NDSU UPPER GREAT PLAINS TRANSPORTATION INSTITUTE

Infrastructure Needs: North Dakota's County, Township and Tribal Roads and Bridges: 2015-2034

Draft Final Report to the North Dakota Legislative Assembly

July 8, 2014

Summary of Study

This report responds to the North Dakota legislature's request for a study of the transportation infrastructure needs of all county and township roads in the state. In this report, infrastructure needs are estimated using the most current production forecasts, traffic estimates, and roadway condition data available. Agricultural and oil-related traffic 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 their Pathways van, which utilizes scientific instruments 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 for calibration of a statewide travel demand model, which was used to forecast future traffic levels.

A detailed Geographic Information System (GIS) model has been developed by the Upper Great Plains Transportation Institute for the entire state using the Citilabs Cube suite of software. The GIS 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.

Using the GIS model, inputs and products are routed to and from wells to minimize time and/or cost, subject to available supplies and capacities. An analogous model is used to predict the trips of each crop produced in each township to elevators and/or processing plants, subject to the demands of these facilities. When all trips have been routed, the individual movements over each road segment are summed to yield the total truck trips per year. Using truck characteristics and typical weights, these trips are converted to equivalent axle loads and trips per day. These two factors, in conjunction with the condition ratings and structural characteristics of roads, are used to estimate the improvements and maintenance expenditures needed for the expected traffic. While the focus is on agricultural and oil-related activities, other movements (such as farm inputs and shipments of manufactured goods) are included in the analysis through the use of baseline estimates derived from 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 increase as traffic volumes grow. For example, a non-impacted road has an expected gravel cycle of five years and a blade interval of once per month, while an impacted section has an expected gravel cycle of two to five years and a blade interval of twice per month. The effective difference is a doubling of the gravel maintenance costs over the same time period.

As shown in Table A, the predicted statewide infrastructure needs are $5.45 billion for the next 20 years. Approximately 54% of these needs can be traced to the 17 oil and gas producing counties. The estimated needs for the 2015-2016 biennium reflect the reconstruction and conversion of a limited number of miles of unpaved roads with more than 500 projected truck trips per day to paved road surfaces.

Table A: Summary of Unpaved Road Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2014 Dollars)

Period	Statewide	Oil Patch	Rest of State
2015-16	$606	$358	$249
2017-18	$548	$299	$249
2019-20	$548	$299	$249
2021-22	$546	$297	$249
2023-24	$542	$293	$249
2025-34	$2,668	$1,423	$1,245
2015-34	**$5,457**	**$2,968**	**$2,489**

Paved Road Needs

As shown in Table B, $2.59 billion in paved road investment and maintenance expenditures will be needed during the next 20 years. Roughly 43% of these expenditures will be needed in the oil and gas producing counties of western North Dakota. Much of the investment will be needed during the first few bienniums as a result of backlogs in road improvements.

Table B: Summary of Paved Road Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2014 Dollars)

Period	Statewide	Oil Patch	Rest of State
2015-16	$377	$186	$191
2017-18	$323	$120	$203
2019-20	$285	$158	$127
2021-22	$236	$133	$103
2023-24	$138	$52	$86
2025-34	$1,326	$513	$812
2015-34	**$2,685**	**$1,162**	**$1,522**

Total Statewide Needs

As shown in Table C, the combined estimate of infrastructure needs for all county and township roads is $8.1 billion over the next 20 years. Half of this estimate relates to projected needs in the oil and gas producing counties of western North Dakota. Unpaved road funding needs comprise approximately 67% of the total. If averaged over the next 20 years, the annualized infrastructure need is equivalent to $407 million per year.

The values shown in Tables A-C 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 C: Summary of All Road Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2014 Dollars)

Period	Statewide	Oil Patch	Rest of State
2015-16	$983	$544	$440
2017-18	$871	$419	$452
2019-20	$833	$457	$376
2021-22	$782	$430	$352
2023-24	$680	$345	$335
2025-34	$3,994	$1,936	$2,057
2015-34	**$8,142**	**$4,130**	**$4,011**

Contents

1. Introduction

In response to a request from the North Dakota Legislature, NDSU's Upper Great Plains Transportation Institute (UGPTI) has 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. The results of both studies were presented to the legislature in January of 2011.

The 2010 study was based on forecasts of increased agricultural production and the addition of 21,500 oil wells over the study timeframe. However, these forecasts quickly became outdated, necessitating a second statewide study in 2012—the results of which 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 (2014) 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 2015-2016 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 in the future 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. For ease of description, these three systems are referred to collectively as local roads. However, 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

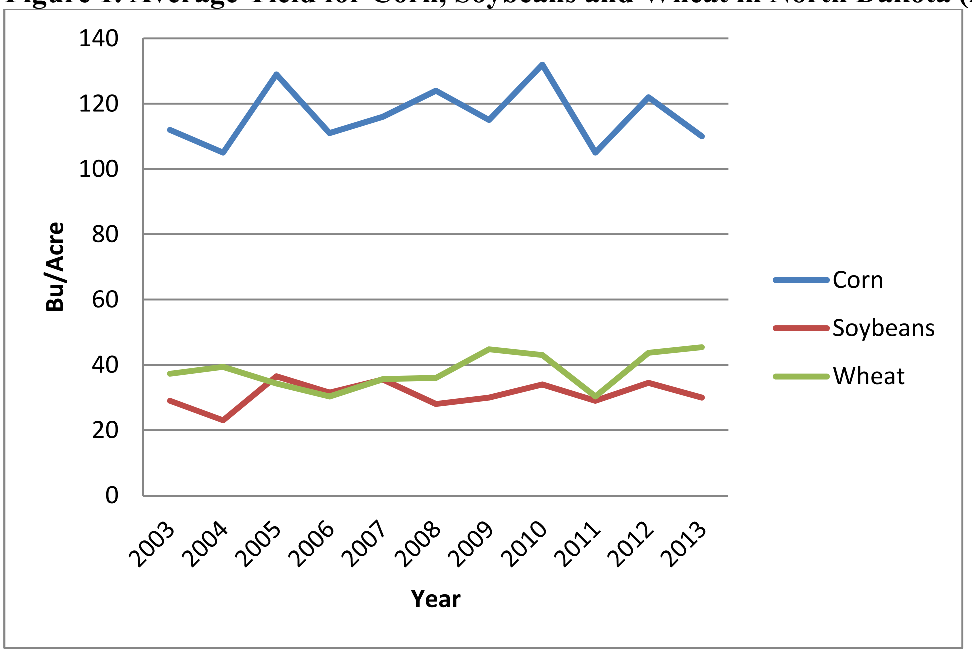
Over the last decade, North Dakota's, local road systems have seen significant changes in traffic patterns, not only in terms of volumes, but also in terms of clustering due to changing land use and the consolidation of transload locations. This section describes major trends in agriculture and oil development 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 due to a variety of factors including: increases in technology, genetically modified varieties, and improved farming practices. 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 (2003-2013)



From year to year, there are significant yield variations which are primarily due to changes in weather, but the overall trend is an increase in yield for all three crops. A trend line analysis of the three crops shows an annual average increase in yield of 2% for corn and soybeans and 4% for wheat.

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 2013, the average statewide yield for wheat was roughly 45 bushels/acre. For soybeans, the average yield was 30 bushels/acre. Corn yield was 110 bushels/acre. Any shift in wheat acreage to corn would represent a 144% increase in yield on average. A shift in soybean acreage to corn would represent a 266% 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 2003 to 2013. 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 (2003-2013)

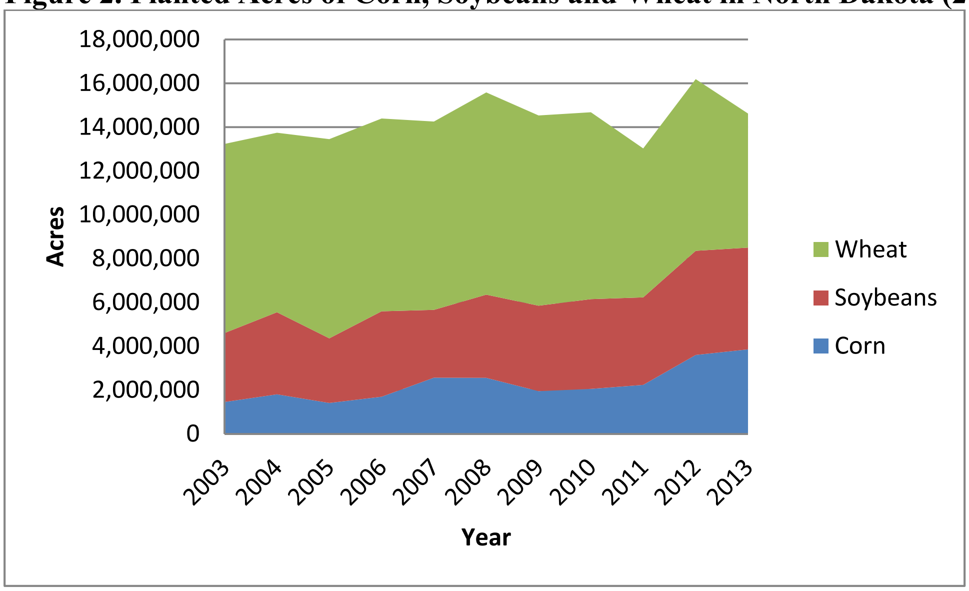
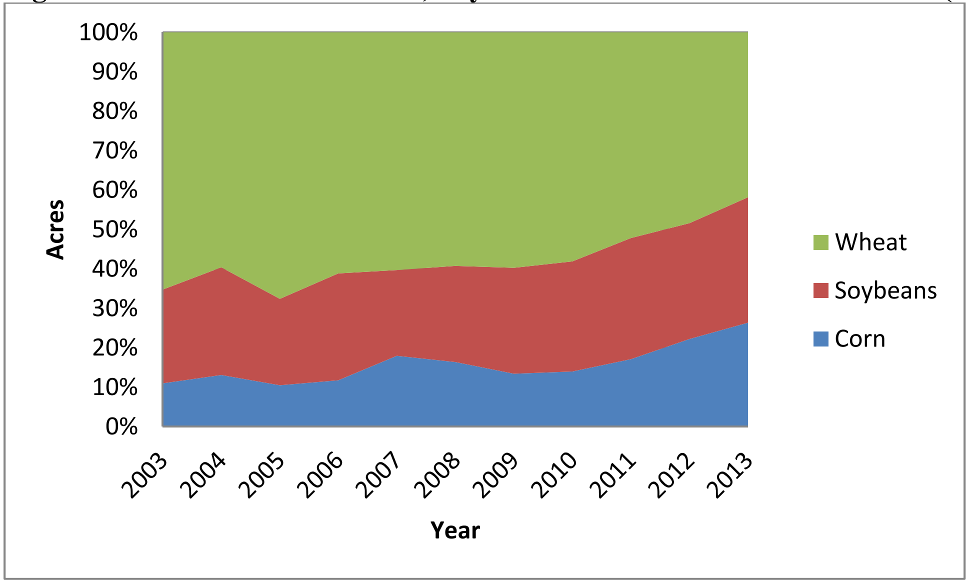


Figure 3 breaks the acreages down by percentage. At the beginning of the period, wheat was planted on nearly 65% of the corn, wheat and soybean acres, soybeans on 25%, and corn on 10%. In 2013, wheat was planted on 41%, soybeans on 31% and corn on 26% of these acres. For reference, in 2013, corn, wheat, and soybeans were planted on 14.6 million acres in North Dakota, which is 72% of all acres planted in North Dakota.

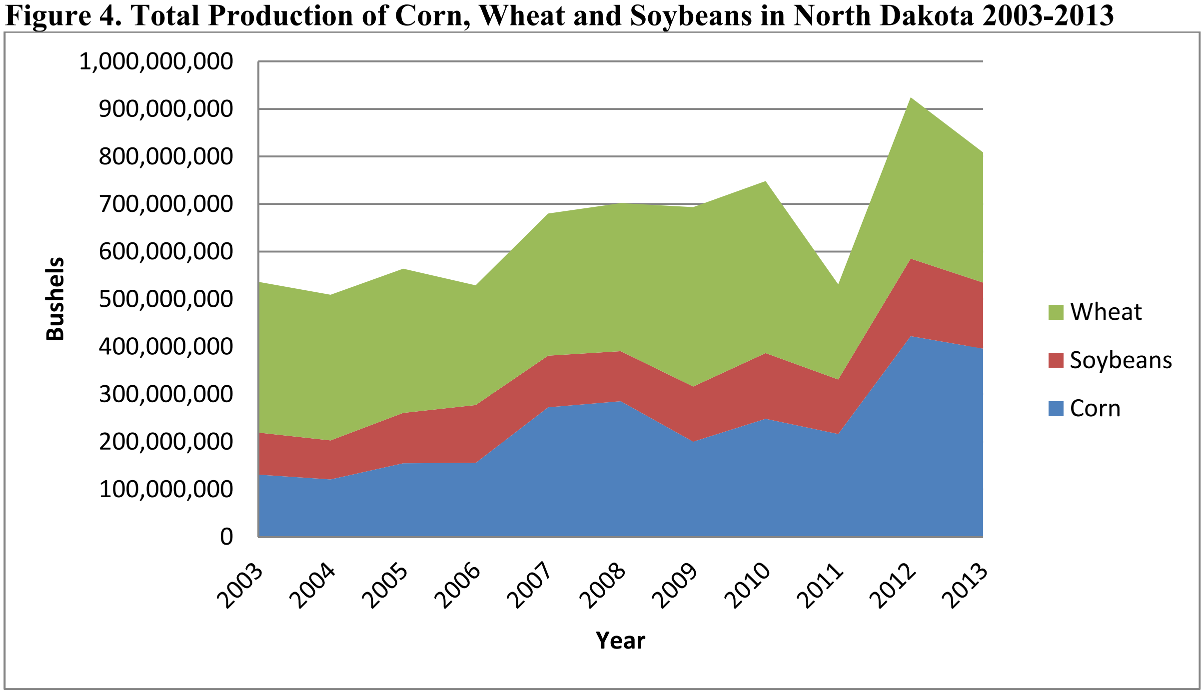
Figure 3. Percent Acres of Corn, Soybeans and Wheat in North Dakota (2003-2013)



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 550 million bushels of corn, wheat and soybeans in 2003 to 800 million bushels in 2013. Excluding 2011's weather related decrease, there is a readily observable upward trend in overall production.

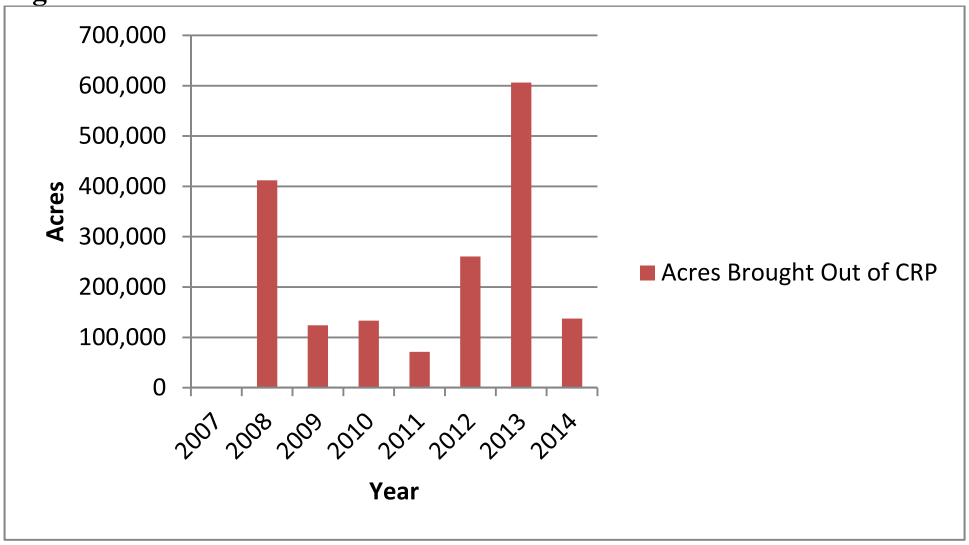
Figure 4. Total Production of Corn, Wheat and Soybeans in North Dakota 2003-2013



2.1.4. Conservation Reserve Program

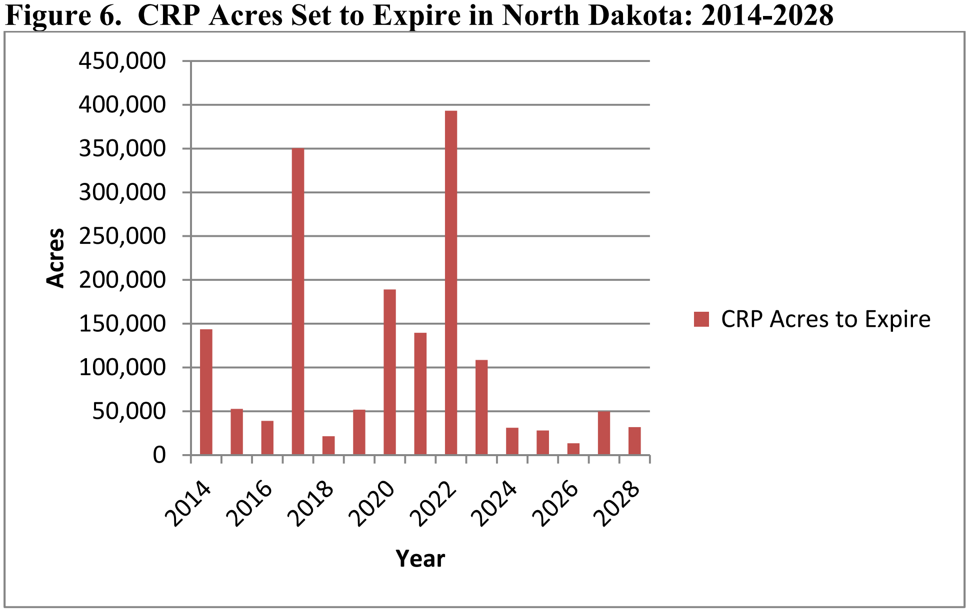
As the farm economy has been positive recently, many North Dakota producers have chosen not to re-enroll acres in the Conservation Reserve Program (CRP). As a result, previously enrolled acres went back into production, thereby increasing truck traffic in areas which, for the recent past, had seen virtually 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



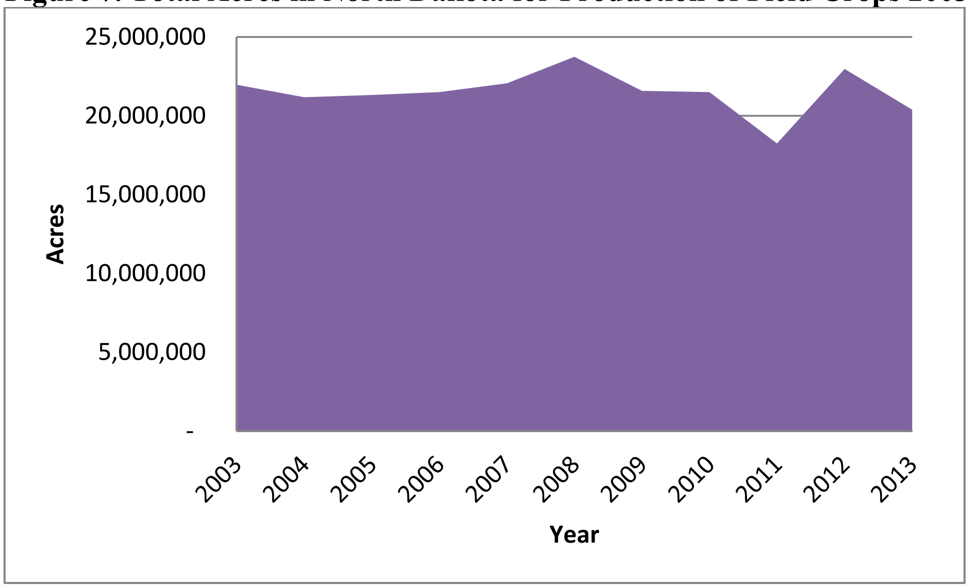
According to the Farm Service Agency, from 2007 to 2014, 1.74 million acres have come out of the CRP in North Dakota. Over the next 10 years, contracts on an additional 1.6 million acres are set to expire. Figure 6 shows the expirations by year through 2028.

