.97
Steele	$51.18	$25.50	$11.25	$87.93
Stutsman	$112.14	$87.43	$2.41	$201.98
Towner	$72.23	$0	$3.15	$75.38
Traill	$71.90	$58.86	$46.90	$177.66
Walsh	$190.62	$71.02	$36.96	$298.60
Ward	$233.72	$120.11	$8.90	$362.73
Wells	$83.95	$47.74	$1.58	$133.27
Williams	$316.62	$148.77	$9.63	$475.02
Total	$6,205.88	$2,176.17	$449.43	$8,831.48

Maps of Improvement Costs and Practices

Figure D.1. Average gravel/scoria cost (per cubic yard)

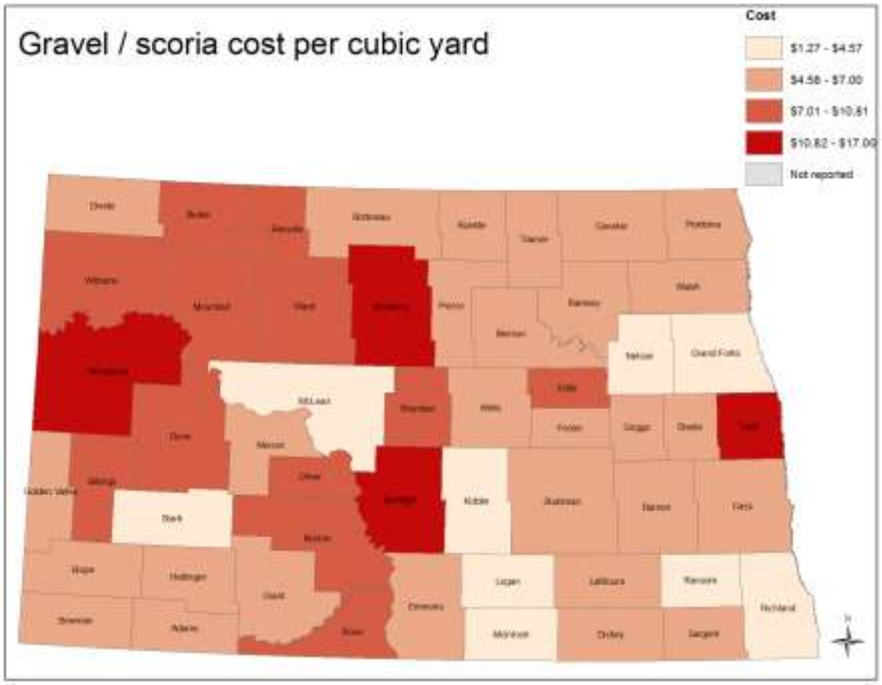


Figure D.2. Average trucking cost (per cubic yard/mile)

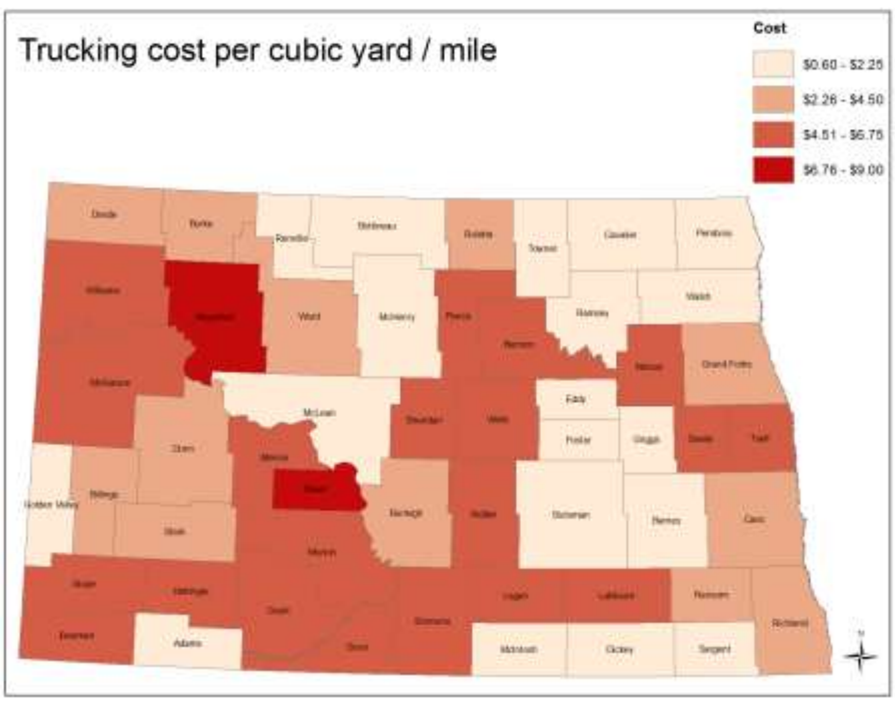


Figure D.3. Average gravel/scoria cost (per one mile of one-inch layer)

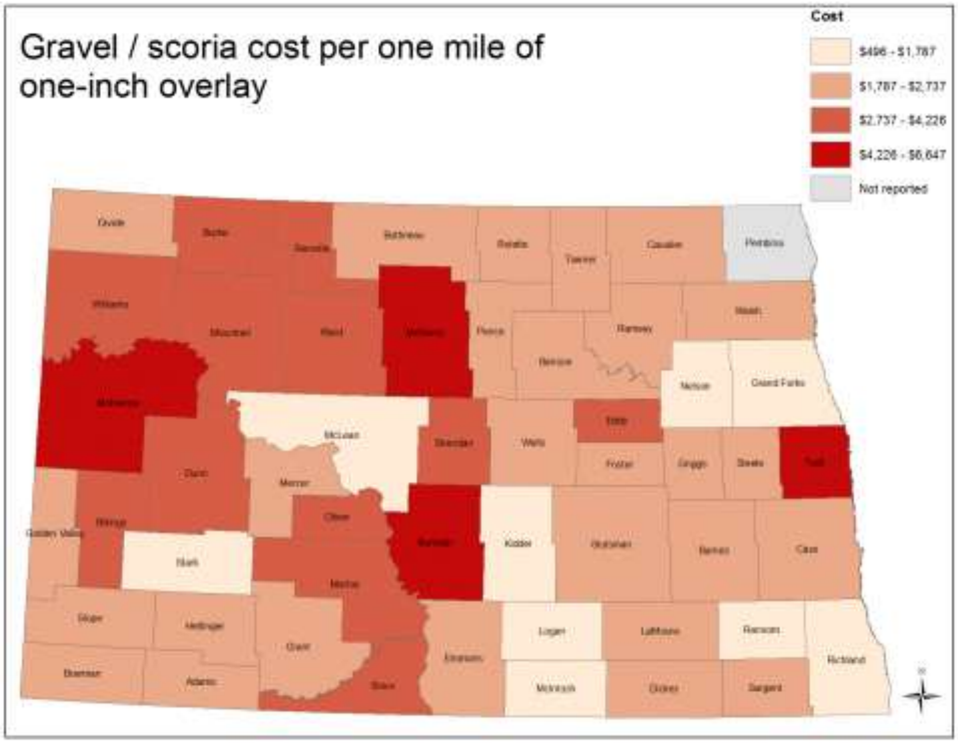


Figure D.4. Average blading cost (per mile)

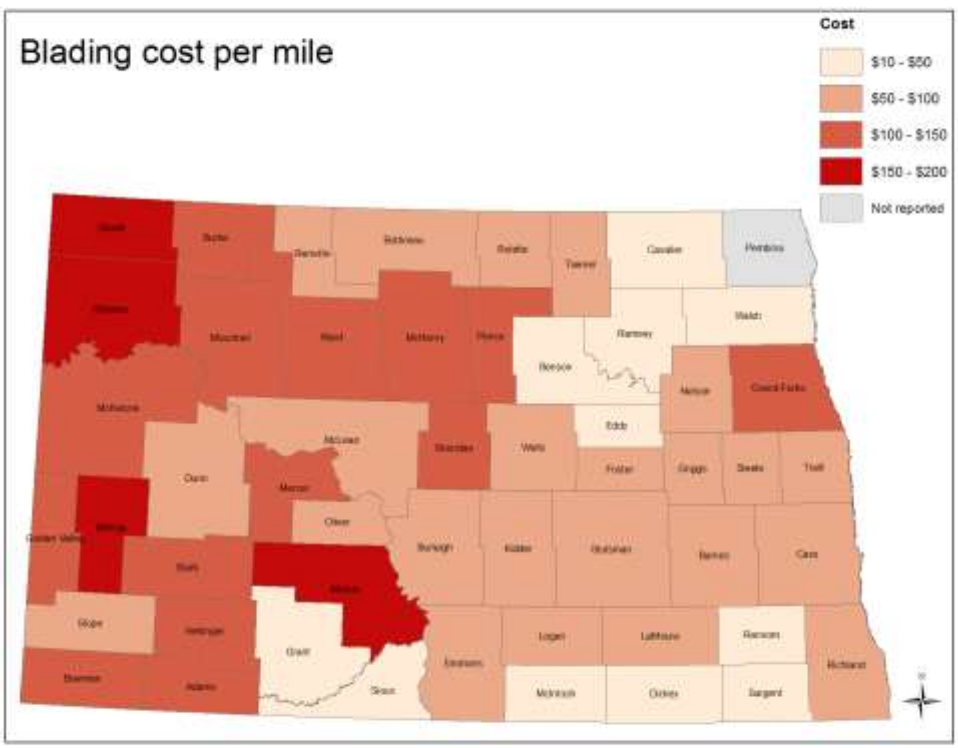


Figure D.5. Average dust suppressant cost (per mile)

