Infrastructure Needs: North Dakota's County, Township and Tribal Roads and Bridges: 2021-2040

Report Requested by North Dakota Legislative Assembly

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Summary of Study

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

A significant data collection effort was undertaken to provide the most complete and current data on the condition of the state's county and township roadway system. Condition information was collected on all county paved roads using the latest smartphone ride and photolog technology. Traffic counts were collected on the county and township road system across the entire state in 2019. The effort was a combination of additional counts requested of NDDOT along with 400 counts and vehicle classifications conducted by NDSU-UGPTI students and a consultant. The data was needed to calibrate a statewide travel demand model, which was used to forecast future traffic levels. The GRIT (Geographic Roadway Inventory Tool) was used to gather and verify county roadway inventory information such as base thickness, pavement age, and pavement thickness, directly from local road authorities.

An enhanced county-level survey was developed to assess unpaved roadway component costs such as blading, gravel purchasing, hauling and placement costs for each of the 53 counties in North Dakota. Training on how to accurately complete the survey was provided to counties via live and recorded webinar. A secondary analysis of survey results was performed to identify significant variations from county to county by region within the state.

For traffic forecasting, the Upper Great Plains Transportation Institute (UGPTI) developed a travel demand model (TDM) for the entire state. The TDM network includes the origins of key inputs to the oil production process (e.g., fresh water, sand, scoria, gravel, 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 TDM, inputs and products are routed to and from wells to minimize time and/or cost, subject to available supplies and capacities. A comparable model is used to predict the trips of each crop produced in each township to elevators and/or processing plants, subject to the demands of these facilities. When all trips have been routed, the individual movements over each road segment are summed to yield the total truck trips per year. Using truck characteristics and typical weights, these trips are converted to equivalent single axle loads (ESALs) 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 also included in the analysis.

Unpaved Road Analysis and Needs

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

As shown in Table A, the predicted statewide unpaved infrastructure needs estimate is $6.14 billion over the next 20 years.

Table A: Summary of Unpaved Road Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2020 Dollars)

Period	Statewide
2021-22	$ 611.08
2023-24	$ 602.19
2025-26	$ 616.21
2027-28	$ 615.89
2029-30	$ 602.76
2031-40	$ 3,008.07
2021-40	**$ 6,056.34**

Paved Road Analysis Needs

As shown in Table B, $2.67 billion in paved road investment and maintenance expenditures will be needed during the next 20 years. Almost 60% of these expenditures will be required in the first decade because of a shortfall of timely investments in previous years.

Table B: Summary of Paved Road Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2020 Dollars)

Period	Statewide
2021-22	$ 388.46
2023-24	$ 406.97
2025-26	$ 304.56
2027-28	$ 264.53
2029-30	$ 222.20
2031-40	$ 1,081.77
2021-40	**$ 2,668.49**

Bridge Needs

Table G shows the estimated bridge investment and maintenance needs for county and township bridges from 2021-2040. Most of the improvement needs are determined by the study's improvement model to be backlog needs and occur during the first study biennium. Based on past discussions with NDDOT Bridge and Local Government Divisions, these needs have been distributed evenly over the first five biennia of the study period because it would not be possible to replace all the eligible bridges in one biennium with existing construction resources.

Table G: Summary of Bridge Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2020 Dollars)

Period	Statewide
2021-22	$94.39
2023-24	$94.40
2025-26	$94.74
2027-28	$94.63
2029-30	$94.48
2031-40	$26.17
2021-40	**$498.81**

Total Statewide Needs

As shown in Tables H and I, the combined estimate of infrastructure needs for all county and township roads is $9.3 billion over the next 20 years. Unpaved road funding needs comprise approximately 66% of the total. If averaged over the next 20 years, the annualized infrastructure need is equivalent to $466 million per year.

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

Table H: Summary of All Road and Bridge Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2020 Dollars)

Period	Statewide
2021-22	$ 1,093.93
2023-24	$ 1,103.56
2025-26	$ 1,015.51
2027-28	$ 975.05
2029-30	$ 919.44
2031-40	$ 4,195.91
2021-40	**$ 9,223.64**

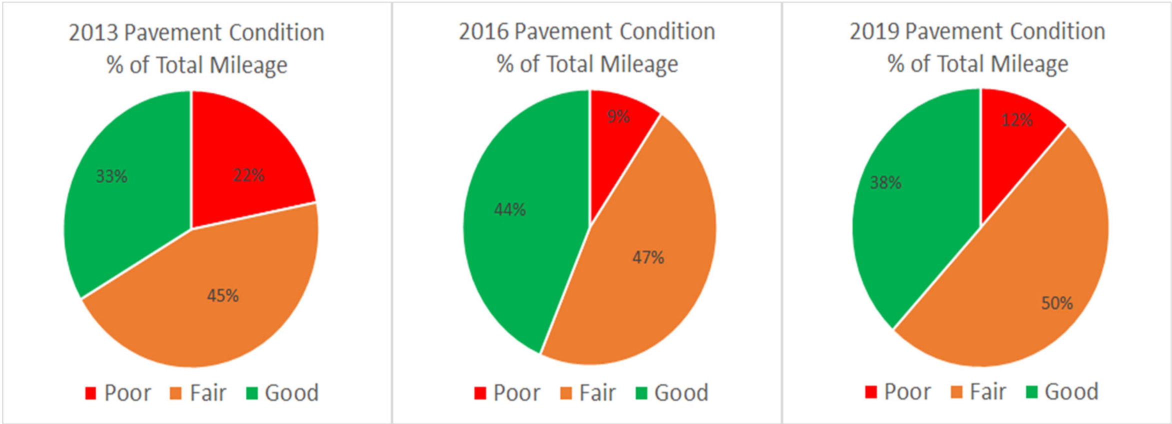
Table I: Summary of All Road and Bridge Investment and Maintenance Needs for Counties, Townships and Tribes in North Dakota (Millions of 2020 Dollars)