Figure 6. CRP Acres Set to Expire in North Dakota: 2014-2028



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 that were 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 2003-2013



2.1.5. Elevator Throughput

Since the mid 1990's there has been an increase in the number of 100+ car grain elevators known as shuttle elevators. 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 volumes of grain marketed at their facilities. In 2002, there were 15 shuttle car elevators in North Dakota. By 2012, there were 54 shuttle elevators in the state. A comparison of the numbers of elevators by shipment categories is shown in Table 1.

Table 1. Elevator Types in North Dakota, 2003 and 2013

Elevator Type	2003	2013	Change
No Rail (0 Car)	41	26	-15
Single (1-25 Cars)	120	112	-8
Multi Car (25-52 Cars)	73	55	-18
Unit (52-100 Cars)	87	45	-42
Shuttle (100+ Cars)	15	54	39
All Types	**336**	**292**	**44**

Over the last decade there has been a decline in the numbers of all types of elevators, with the exception of shuttle elevators—which show nearly a three-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 2003 and 2013 respectively, and is taken directly from the Annual Elevator Marketing Report for the corresponding years.

Figure 8. Elevator Throughput by Elevator Class: 2003

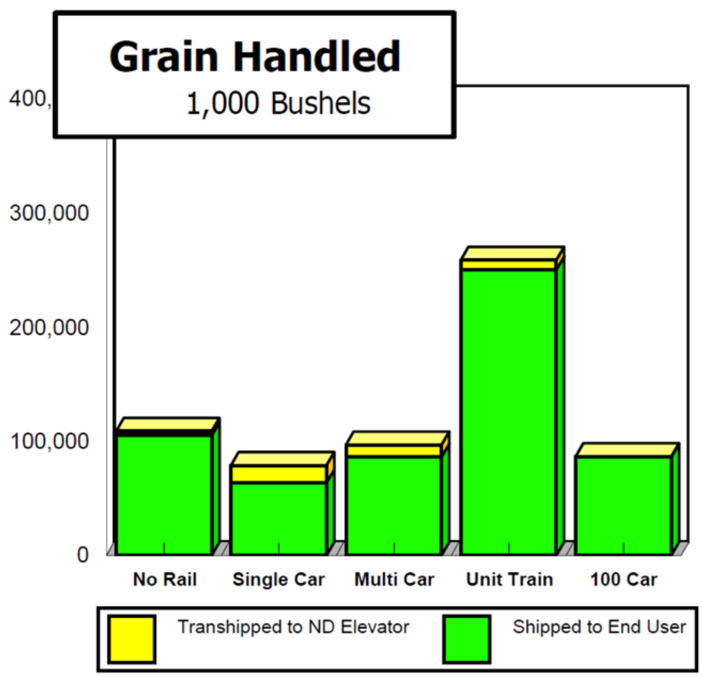
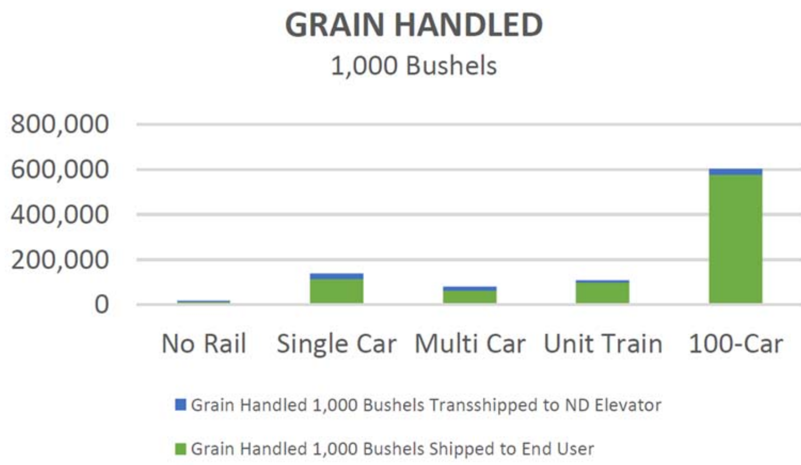


Figure 9. Elevator Throughput by Elevator Class: 2013



As these figures show, a substantially larger percentage of grain was marketed through shuttle elevators in 2013 than in 2003, a change that has an impact on the local road system throughout the state. For example, in 2003, unit and shuttle train elevators marketed roughly 350 million bushels of grain. At that time the combined number of facilities in those two classes was 102 elevators. In 2013, roughly 600 million bushels of grain were marketed through shuttle elevators which represent just 54 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 may have also seen 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

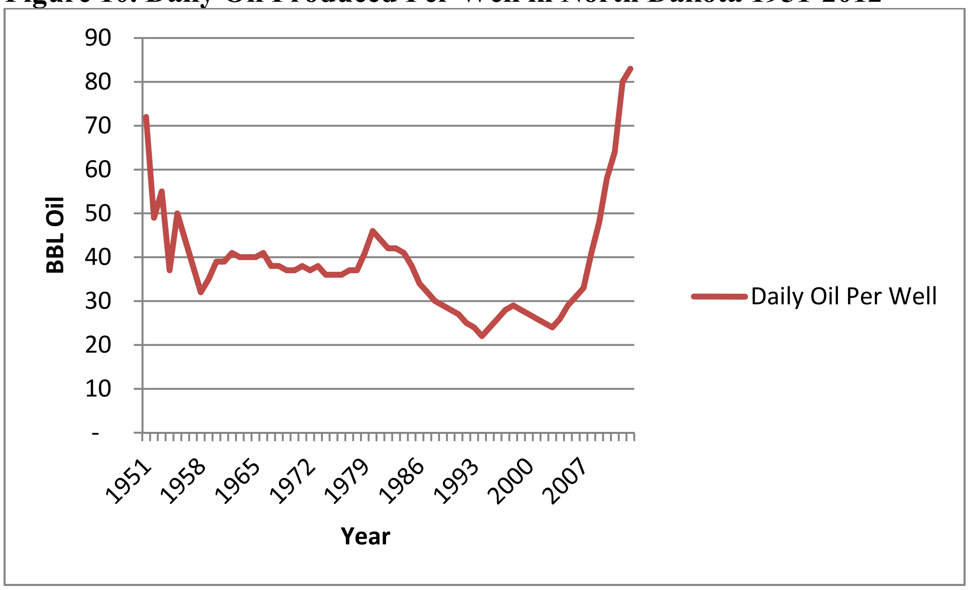
The current oil boom in North Dakota came about as a result of improved technology in oil exploration and extraction. Two primary technological advances have led to increased productivity within the Bakken/Three Forks formations: horizontal drilling and hydraulic fracturing.

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 that are 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.

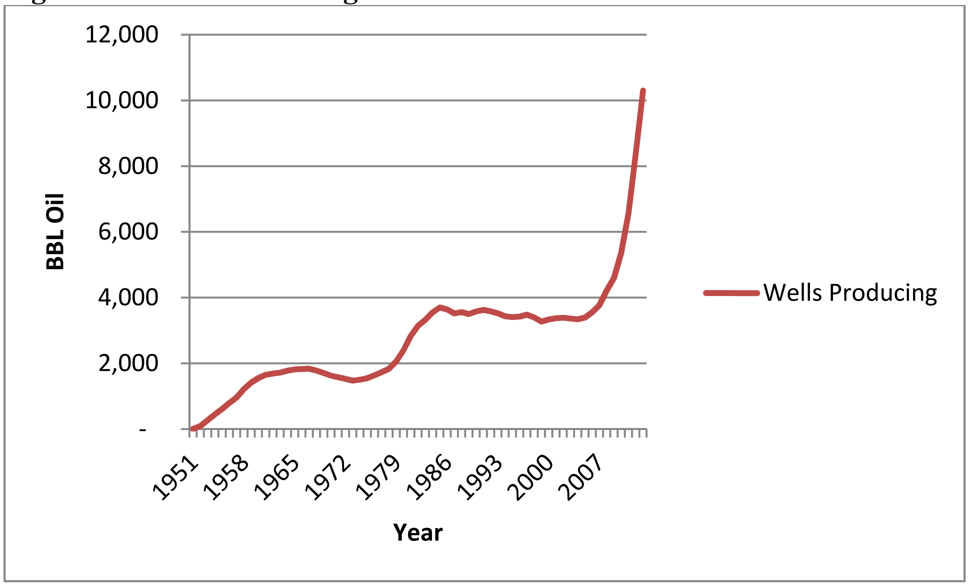
Figure 10. Daily Oil Produced Per Well in North Dakota 1951-2012



2.2.3. Total Number of Wells

The 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 shown in Figure 11. From the late 1970s until mid-2000's the number of producing wells remained relatively constant. With the technological advances in exploration and extraction, the number of producing wells has increased exponentially.

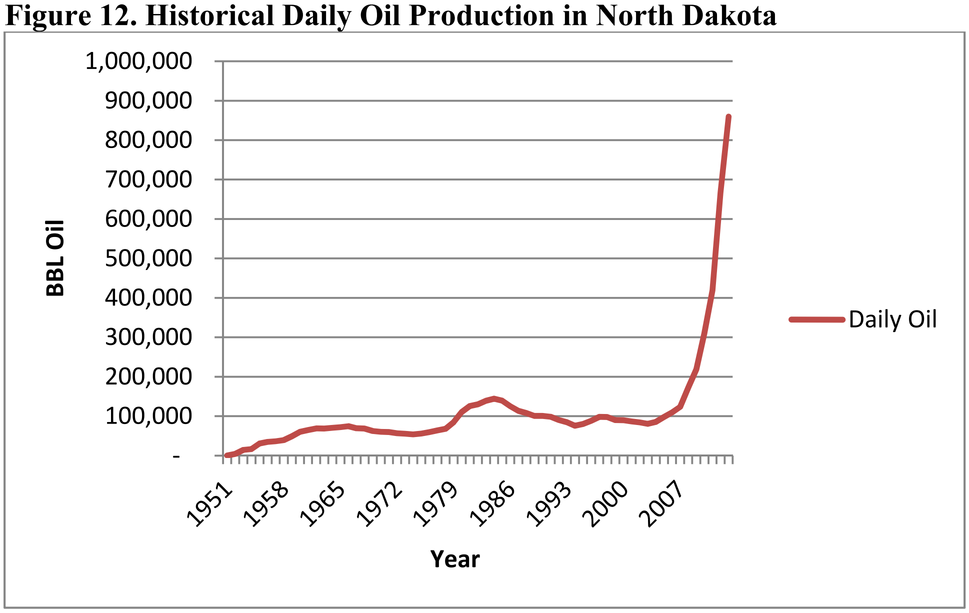
Figure 11. Total Producing Oil Wells in North Dakota: 1951-2012



2.2.4. Total Production

As outlined previously, the 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 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 a range of 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 2010. County level data is not sufficient for use in a traffic model as it is too aggregated to accurately assign traffic to individual roadways, especially at the county level. To further disaggregate this data, the United States Department of Agriculture's (USDA) Crop Data Layer (CDL) was utilized.

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

In this study, NASS county level data is used to approximate sub-county level yield and production rates. For example, if a township is located within Barnes County, the Barnes County average wheat yield is used to approximate the actual township yield. The end result of these processes is the total production by crop for each township in the state. 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 acreages set to expire by year, so 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's (NDPSC) licensed elevator report. Throughput information was obtained from the NDPSC Grain Movement Database, which provides the quantity of each commodity shipped through an elevator by mode and destination.

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.

Each of the 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 Spacing Unit

As a result of discussions with the Oil & Gas Division, the total number of wells per spacing unit is assumed to be 8-12. This number assumes two pads with 4-6 wells per pad per spacing unit.

3.2.3. Well Forecasts

Annual forecasts of new wells were obtained from the Oil & Gas Division of the North Dakota Department of Mineral Resources. In presentations given by Director Lynn Helms, individual county forecasts by year were presented. These county level forecasts are used as a basis for the spatial distribution of new wells described in the next section. The number of wells per year included in the model is presented in Table 2. The number of wells represents the number producing at the midpoint of each 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.

Figure 13 shows the clustering of existing wells in 2014. Green spacing units represent undrilled units, and red units represent units that have completed drilling. The intermediate colors represent spacing units at various stages of development.

Table 2. Total Number of Producing Wells Projected for the Analysis Period

Year	Number of Producing Wells
2014	7,512
2015	9,277
2016	11,042
2017	14,080
2018	17,118
2019	20,112
2020	23,106
2021	24,934
2022	26,763
2023	28,591
2024	30,420
2025	32,248
2026	34,230
2027	36,212
2028	38,194
2029	40,176
2030	42,158
2031	44,096
2032	46,035
2033	47,973
2034	49,912

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 8-12 wells per spacing unit. Once that constraint has been reached, no additional wells may be added.

Figure 14 shows the result of 10 years of forecasted development within the oil countries. The 2024 forecasts are produced based upon the initial spacing unit states and clustering, and through five iterations of the hot spot analysis.

Figure 13. Hot Spot Map of Oilfield Spacing Units 2014

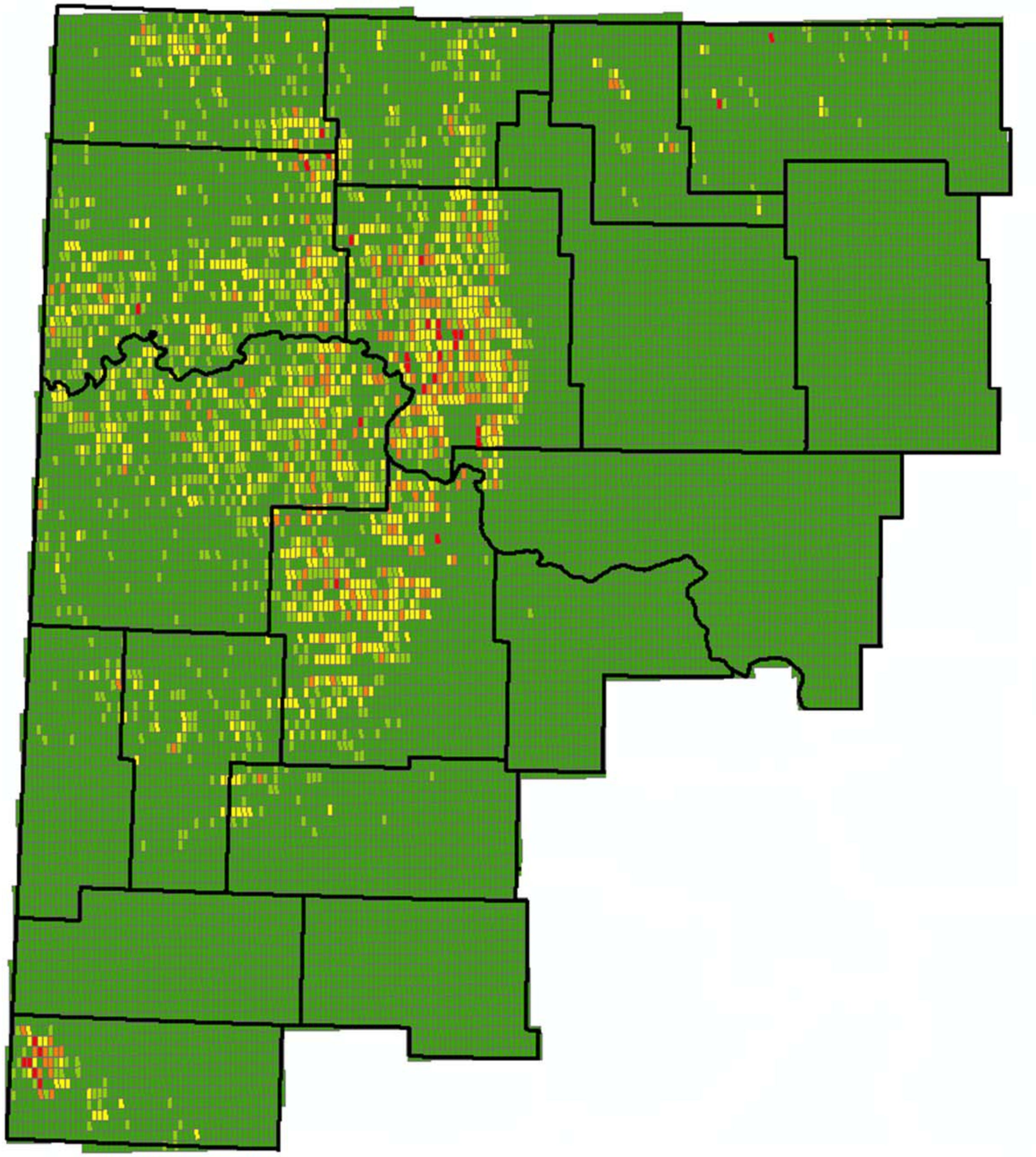
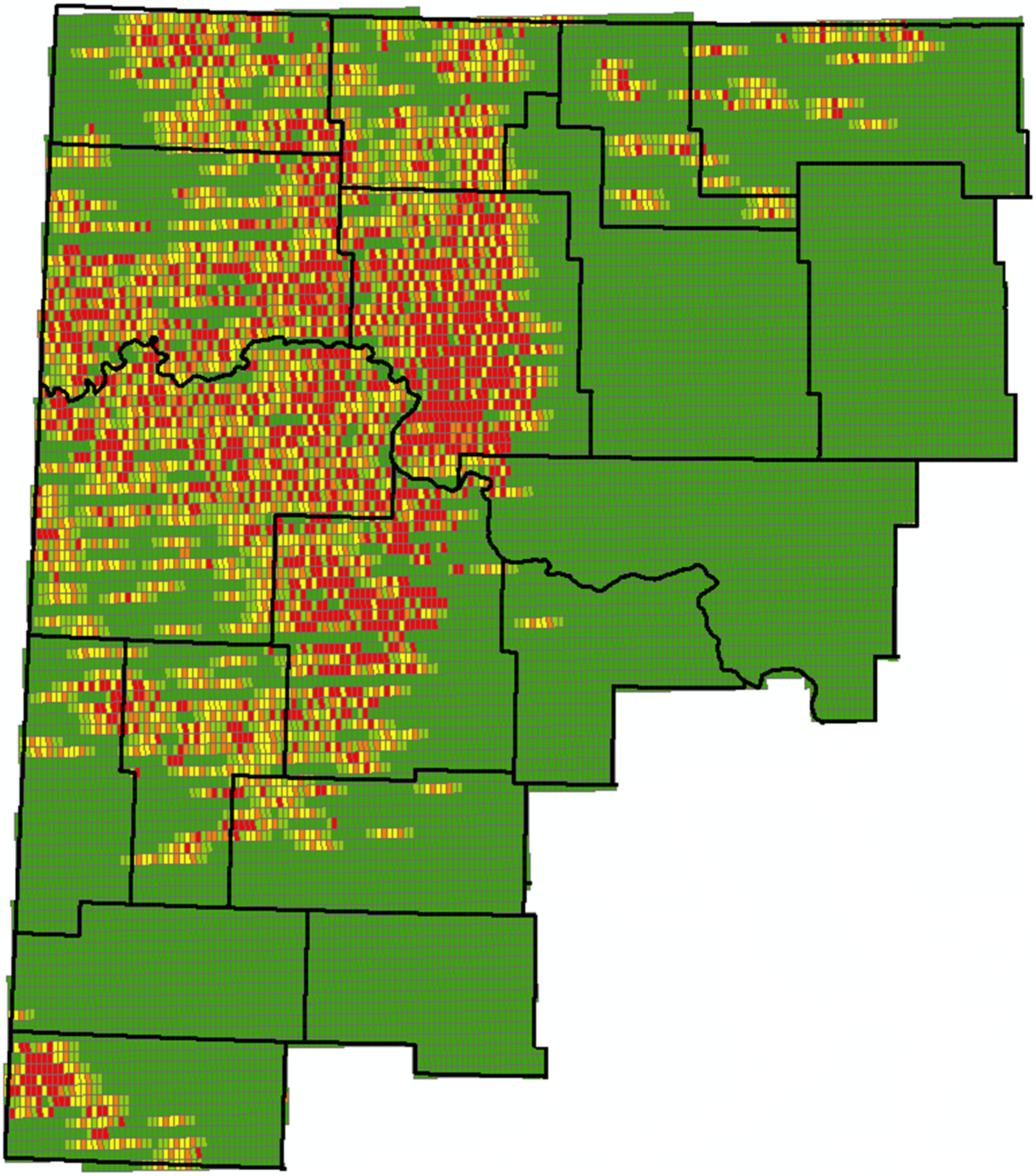


Figure 14. Hot Spot Map of Forecasted Spacing Units 2024



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 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 3, the total number of truck movements is estimated to be 2,300 per well, with approximately half of them representing loaded trips.