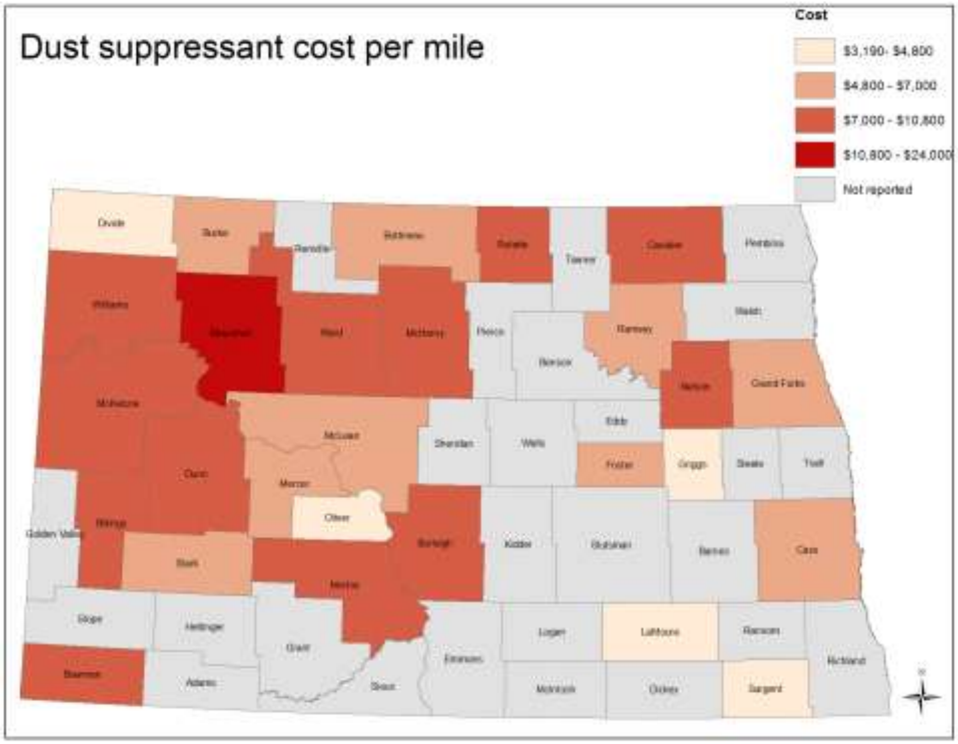


Figure D.6. Low/Medium Traffic Volume Threshold

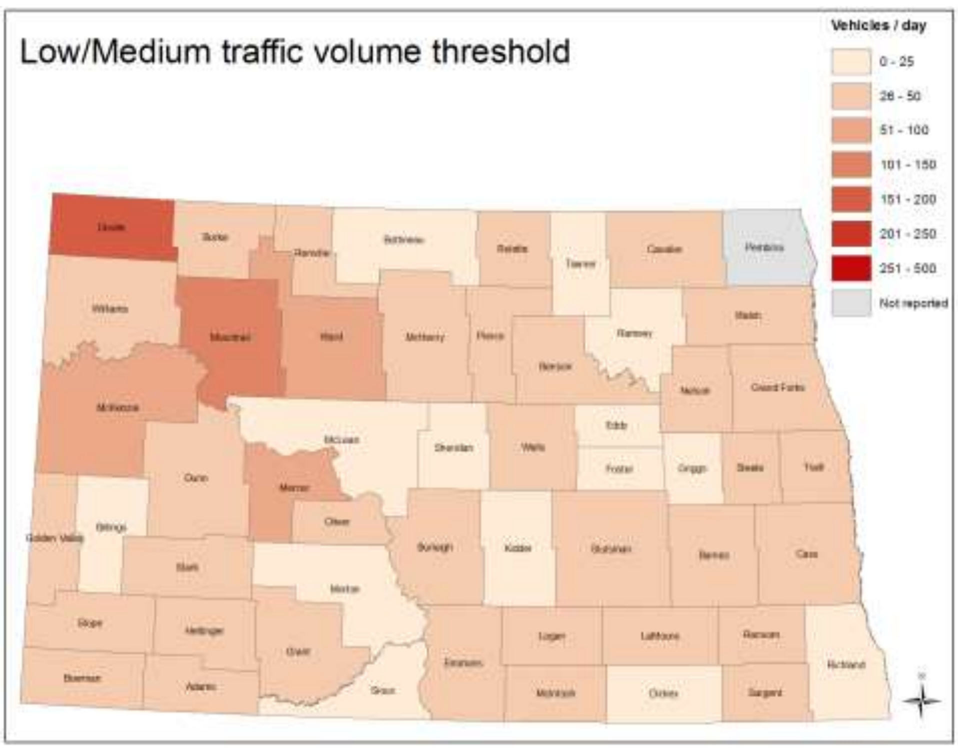


Figure D.7. Medium/High Traffic Volume Threshold

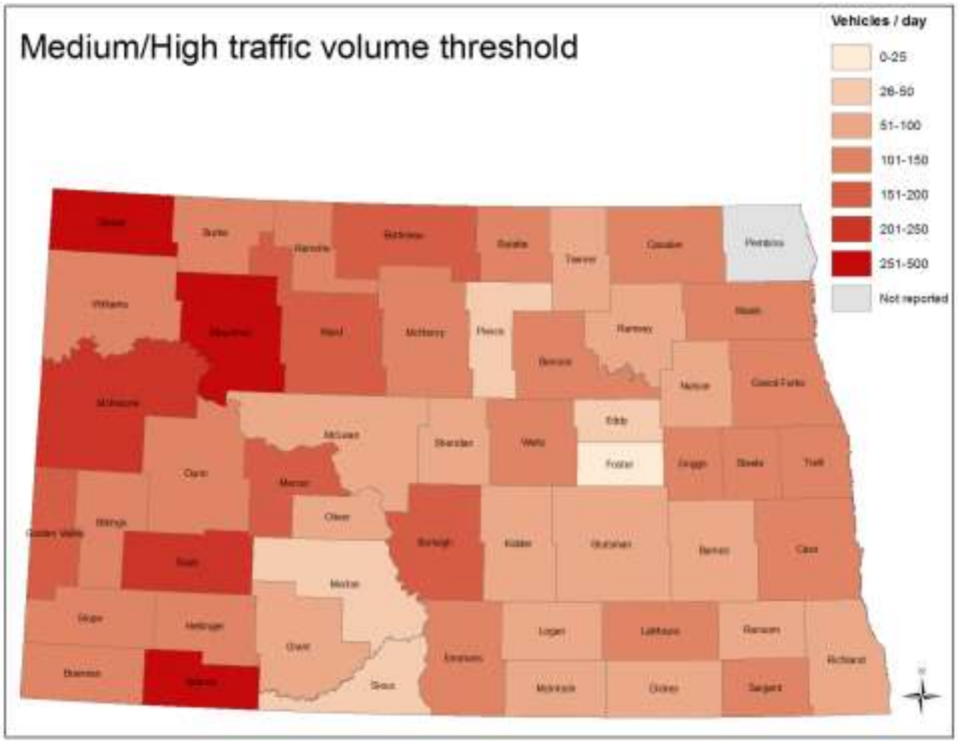


Figure D.8. Blading Frequency, Low Traffic