Period	Unpaved	Paved	Bridges	Total
2021-22	$ 611.08	$ 388.46	$ 94.39	$ 1,093.93
2023-24	$ 602.19	$ 406.97	$ 94.40	$ 1,103.56
2025-26	$ 616.21	$ 304.56	$ 94.74	$ 1,015.51
2027-28	$ 615.89	$ 264.53	$ 94.63	$ 975.05
2029-30	$ 602.76	$ 222.20	$ 94.48	$ 919.44
2031-40	$ 3,008.07	$ 1,081.77	$ 26.17	$ 4,116.01
2021-40	**$ 6,056.34**	**$ 2,668.49**	**$ 498.81**	**$ 9,223.64**

General Comparison with 2013 and 2016 and 2019 Studies

Increased investments in the paved roads during the 2014 and 2016 bienniums improved overall pavement condition as shown in the 2016 chart below in Figure A. However, the 2019 pavement condition data indicates a slight increase in miles of poor-condition roads and a decrease in miles of good-condition roads. This slight decrease in overall pavement condition is likely due to somewhat reduced investments in pavement beginning in the 2018 biennium.

Figure A. Pavement Condition Change from 2013 to 2019



The current 2020 study also shows an increase of approximately $400 million in 20-year pavement needs compared to the 2016 study. Much of the increase is because of inflation of construction and maintenance costs for pavements over the 4 years. Some of the increase is also due to the approximately 140 miles of paved roads added to the system since 2016.

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

Projections of bridge funding needs have increased slightly but are close to the previous study. Both studies showed a large backlog of bridges needing improvements or replacement. The number of bridges needing improvement or replacement declined slightly since 2016, but unit prices have increased since 2016. Bridge inspections are performed every 2 years and during the 4-year period between studies, additional bridges have deteriorated enough that improvement or replacement is suggested.

Contents

1. Introduction

In response to a request from the North Dakota Legislature, NDSU's Upper Great Plains Transportation Institute (UGPTI) estimated county, township, and tribal road and bridge investment needs across the state. HB 1066 of the 2019 Legislative session, provided that distribution of funding to non-oil producing counties would be distributed based on the 2016 UGPTI study and if available, the average of the 2016 study and this study. This report is the fourth in a series of such studies. In 2010, under the direction of the Governor, UGPTI estimated the additional county and local road investment needs in western North Dakota as a result of rapid growth in oil production. The oil study was quickly followed by an analysis of the roadway investments needed to facilitate agricultural logistics. Results of both studies were presented to the Legislature in January 2011.

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

The 2014 study was based on the 2014 forecasts of agricultural and energy production and road construction prices. Specifically, it reflected the addition of 60,000 new wells, higher input and construction costs, and the latest traffic and roadway condition data available. Investment needs were forecast for a 20-year time period.

UGPTI also conducted an infrastructure study in 2016. The 2016 study was the first study that considered a possible reduction in oil exploration and production. Because of uncertainty in crude oil pricing and the resulting drilling activity, three scenarios were estimated based on possible drilling rig counts within the state: 30, 60, and 90 rigs. Throughout the study, the 60-rig scenario was referred to as the "likely scenario."

It has now been 4 years since the last infrastructure study. This report again focuses on county, township, and tribal roads and bridges for 2020 levels of agricultural and energy production using current road construction costs. State highway and city needs are not considered in this study. The state highway needs were presented to the North Dakota Department of Transportation in a separate report. In this report, investment needs are estimated for three classes of road systems: county, township, and tribal – referred to collectively as local roads. In some cases, distinctions are made between county major collector and county local roads. In these instances, "local" refers to a subclassification within a county.

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

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

- Methods of analyzing paved roads and forecasts of paved road funding needs
- Methods of analyzing bridges and forecasts of bridge investment needs