Table 3. Drilling Related Truck Movements

Item	Number of Trucks	Inbound or Outbound
Sand	100	Inbound
Water (Fresh)	450	Inbound
Water (Waste)	225	Outbound
Frac Tanks	115	Both
Rig Equipment	65	Both
Drilling Mud	50	Inbound
Chemical	5	Inbound
Cement	20	Inbound
Pipe	15	Inbound
Scoria/Gravel	80	Inbound
Fuel Trucks	7	Inbound
Frac/cement pumper trucks	15	Inbound
Workover 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. Through 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. The resulting impact is that in 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 4.

Table 4. Mode Split for Outbound Oil from Well Site to Transload Locations

Year	Percent Truck	Percent Pipeline
2014	67%	33%
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%
2024-2034	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 5. 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 be able to identify township roads apart from county non-CMCs, UGPTI and ND-LTAP conducted surveys of all 53 counties in North Dakota. The results of these surveys 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 6 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 6. 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 7 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 con-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 surfaces.

Table 7. 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**

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

During the process of identifying potential data collection sites, it was observed that most locations coincided with current NDDOT data collection spots. While most counts were planned to provide traffic volumes only, NDDOT had not yet started its planned 2013 data collection program, in which it was planning to cover two-thirds of the state. 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 2013 counting cycle. This left the middle one-third of the state as the only area without planned data collection activities. However, UGPTI students and staff collected classification data at approximately 160 locations in the central one-third of the state, thus providing comprehensive statewide coverage.

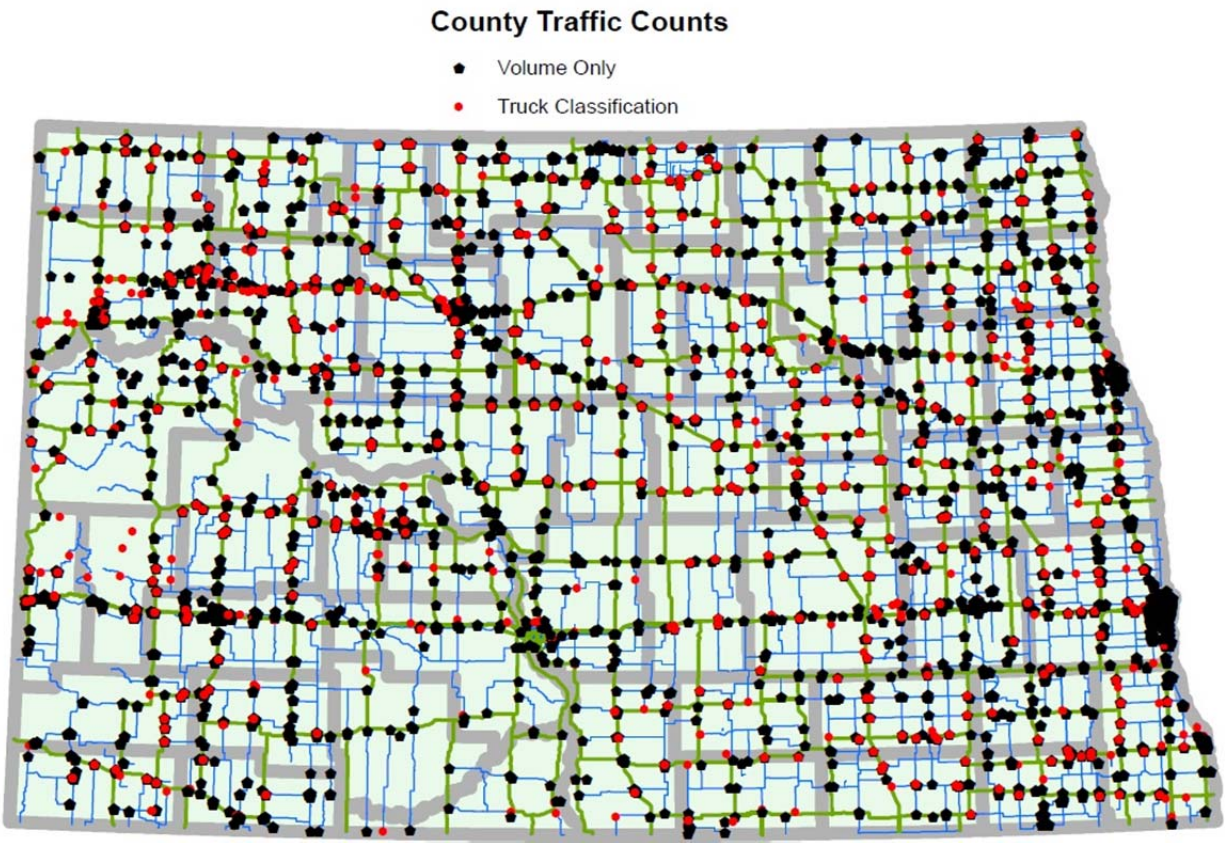
Between NDDOT and UGPTI staff, approximately 670 vehicle classification counts were taken across the state on county and township roads. An additional 1,000+ volume counts were also taken. In addition, 2012 counts conducted by the NDDOT in certain parts of the state were used to provide supplemental traffic information in lightly-traveled areas where significant changes from 2012 to 2013 were not anticipated. Figure 15 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 which involved 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 15. 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 accepted as sufficiently modeling existing traffic can it be used to predict future traffic levels.

5.3.1. Movement Types

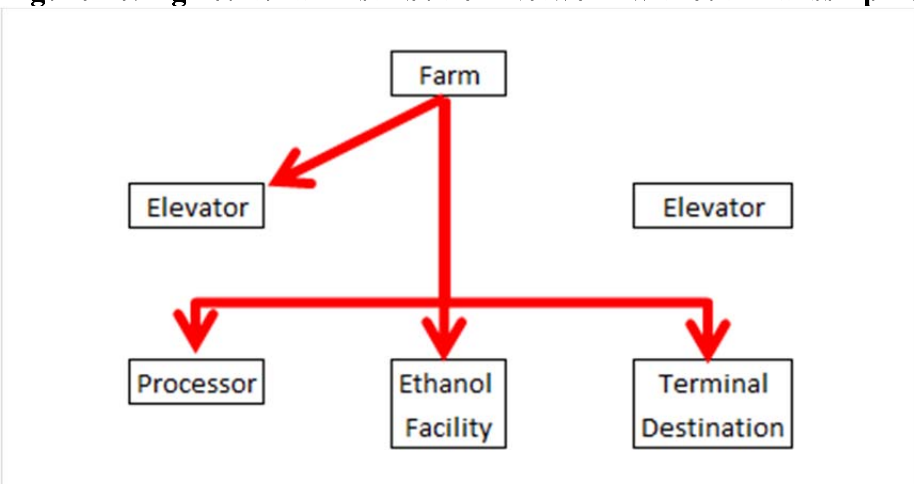
The travel demand model developed for this study consists of 18 individual submodels: 11 for agricultural movements and 7 for oil related movements. Nine of the eleven agricultural submodels represent individual commodities, with the remaining representing fertilizer and transshipment movements. Five 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, due primarily to the increase in shuttle elevators, processors and ethanol facilities.

Figure 16 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 since rail access from individual farms is virtually non-existent.

Figure 16. Agricultural Distribution Network without Transshipments



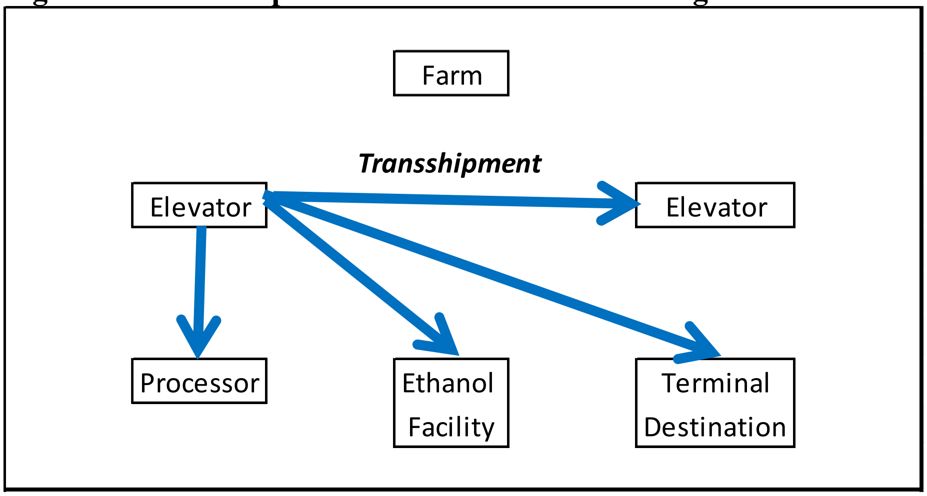
To take advantage of lower shipping rates at higher volumes, grain is commonly shipped between elevators for consolidation. Depending on the final destination of the grain from the elevator, the mode split between truck and rail varies. But as a general rule, as distance increases, truck transportation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

Figure 17 shows 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, the 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

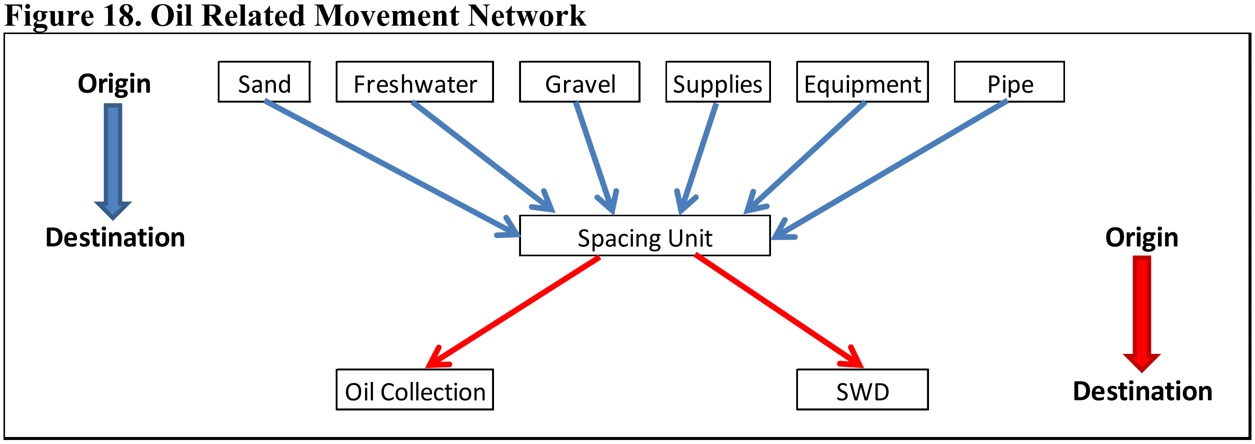
In contrast to the agricultural model where the base unit of production and related origin is the township, the oil model's base unit of production is the spacing unit, which functions as both an origin and destination as time progresses. Figure 18 provides a simplified diagram of the modeled oil-related 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 17. Transshipment Movements within an Agricultural Network



Within the model framework both the 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 18. 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 upon 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 in this case 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. Since assumptions have been 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 of the individual segments was assigned a travel speed based upon posted speed or roadway class, and from this 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 at the outset of this section 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 entire 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. Comparison of the modeled traffic flows to the 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 effectively 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 the unpaved county and local roads focuses on traffic levels and existing practices as reported by counties and townships in survey responses. Each county was analyzed separately, which allows the study to focus on county-level needs based upon existing practices and expectations.

6.1.1. Traffic Classification

Within each county, unpaved roads were classified by daily truck estimates. Classification ranges are shown in Table 8. 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 have indicated 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, which is consistent with traffic levels previously reported. The surveys are presented in Appendix A.

Table 8: 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 gravel and blading cycles on gravel roads within their jurisdiction. If the county was located within the oil patch, gravel and blading cycles on gravel roads were asked for both non-impacted gravel roads and impacted gravel roads. The consensus from the survey responses was that on impacted roads, the gravel interval decreases and the number of bladings per month increases. For example, a non-impacted road has a gravel cycle of five years and a blade interval of once per month, while an impacted section has a gravel cycle of two to three years and a blade interval of twice per month. The effective difference is a doubling of the gravel maintenance costs over the same time period. On the low-impact road sections, increased blading activity is implemented to maintain roadway surface condition. For roads outside the oil patch, a similar response to higher traffic levels is expected, and there will be an increase in gravel application and blading frequency to maintain the roadway surface.

Improvement types considered include the following: increased regraveling frequency, intermediate improvements, and asphalt surfacing. The first and the last improvement types are the most straightforward; as traffic increases, the application of gravel increases. Once traffic reaches a very high level, life cycle costs deem an asphalt surface to be the more cost-effective improvement type. The intermediate category of improvements includes base stabilization and armor coat treatments. There is no single intermediate improvement which can be applied to each county in North Dakota for this category because of differing soil types, moisture levels, and skill and equipment availability. Types of intermediate improvements include the use of stabilizers such as Base 1 from Team Labs, Permazyme from Pacific Enzymes, and asphalt and cement stabilization. Stabilization has had limited use on county roads in North Dakota according to interviews with county road supervisors. Recent trials have yielded mixed results, with some positive cases resulting in reduced maintenance costs. However, the longevity of these types of treatments are unknown, particularly performance under the freeze/thaw cycle in North Dakota.

The goal of stabilization is to add structure, minimize use of new aggregate or preserve existing aggregate, reduce susceptibility to moisture and provide a base upon which to apply an armor coat. Cost estimates reported in the county surveys list Base One treatments at $5,000-$7,000 per mile, Permazyme treatments averaging $12,000 per mile, and concrete stabilization ranging from $60,000-$100,000 per mile. As mentioned above, the life of these treatments are unknown, as historical performance data is unavailable. If Base One application would occur annually, Permazyme biennially, and concrete stabilization once per decade, the cost per year would be equal. 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.

Maintenance types by traffic category are shown in Table 9. The low-impact category receives a low volume average maintenance type, as reported by county representatives. In the county survey, county representatives were asked about the maintenance practices on an average non-impacted roadway, and the responses are used to calculate the county average cost used for baseline traffic levels. As traffic increases beyond baseline numbers, survey responses indicate that the intervals of gravel overlays and blading decrease, with a corresponding increase in annualized cost represented in the elevated and moderate categories. The high and very high categories represent an increase of 150%-200% over the average maintenance with the addition of a dust suppressant application.

Table 9: Improvement Types for Unpaved Roads by Traffic Category

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

It is entirely possible that at the very high and potentially high categories of traffic on gravel roads that 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. This study does simulate surface type changes on gravel roads with truck volumes greater than 500 trucks per day and segment lengths greater than five miles. Using a reconstruction cost of $1.5 million per mile for full reconstruction of these gravel surfaces, the estimated cost of upgrading these 39.3 miles is estimated at an additional $58 million and are implemented in the first period of the analysis.

6.1.3. Projected Investment Needs

The projected costs by time period, region, and functional class are summarized in Table 10. The total projected statewide need over the 20-year analysis period is roughly $5.45 billion. Approximately 53% of these needs can be traced to the 17 oil and gas producing counties of western North Dakota.

Table 10: Unpaved Road Investment Needs (Millions of 2014 Dollars)

Time Period	Statewide	Oil Patch	Rest of State
2015-2016	$606.4	$ 357.7	$ 248.6
2017-2018	$ 547.9	$ 299.2	$ 248.7
2019-2020	$ 547.5	$ 298.6	$ 248.9
2021-2022	$ 545.6	$ 296.6	$ 249.0
2023-2024	$ 541.9	$ 292.7	$ 249.2
2025-2034	$ 2,667.5	$ 1,422.9	$ 1,244.6
2015-2034	$ 5,456.7	$ 2,967.8	$ 2,489.0

The estimated needs are shown by jurisdiction for the 2015-2016 biennium in Table 11. 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 unorganized township roads and township roads for which the county assumes maintenance responsibility. Per the survey of townships, an estimated 45% of organized township roads 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 12.

Table 11: Unpaved Road Investments Needs, by Jurisdiction (2015-2016)

Jurisdiction and/or Maintenance Resp.	Road Class	Needs (Millions)	Percent of Needs
County	CMC	$138.20	
	Non-CMC/Twp.	$293.50	
	County Total	$373.30	68%
Township		$170.10	31%
Tribal		$4.60	1%
All Jurisdictions		**$606.4**	**100%**

Table 12: Unpaved Road Investment Needs, by Jurisdiction (2015-2034)

Jurisdiction and/or Maintenance Resp.	Road Class	Needs (Millions)	Percent of Needs
County	CMC	$975.73	
	Non-CMC/Twp.	$2,753.20	
	County Total	$3,670.93	68%
Township		$1,662.72	31%
Tribal		$64.78	1%
All Jurisdictions		**$5,456.4**	**100%**

Table 13 presents the unpaved road needs by county for the 2015-2016 biennium, as well as for the total study period.

Table 13: Unpaved Road Needs by County

County	2015-2016	2015-2034
Adams	$7.7	$76.7
Barnes	$9.3	$93.4
Benson	$4.9	$49.2
Billings	$13.4	$128.3
Bottineau	$7.0	$69.8
Bowman	$7.0	$69.1
Burke	$12.8	$126.8
Burleigh	$7.8	$78.5
Cass	$26.8	$268.4
Cavalier	$9.3	$93.1
Dickey	$9.1	$90.9
Divide	$10.0	$99.1

County	2015-2016	2015-2034
Dunn	$43.5	$294.5
Eddy	$1.9	$18.9
Emmons	$2.6	$25.7
Foster	$2.3	$23.5
Golden Valley	$8.9	$88.8
Grand Forks	$13.3	$132.6
Grant	$5.3	$52.6
Griggs	$5.1	$51.6
Hettinger	$2.9	$28.6
Kidder	$5.9	$59.0
LaMoure	$1.4	$14.3
Logan	$2.2	$22.3
McHenry	$22.9	$228.3
McIntosh	$2.0	$20.1
McKenzie	$92.1	$501.2
McLean	$17.0	$169.3
Mercer	$9.1	$90.7
Morton	$10.6	$105.5
Mountrail	$24.8	$229.3
Nelson	$4.8	$48.4
Oliver	$3.8	$38.3
Pembina	$10.3	$102.7
Pierce	$8.9	$89.0
Ramsey	$5.5	$55.2
Ransom	$2.1	$20.6
Renville	$3.7	$36.9
Richland	$16.2	$162.2
Rolette	$5.7	$57.0
Sargent	$5.5	$55.5
Sheridan	$2.3	$23.3
Sioux	$4.9	$49.4
Slope	$4.8	$47.9
Stark	$19.8	$195.3
Steele	$3.8	$38.6
Stutsman	$7.3	$73.3
Towner	$5.3	$53.6
Traill	$4.3	$42.7
Walsh	$21.8	$218.5
Ward	$18.8	$187.3
Wells	$5.6	$55.6

County	2015-2016	2015-2034
Williams	$42.3	$405.2
Total	**$606.4**	**$5,456.7**

The next section of the report focuses on paved roads. First, the structural data collected throughout the state during 2013 are described, including the non-destructive testing methods used. Next, the results of the statewide data collection effort are described, followed by a description of the methods used to analyze paved roads and estimate investment needs.