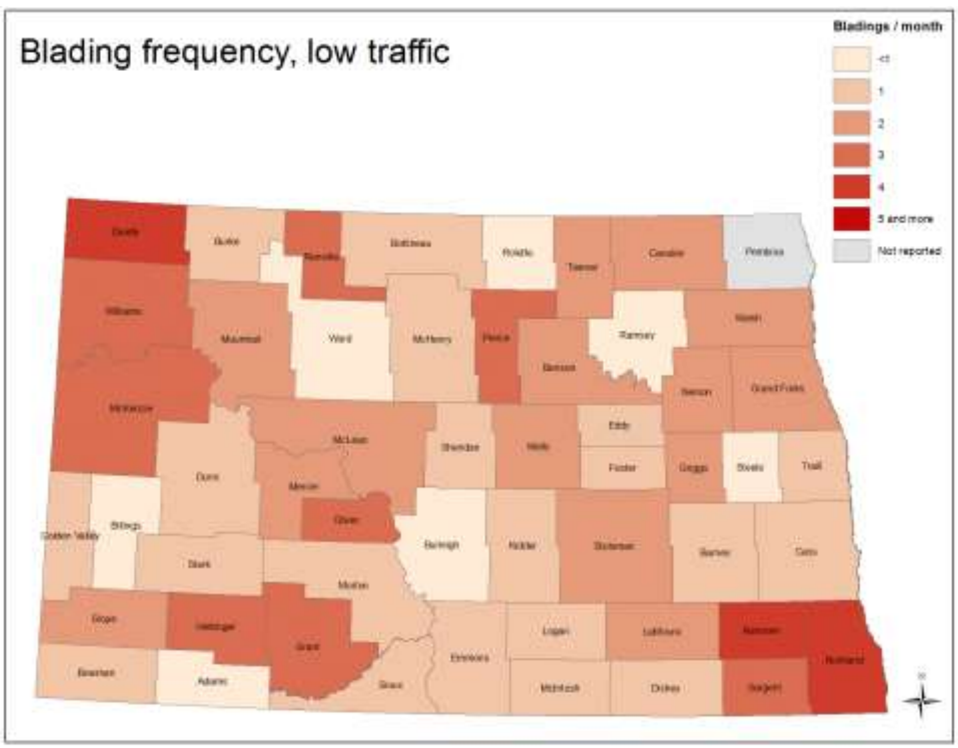


Figure D.9. Blading Frequency, Medium Traffic

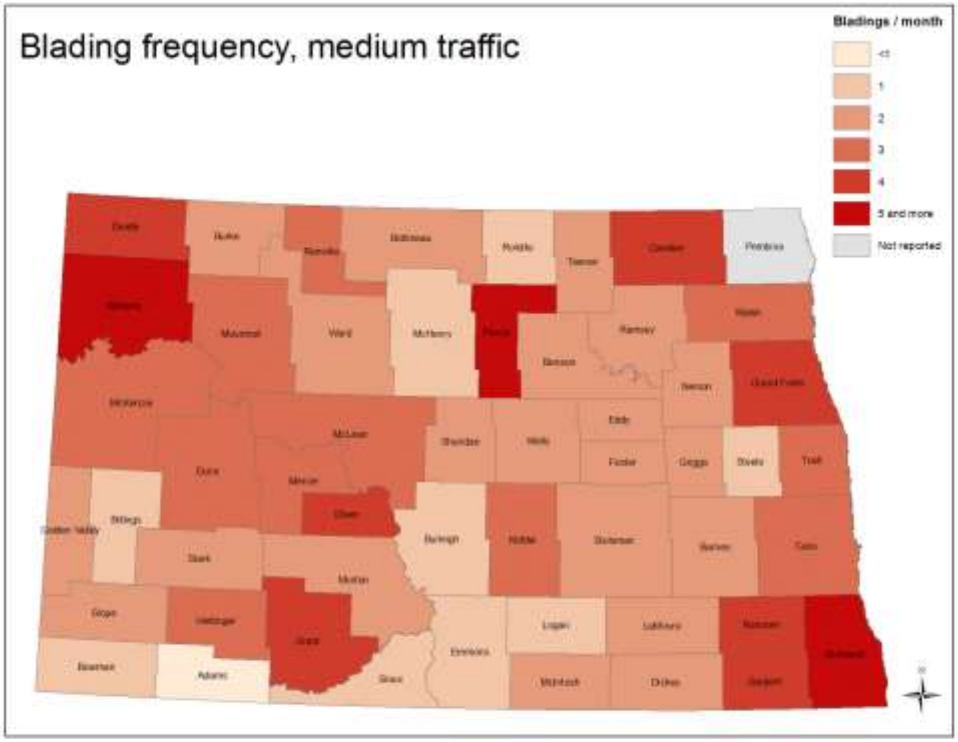


Figure D.10. Blading Frequency, High Traffic

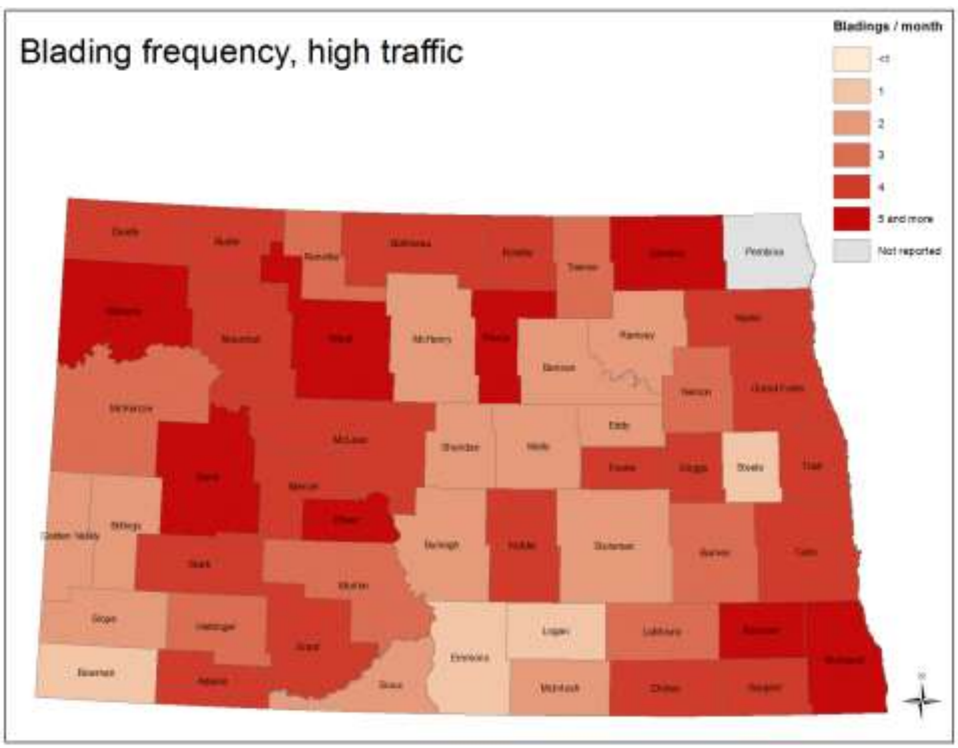


Figure D.11 Regraveling Thickness on Annual Basis, Low Traffic [6]