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

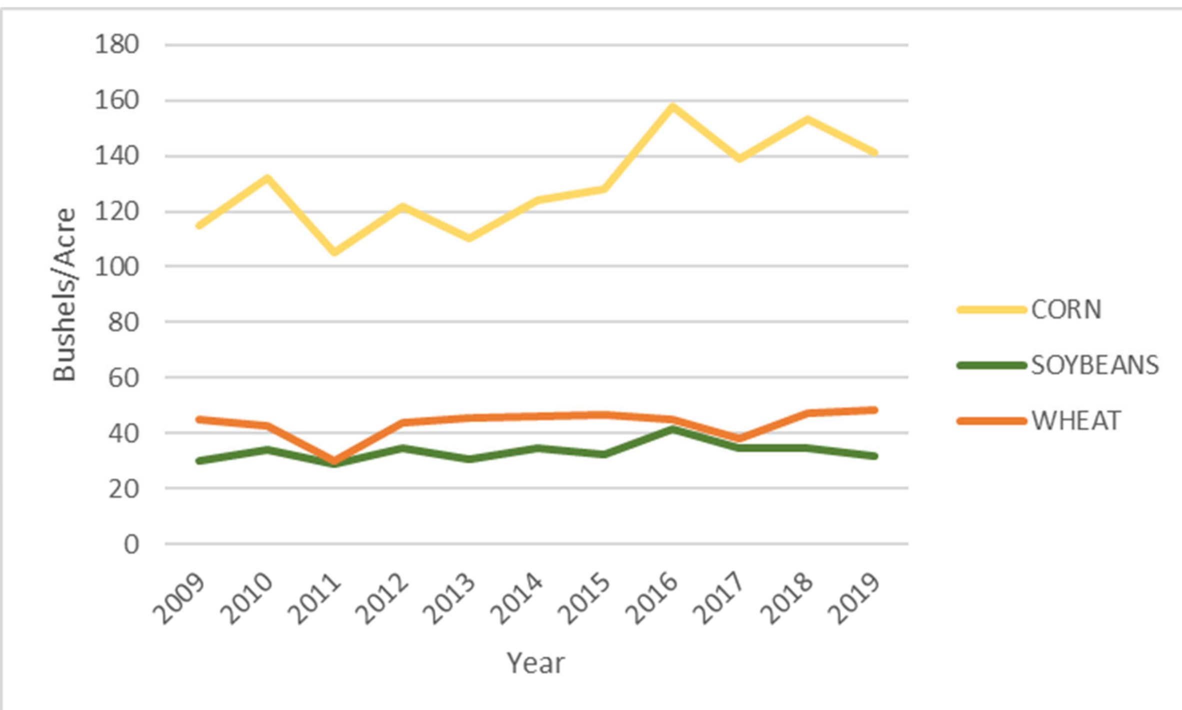
During the last decade, North Dakota's, local road systems have seen significant changes in traffic patterns, not only in terms of volumes, but also in terms of clustering due to changing land use and the consolidation of transload locations. This section describes major trends in agriculture and oil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

2.1. Agricultural Trends

2.1.1. Yield

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

Figure 1. Average Yield for Corn, Soybeans and Wheat in North Dakota 2009-2019 (bushels per acre)



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

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

2.1.2. Crop Mix

Crop mix refers to the percentage of land used to produce each commodity. As shown in Figure 1, the three major commodities have different yield rates. In 2019, the average statewide yield for wheat was roughly 48.5 bushels/acre. For soybeans, the average yield was 32 bushels/acre. Corn yield was 141 bushels/acre. Any shift in wheat acreage to corn would represent a 188% increase in yield on average. A shift in soybean acreage to corn would represent a 333% increase in yield on average. These increases directly correspond to increases in truck traffic. Moreover, the fertilizer requirements for corn production versus wheat production are nearly double, so an increase in inbound input movements is expected as well.

Again, using the largest three commodities by acreage for comparative purposes, Figure 2 shows the number of acres by year planted of corn, soybeans and wheat in North Dakota from 2009 to 2019. 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 (2009-2019)