7. Pavement Structural Data

7.1. Introduction

The accuracy of this study's road needs forecasts is closely tied to the accuracy of the required input data. For paved roads, this data includes pavement layer thicknesses and structural information. While previous needs studies undertaken by UGPTI relied upon survey results to build assumptions about pavement structure, this study used an extensive nondestructive pavement testing (NDT) effort to remove much of the uncertainty related to survey responses.

Nondestructive test data served several purposes in this study's pavement analysis procedure. First, layer type, thickness, and elastic modulus are inputs to the AASHTO-based (American Association of State Highway and Transportation Officials) Structural Number (SN) equation which describes the capability of the existing pavement 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 necessary for this study's pavement analysis procedure. It is important to 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 a sample of more than 1,500 miles of paved roads was selected for testing. This included more than 6,000 test locations on 169 segments across 37 counties.

Sample segments were selected based on GIS data from a variety of sources. North Dakota GIS Hub provided road centerline data, municipal boundaries, agricultural production facilities and other traffic generators. NDDOT provided spatial data for recently improved paved roads.

Separate sampling plans were developed for oil-impacted and non-oil-impacted counties in order to reflect the pavement demands of each region and to distribute the total number of tested miles relatively evenly between regions. The oil-impacted western counties were sampled for all rural paved county and local road segments which had not been recently improved based on NDDOT data. This represented over 800 miles of test segments. Eastern counties were sampled for rural paved county and local road segments within five miles of major traffic generators (including agricultural production facilities) and which had not been recently improved. This represented over 700 miles of test segments. Finally, to reflect the study's network-level approach and the need for multiple NDT test points on each segment to achieve reliable data, segments less than one mile long were excluded from testing.

During testing it was discovered that some segments were unable to be tested for one of two reasons. First, a number of roads which had been designated "Paved" in ND GIS Hub data were either no longer paved or had deteriorated to the point that nondestructive testing was impossible. Other segments were precluded from testing because of ongoing road construction at the time of testing.

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

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 length of each test segment, 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) is a device which 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 by using various computational methods. 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 all selected segments. Testing was conducted in August and September 2013. 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 21,560 deflection basins. Full test specifications are shown in Table 14.

Table 14. Falling Weight Deflectometer Test Specifications

Maximum Test Spacing	0.25 mi (1320 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 over 90 percent of backcalculated moduli fell within reasonable range.

7.3. Results

The inter-system quality control process described above resulted in a database in which over 90% of backcalculated layer moduli fell within defined reasonable ranges as described in Table 15. The remaining unreasonable deflection basins were removed from the results database.

Table 15. Reasonable Layer Moduli Ranges

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

As this testing effort included only a sample of paved county and local roads throughout the state, some assumptions had to be made about pavement structure on non-tested roads. For counties with at least 15 miles of test results, it was assumed that non-tested paved roads would consist of a similar structure. For counties with less than 15 miles of tested roadway, region-wide averages for layer type, thickness and moduli were applied to non-tested paved roads.

Tables 16, 17, 18 and 19 describe countywide, regional, and statewide pavement layer and moduli results. County averages are displayed for the 22 counties with more than 15 miles of tested roadway. Eighteen other counties include tested roads but their county-specific averages do not appear here. A more detailed summary of nondestructive test results is available in Appendix B.

Table 16. Nondestructive Test Results, Aggregated by County

County	Asphalt Concrete Thickness (in)	Granular Base Thickness (in)	Asphalt Concrete Modulus at 77°F (ksi)	Unbound Base Modulus (ksi)	Subgrade Modulus (ksi)
Barnes	8.4	3	221.8	25.7	6.5
Bottineau	8.4	3.1	226.6	30.8	8.1
Bowman[1]	1.9	4.9	135.4	88.6	7.5
Cass	9.3	3.3	293.8	37.8	8.7
Dickey	8.2	2.9	230.1	26.6	6.3
Foster	6.1	3	134.7	22	6.6
Grand Forks	9.9	2.8	288	25.8	9.2
McHenry	8.2	2.5	230.3	29.5	8.7
McKenzie	7.9	3.5	236.7	22.5	7
McLean	8.1	1.9	229.4	32.8	5.8
Mercer	7.2	3.5	174.1	21.2	6.6
Mountrail	7.2	4.3	204.9	23.5	4.9
Pembina	7.3	2.4	184.4	24.2	7.2
Renville	9.2	2.5	223.9	26.1	6.6
Richland	8.5	4.2	205.1	27.8	7.7
Stark	7.3	2.1	255.7	25.8	8.3
Steele	5.8	5.8	304.2	27.7	8.6
Stutsman	8.9	4.4	172.7	26.7	7.9
Traill	8.8	3.6	228.3	31.6	7.2
Walsh	7.6	4.3	195.4	26.2	7
Ward	7.7	2.9	265.1	31.7	6.5
Williams	7.5	4.2	169.5	24.1	7.1

[1] Special considerations were applied to NDT results in Bowman County, where local paving practice is to apply a double chip seal over granular base. This structural composition is difficult to analyze using GPR because of potential penetration of chip seal binder into the granular base material. These atypical sections were identifiable in GPR results as two-layer structures with top layer thickness of approximately 5-10 inches. For the purpose of data display, one inch of this top layer is assumed to be asphalt with the remaining thickness assumed granular base. Untested segments in Bowman County are assumed to have similar composition. This study's pavement analysis will consider the combined elastic modulus of these chip seal/base structures.

Table 17. 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	7.8	3.1	239.5	31	7.2
Non-Impacted	8.3	3.7	237.2	30.5	7.66
Statewide	8.1	3.2	238.4	30.8	7.43

Table 18. Typical Structure of County and Local Roads in North Dakota

Layer	Layer Thickness (Inches)			
	Minimum	Average	Maximum	Standard Deviation
Asphalt Concrete (surface)	3.3	8.1	12.6	1.9
Granular Base	0	3.2	15	2.5

Table 19. 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	74.6	238.4	686.1	85.89
Granular Base	6.40	30.75	83.00	11.14
Subgrade	3.40	7.43	20.80	1.98

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 2012 study. For the most part, the same methods and models have been used, but expanded data collection efforts have reduced uncertainty and improved the accuracy of this study's county and township paved roads needs forecasts.

More than 5,600 miles of paved county and local roads (exclusive of city streets) are traveled by agricultural and oil related traffic and other highway users. Some of these roads are under the jurisdiction of governments or agencies other than counties, such as townships, municipal governments, the Bureau of Indian Affairs (BIA), and the Forest Service. City streets and Forest Service roads are excluded from the study.[2] 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 in the United States. The equations are expressed in equivalent single axle loads (ESALs). In this metric, the weights of various axle configurations (e.g., single, tandem, and tridem axles) are converted to a uniform measure of pavement impact. With this concept, the service life of a road can be expressed in ESALs instead of truck trips.

An ESAL factor for a specific axle represents the impact of that axle in comparison to an 18,000-pound single axle. The effects are nonlinear. For example, a 16,000-pound single axle followed by a 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.[3] An increase in a single-axle load from 18,000 to 22,000 pounds more than doubles the pavement impact, increasing the ESAL factor from 1.0 to 2.44. Because of these nonlinear relationships, even modest illegal overloads (e.g. 22,000 pounds on a single axle) can significantly reduce pavement life.

[2] 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.

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

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 earlier in Table 3. The characteristics of these trips are depicted in Table 20. 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 20. These vehicles (which exceed the maximum vehicle weight limit) travel under special permits. In comparison, a truck used to transport sand while complying with Bridge Formula B weighs 76,000 pounds and generates an ESAL factor of 2.24. Nevertheless, based on enforcement data from the North Dakota Highway Patrol and the results of special studies at truck weigh stations, it has been estimated that 25% of these trucks are overloaded. The typical overloaded vehicle weighs 90,000 pounds with an ESAL factor of 3.78 (instead of 2.24).

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

Table 20: 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 21, 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 21: 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

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

The results of the condition assessment are summarized in Table 22, which shows that 9% of paved county and township road miles are in very good condition, meaning they have recently been improved. This group includes 244 miles of improvements in western North Dakota funded by a 2011 appropriation from the North Dakota Legislature. As shown in Table 22, another 62% of paved road miles are in good condition; 20% are in fair condition. Only 9% of paved road miles are rated as poor. Road condition ratings for each county are shown in Appendix C.

Table 22: Conditions of Paved County and Township Roads in North Dakota in 2014

Condition	Miles	Percent
Very Good	520	9%
Good	3,557	62%
Fair	1,163	20%
Poor	339	6%
Very Poor	146	3%
All	5,722	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 overlain or resurfaced. Roads that have not yet been resurfaced or have recently been reconstructed may have only surface and aggregate sub-base layers.

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

Layer thicknesses and strengths have been measured using the nondestructive testing and back-calculation process described elsewhere. Statewide values are shown in Tables 23 and 24.

Table 23. Typical Structure of County and Local Roads in North Dakota

Layer	Layer Thickness (Inches)			
	Minimum	Average	Maximum	Standard Deviation
Asphalt Concrete (surface)	3.3	8.1	12.6	1.9
Granular Base	0	3.2	15	2.5

Table 24. 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	74.6	238.4	686.1	85.89
Granular Base	6.40	30.75	83.00	11.14
Subgrade	3.40	7.43	20.80	1.98

Back-calculated 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

Four types of road improvements are analyzed in this study: (1) reconstruction, (2) mine and blend, (3) resurfacing, and (4) resurfacing with widening. If a pavement is not too badly deteriorated, normal resurfacing is a cost-effective method of restoring structural capacity. In this type of improvement, a new asphalt layer is placed on top of the existing pavement. The thickness of the layer may vary. However, it may be as thick as 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.[4] 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.

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.[5] 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

[4] 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.

[5] 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.

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, 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 25 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 treatment in those counties.

Table 25: 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	East	$3,333	$1,429	$5,714	$11,429	**$21,905**
	West	$3,333	$1,429	$5,714	$15,238	**$25,714**

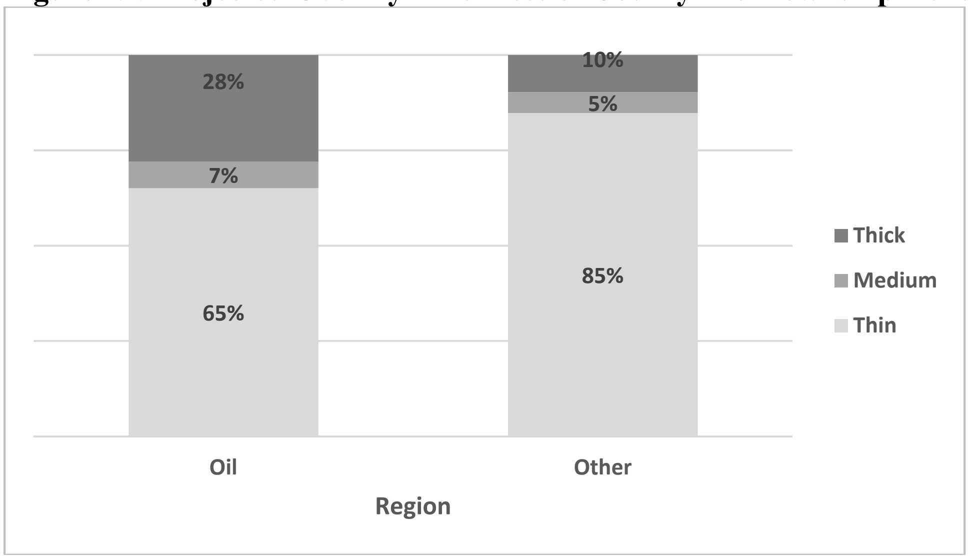
8.9. Forecasted Improvement Needs

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 19, roughly 28% of the paved road miles in oil- and gas-producing counties are expected to need thick overlays or major rehabilitation. Another 7%will require moderate overlays. Thin overlays will suffice for 65% of the miles in these counties. Roughly 10% of the miles in the remainder of the state will require thick overlays or major rehabilitation. An additional 5% will require overlays of 2-3 inches.

Figure 19: Projected Overlay Thickness of County and Township Roads, by Region

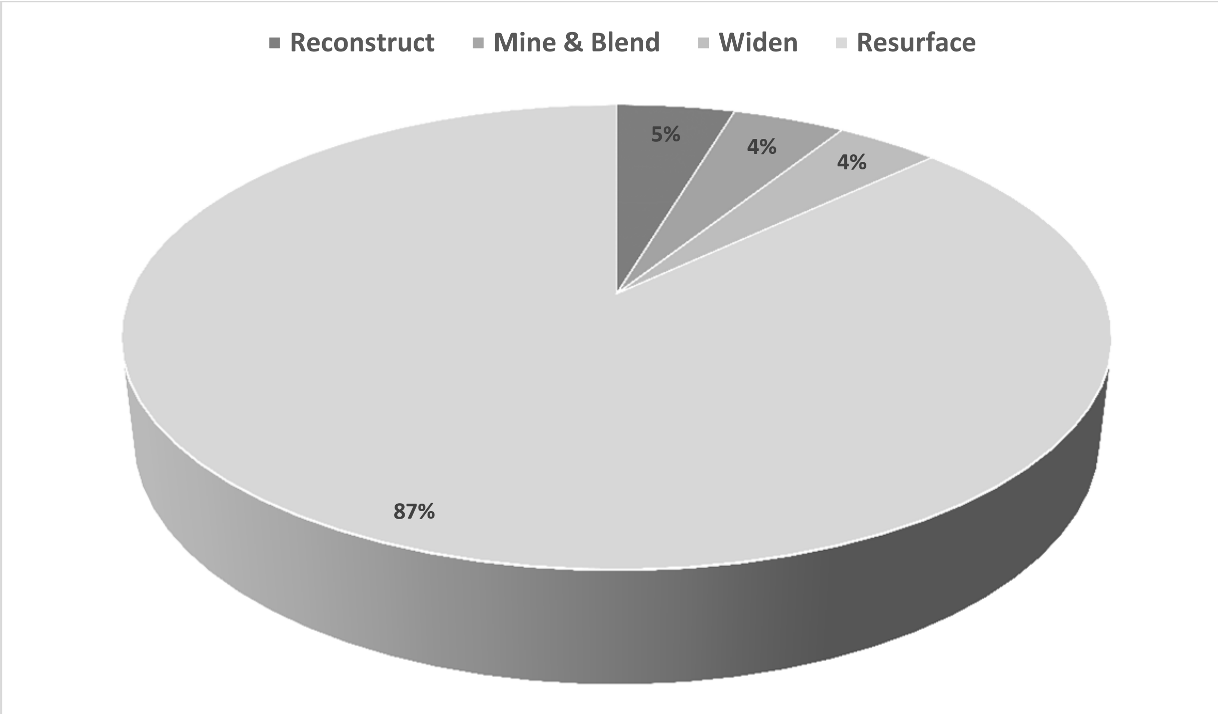


8.9.2. Miles Improved

As shown in Figure 20, approximately 9% 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 4% 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 20: Percent of County and Township Paved Road Miles by Improvement Type

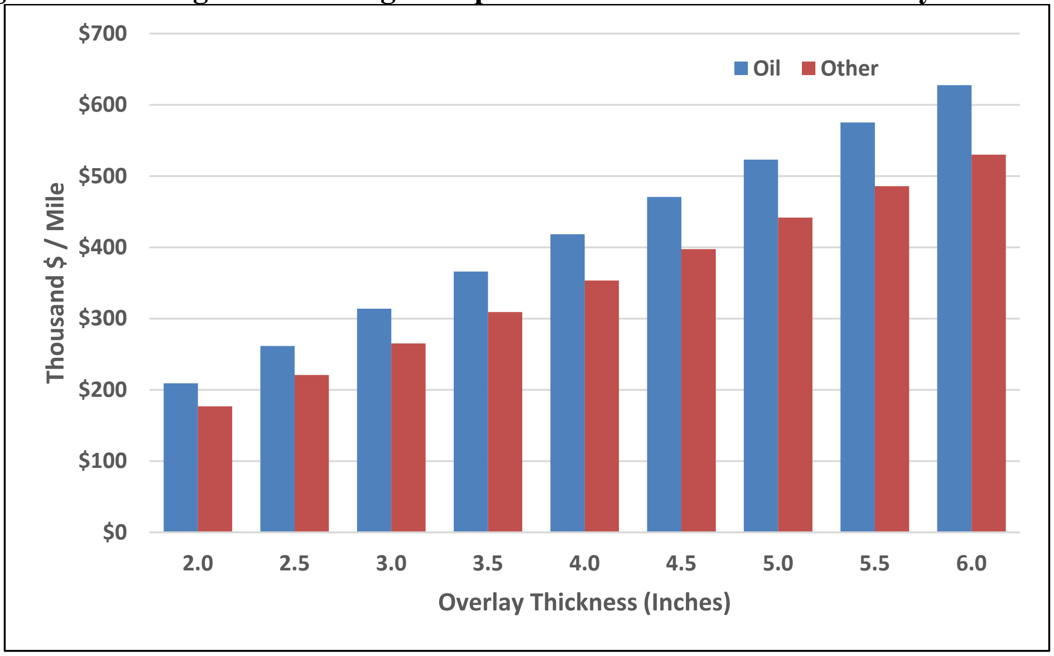


8.9.3. Improvement Costs per Mile

The resurfacing cost of each segment is estimated from the inches of overlay needed and a unit cost calculated determined from recent NDDOT bid and plan documents as $4,359 per inch of pavement per foot surface width in oil and gas producing counties and $3,681 in the remainder of the state. With these unit costs, a two-inch overlay costs roughly $209,000 per mile for a 24-foot roadway in the oil-impacted region and $177,000 in the non-impacted region (Figure 21). A three-inch overlay costs roughly $314,000 per mile, while a five-inch overlay results in a cost of $523,000 per mile[6]. Similar overlay thicknesses in non-oil-impacted counties cost roughly $265,000 and $442,000

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

Figure 21. Average Resurfacing Cost per Mile as a Function of Overlay Thickness



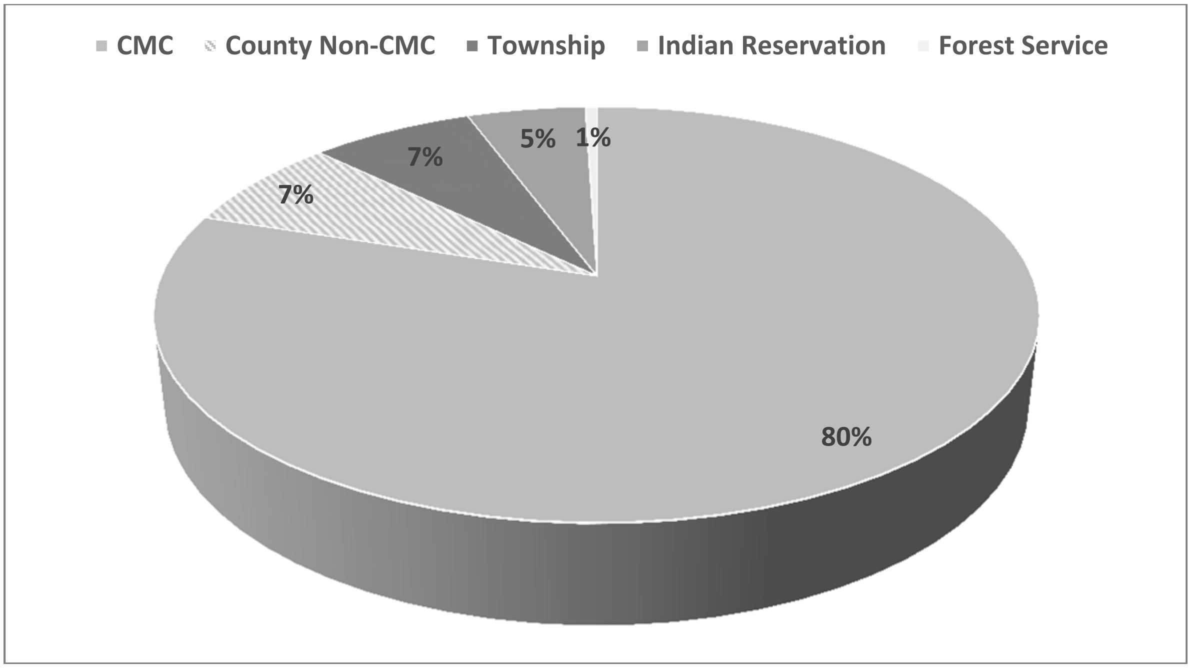
Major rehabilitation costs are estimated using NDDOT unit cost data. Reconstruction cost is estimated at $1,500,000 per mile in oil and gas producing counties and $1,250,000 per mile in the rest of the state. Mine and blend treatment is expected to cost roughly $1,000,000 per mile and $600,000 per mile in impacted and non-impacted regions, respectively. Segments selected for sliver widening are assigned a widening cost of $87,500 per added foot width (in addition to overlay cost) in the oil-impacted region, and $77,500 in the non-impacted counties.