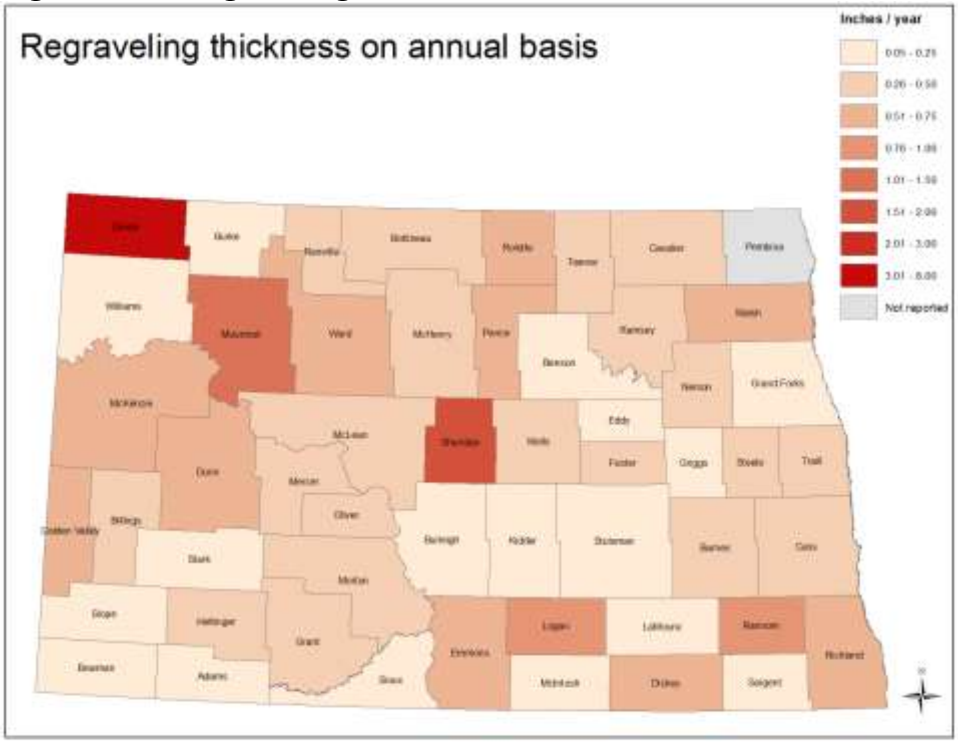
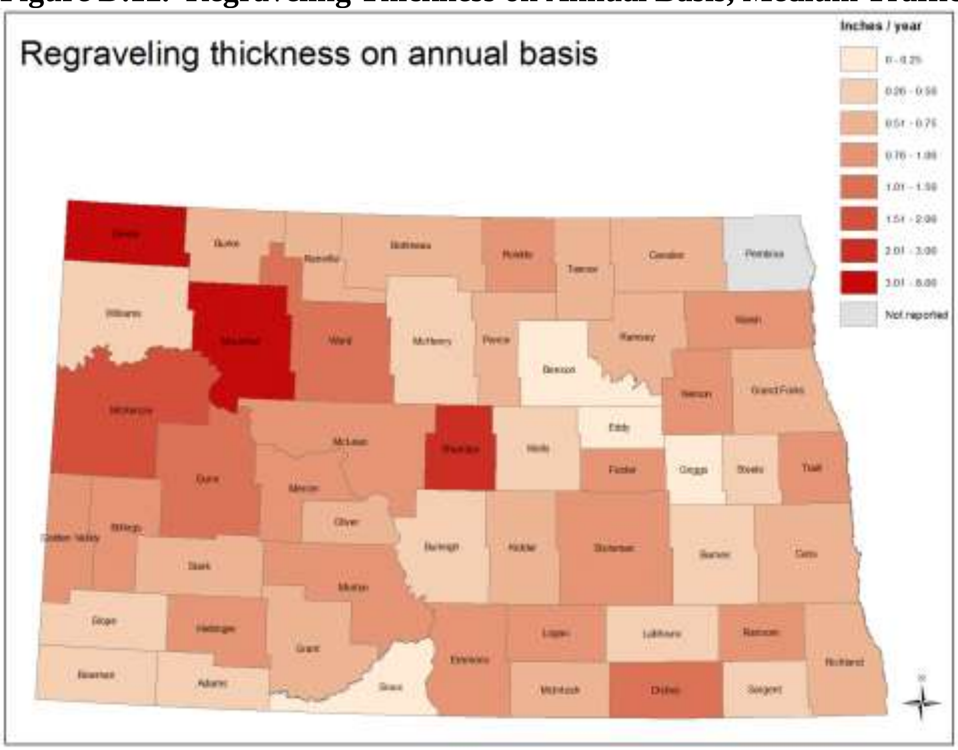
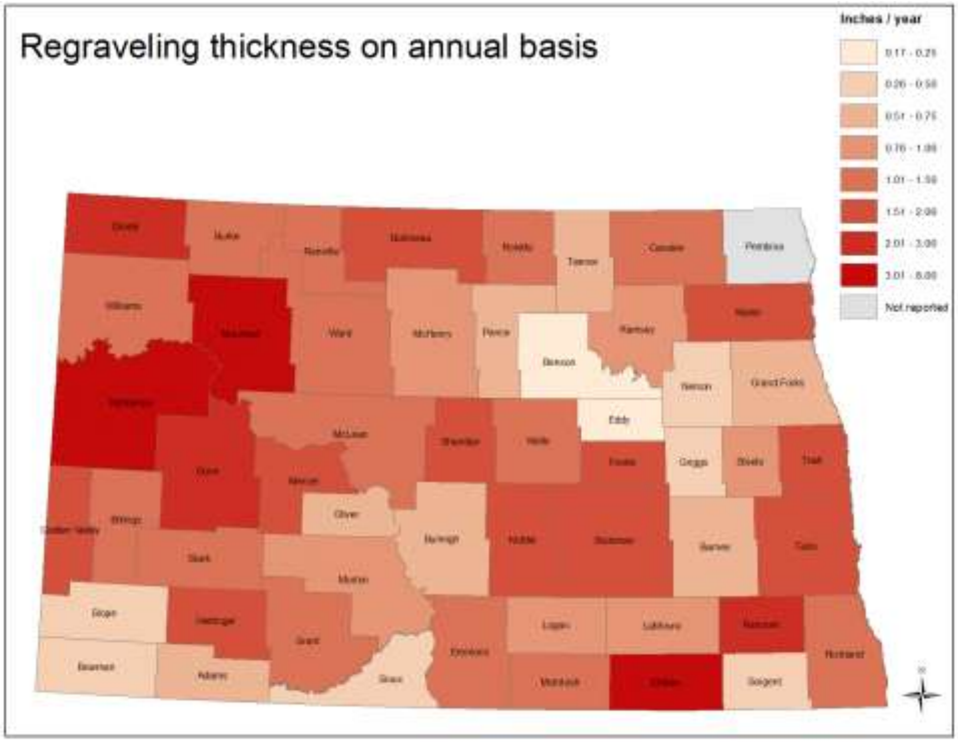


Figure D.12. Regraveling Thickness on Annual Basis, Medium Traffic



[6] Fig. D.11 – D.13 present the thickness of gravel placed during a single regraveling divided per regraveling frequency (measured in years).

Figure D.13. Regraveling Thickness on Annual Basis, High Traffic



15. Appendix E: Bridge Component Deterioration Models

Substructure Model

Substructure_Rating=8.3589+0.2510Prestressed_Concrete-0.4877Steel-0.5085Timber-0.9304Recon+0.7520Bismark+0.1572Devils_Lake+0.3660Dickinson+0.2881Grand_Forks+0.0525Minot+0.6307Valley_City+0.1990Williston-0.0518Age+0.0002Age2

LR Statistics For Type 3 Analysis			
Source	DF	Chi-Square	Pr > ChiSq
Type	3	223.97	<.0001
Recon	1	252.96	<.0001
District	7	196.84	<.0001
Age	1	256.04	<.0001
Age2	1	24.75	<.0001

Superstructure Model

Superstructure_Rating=8.0393+0.3359Prestressed_Concrete-0.4476Steel-0.5569Timber-0.7581Recon+0.6312Bismark+0.3162Devils_Lake+0.1894Dickinson+0.3757Grand_Forks+0.1725Minot+0.4235Valley_City+0.1819Williston-0.0283Age+0Age2

LR Statistics For Type 3 Analysis			
Source	DF	Chi-Square	Pr > ChiSq
Type	3	342.37	<.0001
Recon	1	221.15	<.0001
District	7	163.66	<.0001
Age	1	102.70	<.0001
Age2	1	1.30	0.2544

Deck Model

Deck_Rating=8.0943+0.1575Prestressed_Concrete-0.3962Steel-0.273Timber-0.5836Recon+0.8118Bismark+0.5385Devils_Lake+0.3048Dickinson+0.6069Grand_Forks+0.5606Minot+0.6936Valley_City+0.2470Williston-0.0457Age+0.0002Age2

LR Statistics For Type 3 Analysis			
Source	DF	Chi-Square	Pr > ChiSq
Type	3	109.51	<.0001
Recon	1	108.72	<.0001
District	7	241.40	<.0001
Age	1	211.86	<.0001
Age2	1	38.93	<.0001

Notes:
1) Material type: left-out variable is Concrete
2) District: left-out variable is Fargo

16. Appendix F: National Bridge Inventory (NBI) Bridge Status Definition

Entries are:

0: Non-deficient
1: Structurally deficient
2: Functionally obsolete

In order to be considered for either the structurally deficient or functionally obsolete classification, the first digit of Highway Route must be Route On Structure and Structure Length >= 20'.