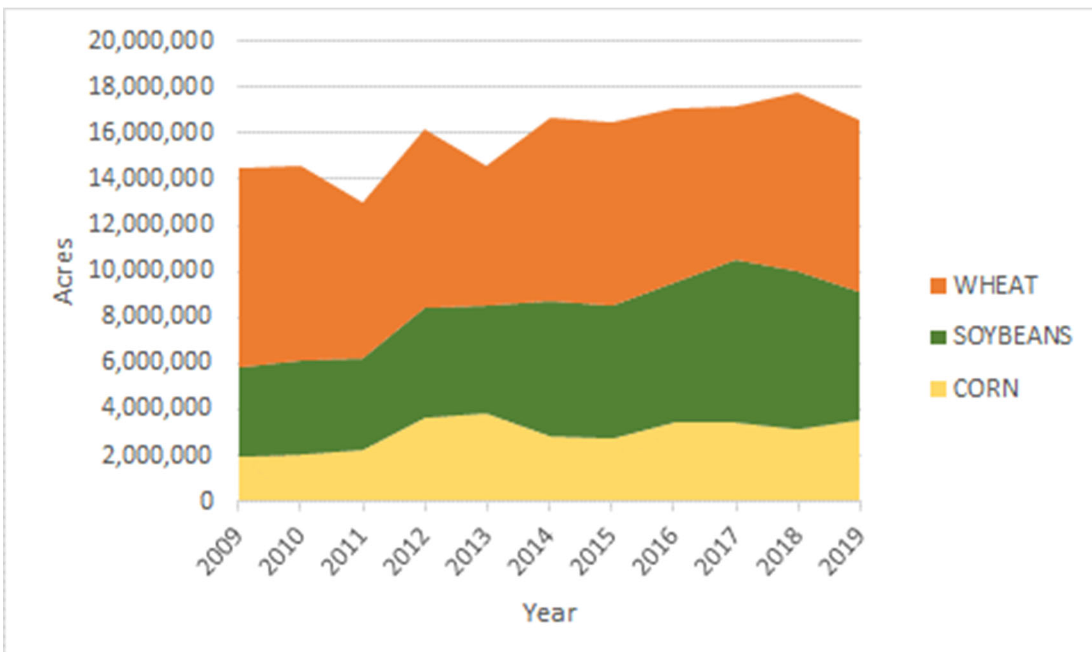
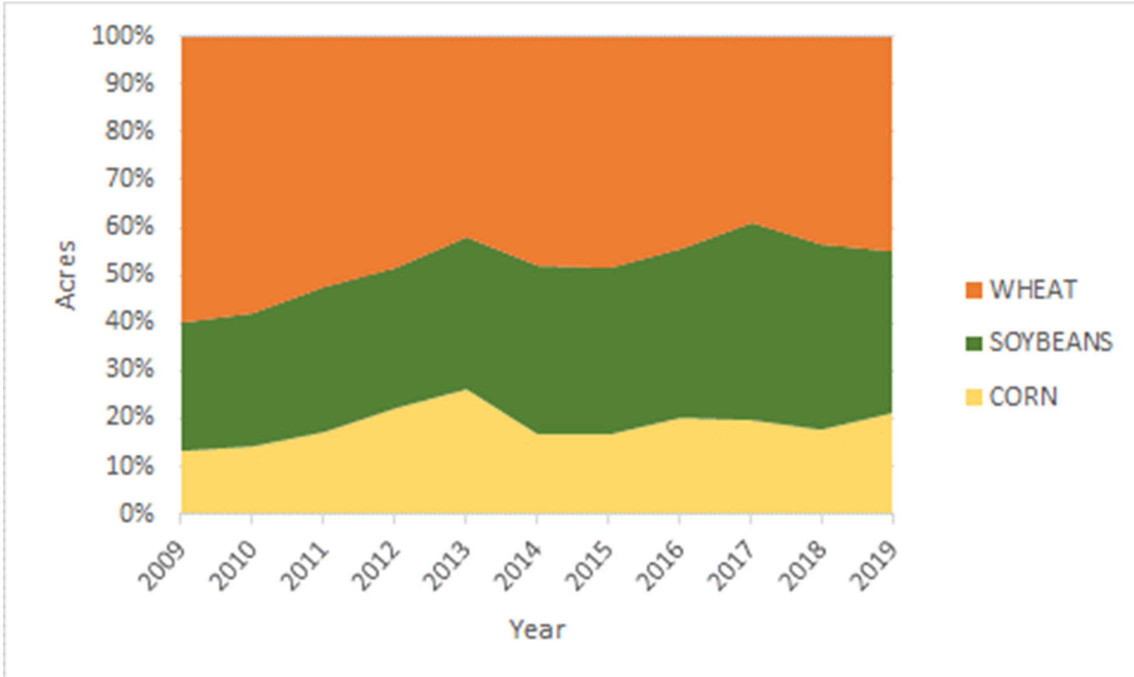


Figure 3 breaks the acreages down by percentage. At the beginning of the period, wheat was planted on nearly 60% of the total acres planted to corn, wheat and soybeans with soybeans on 36%, and corn on 14%. In 2019, wheat was planted on 45%, soybeans on 34% and corn on 21% of these acres. For reference, in 2019, corn, wheat, and soybeans were planted on 16.6 million acres in North Dakota, 70% of all acres planted in North Dakota.

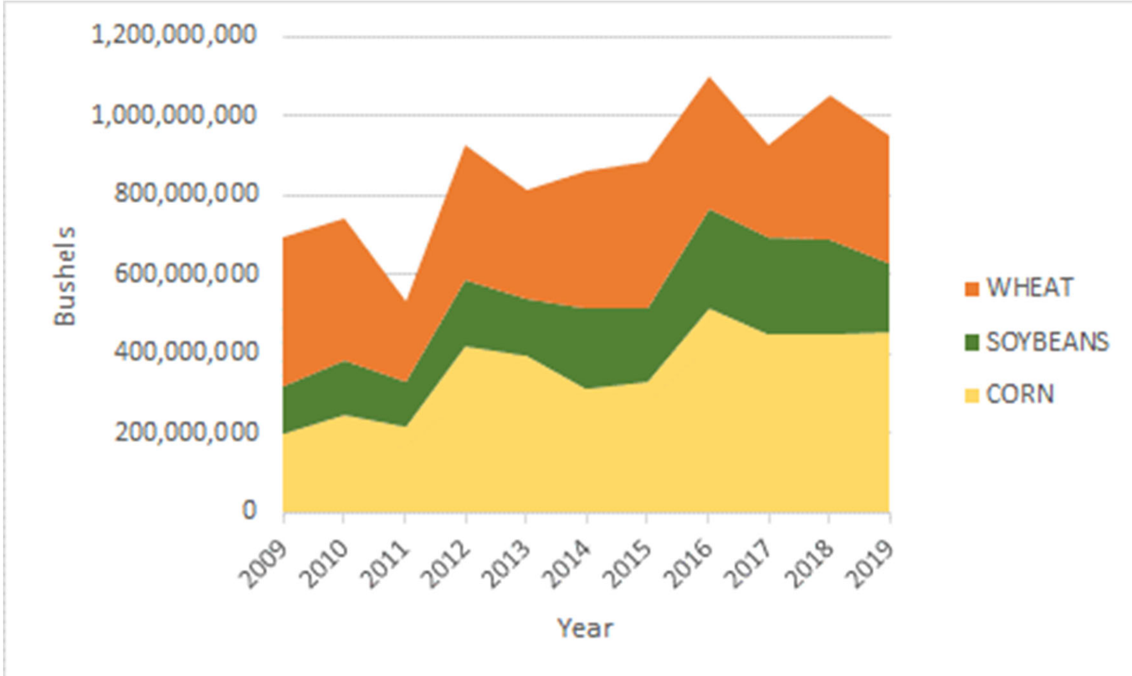
Figure 3. Percent Acres of Corn, Soybeans and Wheat in North Dakota (2009-2019)



2.1.3. Total Production

Because of 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 increased from roughly 693 million bushels of corn, wheat and soybeans in 2009 to 950 million bushels in 2019. Excluding 2011's weather-related decrease, there is a readily observable upward trend in overall production.