The results of the analysis are summarized in Tables 26 and 27. Table 26 shows the projected improvements and costs for each biennium during the next 10 years, a projected subtotal for the 2015-2024 period, and a grand total for 2015-2034. Analogous information is shown in Table 27 for oil- and gas-producing counties. The values in Table 27 are included in Table 26. Appendix D describes total paved road needs by county.

A total of 515 miles of paved county and township roads in North Dakota must be reconstructed or reclaimed because of poor condition or deficient width (Table 26). Another 230 miles are candidates for widening. The remaining 4,978 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.

The estimated cost for all county and township roads is approximately $2,760 million or $138 million per year. Roughly 20% of the expected cost is due to major rehabilitation. Five percent is attributable to widening. Resurfacing accounts for 33%. The remaining 42% is linked to routine maintenance. Approximately 80% of all investment needs can be traced to CMC routes (Figure 22).

Figure 22: Projected County and Township Paved Road Investments by Functional Class



Approximately $1,179 million (43%) of the projected statewide need can be traced to oil- and gas-producing counties (Table 27). Thirty-six percent of the widening cost and 70 percent 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 over half of the reconstruction and 90% of the widening costs needed during the first two biennia. Twenty-seven 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 $181,260 per mile. The average routine maintenance cost is $10,043 per mile per year. For roads that do not require major rehabilitation or widening, the annualized cost per mile is roughly $19,106 per year. Once deferred investment needs have been taken care of and regular preservation maintenance is practiced on all segments, annualized costs should stabilize near this level. However, as noted earlier, most of the roads with potential width issues have not been addressed in this analysis if the projected overlay thickness is 2 inches. These costs have not been eliminated. Instead, they have been deferred to a future funding period.

Table 26: Statewide Summary of Forecasted Improvements and Costs for Paved County and Township Roads ($Millions)

Period	Resurfacing		Widening		Reconstruction		Mine & Blend		Maintenance Cost	Total Cost
	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost		
2015-2016	385	$80	120	$79	38	$56	103	$75	$108	$397
2017-2018	317	$62	88	$57	28	$39	122	$79	$108	$346
2019-2020	291	$53	22	$12	82	$117	18	$15	$110	$306
2021-2022	193	$33	0	$0	73	$107	8	$7	$111	$258
2023-2024	136	$24	0	$0	1	$2	0	$0	$113	$138
2015-2024	**1,322**	**$252**	**230**	**$148**	**222**	**$321**	**251**	**$176**	**$550**	**$1,445**
2025-2029	365	$66	0	$0	13	$18	0	$0	$293	$378
2030-2034	3,291	$584	0	$0	30	$45	0	$0	$306	$936
2015-2034	**4,978**	**$902**	**230**	**$148**	**264**	**$384**	**251**	**$176**	**$1,149**	**$2,760**

Table 27: Summary of Forecasted Improvements and Costs for Paved County and Township Roads in Oil and Gas Producing Counties ($Millions)

Period	Resurfacing		Widening		Reconstruction		Mine & Blend		Maintenance Cost	Total Cost
	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost		
2015-2016	132	$37	31	$23	34	$51	34	$34	$38	$183
2017-2018	97	$23	27	$25	19	$29	14	$14	$39	$129
2019-2020	116	$24	9	$6	60	$89	9	$9	$39	$167
2021-2022	53	$11	0	$0	64	$96	7	$7	$39	$152
2023-2024	33	$7	0	$0	1	$2	0	$0	$39	$48
2015-2024	**431**	**$102**	**67**	**$54**	**178**	**$267**	**64**	**$64**	**$194**	**$679**
2025-2029	157	$33	0	$0	11	$16	0	$0	$101	$150
2030-2034	958	$200	0	$0	30	$45	0	$0	$105	$350
2015-2034	**1,546**	**$335**	**67**	**$54**	**219**	**$328**	**64**	**$64**	**$400**	**$1,179**

8.9.4. Indian Reservation Roads

Thus far, only county and township 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, since 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 28, which shows the forecasted improvements and costs for all tribal road segments and specifically for those routes in oil-producing regions. The values in column 2 of Table 28 are included in the values in column 3. Altogether, 224 miles of paved IRR are captured in the analysis. Roughly 30% of these miles may need reconstruction due to poor condition, poor subgrade, or inadequate width. It is assumed that the remaining 157 miles can still be effectively resurfaced. The forecasted improvements are shown by funding period for paved and unpaved roads in Table 29.

Table 28: Summary of Indian Reservation Paved Road Investment Analysis

Projected Improvement or Cost	Oil Impacted Region	Total: North Dakota
Miles Resurfaced	31	145
Resurfacing Cost (Million$)	$6.8	$26.2
Miles Widened	3	11
Widening Cost (Million$)	$1.7	$8.4
Miles Reconstructed	22	22
Reconstruction Cost (Million$)	$32.8	$32.8
Miles Reclaimed	14	45
Mine & Blend Cost (Million$)	$13.5	$32.4
Maintenance Cost (Million$)	$14.3	$42.7
Total Cost (Million$)	$69.0	$142.4

Table 29: Summary of Projected Investment Needs for Impacted Indian Reservation Roads

Period	Paved	Unpaved	Total
2015-2016	$37.3	$4.77	$42.07
2017-2018	$33.0	$4.20	$37.20
2019-2020	$10.9	$4.03	$14.93
2021-2022	$4.7	$4.07	$8.77
2023-2024	$4.6	$4.03	$8.63
2025-2029	$17.5	$3.93	$21.43
2030-2034	$34.4	$3.82	$38.22

9. Bridge Analysis

9.1. Introduction

Bridges are the link upon which North Dakota's county and township roads rely to carry people and goods safely and efficiently over obstacles both natural and manmade. Ideally, these structures allow the highway network to meet the needs of the travelling public; however, bridge inadequacy 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 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 2,327 NBI (2013) 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 are not included in the NBI database and are not considered in this study's needs forecasts.

To support statistical significance, a complete NBI (2012) 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 3,505 bridges in the state.

9.2.1. Condition of County and Township Bridges

Table 30 summarizes the age distribution of county- and township-owned bridges in North Dakota based on the 2013 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 were built more than 75 years ago; this accounts for 15% of the total bridges. Although 50 years was historically considered the design life of many bridges, service lives can be extended through diligent maintenance and rehabilitation.

Table 30: Age distribution of county, township, and city owned bridges in ND

Age (Years)	Frequency of Bridges	Percent	Cumulative Frequency	Cumulative Percent
≤ 20	269	11%	269	11%
> 20 and ≤ 30	322	13%	591	24%
> 30 and ≤ 40	498	21%	1,089	45%
> 40 and ≤ 50	442	18%	1,531	63%
> 50 and ≤ 75	610	25%	2,141	88%
> 75	286	12%	2,427	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 31. 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 32, and in an alternative format in Table 33.

Table 31: 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 32: 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	71	3.9%	116	4.6%	109	4.3%
8	362	19.8%	699	27.4%	537	21.1%
7	585	31.9%	741	29.1%	644	25.3%
6	440	24.0%	501	19.7%	492	19.3%
5	282	15.4%	324	12.7%	459	18.0%
4	71	3.9%	128	5.0%	215	8.4%
3	12	0.7%	33	1.3%	78	3.1%
2	4	0.2%	3	0.1%	8	0.3%
1	1	0.1%	1	0.0%	1	0.0%
0	1	0.1%	1	0.0%	3	0.1%

Table 33: Component Ratings [alternative format]

Component Ratings	Deck		Superstructure		Substructure	
	Bridges	Percent	Bridges	Percent	Bridges	Percent
Good (7-9)	1018	55.6%	1556	61.1%	1290	50.7%
Fair (5-6)	724	39.5%	825	32.4%	951	37.4%
Poor (3-4)	83	4.5%	161	6.3%	293	11.5%
Critical (0-2)	6	0.3%	5	0.2%	12	0.5%

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 50 percent of bridges in North Dakota have a sufficiency rating greater than 85%. Twenty-eight 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 29% 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, road centerline data from the North Dakota GIS Hub Data Portal was used to identify bridges carried by roads with surface type "Trail," "Graded & Drained" or "Unimproved." This captured 237 of the study's total database of 2,327 bridges.

Next, the full county and township bridge database was filtered to isolate 1,600 non-federal-aid structures, from which each bridge and associated road segment were examined in Google Earth to determine road maintenance status. Minimum maintenance roads were identified as those with grass clearly visible in either travel lane. 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 3505 North Dakota bridges in the 2012 NBI database. They were validated using the updated 2013 NBI database.

The multivariate component deterioration models include four effects: bridge type, average daily traffic, reconstruction history, and bridge jurisdiction or location. For the deck model, the effect of deicing salt is also captured by introducing a maintenance authorization effect.

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 2014 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 are 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 three material types (concrete, steel, and timber). Two categories of average daily traffic volume are identified: high (≥4,500 vehicles/day) and low (<4500 vehicles/day). The regional transportation district variable includes eight classes and captures differences attributable to the bridges' geographic and jurisdictional location. For the deck model, the effect of deicing salt and chemical usage is captured by grouping the maintenance responsible agencies of state and city together.

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 34.

Table 34: 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.

It is important to 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 ten 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. Sufficiency rating cannot, therefore, be reasonably forecasted for bridges which have received major improvement. For this reason, 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 four subcategories based the type of structure which will replace the existing bridge:

1. New bridge with 28-foot width
2. New bridge with 32-foot width
3. Single barrel reinforced concrete box culvert
4. 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 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, for example, unknown foundation, poor substructure condition, and timber superstructure. Finally, in order 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 and 28 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 bridge which receive 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. Project Prioritization

Based on the 2013 North Dakota bridge inventory and the improvement criteria used in this model, it is apparent that county and local bridges face a significant backlog in needs. A long-term strategy will be required to address the extent of this current backlog. This study recognizes that prioritization of current needs is the responsibility of each county. Self-prioritization of needs, then, is the first solution offered here.

Alternatively, this study offers a theoretical breakdown of biennial bridge needs using a multi-level prioritization strategy, with the goal of addressing the bridges in order of essentiality to the public within a 10-year timeframe. The following hierarchy was defined to assign a priority score to bridges which were forecasted for rehabilitation or replacement in a given year:

1. Jurisdiction (highest first)
2. Detour vehicle-miles traveled (highest first)
3. Maximum truck volume in analysis period (highest first)
4. Sufficiency Rating (lowest first)
5. Age (oldest first)

Detour vehicle-miles traveled and truck volume criteria were based upon volume forecasts generated from this study's detailed statewide travel demand model. Detour distance is available in NBI.

A biennial spending cap of $64 million per biennium was imposed and needs filled based on the described criteria until this cap was met. The process was repeated for each analysis year until backlogged needs were completely addressed.

9.3.4. Cost Model

Preventive maintenance cost estimates used an annual unit cost of $0.24 per square foot 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 (2009-2014) NDDOT bid reports and plan documents. Costs were adjusted to reflect 2014 dollars. The type of replacement structure was based on the criteria described in the Improvement Selection Model section of this chapter.

A deficient bridge which is 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. Based on recent project history, bridge replacement projects in oil-impacted counties generally cost more than similar projects in the rest of the state. Unit replacement costs in oil-impacted and non-impacted counties were $275 per square foot and $250 per square foot deck area, respectively. 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, 2015-2034, are $328.2 million. Total forecasted needs by county 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 36.

9.4.2. Summary of Bridge Study Component

In this study, inventory and condition data from the 2013 National Bridge Inventory have been used to identify county and township bridges which exist on maintained roads and require maintenance, rehabilitation or replacement in years 2014 through 2034. 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 in order 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 35: Total County and Township Bridge Needs by County, in Thousands of 2014 Dollars

County	Rehabilitation and Replacement		Preventive Maintenance Cost	Total Cost
	Bridges	Cost		
Adams	3	$1,200	$187	$1,387
Barnes	2	$1,733	$395	$2,129
Benson	3	$978	$65	$1,043
Billings	3	$1,493	$203	$1,696
Bottineau	27	$19,416	$426	$19,841
Bowman	6	$1,723	$134	$1,856
Burke	0	$0	$52	$52
Burleigh	6	$2,241	$348	$2,589
Cass	29	$21,068	$2,617	$23,685
Cavalier	7	$3,000	$79	$3,079
Dickey	0	$0	$392	$392
Divide	2	$800	$53	$853
Dunn	7	$3,739	$276	$4,015
Eddy	1	$726	$211	$937
Emmons	3	$2,101	$272	$2,373
Foster	2	$804	$87	$891
Golden Valley	6	$3,731	$115	$3,846
Grand Forks	36	$17,722	$1,325	$19,047
Grant	16	$17,691	$551	$18,242
Griggs	3	$2,828	$187	$3,015
Hettinger	24	$18,843	$420	$19,262
LaMoure	7	$7,495	$401	$7,896
Logan	2	$455	$64	$519
McHenry	21	$12,329	$342	$12,671
McIntosh	2	$1,000	$16	$1,016
McKenzie	6	$1,951	$453	$2,404
McLean	3	$1,916	$285	$2,201
Mercer	3	$1,307	$470	$1,777
Morton	57	$29,865	$924	$30,789
Mountrail	1	$400	$158	$558
Nelson	2	$2,562	$220	$2,782
Oliver	0	$0	$144	$144
Pembina	12	$9,628	$726	$10,353
Pierce	0	$0	$0	$0

County	Rehabilitation and Replacement		Preventive Maintenance Cost	Total Cost
	Bridges	Cost		
Ramsey	5	$2,400	$143	$2,543
Ransom	3	$4,142	$336	$4,478
Renville	0	$0	$163	$163
Richland	30	$18,553	$1,171	$19,724
Rolette	1	$400	$18	$418
Sargent	2	$800	$21	$821
Sioux	0	$0	$43	$43
Slope	2	$609	$219	$828
Stark	23	$11,975	$539	$12,514
Steele	7	$3,744	$371	$4,115
Stutsman	6	$5,241	$327	$5,567
Towner	4	$1,370	$75	$1,445
Traill	33	$31,038	$1,053	$32,090
Walsh	54	$29,769	$1,034	$30,803
Ward	5	$3,612	$382	$3,994
Wells	2	$1,208	$244	$1,452
Williams	10	$3,677	$167	$3,844
Statewide	**489**	**$309,283**	**$18,903**	**$328,185**

Table 36: Statewide Summary of Forecasted Needs for County and Township Bridges ($000)

Period	Rehabilitation		Replacement		Improved Bridges	Maintenance Cost	Total Cost	Total from 2012 Study
	Bridges	Cost	Bridges	Cost				
Backlog	**99**	**$57,466**	**384**	**$247,280**	**483**		**$306,400**	**$288,090**
2015-2016	20	$11,637	77	$49,617	97	$1,890	$63,061	
2017-2018	20	$11,637	77	$49,617	97	$1,890	$63,061	
2019-2020	20	$11,637	77	$49,617	97	$1,890	$63,061	
2021-2022	20	$11,637	77	$49,617	97	$1,890	$63,061	
2023-2024	19	$10,918	76	$48,814	95	$1,890	$61,540	
2025-2029	0	$0	4	$3,537	4	$4,726	$8,057	
2030-2034	0	$0	2	$1,000	2	$4,726	$5,520	
2015-2034	**99**	**$57,466**	**390**	**$251,817**	**489**	**$18,903**	**$328,185**	**$290,456**

10. Conclusions

This report outlines the study undertaken 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 estimated 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.

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/resources/reports/details.php?id=o12

11. Appendix A: Cost and Practices Surveys

A1: County Survey:

County Road Needs Study

County: ________________________________

Contact: ________________________ ________________ ___________________
Name Phone Email

Preparer: ________________________ Date Prepared: ________________________

Gravel Road Costs

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

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

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

(Please circle one)

Road Maintenance and Practices

Gravel Road Practices

Please report blading and graveling frequency for county gravel roads.

Blading Frequency

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

Regraveling Frequency

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

Stabilization

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

If answered "Currently use", please specify type of stabilization, cost per application and application frequency____
____
____

Dust Suppressant – Does your county use dust stabilization on heavily impacted roads? If so – what plays into the decision on which roads receive dust suppressant treatment?

How would you classify the average gravel road condition in your county?
❑Very Good ❑Good ❑Fair ❑Poor

Paved Road Practices

Please report typical paved road maintenance practices used in your county.

Typical overlay frequency: _______________
Typical overlay thickness: ________________
Is roadway width due to repeated overlay treatment an issue in your county?
❑Yes ❑No
If so – what is the estimated number of miles affected?

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

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

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A2: Oil County Survey:

County Road Oil Development Impact Study

County: ______________________________

Contact: ______________________ ________________ __________________

Name Phone Email

Preparer: ______________________ Date Prepared: ______________________

Gravel Road Costs

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

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

Average Gravel/Scoria Overlay Thickness ______________________ Cubic yd/mile or Inches

(Please circle one)

Road Maintenance and Oil Impact Mitigation Practices

Gravel Road Practices

Please report blading and graveling frequency for county gravel roads. Two types of gravel roads are listed, those typical gravel roads that are *not* impacted by oil development and those gravel roads that *are* impacted by oil development.

- **Typical Gravel Roads *Not* impacted by oil development (where applicable)**

Blading Frequency

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

Typical Gravel Roads *Not* impacted by oil development cont.

Regraveling Frequency

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

Stabilization

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

If answered "Currently use", please specify type of stabilization, cost per application and application frequency____
____
____

Dust Suppressant – on heavily impacted roads, how often is dust suppressant applied?

How would you classify the average non-oil impacted gravel road condition in your county?:
❑Very Good ❑Good ❑Fair ❑Poor

- **Oil Impacted Gravel Roads (where applicable)**

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)______________________

Typical Gravel Roads *that ARE* impacted by oil development cont.

Stabilization

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

If answered "Currently use", please specify type of stabilization, cost per application and application frequency____
____
____

Dust Suppressant – on heavily impacted roads, how often is dust suppressant applied?

How would you classify the average oil impacted gravel road condition in your county?:
❑Very Good ❑Good ❑Fair ❑Poor

What additional maintenance practices are being used to mitigate the impacts of oil development on the county gravel roads?____________________________________
____

Paved Road Practices

Please report paved road maintenance practices used in response to oil-related traffic.

Typical overlay frequency: ________________
Typical overlay thickness: _________________
Is roadway width due to repeated overlay treatment an issue in your county?
❑Yes ❑No
If so – what is the estimated number of miles affected?

What maintenance practices are being used to mitigate the impacts of oil-related traffic on the county paved roads *until* the county can reconstruct or resurface the pavement?
____
____

Comments or Suggestions (please use back of sheet if needed):

A3: Township Survey:

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:

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12. Appendix B: Falling Weight Deflectometer Results

Dynatest®
Pavement Engineering Specialists & Equipment

STATEWIDE NONDESTRUCTIVE PAVEMENT TESTING AND ANALYSIS

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, 2014

PROJECT REPORT

Dynatest Consulting, Inc. *Pavement Engineering Specialists and Equipment*
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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 consisted of collecting non-destructive pavement deflection data on approximately 1,500 miles of county and township roads across North Dakota, covering 37 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 08/05 through 9/21/2013 in 6,259 locations across 169 segments. 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 21,560 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 interprocedural 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 interprocedural 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 90.3% of the entire dataset, an increase from 86% obtained after the round of analyses.