Structurally Deficient

1. A condition rating of 4 or less for
    - Item 58 – Deck; or
    - Item 59 – Superstructures; or
    - Item 60 – Substructures; or
    - Item 62 – Culvert and Retaining Walls[1]

Or

2. An appraisal rating of 2 or less for
    - Item 67 - Structural Condition; or
    - Item 71 - Waterway Adequacy[2]

Functionally Obsolete

1. An appraisal rating of 3 or less for
    - Item 68 – Deck Geometry
    - Item 69 – Underclearances[3] ; or
    - Item 72 – Approach Roadway Alignment

Or

2. An appraisal rating of 3 for
    - Item 67 – Strucural Condition; or
    - Item 71 – Waterway Adequacy[7]

Any bridge classified as structurally deficient is excluded from the functionally obsolete category.

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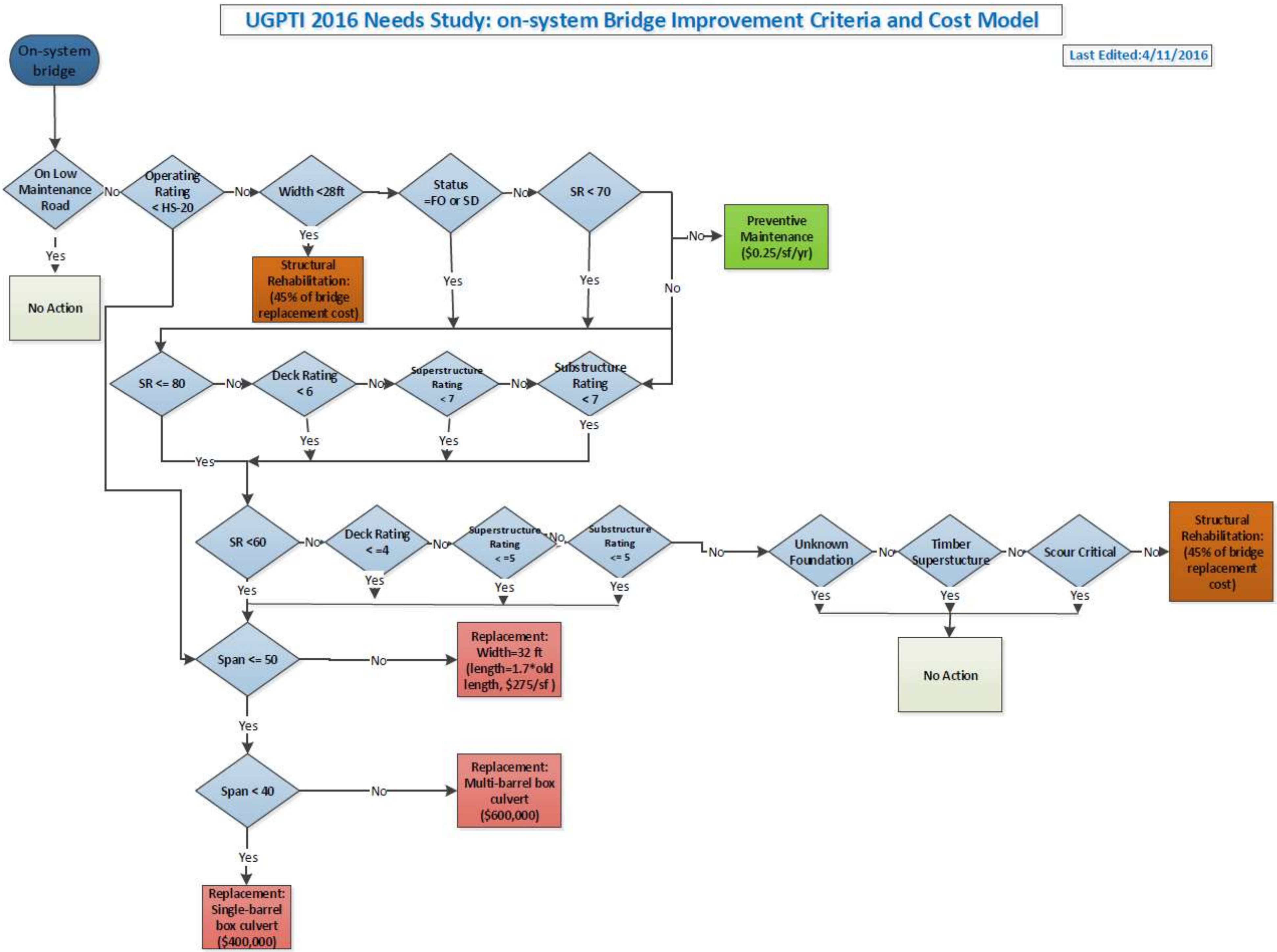
[1] Culvert and Retaining Walls (Item 62) applies only if the last two digits of Design Main (Item 42) are coded Frame or Culvert

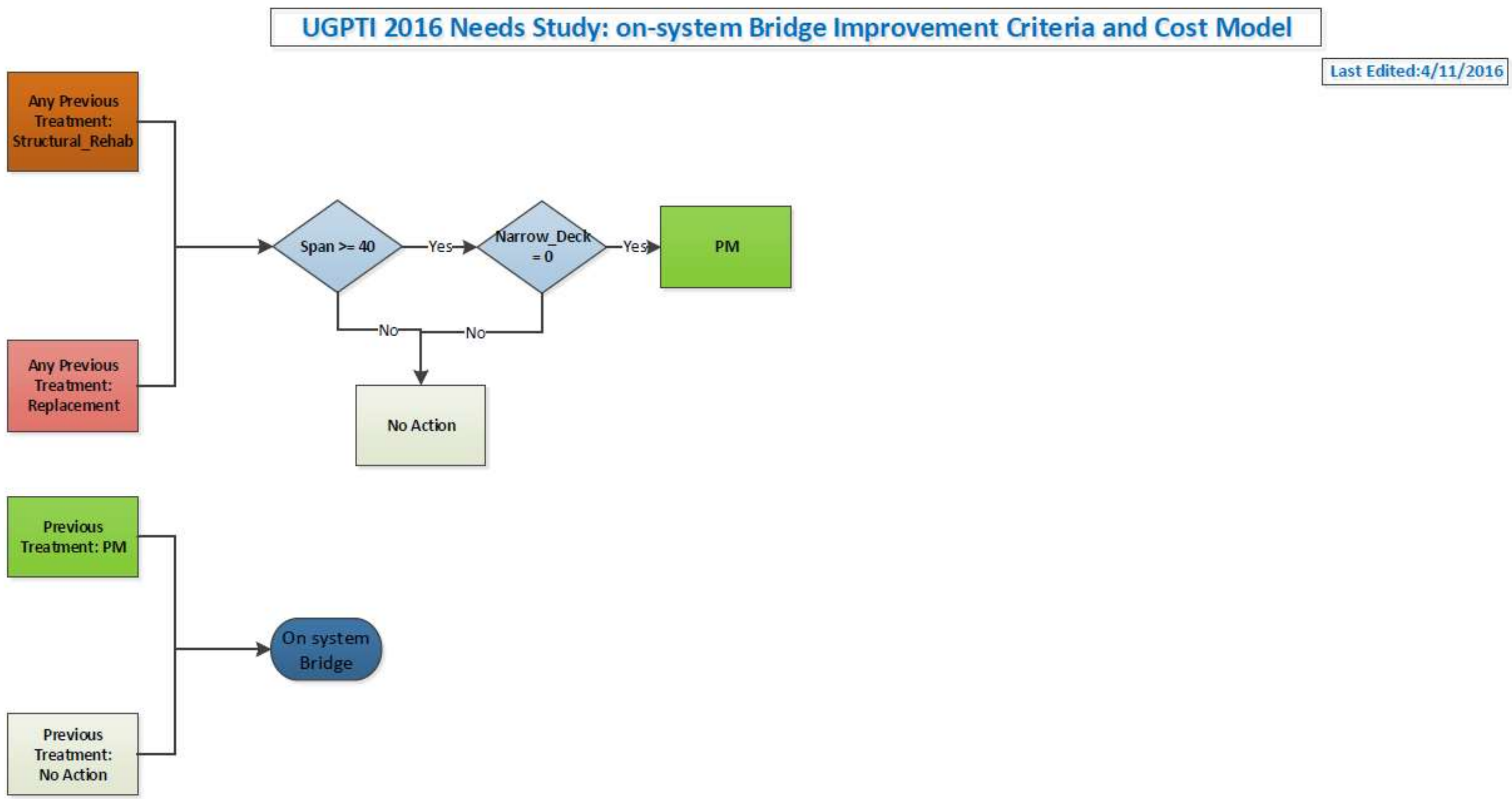
[2] Waterway Adequacy (Item 71) applies only if the last digit of Design Main (Item 42) is coded other (0), Waterway (5), Highway-Waterway (6), Railroad-Waterway (7), Hwy-Waterway-RR (8) or Relief for Waterway (9)