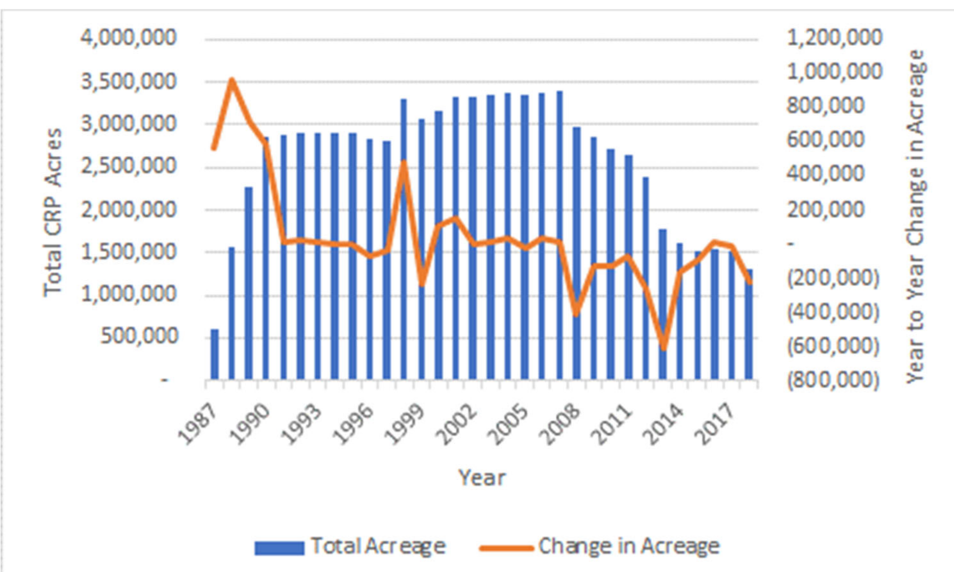
Figure 4. Total Production of Corn, Wheat and Soybeans in North Dakota 2009-2019



2.1.4. Conservation Reserve Program

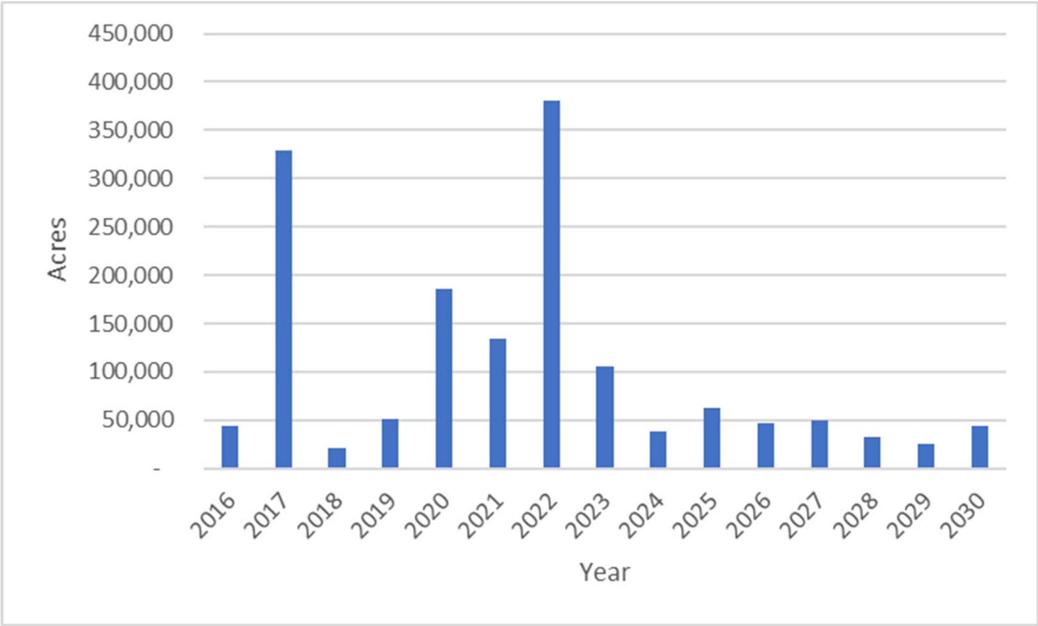
As the farm economy has been positive recently, many North Dakota producers have chosen not to re-enroll acres in the Conservation Reserve Program (CRP). As a result, previously enrolled acres went back into production, increasing truck traffic in areas which, for the recent past, had seen virtually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