The great majority of backcalculated surface layer moduli values fell between 130 and 520 ksi, which is very reasonable for hot mix asphalt layers at various deterioration phases. Only 2.6% of the data values were higher than 750 ksi (high boundary), and 3.3% were lower than 50 ksi (low boundary). The majority of backcalculated base layer moduli values fell between 15 and 50 ksi, which is reasonable for granular base layers. Values unexpectedly higher than 75 ksi were observed in 6.5% of the deflection basins analyzed. The great majority of backcalculated subgrade layer moduli were within 6 and 14 ksi.

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Webpage: www.dynatest.com · E-mail: usa@dynatest.com

Since the amount of data analyzed was very large, a practical database compiling all the data was created in Microsoft Excel™. A simple form was prepared help visualize the raw data (deflections) and the backcalculation results. This tool, called Pavement Analysis Tool, was provided as part of the project deliverables.

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)

Report Prepared by Regis L. Carvalho, Ph.D.
Project Manager

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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 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.

Non-destructive deflection testing was performed in 1500 miles of paved county and township roads across 37 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 08/05 through 9/21/2013 in 6,259 locations across 169 segments. Two different load levels were applied in two replicates of each. The backcalculation of layer moduli was performed for each one of the 21,560 deflection basins collected.

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. A set of maps was created and the list of segments was imported into a geodatabase for accurate identification in the field.

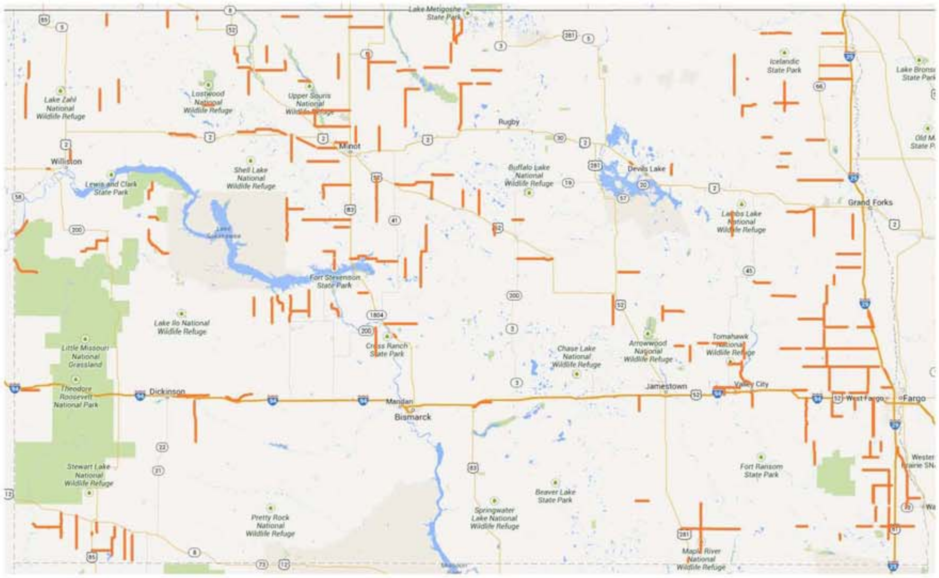

Figure 1. General overview of site locations.

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.

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.

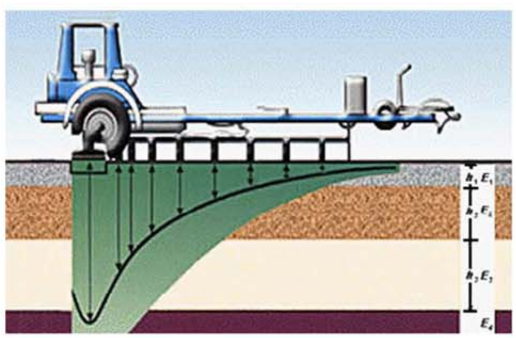

Figure 3. Schematic representation of FWD testing.

3.2 Tested Features and Procedures

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

3

Table 1 . Falling Weight Deflectometer Testing Specifications.

Maximum test spacing	0.25 mi (1320 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

3.2.1 Test Spacing and location with cross section

The test spacing was 0.25 mi (1320 ft) between test points. It was defined that any segment would have at least 9 test locations. The test space was reduced from 0.25 mi to a smaller value whenever the segment was shorter than 2 miles. All segments were tested in one direction only. 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 spacing from the center of the load 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

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 with a digital camera mounted on the vehicle at regular intervals of 0.1 miles. 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 an arrow board to alert live traffic and increase safety.

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.

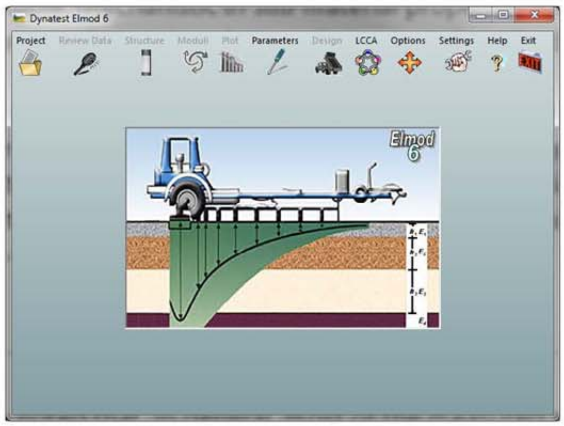

Figure 4. ELMOD 6.1 opening screen.

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 interprocedural 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 interprocedural 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 interprocedural optimization.

Figure 5. Interprocedural optimization flowchart.

After the first round of GPR analyzed data was provided, the backcalculation was performed in all 21,560 deflection basins. 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 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 4. The website http://www.wunderground.com/ (Weather Underground) was used.

Table 4. 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 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 5. 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 5. Reasonable Range of Values for Backcalculated Layer Moduli.

Layer Type	Minimum (ksi)	Maximum (ksi)
Asphalt Concrete	50	2000
Granular Base	10	100
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 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 3,534 deflection basins with unreasonable results out of 25,160 in the entire dataset. These deflection basins were reevaluated with manually input seed values. The basins in which unreasonable results still persisted were flagged and sent with a suggestion of possible sublayer combination to Infrasense for a new thickness analysis. After Infrasense reanalyzed the flagged data, a second iteration was done including the new thicknesses. The number of deflection basins with unreasonable results dropped to 2,842. This process was repeated one more time; this time only redoing the backcalculation. The final number of deflection basis with unreasonable results was 2,443, which corresponds to 9.7% of the entire dataset. Figure 6 illustrates the improvement along the three iterations performed in the project.

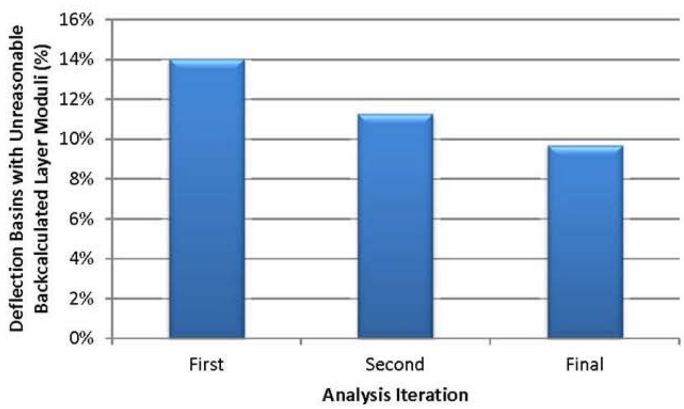

Figure 6. Deflection basins with unreasonable results by analysis iteration.

Typical backcalculation analysis yields 80 to 90% reasonable and accurate results when project level data is used. The number may raise to 95% after improvement techniques are used (e.g., seeding values, increasing range of solution domain, grouping layers, etc...) The total of 90.3% of deflection basins with good results obtained at the end of the analysis process is very satisfactory, especially in a network level project.

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. Therefore limited statistical

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compilation of the data is provided here. The purpose is to provide a snapshot of the backcalculated layer moduli variation across all segments.

The distribution of all surface layer moduli backcalculated at reference temperature (77°F) is provided in Figure 7. The average modulus was 265 ksi. The great majority of values fell between 130 and 520 ksi, which is very reasonable for hot mix asphalt layers at various deterioration phases. Only 2.6% of the data values were higher than 750 ksi, which was defined as high boundary, and 3.3% 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).

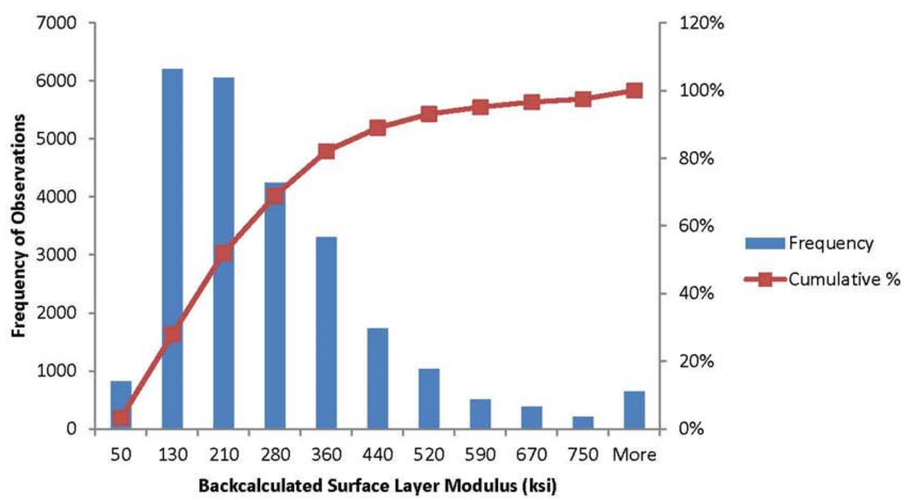

Figure 7. Backcalculated surface layer moduli distribution at reference temperature (77°F).

The distribution of base layer backcalculated moduli is shown in Figure 8. The average value for the entire project was 30 ksi. The majority of values fell between 15 and 50 ksi, which is reasonable for granular base layers. Values unexpectedly higher than 75 ksi were observed in 6.5% of the deflection basins analyzed.

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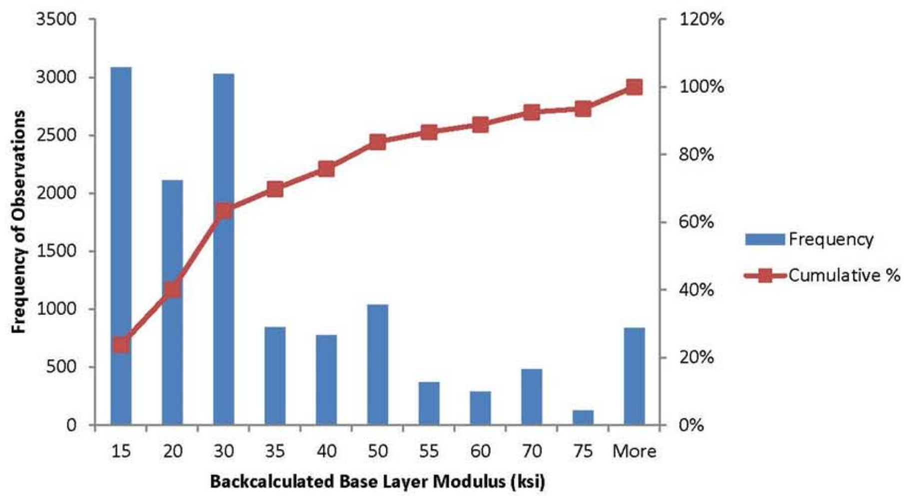

Figure 8. Backcalculated base layer moduli distribution.

The distribution of subgrade layer moduli is provided in Figure 9. As expected, few data points were found at unrealistic high values above 30 ksi (0.4%). The average for the entire dataset was 9 ksi, and the great majority within 6 and 14 ksi.

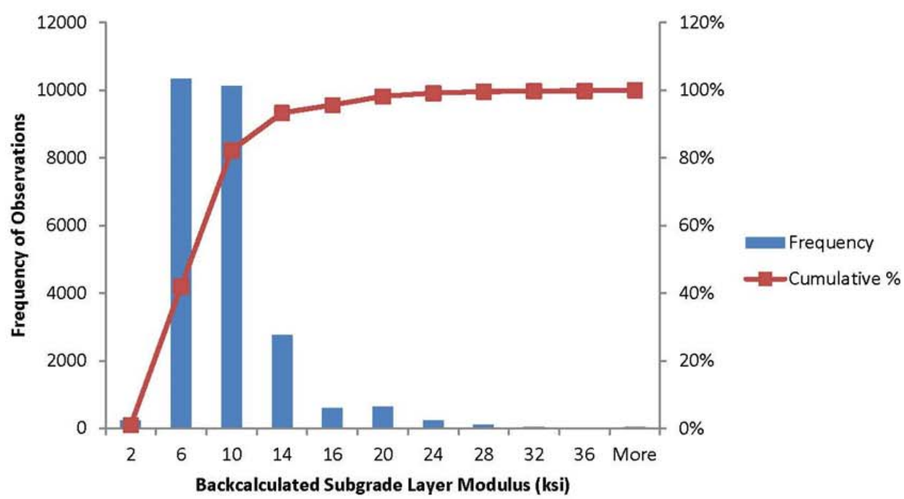

Figure 9. Backcalculated subgrade layer moduli distribution.

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4.4 Pavement Analysis Tool

The dataset analyzed contained over 25,000 deflection basins in more than 6,200 locations. A database compiling all the data was created in Microsoft Excel™. A simple form was prepared to help visualize the raw data (deflections) and the backcalculation results. 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.

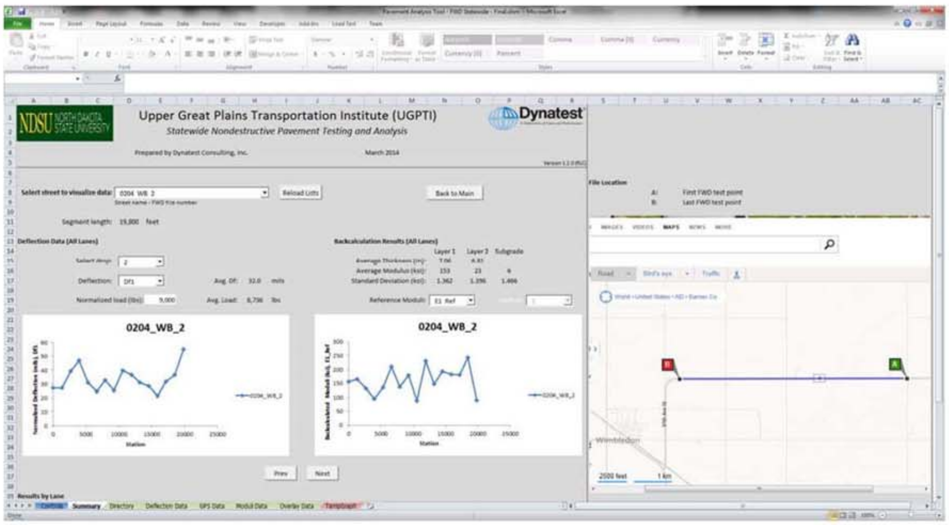

Figure 10. Overview of the summary screen of the Pavement Analysis Tool.

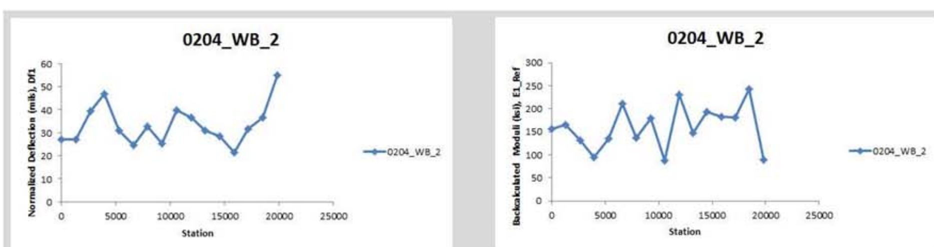

Figure 11. Example of deflection and backcalculated layer moduli plots.

Results by Lane

Average Df1 (mils):	32.5
Standard Deviation Factor[1]:	1.270
84th Percentile:	41.2
Average Modulus E1_Ref (ksi):	153
Standard Deviation Factor[1]:	1.362
84th Percentile:	113

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)
  - 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:
    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)

6. CONCLUSIONS

This project consisted of collecting non-destructive pavement deflection data on approximately 1,500 miles of county and township roads across North Dakota, covering 37 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 08/05 through 9/21/2013 in 6,259 locations across 169 segments. Two different load levels were applied (9,000 and 12,000 lbs) with two replicates for each load. The backcalculation of layer moduli was performed for each one of the 21,560 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. Instead, Dynatest and Infrasense worked closely together during the analysis period and developed an interprocedural 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 interprocedural 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 90.3% of the entire dataset.

The great majority of surface layer backcalculated moduli values were between 130 and 520 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 50 ksi, which is also very reasonable for granular base layers. And finally the subgrade layer backcalculated moduli varied between 6 and 14 ksi.

Since the amount of data analyzed was very large, a practical database compiling all the data was created in Microsoft Excel™. A simple form was prepared help visualize the raw data (deflections) and the backcalculation results. This tool, called Pavement Analysis Tool, was provided as part of the project deliverables.

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)

HEAVY WEIGHT DEFLECTOMETER

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.