[3] Underclearances (Item 69) applies only if the last digit of Design Main (Item 42) is coded Other (0), Highway (1), Railroad (2), Highway-Railroad (4), Highway-Waterway (6), Railroad-Waterway (7) or Hwy-Waterway-RR (8)

17. Appendix G: Bridge Improvement Decision Model Flowchart

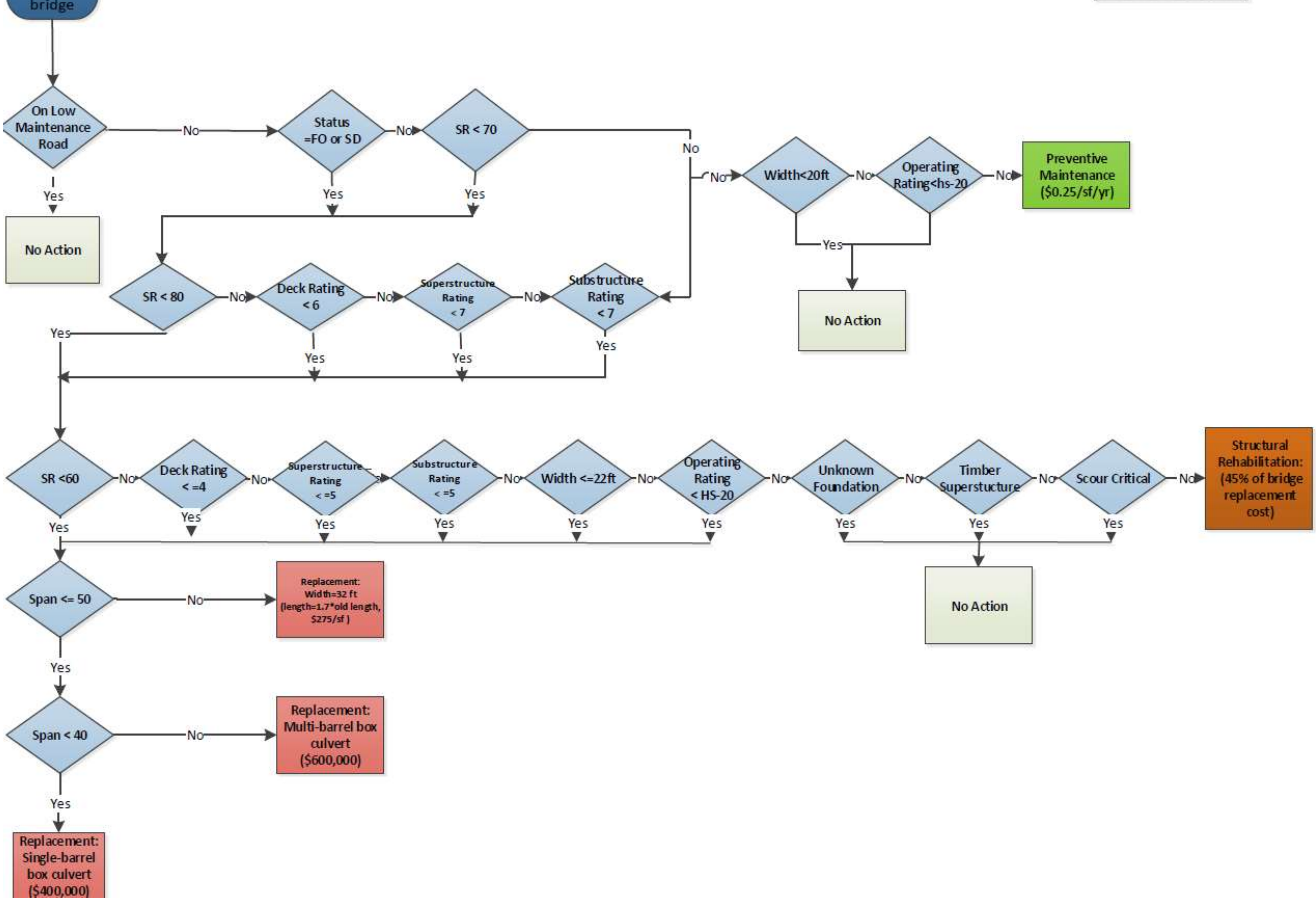


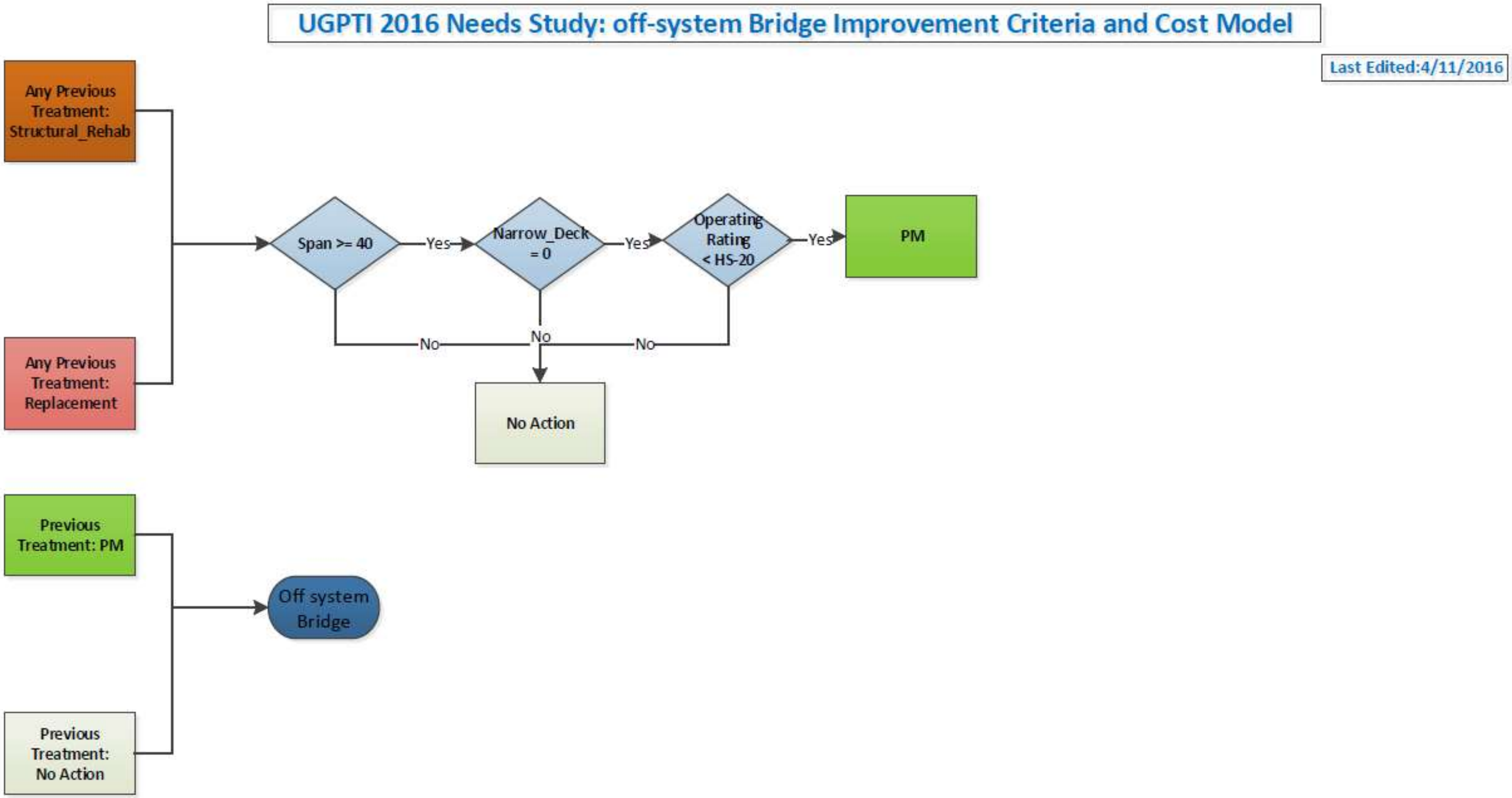
UGPTI 2016 Needs Study: on-system Bridge Improvement Criteria and Cost Model
Last Edited:4/11/2016
On-system bridge
On Low Maintenance Road
Yes
No Action
No
Operating Rating < HS-20
No
Width <28ft
Yes
Structural Rehabilitation: (45% of bridge replacement cost)
Status =FO or SD
No
SR < 70
Yes
Yes
No
Preventive Maintenance ($0.25/sf/yr)
No
SR <= 80
No
Deck Rating < 6
No
Superstructure Rating < 7
No
Substructure Rating < 7
Yes
Yes
Yes
Yes
SR <60
No
Deck Rating < =4
No
Superstructure Rating < =5
No
Substructure Rating <= 5
No
Unknown Foundation
No
Timber Superstucture
No
Scour Critical
No
Structural Rehabilitation: (45% of bridge replacement cost)
Yes
Yes
Yes
Yes
Yes
Yes
Yes
No Action
Span <= 50
No
Replacement: Width=32 ft (length=1.7*old length, $275/sf)
Yes
Span < 40
No
Replacement: Multi-barrel box culvert ($600,000)
Yes
Replacement: Single-barrel box culvert ($400,000)