Figure 5. CRP Acres in North Dakota Not Renewed: 2007-2019



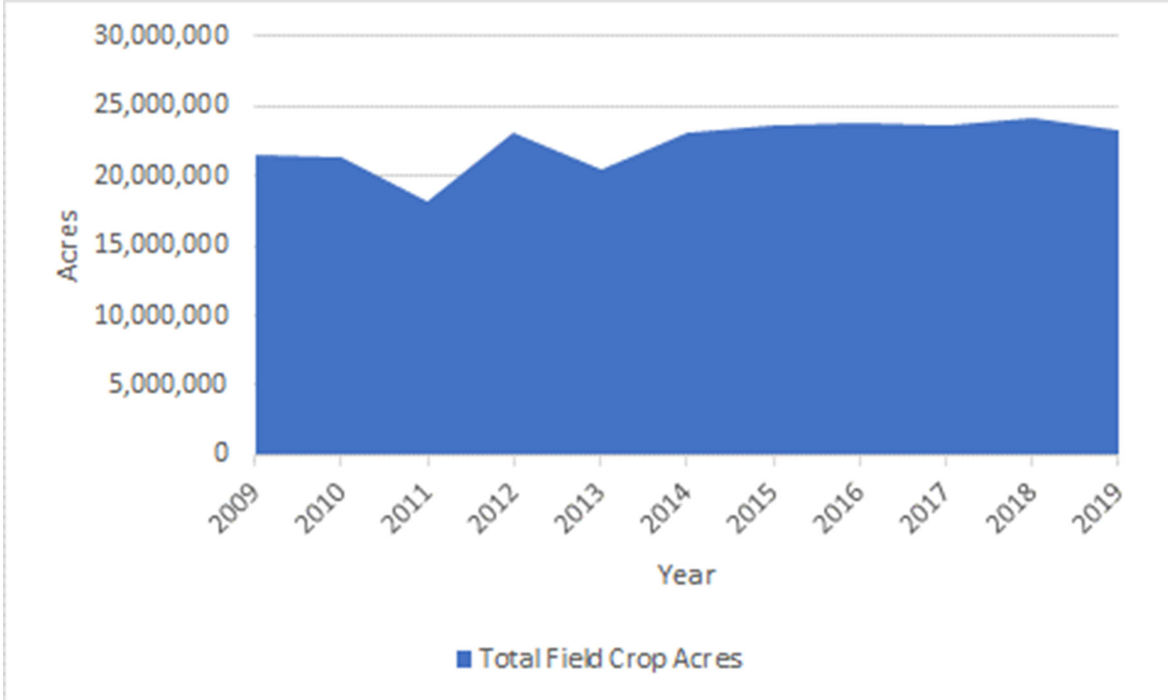
Over the next 10 years, contracts on an additional 1.16 million acres are set to expire. Figure 6 shows the expirations by year through 2030.

Figure 6. CRP Acres Set to Expire in North Dakota: 2016-2030



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 2009, Figure 7 shows the total number of acres of land in North Dakota used for production of field crops. If additional data regarding the timing and location of the contract expirations were available, the changes could be estimated. However, any impacts are not expected to be significant compared 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 2009-2019



2.1.5. Elevator Throughput

Since the mid 1990s there has been an increase in the number of grain elevators that can handle and load 100 or more rail cars. These shuttle elevators receive a discounted rail rate in exchange for guaranteed volumes and service times. Discounted transportation rates allow shuttle elevators to expand their draw areas through higher spot prices, thereby increasing the total volume of grain marketed at their facilities. In 2002, there were 15 shuttle elevators in North Dakota. By 2019, there were 64 shuttle elevators. A comparison of the numbers of elevators by shipment categories is shown in Table 1.

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

Elevator Type	2009	2019	Change
No Rail (0 Car)	26	10	-16
Single (1-25 Cars)	114	87	-27
Multi Car (25-52 Cars)	60	49	-11
Unit (52-100 Cars)	56	48	-8
Shuttle (100+ Cars)	45	64	19
All Types	**301**	**258**	**-43**

During the last decade there has been a decline in the numbers of all types of elevators, with the exception of shuttle elevators. Shuttle elevators experienced a 2.5-fold increase. The number of elevators by type tells only part of the story with regard to changes in agricultural marketing in North Dakota. The Annual Elevator Marketing Report compiled by UGPTI provides total throughput by elevators in each class. Figures 8 and 9 show the total throughput by elevator class in 2009 and 2019 respectively, and is taken directly from the Annual Elevator Marketing Report for the corresponding years.