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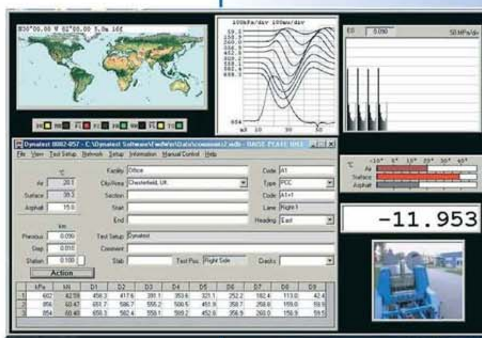
A-2

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

Dynatest®
Equipment & Pavement Engineering Specialists

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Rev. 010112-15

A-3

13. Appendix C: Paved Road Conditions, by County

County	Condition	Miles	Percent
Adams	Good	1.6	7%
Adams	Fair	1	4%
Adams	Poor	14.7	62%
Adams	Very Poor	6.2	26%
Barnes	Very Good	5.8	2%
Barnes	Good	158.6	69%
Barnes	Fair	58.1	25%
Barnes	Poor	5.7	2%
Barnes	Very Poor	2.7	1%
Benson	Very Good	1.1	1%
Benson	Good	58.6	50%
Benson	Fair	54	46%
Benson	Poor	3	3%
Benson	Very Poor	0.6	0%
Billings	Very Good	3.6	8%
Billings	Good	42.5	91%
Billings	Fair	0.4	1%
Bottineau	Very Good	52.9	26%
Bottineau	Good	129.1	64%
Bottineau	Fair	18.6	9%
Bottineau	Poor	0.4	0%
Bowman	Very Good	5.5	4%
Bowman	Good	37.2	28%
Bowman	Fair	49	38%
Bowman	Poor	33.5	26%
Bowman	Very Poor	5.4	4%
Burke	Very Good	15.7	31%
Burke	Good	28.5	55%
Burke	Fair	6	12%
Burke	Poor	0.2	0%
Burke	Very Poor	1	2%
Burleigh	Very Good	7.9	3%
Burleigh	Good	208.1	87%
Burleigh	Fair	20.5	9%
Burleigh	Poor	2.1	1%
Cass	Very Good	61.1	19%
Cass	Good	189.8	60%
Cass	Fair	50.2	16%
Cass	Poor	13.7	4%

County	Condition	Miles	Percent
Cass	Very Poor	3.3	1%
Cavalier	Very Good	5.8	8%
Cavalier	Good	51.9	73%
Cavalier	Fair	6.7	9%
Cavalier	Poor	2.1	3%
Cavalier	Very Poor	5	7%
Dickey	Good	57.1	67%
Dickey	Fair	27.1	32%
Dickey	Poor	0.2	0%
Dickey	Very Poor	0.2	0%
Divide	Very Good	17.1	40%
Divide	Good	25.2	59%
Divide	Fair	0.2	0%
Dunn	Very Good	12.3	24%
Dunn	Good	17.6	34%
Dunn	Fair	12.4	24%
Dunn	Poor	2.5	5%
Dunn	Very Poor	6.3	12%
Eddy	Very Good	5.3	7%
Eddy	Good	33.3	47%
Eddy	Fair	25.9	36%
Eddy	Poor	6.1	8%
Eddy	Very Poor	1	1%
Emmons	Good	11	60%
Emmons	Very Poor	7.4	40%
Foster	Very Good	5.9	6%
Foster	Good	54.6	60%
Foster	Fair	27.1	30%
Foster	Poor	3	3%
Foster	Very Poor	0.5	1%
Golden Valley	Good	12.5	52%
Golden Valley	Fair	9.2	39%
Golden Valley	Poor	1.2	5%
Golden Valley	Very Poor	1	4%
Grand Forks	Very Good	7.5	3%
Grand Forks	Good	114.8	41%
Grand Forks	Fair	119.9	43%
Grand Forks	Poor	28	10%
Grand Forks	Very Poor	8.7	3%
Grant	Good	10.4	100%
Griggs	Very Good	4	10%

County	Condition	Miles	Percent
Griggs	Good	32.9	85%
Griggs	Fair	1.4	4%
Griggs	Poor	0.3	1%
Hettinger	Very Good	3.2	18%
Hettinger	Good	12.5	71%
Hettinger	Fair	1.7	10%
Hettinger	Poor	0.2	1%
Kidder	Very Good	4	7%
Kidder	Good	39.9	67%
Kidder	Fair	8.8	15%
Kidder	Poor	1.8	3%
Kidder	Very Poor	4.6	8%
LaMoure	Good	96	62%
LaMoure	Fair	49.7	32%
LaMoure	Poor	7.8	5%
LaMoure	Very Poor	1.4	1%
Logan	Good	8.4	76%
Logan	Poor	2.6	24%
McHenry	Very Good	18.5	19%
McHenry	Good	69.6	73%
McHenry	Fair	7.4	8%
McIntosh	Very Good	4.7	6%
McIntosh	Good	46.5	55%
McIntosh	Fair	29.5	35%
McIntosh	Poor	2.5	3%
McIntosh	Very Poor	1.7	2%
McKenzie	Very Good	23.5	18%
McKenzie	Good	74.5	56%
McKenzie	Fair	20.1	15%
McKenzie	Poor	7	5%
McKenzie	Very Poor	7.9	6%
McLean	Very Good	12.4	8%
McLean	Good	94.8	61%
McLean	Fair	35.5	23%
McLean	Poor	9.5	6%
McLean	Very Poor	2.8	2%
Mercer	Very Good	5.4	5%
Mercer	Good	88.8	78%
Mercer	Fair	12.3	11%
Mercer	Poor	5.9	5%
Mercer	Very Poor	1.3	1%

County	Condition	Miles	Percent
Morton	Very Good	0.2	0%
Morton	Good	90.4	93%
Morton	Fair	5.1	5%
Morton	Poor	1.2	1%
Morton	Very Poor	0.2	0%
Mountrail	Very Good	29.6	17%
Mountrail	Good	69.2	40%
Mountrail	Fair	37.2	22%
Mountrail	Poor	23	13%
Mountrail	Very Poor	13	8%
Nelson	Good	68.9	84%
Nelson	Fair	7.9	10%
Nelson	Poor	4.7	6%
Oliver	Good	22.3	82%
Oliver	Fair	5.1	18%
Pembina	Very Good	8.2	4%
Pembina	Good	98.8	51%
Pembina	Fair	69.5	36%
Pembina	Poor	9.2	5%
Pembina	Very Poor	9.8	5%
Pierce	Very Good	0.8	7%
Pierce	Good	9.4	93%
Ramsey	Very Good	8.5	7%
Ramsey	Good	101.8	88%
Ramsey	Fair	4.9	4%
Ramsey	Poor	0.2	0%
Ransom	Very Good	1	2%
Ransom	Good	45.2	76%
Ransom	Fair	12.8	21%
Ransom	Poor	0.5	1%
Ransom	Very Poor	0.2	0%
Renville	Very Good	8.3	10%
Renville	Good	67.9	80%
Renville	Fair	7.3	9%
Renville	Poor	1.6	2%
Richland	Very Good	17.3	7%
Richland	Good	157.1	64%
Richland	Fair	58.8	24%
Richland	Poor	10.3	4%
Richland	Very Poor	2.7	1%
Rolette	Very Good	18.3	14%

County	Condition	Miles	Percent
Rolette	Good	48.6	37%
Rolette	Fair	26.1	20%
Rolette	Poor	8	6%
Rolette	Very Poor	30.4	23%
Sargent	Good	73.6	81%
Sargent	Fair	10	11%
Sargent	Poor	6.6	7%
Sargent	Very Poor	1.1	1%
Sheridan	Good	14.2	65%
Sheridan	Fair	6.4	29%
Sheridan	Poor	0.2	1%
Sheridan	Very Poor	1	5%
Sioux	Good	3.3	7%
Sioux	Fair	43.2	92%
Sioux	Poor	0.3	1%
Sioux	Very Poor	0.1	0%
Slope	Good	0.9	69%
Slope	Fair	0.4	31%
Stark	Very Good	15.3	15%
Stark	Good	80.2	78%
Stark	Fair	1	1%
Stark	Poor	6.3	6%
Steele	Very Good	12.8	17%
Steele	Good	55.1	73%
Steele	Fair	7.9	10%
Steele	Very Poor	0.1	0%
Stutsman	Very Good	9.6	4%
Stutsman	Good	115.1	51%
Stutsman	Fair	52.2	23%
Stutsman	Poor	45.9	20%
Stutsman	Very Poor	4	2%
Towner	Good	0.3	100%
Traill	Very Good	8.4	6%
Traill	Good	93.6	63%
Traill	Fair	32	21%
Traill	Poor	12.5	8%
Traill	Very Poor	2.6	2%
Walsh	Very Good	18.4	10%
Walsh	Good	97.8	56%
Walsh	Fair	42.8	24%
Walsh	Poor	14	8%

County	Condition	Miles	Percent
Walsh	Very Poor	2.3	1%
Ward	Very Good	21.3	7%
Ward	Good	200.4	66%
Ward	Fair	58	19%
Ward	Poor	22.1	7%
Ward	Very Poor	3.3	1%
Wells	Very Good	6.9	6%
Wells	Good	70.8	63%
Wells	Fair	19.6	18%
Wells	Poor	12.9	12%
Wells	Very Poor	1.7	2%
Williams	Very Good	51.6	28%
Williams	Good	129.1	70%
Williams	Fair	0.5	0%
Williams	Poor	2.2	1%
Williams	Very Poor	1	1%

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 2014 Dollars)

County	2015-2016	2017-2018	2019-2020	2021-2022	2023-2024	2025-2034	2015-2034
Adams	$7.7	$7.7	$7.7	$7.7	$7.7	$38.4	$76.7
Barnes	$9.3	$9.3	$9.3	$9.3	$9.4	$46.7	$93.4
Benson	$4.9	$4.9	$4.9	$4.9	$4.9	$24.6	$49.2
Billings	$13.4	$13.5	$13.5	$13.4	$13.2	$61.3	$128.3
Bottineau	$7.0	$7.0	$7.0	$7.0	$7.0	$34.8	$69.8
Bowman	$7.0	$7.0	$6.9	$6.9	$6.9	$34.3	$69.1
Burke	$12.8	$12.7	$12.8	$12.8	$12.8	$63.0	$126.8
Burleigh	$7.8	$7.8	$7.8	$7.8	$7.8	$39.3	$78.5
Cass	$26.8	$26.8	$26.9	$26.9	$26.9	$134.2	$268.4
Cavalier	$9.3	$9.3	$9.3	$9.3	$9.3	$46.5	$93.1
Dickey	$9.1	$9.1	$9.1	$9.1	$9.1	$45.5	$90.9
Divide	$10.0	$10.0	$10.0	$10.0	$9.9	$49.1	$99.1
Dunn	$43.5	$29.1	$29.2	$28.9	$28.3	$135.6	$294.5
Eddy	$1.9	$1.9	$1.9	$1.9	$1.9	$9.5	$18.9
Emmons	$2.6	$2.6	$2.6	$2.6	$2.6	$12.8	$25.7
Foster	$2.3	$2.3	$2.3	$2.3	$2.3	$11.7	$23.5
Golden Valley	$8.9	$9.4	$9.1	$9.1	$9.0	$43.3	$88.8
Grand Forks	$13.3	$13.3	$13.3	$13.3	$13.3	$66.3	$132.6
Grant	$5.3	$5.3	$5.3	$5.3	$5.3	$26.3	$52.6
Griggs	$5.1	$5.1	$5.2	$5.2	$5.2	$25.8	$51.6
Hettinger	$2.9	$2.9	$2.9	$2.9	$2.9	$14.3	$28.6
Kidder	$5.9	$5.9	$5.9	$5.9	$5.9	$29.5	$59.0
LaMoure	$1.4	$1.4	$1.4	$1.4	$1.4	$7.1	$14.3
Logan	$2.2	$2.2	$2.2	$2.2	$2.2	$11.1	$22.3
McHenry	$22.9	$22.9	$22.9	$22.9	$22.9	$113.8	$228.3
McIntosh	$2.0	$2.0	$2.0	$2.0	$2.0	$10.0	$20.1
McKenzie	$92.1	$48.4	$48.2	$47.5	$46.6	$218.4	$501.2
McLean	$17.0	$16.9	$16.9	$16.9	$17.0	$84.6	$169.3
Mercer	$9.1	$9.1	$9.1	$9.1	$9.1	$45.1	$90.7
Morton	$10.6	$10.6	$10.6	$10.5	$10.6	$52.8	$105.5
Mountrail	$24.8	$24.1	$24.1	$23.7	$22.9	$109.7	$229.3
Nelson	$4.8	$4.8	$4.8	$4.8	$4.8	$24.2	$48.4
Oliver	$3.8	$3.8	$3.8	$3.8	$3.8	$19.2	$38.3
Pembina	$10.3	$10.3	$10.3	$10.3	$10.3	$51.4	$102.7
Pierce	$8.9	$8.9	$8.9	$8.9	$8.9	$44.5	$89.0
Ramsey	$5.5	$5.5	$5.5	$5.5	$5.5	$27.6	$55.2

Table D.1: County and Township Unpaved Road Investment Needs, by County and Period (Millions of 2014 Dollars)							
County	**2015-2016**	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2034**	**2015-2034**
Ransom	$2.1	$2.1	$2.1	$2.1	$2.1	$10.3	$20.6
Renville	$3.7	$3.7	$3.7	$3.7	$3.7	$18.4	$36.9
Richland	$16.2	$16.2	$16.2	$16.2	$16.2	$81.1	$162.2
Rolette	$5.7	$5.7	$5.7	$5.7	$5.7	$28.5	$57.0
Sargent	$5.5	$5.5	$5.6	$5.6	$5.6	$27.8	$55.5
Sheridan	$2.3	$2.3	$2.3	$2.3	$2.3	$11.6	$23.3
Sioux	$4.9	$4.9	$4.9	$4.9	$5.0	$24.7	$49.4
Slope	$4.8	$4.9	$4.8	$4.8	$4.8	$23.9	$47.9
Stark	$19.8	$19.7	$19.7	$19.6	$19.6	$97.0	$195.3
Steele	$3.8	$3.9	$3.9	$3.9	$3.9	$19.3	$38.6
Stutsman	$7.3	$7.3	$7.3	$7.3	$7.3	$36.7	$73.3
Towner	$5.3	$5.3	$5.4	$5.4	$5.4	$26.8	$53.6
Traill	$4.3	$4.3	$4.3	$4.3	$4.3	$21.4	$42.7
Walsh	$21.8	$21.8	$21.8	$21.9	$21.9	$109.3	$218.5
Ward	$18.8	$18.8	$18.8	$18.8	$18.8	$93.3	$187.3
Wells	$5.6	$5.6	$5.6	$5.6	$5.6	$27.8	$55.6
Williams	$42.3	$41.8	$41.9	$41.5	$40.5	$197.3	$405.2
Total	$606.4	$547.9	$547.5	$545.6	$541.9	$2,667.5	$5,456.7

Table D.2: County and Township Paved Road Investment Needs, by County and Period (Millions of 2014 Dollars)						
County	**Miles Resurfaced**	**Miles Widened**	**Miles Reclaimed/ Reconstructed**	**Total Miles Improved**	**Total Cost (Million$)**	**Annual Cost per Mile**
Adams	8	0	15.5	23.5	$14.84	$31,515
Barnes	196.1	19.4	15.3	230.8	$98.44	$21,325
Benson	109.8	6.6	0.9	117.2	$44.16	$18,834
Billings	46.2	0	0.3	46.5	$18.79	$20,217
Bottineau	184.9	11	5	200.9	$89.98	$22,395
Bowman	98.5	14.8	17.4	130.6	$81.75	$31,299
Burke	43.9	0	7.5	51.4	$30.92	$30,092
Burleigh	238.6	0	0	238.6	$81.31	$17,041
Cass	299	2.5	16.7	318.1	$139.80	$21,972
Cavalier	65.5	0	6	71.5	$27.28	$19,083
Dickey	60.1	9.3	15.3	84.7	$56.18	$33,174
Divide	39.1	0	3.3	42.4	$21.10	$24,862
Dunn	37.5	3.2	10.4	51.1	$34.09	$33,337
Eddy	55.9	11.7	4.2	71.7	$35.63	$24,857
Emmons	11	0	7.4	18.4	$9.46	$25,755
Foster	83.8	6.8	0.5	91.1	$36.14	$19,845
Golden Valley	22.6	0	1.3	23.9	$10.33	$21,648
Grand Forks	253.1	6.9	18.9	278.9	$114.70	$20,563
Grant	10.4	0	0	10.4	$3.58	$17,254
Griggs	38.3	0	0.3	38.5	$13.34	$17,301
Hettinger	17.5	0	0	17.5	$6.05	$17,262
Kidder	52.8	0	6.4	59.2	$22.86	$19,310
LaMoure	144.3	5.2	5.5	154.9	$57.43	$18,534
Logan	11	0	0	11	$3.61	$16,380
McHenry	87.4	0.2	8	95.6	$47.48	$24,847
McIntosh	83.3	0	1.7	85	$29.31	$17,247
McKenzie	101.9	0	31.2	133	$102.06	$38,359
McLean	98.6	1.6	54.7	155	$131.29	$42,359
Mercer	97.7	4	11.9	113.6	$62.51	$27,504
Morton	93.3	2.7	1.3	97.3	$38.92	$20,002
Mountrail	94.6	0	77.5	172	$165.20	$48,023
Nelson	68.6	9	3.9	81.5	$35.39	$21,702
Oliver	26.9	0.4	0	27.4	$13.08	$23,875
Pembina	160.7	11.4	23.4	195.5	$79.78	$20,408
Pierce	8.9	0.2	1.1	10.2	$5.23	$25,703

Ramsey	115.5	0	0	115.5	$39.95	$17,302
Ransom	59.4	0	0.2	59.7	$22.24	$18,625
Renville	78.7	0.3	6.1	85	$43.00	$25,289
Richland	223.9	12	10.2	246.2	$103.34	$20,989
Rolette	99.9	0	31.6	131.4	$59.92	$22,797
Sargent	85.7	0.4	5.1	91.2	$36.84	$20,188
Sheridan	20.7	0	1.2	21.9	$8.19	$18,673
Sioux	43.3	3.3	0.3	46.9	$20.56	$21,919
Slope	1.3	0	0	1.3	$0.53	$19,681
Stark	90.6	2.7	9.5	102.8	$59.79	$29,081
Steele	63.7	12.1	0.1	75.9	$31.22	$20,560
Stutsman	201.8	11.6	13.4	226.8	$89.10	$19,639
Towner	0.3	0	0	0.3	$0.10	$16,536
Traill	129.8	7	12.2	149	$68.20	$22,880
Walsh	146	21.7	7.4	175.1	$76.16	$21,741
Ward	276.9	4.2	24.1	305.1	$154.27	$25,278
Wells	104.6	2.6	4.7	111.9	$41.16	$18,397
Williams	144.9	25.4	14.1	184.4	$127.62	$34,601
Total	4,936.30	230.1	513	5,679.40	$2,744.16	$24,159

Table D.3: County and Township Paved Road Investment Needs by County and Period (Thousands of 2014 Dollars)							
County	**2015-2016**	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2034**	**2015-2034**
Adams	$1,316	$9,724	$420	$420	$420	$2,535	$14,835
Barnes	$11,889	$14,566	$12,600	$6,819	$5,115	$47,453	$98,442
Benson	$5,005	$3,222	$3,523	$2,615	$2,538	$27,259	$44,162
Billings	$961	$1,211	$855	$1,313	$842	$13,606	$18,788
Bottineau	$9,082	$7,907	$6,050	$5,267	$4,449	$57,227	$89,982
Bowman	$30,967	$15,069	$7,350	$4,414	$2,885	$21,064	$81,749
Burke	$3,213	$1,054	$3,113	$7,104	$917	$15,515	$30,916
Burleigh	$4,668	$4,260	$4,260	$4,260	$4,364	$59,492	$81,304
Cass	$12,578	$19,326	$12,330	$8,302	$7,515	$79,752	$139,803
Cavalier	$5,087	$1,276	$1,276	$1,276	$1,288	$17,072	$27,275
Dickey	$6,586	$6,817	$16,152	$3,527	$2,896	$20,200	$56,178
Divide	$758	$914	$758	$4,232	$805	$13,635	$21,102
Dunn	$11,768	$3,079	$4,766	$1,026	$995	$12,450	$34,084
Eddy	$8,592	$5,088	$3,118	$1,644	$1,621	$15,572	$35,635
Emmons	$3,293	$1,815	$328	$328	$328	$3,372	$9,464
Foster	$7,706	$7,842	$4,242	$2,020	$1,626	$12,703	$36,139
Golden Valley	$2,443	$811	$1,031	$826	$426	$4,791	$10,328
Grand Forks	$24,211	$12,370	$7,488	$6,659	$6,277	$57,695	$114,700
Grant	$185	$185	$185	$185	$185	$2,649	$3,574
Griggs	$857	$688	$856	$1,361	$1,746	$7,829	$13,337
Hettinger	$340	$571	$313	$313	$410	$4,106	$6,053
Kidder	$1,379	$5,169	$1,725	$1,863	$1,922	$10,802	$22,860
LaMoure	$7,489	$7,983	$4,502	$4,514	$4,516	$28,423	$57,427
Logan	$632	$197	$197	$197	$197	$2,190	$3,610
McHenry	$4,548	$4,834	$9,076	$4,237	$2,449	$22,340	$47,484
McIntosh	$1,916	$2,522	$1,669	$1,837	$1,517	$19,847	$29,308
McKenzie	$16,120	$11,320	$16,927	$18,571	$4,057	$35,062	$102,057

Table D.3: County and Township Paved Road Investment Needs by County and Period (Thousands of 2014 Dollars)							
County	**2015-2016**	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2034**	**2015-2034**
McLean	$7,502	$8,344	$27,732	$46,471	$3,340	$37,898	$131,287
Mercer	$6,961	$7,460	$7,475	$6,848	$4,842	$28,923	$62,509
Morton	$3,201	$3,246	$2,439	$2,049	$2,504	$25,476	$38,915
Mountrail	$42,453	$17,061	$42,668	$6,761	$3,947	$52,312	$165,202
Nelson	$2,129	$7,452	$4,060	$2,268	$1,920	$17,559	$35,388
Oliver	$1,546	$759	$759	$759	$812	$8,440	$13,075
Pembina	$9,382	$18,141	$10,540	$4,430	$6,206	$31,079	$79,778
Pierce	$215	$442	$215	$1,590	$215	$2,555	$5,232
Ramsey	$2,432	$2,590	$3,398	$5,120	$2,578	$23,835	$39,953
Ransom	$2,212	$1,441	$1,616	$1,415	$1,385	$14,165	$22,234
Renville	$2,012	$2,404	$3,301	$2,407	$1,905	$30,967	$42,996
Richland	$9,296	$15,191	$10,772	$9,707	$5,947	$52,424	$103,337
Rolette	$6,637	$18,398	$2,614	$2,642	$2,664	$26,966	$59,921
Sargent	$5,629	$2,146	$3,036	$2,129	$2,528	$21,369	$36,837
Sheridan	$1,015	$1,185	$405	$392	$392	$4,801	$8,190
Sioux	$5,352	$1,037	$837	$844	$850	$11,634	$20,554
Slope	$24	$24	$24	$24	$24	$410	$530
Stark	$12,138	$5,701	$3,145	$6,820	$4,170	$27,818	$59,792
Steele	$4,153	$6,022	$1,461	$1,361	$1,514	$16,706	$31,217
Stutsman	$19,107	$13,096	$6,143	$6,089	$4,408	$40,256	$89,099
Towner	$5	$5	$5	$5	$5	$74	$99
Traill	$12,771	$7,739	$5,364	$8,335	$3,543	$30,447	$68,199
Walsh	$16,074	$9,997	$6,899	$4,884	$4,503	$33,801	$76,158
Ward	$24,550	$22,384	$13,867	$9,138	$5,623	$78,708	$154,270
Wells	$7,053	$3,897	$2,150	$2,827	$2,351	$22,884	$41,162
Williams	$7,563	$19,615	$19,292	$27,026	$6,700	$47,420	$127,616