UGPTI 2016 Needs Study: on-system Bridge Improvement Criteria and Cost Model
Last Edited:4/11/2016
Any Previous Treatment: Structural_Rehab
Any Previous Treatment: Replacement
Span >= 40
Yes
Narrow_Deck = 0
Yes
PM
No
No
No Action
Previous Treatment: PM
Previous Treatment: No Action
On system Bridge

UGPTI 2016 Needs Study: off-system Bridge Improvement Criteria and Cost Model

Last Edited:4/11/2016





UGPTI 2016 Needs Study: off-system Bridge Improvement Criteria and Cost Model
Last Edited:4/11/2016
Any Previous Treatment: Structural_Rehab
Any Previous Treatment: Replacement
Span >= 40
Yes
Narrow_Deck = 0
Yes
Operating Rating < HS-20
Yes
PM
No
No
No
No Action
Previous Treatment: PM
Off system Bridge
Previous Treatment: No Action

18. Comments Received and Action Taken

18. Public Input and Stakeholder Outreach:

Through-out the study, enhanced outreach efforts were made in order to improve necessary study data and to keep stakeholders informed. Following, the 2015 legislature, NDDOT hosted regional meetings to present to the counties how the legislative funding would be distributed. At these meetings, UGPTI was asked to present how it would approach the 2015-16 study. This information dissemination was important to for preparation of the new steps pursued by UGPTI staff.

With regard to gravel data, UGPTI staff worked with the Association of Counties to identify a panel of road managers from various counties to give advice toward an improved survey instrument. After developing the new survey instrument, several webinars were hosted by UGPTI Local Technical Assistance Staff (LTAP) to train county representatives in using the instrument. The webinar was recorded for later review.

The gravel survey instrument was sent to each county and information letters were also sent to the county auditor as well as the county commissioners. By the spring of 2016, all 53 counties had responded to this survey.

A similar survey was released to the association of townships at regional meetings. By the spring of 2016 approximate 650 townships had responded – nearly 50% of the organized townships.

The 2015 legislature had directed UGPTI to create an asset management process for improving data for future studies. UGPTI developed the Geographic Road Information Toolkit (GRIT) for the purpose of getting county pavement history data and for presenting to the counties the data that was collected for traffic and pavement condition.

The draft study was released for public comment on August 30, 2016. An announcement was sent out via the North Dakota Association of Counties to inform stakeholders of the draft study availability. The North Dakota Legislature was alerted through an email announcement from the UGPTI Advisory Council chair. The study document was posted on the UGPTI website and an email link was provided for accepting comments.

During the comment period, UGPTI received one comment via the email link. It was a request for clarification on one counties number of bridges. The issue was resolved by directing the county to another part of the report that showed tabular data versus just a pie chart.

To facilitate additional comments, UGPTI partnered with NDDOT to host 5 regional meetings in September and October. The meeting locations and attendance are as follows:

NDDOT/UGPTI County Road Study Regional Meetings

Dickinson – September 13, 2016

Jeff Baranko	Billings County
Vawnita Best	McKenzie County
Gary Brennan	Brosz Engineering
Dan Brosz	Brosz Engineering
Tommy Brown	KLJ
Richard Cayko	McKenzie County
Daryl Dukart	Dunn County
Alan Dybing	UGPTI
Jay Elkins	Stark County Commission
Kyle Frank	Slope County
Bryon Fuchs	NDDOT
Curt Glasoe	NDLTAP
Dale Heglund	NDLTAP
Al Heiser	Stark County
Neil Hofland	Bowman County
KC Homiston	Highlands Engineering
Justin Hyndman	KLJ
Jeff Iverson	Billings County
M Jaroszynski	UGPTI
Suhail Kanwar	McKenzie County
Andrew Krebs	KLJ
Pete Kuntz	Stark County
Nathan Miller	Bowman County
Todd Miller	Stark County
Mike Njos	Highlands Engineering
Dale Powell	Slope County
Andrew Schrank	Highlands Engineering
Brad Wentz	UGPTI
Pete Wirtzfeld	Golden Valley County
M Zimmerman	Dunn County

Stanley – September 14, 2016

Tim Arens	Ackerman-Estvold
Harry Bergstad	McHenry County Commission
Greg Boschee	Mountrail County
Gerald Brady	Divide County
Brian Brunner	McHenry County Commission
Scott Duerre	Mountrail County
Alan Dybing	UGPTI
Jeff Ebsch	Brosz Engineering
Lonnie Fleck	Interstate Engineering
Bryon Fuchs	NDDOT
K Fulsebakke	Bottineau County
Z Gaaskjolen	Brosz Engineering
Ritch Gimble	Bottineau County
Susan Hagen	Divide County
Bryan Haugenoe	Divide County
Jana Heberlie	Mountrail County
Dale Heglund	NDLTAP
Jim Hennessy	Mountrail County
Joan Holkem	Mountrail County
Kent Indvik	Wold Engineering
M Jaroszynski	UGPTI
Debbie Kuryn	Burke County Commission
A Langehaug	Renville County
Dana Larsen	Ward County
Don Longmuir	Mountrail County
Dennis Nelson	Williams County
Rory Nelson	ND Governor's Office
Trudy Ruland	Mountrail County Commission
Travis Schmit	Ward County
Kenny Tetrault	Burke County
Mary Trahan	Mountrail County
Garrett Volk	Mountrail County
Brad Wentz	UGPTI
Andrew Wrucke	UGPTI

Mandan – September 15, 2016

Mike Aubol Morton County
Denise Brown NDLTAP
Alan Dybing UGPTI
Bryon Fuchs NDDOT
Jim Grey McLean County
Marcus Hall Burleigh County
Dale Heglund NDLTAP
Tim Horner UGPTI
M Jaroszynski UGPTI
Nate Krikkorian Morton County
Kent Leben NDDOT
Michael Lawler Emmons County
Sharon Lipsh Walsh County
Lee Meier Hettinger County
Kenneth Miller Mercer County
Elroy Opp Mercer County
Keith Payne Grant County Commission
Michael Rivinius Wold Engineering
Don Roth Grant County Commission
Garlin Schmidt Emmons County
Jeri Schmidt Hettinger County
Dan Schriock Burleigh County
Mel Southard Wells County
Perry Turner McIntosh County Commission
Brad Wentz UGPTI
Andrew Wrucke UGPTI
Alton Zenker Grant County Commission

Devils Lake – September 28, 2016

Paul Bjornson KLJ
Les Ellingson Benson County
Leanna Emmer NDLTAP
Kevin Fieldsend Ramsey County
Bryon Fuchs NDDOT
Larry Halverson Towner County
Dale Heglund NDLTAP
M Jaroszynski UGPTI
Matt Johnson Wold Engineering
Terry Johnston Cavalier County
Luther Meberg Walsh County Commission
Jeff Pfau Eddy County Commission
Kevin Rinas Towner County
Steve Thompson Interstate Engineering
Mark Verke NDIRF
Terry Vote Towner County
Brad Wentz UGPTI
Andrew Wrucke UGPTI