Figure 8. Elevator Throughput by Elevator Class: 2009

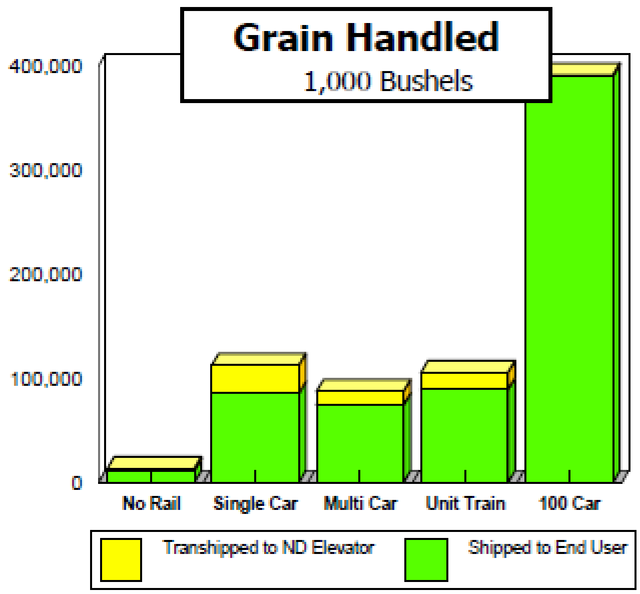
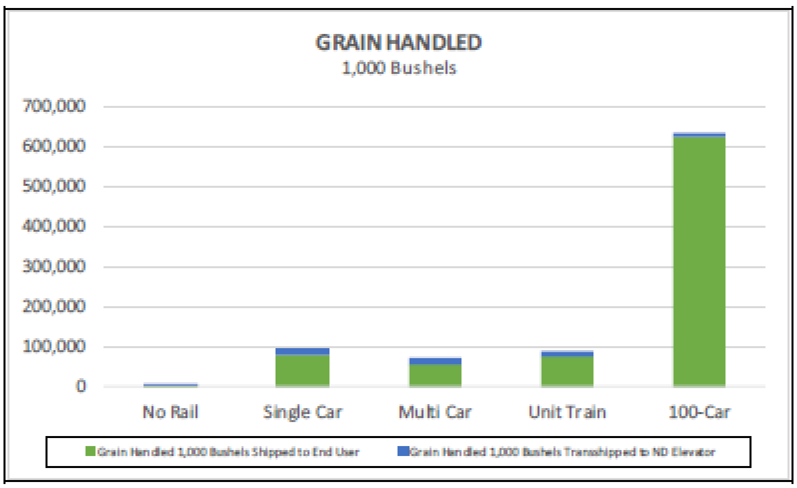


Figure 9. Elevator Throughput by Elevator Class: 2019



As these figures show, a substantially larger percentage of grain was marketed through shuttle elevators in 2019 than in 2009, a change that has an impact on the local road system throughout the state. For example, in 2009, unit and shuttle train elevators marketed roughly 500 million bushels of grain. At that time the combined number of facilities in those two classes was 101 elevators. In 2019, roughly 630 million bushels of grain were marketed through shuttle elevators which represent just 64 facilities statewide. The result of this change is consolidation of higher levels of truck traffic at fewer destination points. Often these shuttle elevators are located on or near state highways, but the county major collector (CMC) and other county routes where traffic is consolidated also may see increased truck traffic, depending on the location and network density near these facilities.

2.1.6. Combined Impact of Factors

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

2.2. Oil Production Trends

2.2.1. Technology

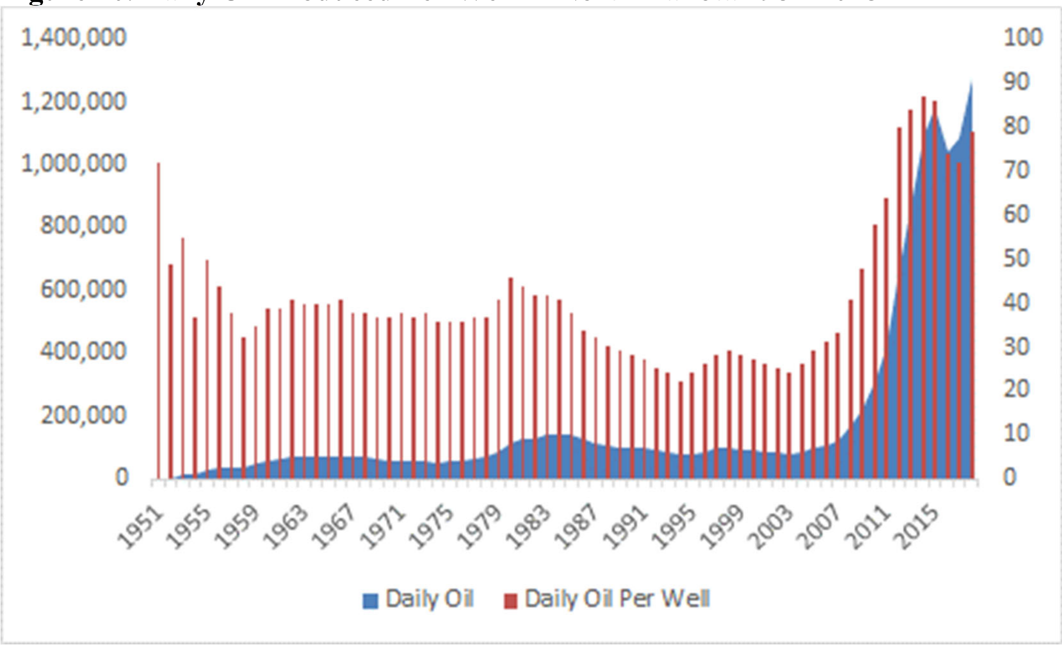
The current oil boom in North Dakota came about as a result of improved technology in oil exploration and extraction. Two primary technological advances have led to increased productivity within the Bakken/Three Forks formations: horizontal drilling and hydraulic fracturing.

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

2.2.2. Well Productivity

As a result of the improved extraction technology, the average productivity of a North Dakota oil well has dramatically increased. From 2005-2018 average oil well production increased from 25 BBL oil/day to 79 BBL oil/day. Figure 10 shows the daily average statewide oil production per well by year and daily oil production by year in North Dakota since the first well was drilled in 1951.