Table D.4: Estimated Improvement Needs for Unpaved Indian Reservation Roads, by County (Millions of 2014 Dollars)							
County	**2015-2016**	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2034**	**2015-2034**
Benson	$2,878	$783	$943	$607	$679	$8,214	$14,104
Dunn	$10,885	$2,501	$4,188	$418	$418	$2,698	$21,108
McKenzie	$5,528	$2,277	$2,324	$682	$311	$2,231	$13,353
McLean	$743	$4,357	$354	$551	$591	$4,315	$10,911
Mercer	$2,898	$251	$444	$142	$142	$708	$4,585
Mountrail	$3,914	$4,411	$558	$202	$202	$9,734	$19,021
Rolette	$5,161	$17,380	$1,329	$1,329	$1,481	$12,998	$39,678
Sioux	$5,310	$995	$795	$795	$795	$10,993	$19,683

Table D.5: Estimated Improvement Needs for Paved Indian Reservation Roads, by County (Thousands of 2014 Dollars)							
County	**2015-2016**	**2017-2018**	**2019-2020**	**2021-2022**	**2023-2024**	**2025-2034**	**2015-2034**
Benson	$2,878	$783	$943	$607	$679	$8,214	$14,104
Dunn	$10,885	$2,501	$4,188	$418	$418	$2,698	$21,108
McKenzie	$5,528	$2,277	$2,324	$682	$311	$2,231	$13,353
McLean	$743	$4,357	$354	$551	$591	$4,315	$10,911
Mercer	$2,898	$251	$444	$142	$142	$708	$4,585
Mountrail	$3,914	$4,411	$558	$202	$202	$9,734	$19,021
Rolette	$5,161	$17,380	$1,329	$1,329	$1,481	$12,998	$39,678
Sioux	$5,310	$995	$795	$795	$795	$10,993	$19,683

Table D.6: Estimated Bridge Improvement Needs, by County (Thousands of 2014 Dollars)				
County	Rehabilitation and Replacement		Preventive Maintenance Cost	Total Cost
	Bridges	Cost		
Adams	3	$1,200	$187	$1,387
Barnes	2	$1,733	$395	$2,129
Benson	3	$978	$65	$1,043
Billings	3	$1,493	$203	$1,696
Bottineau	27	$19,416	$426	$19,841
Bowman	6	$1,723	$134	$1,856
Burke	0	$0	$52	$52
Burleigh	6	$2,241	$348	$2,589
Cass	29	$21,068	$2,617	$23,685
Cavalier	7	$3,000	$79	$3,079
Dickey	0	$0	$392	$392
Divide	2	$800	$53	$853
Dunn	7	$3,739	$276	$4,015
Eddy	1	$726	$211	$937
Emmons	3	$2,101	$272	$2,373
Foster	2	$804	$87	$891
Golden Valley	6	$3,731	$115	$3,846
Grand Forks	36	$17,722	$1,325	$19,047
Grant	16	$17,691	$551	$18,242
Griggs	3	$2,828	$187	$3,015
Hettinger	24	$18,843	$420	$19,262
LaMoure	7	$7,495	$401	$7,896
Logan	2	$455	$64	$519
McHenry	21	$12,329	$342	$12,671
McIntosh	2	$1,000	$16	$1,016
McKenzie	6	$1,951	$453	$2,404
McLean	3	$1,916	$285	$2,201
Mercer	3	$1,307	$470	$1,777
Morton	57	$29,865	$924	$30,789
Mountrail	1	$400	$158	$558
Nelson	2	$2,562	$220	$2,782
Oliver	0	$0	$144	$144
Pembina	12	$9,628	$726	$10,353
Pierce	0	$0	$0	$0
Ramsey	5	$2,400	$143	$2,543

Table D.6: Estimated Bridge Improvement Needs, by County (Thousands of 2014 Dollars)				
County	**Rehabilitation and Replacement**		**Preventive Maintenance Cost**	**Total Cost**
	Bridges	**Cost**		
Ransom	3	$4,142	$336	$4,478
Renville	0	$0	$163	$163
Richland	30	$18,553	$1,171	$19,724
Rolette	1	$400	$18	$418
Sargent	2	$800	$21	$821
Sioux	0	$0	$43	$43
Slope	2	$609	$219	$828
Stark	23	$11,975	$539	$12,514
Steele	7	$3,744	$371	$4,115
Stutsman	6	$5,241	$327	$5,567
Towner	4	$1,370	$75	$1,445
Traill	33	$31,038	$1,053	$32,090
Walsh	54	$29,769	$1,034	$30,803
Ward	5	$3,612	$382	$3,994
Wells	2	$1,208	$244	$1,452
Williams	10	$3,677	$167	$3,844
Statewide	**489**	**$309,283**	**$18,903**	**$328,185**

Table D.7: Total Estimated Road and Bridge Investment Needs, by County (Millions of 2014 Dollars)				
County	**Unpaved Road Needs**	**Paved Road Needs**	**Bridge Needs**	**Total Needs**
Adams	$76.7	$14.84	$1.387	$92.93
Barnes	$93.4	$98.44	$2.129	$193.97
Benson	$49.2	$44.16	$1.043	$94.40
Billings	$128.3	$18.79	$1.696	$148.79
Bottineau	$69.8	$89.98	$19.841	$179.62
Bowman	$69.1	$81.75	$1.856	$152.71
Burke	$126.8	$30.92	$0.052	$157.77
Burleigh	$78.5	$81.31	$2.589	$162.40
Cass	$268.4	$139.80	$23.685	$431.89
Cavalier	$93.1	$27.28	$3.079	$123.46
Dickey	$90.9	$56.18	$0.392	$147.47
Divide	$99.1	$21.10	$0.853	$121.05
Dunn	$294.5	$34.09	$4.015	$332.61
Eddy	$18.9	$35.63	$0.937	$55.47
Emmons	$25.7	$9.46	$2.373	$37.53
Foster	$23.5	$36.14	$0.891	$60.53
Golden Valley	$88.8	$10.33	$3.846	$102.98
Grand Forks	$132.6	$114.70	$19.047	$266.35
Grant	$52.6	$3.58	$18.242	$74.42
Griggs	$51.6	$13.34	$3.015	$67.96
Hettinger	$28.6	$6.05	$19.262	$53.91
Kidder	$59.0	$22.86	$0	$81.86
LaMoure	$14.3	$57.43	$7.896	$79.63
Logan	$22.3	$3.61	$0.519	$26.43
McHenry	$228.3	$47.48	$12.671	$288.45
McIntosh	$20.1	$29.31	$1.016	$50.43
McKenzie	$501.2	$102.06	$2.404	$605.66
McLean	$169.3	$131.29	$2.201	$302.79
Mercer	$90.7	$62.51	$1.777	$154.99
Morton	$105.5	$38.92	$30.789	$175.21
Mountrail	$229.3	$165.20	$0.558	$395.06
Nelson	$48.4	$35.39	$2.782	$86.57
Oliver	$38.3	$13.08	$0.144	$51.52
Pembina	$102.7	$79.78	$10.353	$192.83
Pierce	$89.0	$5.23	$0	$94.23
Ramsey	$55.2	$39.95	$2.543	$97.69

Table D.7: Total Estimated Road and Bridge Investment Needs, by County (Millions of 2014 Dollars)				
County	**Unpaved Road Needs**	**Paved Road Needs**	**Bridge Needs**	**Total Needs**
Ransom	$20.6	$22.24	$4.478	$47.32
Renville	$36.9	$43.00	$0.163	$80.06
Richland	$162.2	$103.34	$19.724	$285.26
Rolette	$57.0	$59.92	$0.418	$117.34
Sargent	$55.5	$36.84	$0.821	$93.16
Sheridan	$23.3	$8.19	$0	$31.49
Sioux	$49.4	$20.56	$0.043	$70.00
Slope	$47.9	$0.53	$0.828	$49.26
Stark	$195.3	$59.79	$12.514	$267.60
Steele	$38.6	$31.22	$4.115	$73.94
Stutsman	$73.3	$89.10	$5.567	$167.97
Towner	$53.6	$0.10	$1.445	$55.15
Traill	$42.7	$68.20	$32.090	$142.99
Walsh	$218.5	$76.16	$30.803	$325.46
Ward	$187.3	$154.27	$3.994	$345.56
Wells	$55.6	$41.16	$1.452	$98.21
Williams	$405.2	$127.62	$3.844	$536.66
Total	$5,456.7	$2,744.16	$328.19	$8,529.05

15. Appendix E: Bridge Component Deterioration Models

Substructure Model

Substructure Rating =
8.744 + 0.471*RECON + 0.152*ADTL -0.451* Timber – 0.605*Steel -0.072*Age + 0.0003*Age2 + 0.792*Bismarck + 0.620*Valley_City + 0.221*Devils_Lake + 0.451*Minot + 0.345*Dickinson + 0.395*Grand_Forks + 0.145*Williston

R-squared = 0.55

Superstructure Model

Superstructure Rating =
8.721 + 0.418*Recon + (0.031*ADTL) – 0.579*Timber – 0.584*Steel – 0.052*Age + 0.00015*Age2 + 0.539*Bismarck + 0.332*Valley_City + 0.247*Devils_Lake + 0.599*Minot + 0.124*Dickinson +0.378*Grand_Forks + (0.055*Williston)

R-squared = 0.55

Deck Model

Deck Rating=
8.170 + 0.621*Recon +0.427*ADTL -0.382*Timber -0.430*Steel - 0.169*maint_salt - 0.061*Age + 0.00029*Age2 + 0.712*Bismarck + 0.625*Valley_City + 0.270*Devils_Lake + 0.733*Minot + 0.265*Dickenson + 0.666*Grand_Forks – (0.040*Williston)
R-squared = 0.47

Notes:
1) ADT: 4500,and 4500+
2) Material type: left-out variable is Concrete
3) District: left-out variable is Fargo
4) the variables in red means they are not statistically significant at 90% confidence level. For ADTL, they should not considered in the equation; for Williston, that just simply mean Williston has no difference than Fargo in terms of Deck and Super structure ratings.

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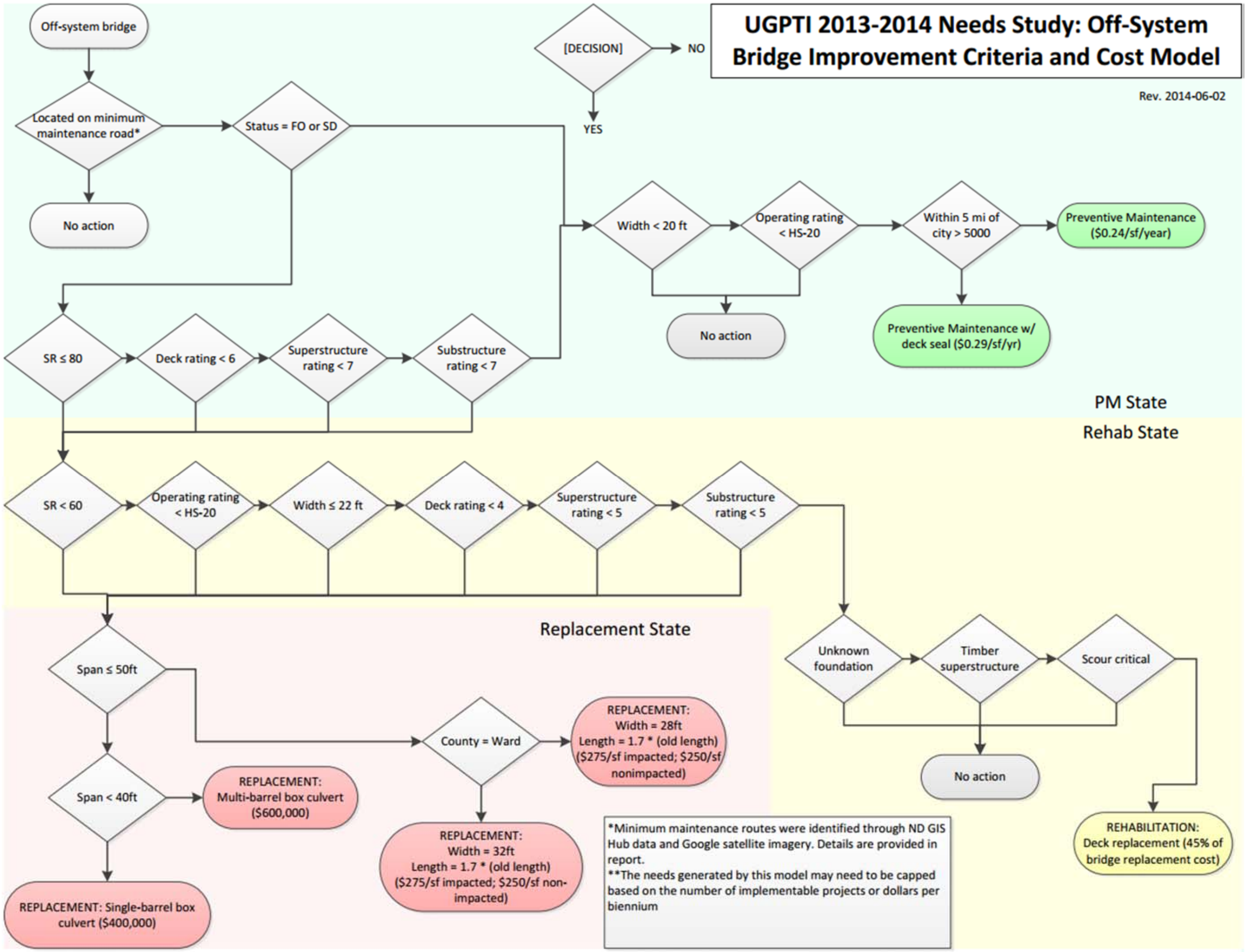
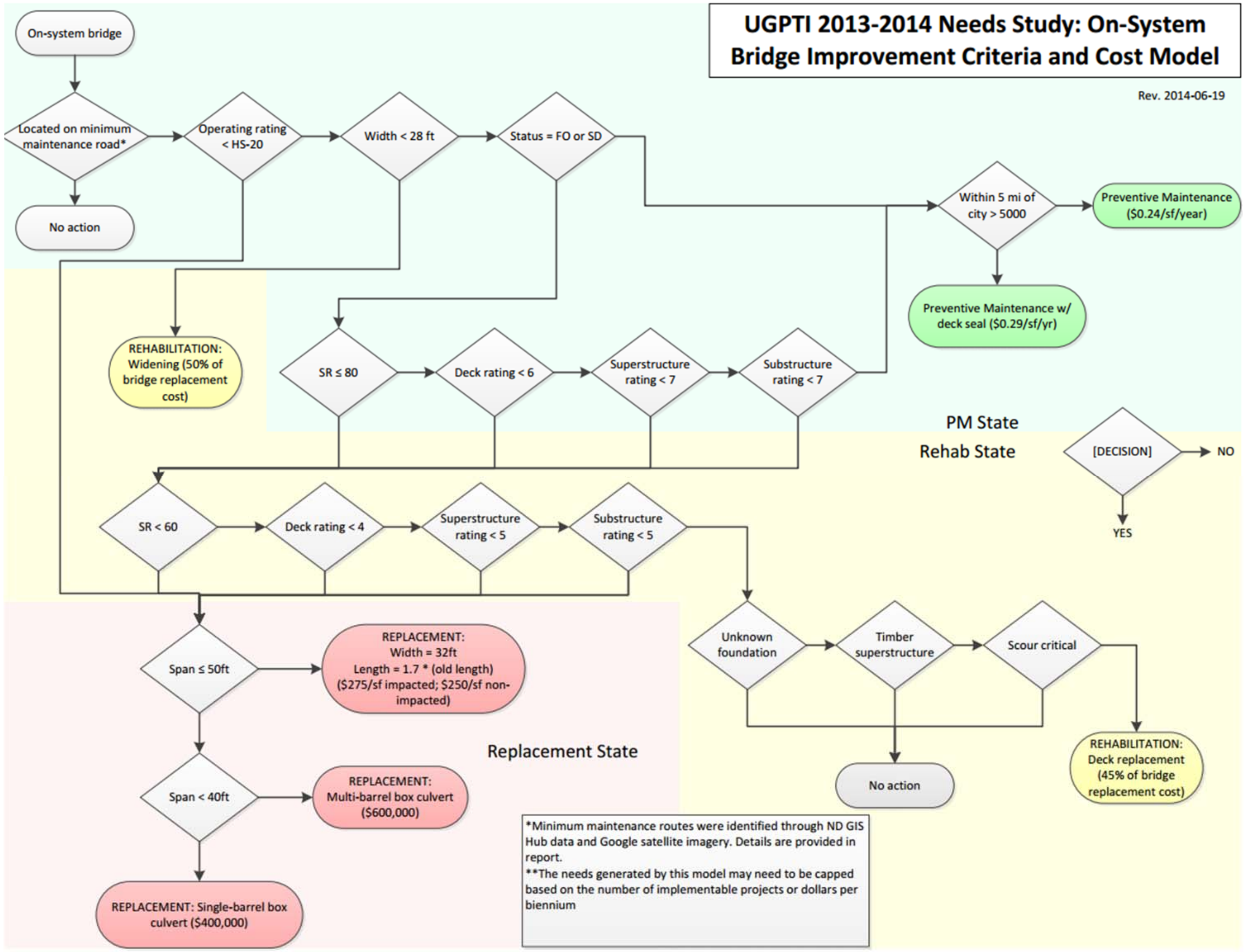
[1] Culvert and Retaining Walls (Item 62) applies only if the last two digits of Design Main (Item 42) are coded Frame or Culvert

[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 2013-2014 Needs Study: On-System Bridge Improvement Criteria and Cost Model
Rev. 2014-06-19
On-system bridge
Located on minimum maintenance road*
No action
Operating rating < HS-20
Width < 28 ft
Status = FO or SD
Within 5 mi of city > 5000
Preventive Maintenance ($0.24/sf/year)
Preventive Maintenance w/ deck seal ($0.29/sf/yr)
REHABILITATION: Widening (50% of bridge replacement cost)
SR ≤ 80
Deck rating < 6
Superstructure rating < 7
Substructure rating < 7
PM State
Rehab State
[DECISION]
NO
YES
SR < 60
Deck rating < 4
Superstructure rating < 5
Substructure rating < 5
Unknown foundation
Timber superstructure
Scour critical
No action
REHABILITATION: Deck replacement (45% of bridge replacement cost)
Span ≤ 50ft
REPLACEMENT: Width = 32ft Length = 1.7 * (old length) ($275/sf impacted; $250/sf non-impacted)
Replacement State
Span < 40ft
REPLACEMENT: Multi-barrel box culvert ($600,000)
REPLACEMENT: Single-barrel box culvert ($400,000)
*Minimum maintenance routes were identified through ND GIS Hub data and Google satellite imagery. Details are provided in report.
**The needs generated by this model may need to be capped based on the number of implementable projects or dollars per biennium