Valley City – September 29, 2016

Mike Bassingthwaite Interstate Engineering
Megan Bouret UGPTI
Curtis Crowe Cass County
Damon DeVillers Interstate Engineering
Bryon Fuchs NDDOT
Ben Gates Steele County
Dale Heglund NDLTAP
Tim Horner UGPTI
Michael Jaroszynski UGPTI
Kerry Johnson Barnes County
Matt Lange KLJ
Corwyn Martin Trail County
Shawn Mayfield KLJ
Myron Moteberg Steele County
Wayne Oien Griggs County
Jesse Sedler Interstate Engineering
Kitty Showers Trail County
Richard Sieg Cass County
Jamie Smith Barnes County
Mark Verke NDIRF
Brad Wentz UGPTI
Nick West Grand Forks County
Lauren Worrel Lamoure County
Andrew Wrucke UGPTI

Various questions and comments were raised at the regional meetings. The comments and responses are shown in the following table:

Regional Meetings - UGPTI County Roads Needs study comments & feedback

Location	**Comment**
8/31 via email	This email has website link to UGPTI study and it shows zero dollars needs for McKenzie County bridges which baffles me since we have been spending large sums of money on improving and repairing our bridges. Any help with this matter will be greatly appreciated. UGPTI Response: McKenzie County was referring to the pie chart – not the table of values and the pie chart was not able to clearly depict the bridge amount as bridges were so much smaller than the large pavement and gravel needs of McKenzie county. This was explained to McKenzie County at the Dickinson regional meeting.
9/13 Dickinson	Overall feeling: the report provides a statewide snapshot and shows counties are better off if we aggregate the effects at the state level, but individual counties feel differently. This was discussed at the regional meeting and was referring to the slide that showed that pavement ride and condition had improved on a statewide basis but the responder wanted it know that this may not apply to every county.
9/13 Dickinson	How are you measuring wind farm impacts vs. oil impacts? UGPTI responded that wind farm impacts are not being studied as they are of such short duration and difficult to model with respect to roads and routing.
9/13 Dickinson	Are projects from the current year (2016) included in this study? UGPTI responded that they are if they have been made know to NDDOT.
9/13 Dickinson	Is gravel one of the commodities for trucks considered by the model? UGPTI responded that gravel hauling is not considered in the model due to sporadic and unpredictable nature of gravel hauling.
9/13 Dickinson	Instead of 30-60-90 rig scenarios, consider doing a study for $30-$60-$90/barrel oil price. Oil activity is limited to only a small part of the state. Highly affected areas should be subsidized. Legislature should be aware that there is still a lot of oil-related traffic despite production decline. UGPTI agreed that oil traffic remains high in the “oil patch” in Western N.D. In the terms of scenarios, it is easier to determine traffic generated by oil activity using the number of operating rigs than relying on oil barrel price. Oil rigs are located in certain places, and we can predict their future locations along with the associated traffic. Simultaneously, there is no straightforward relationship between oil price and traffic levels, as the volume of oil production could vary within the same barrel price. In addition, UGPTI depends on ND Oil and Gas to predict oil rigs and they predict rigs more so than price.
9/13 Dickinson	We’d like to get more details on what other counties are doing in the terms of gravel road maintenance, i.e. what are their procedures/requirements on roads with heavy traffic

	UGPTI pointed to the final report, which will include much more detailed information than the tables presented during the meetings. Additionally, all county survey responses will be posted online.
9/13 Dickinson	Is there consideration to send more dollars to western counties? How are we going to make sure that funding is equitable? UGPTI responded that this report should provide a clear idea of the current needs and serve as the guideline for allocating funds across particular regions.
9/14 Stanley	Does the study provide any implications in the terms of future paving – does the study suggest that the most heavily utilized gravel roads should be paved? UGPTI explained that the paving upgrades were not considered by the study; however, it is suggested that each county would evaluate the benefits and costs of paving roads that fall into the high and very high traffic categories. Pavement and maintenance costs are varied by county, and therefore, the cost threshold for justifying converting gravel into asphalt surface is different for each county.
9/14 Stanley	How do we choose what is considered low/medium/high traffic in the gravel road survey? UGPTI responded that each county could designate the L/M/H traffic levels at its own discretion, depending on the observed traffic levels. We suggest using your own judgement and adopting ranges distinguishing heavy traffic roads from others.
9/14 Stanley	Please note that there is a difference between our needs vs. our funding abilities in the terms of road maintenance. We want and need to do blading and regraveling more frequently, but we can't afford it. The study should clearly indicate that counties' needs exceed their financial constraints. UGPTI explained that one of the study's major purposes is to collect the data on maintenance practices, and determine whether they correspond with the actual needs, based on the observed traffic levels. Funding additional maintenance activities depends on resource availability and decisions made by the Legislature.
9/14 Stanley	What about township surveys – did they receive the same survey? Were the responses published anywhere? We want to know which townships responded. We don't want to have a situation where a township ignores the survey, and that affects our funding! UGPTI clarified that townships received a simplified, shorter version of the survey. The response rate was approximately 45%. UGPTI plans to publish the responses online. The county surveys serve as the primary source of information and funding should not be affected by low response rates among townships.
9/14 Stanley	What is the inflation factor for the prices included in the study? UGPTI responded that all prices in the report are given at 2016 level
9/14 Stanley	We have seen that prices slightly decreased, but now there is no competition among contractors. We're paving less and less, so they are not interested. Therefore, prices are higher again… as they make up their losses.
9/14 Stanley	This study was started by NDAOGPC – sometimes we lose track of they do for us… This report now serves as a "state bible" for the legislators.

9/14 Stanley	How do you calculate overlay thickness? UGPTI pointed to specific pages of the Study Report, which explains the methodology.
9/14 Stanley	Do you track the information on prices/ expenses reported by counties to NDDOT? *(that was a question to NDDOT and NDDOT responded that they do track prices on project components)*
9/14 Stanley	Burke County: specific comments regarding missing/incorrect numbers in paved road statistics UGPTI updated the data for Burke Co.
9/15 Mandan	Change in pavement condition, is the data correct? UGPTI confirmed the accuracy of the presented data.
9/15 Mandan	The condition of pavement data seems to be collected on light-traffic roads…. Although that might be also a statewide average. UGPTI confirmed that the data is summarized and aggregated at the state level; numbers for specific counties may be significantly different.
9/15 Mandan	Where did you get the data for bridges? UGPTI responded that bridge data was taken from the National Bridge Inventory and the NDDOT bridge inventory.
9/15 Mandan	What about minor structures, are they considered? UGPTI clarified that the study does not consider bridges with total span length less than 20 ft, as well as bridges on trails and unimproved roads. Box culverts are also excluded from consideration. It is hoped to include minor structures in future studies based on UGPTI entering of past minor structure data into GRIT and individual counties updated that data. Minor structures have not tracked by NDDOT since the 1980's
9/15 Mandan	Bridge map: we have 57 major + 59 minor structures, but there are only 36 on the map… What about the rest? As above – smaller and minor structures were not considered by this study.
9/28 Devils Lake	What is the difference between a rig and a well? UGPTI explained the difference (a rig is a device used to drill oil wells)
9/28 Devils Lake	Few basic questions about using GRIT. UGPTI staff responded to all specific questions regarding GRIT and explained how to use GRIT.
9/29 Valley City	Was there any discussion of creating a bridge fund? UGPTI responded that they haven't not heard any such discussions.
9/29 Valley City	If we conduct maintenance, do we need to update the information in GRIT? If we overlay the road, will it override the data? We paved the road but it still shows up as gravel in GRIT, why? UGPTI confirmed that any changes of the road characteristics resulting from maintenance or other reasons or should be updated in GRIT. UGPTI handled the specific issue of data inconsistency with the county.

9/29 Valley City	Is the GRIT a project document? UGPTI explained that GRIT is a planning document.
9/29 Valley City	How do we print reports from GRIT? UGPTI responded that GRIT is unable to print reports at this moment. Print function can be used only for printing maps.
9/29 Valley City	Could we enter data to GRIT on-site using a phone? Will the phone automatically add X-Y coordinates? UGPTI responded that GRIT is designed to be used on mobile devices. GRIT can retrieve the coordinates using the device GPS.
9/29 Valley City	GRIT: please remember that smaller counties are less computer-savvy! UGPTI reminded all participants about the resources provided for GRIT users, including webinars, online manuals, and individual guidance available from UGPTI staff via phone or email.

Some counties provided updated pavement data after the regional meeting. This resulted in a net increase of approximately 33 miles of pavement that was added to the study statewide database. Counties with updated mileage included Bottineau, Logan, Mountrail, Pembina, Stark, and Traill.

The pavement analysis was performed with these changes and overall tables were updated in the report accordingly.