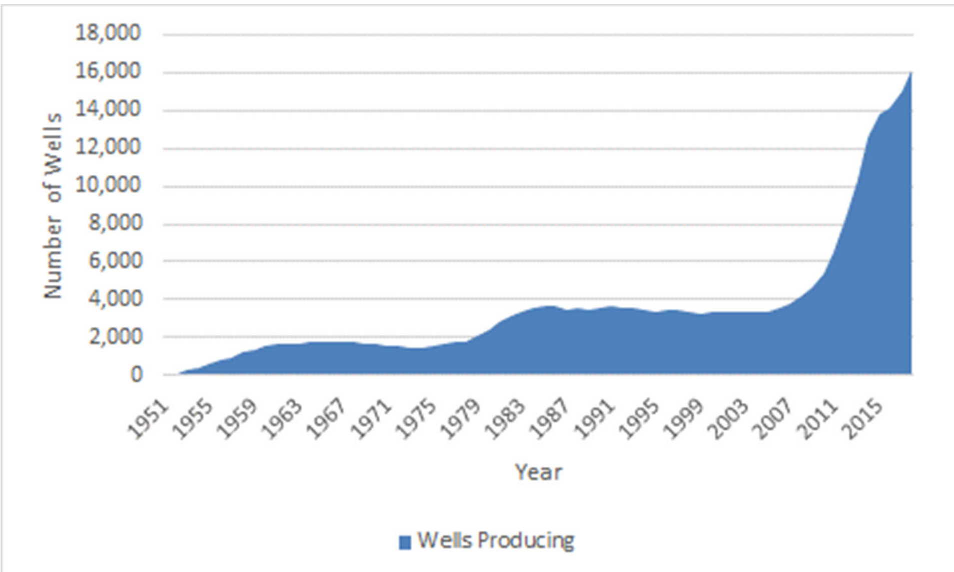
Figure 10. Daily Oil Produced Per Well in North Dakota 1951-2018



2.2.3. Total Number of Wells

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

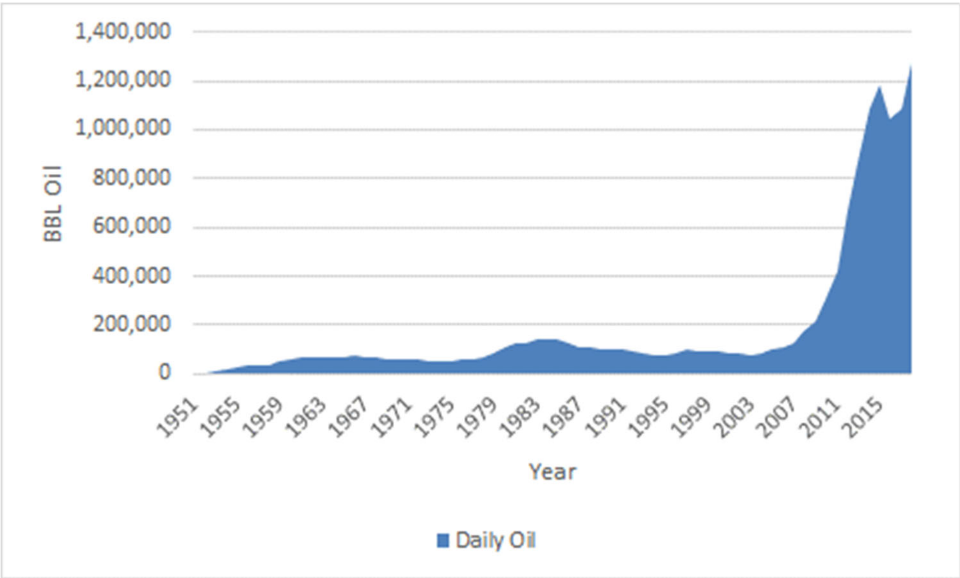
Figure 11. Total Producing Oil Wells in North Dakota (1951-2018)



2.2.4. Total Production

As outlined previously, productivity per well has increased while the total number of wells has increased as well. The combination of these two trends has resulted in a significant surge in the total statewide production of oil. Figure 12 shows the historical daily oil production from 1951 to 2018.

Figure 12. Historical Daily Oil Production in North Dakota (1951-2018)



2.2.5. Changes in Forecasted Development

Throughout the initial development of the Bakken and Three Forks formations, there was a degree of uncertainty about the extent and duration of the potential development of the play. In 2010, at the request of the North Dakota Department of Commerce and the North Dakota Oil and Gas Producing Counties Association, UGPTI conducted a study to estimate the additional road needs due to oil development impacts on county and township roads. At that time, the estimated scope and duration of the play was a total of 21,250 new wells over a 20-year timeframe.

Beginning in 2011, UGPTI conducted a study at the direction of the North Dakota Legislature to estimate statewide needs for county and township roads. This study updates that effort. At the conclusion of that study, the estimated number of new wells was 45,000. The current forecast for total new wells is 55,000. It is expected that as more is known about the development of the play, 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. Modeled Commodities

The discussion of agricultural production in Section 2 of this report focused on the three largest commodities in North Dakota: corn, wheat and soybeans. In addition to these commodities, truck movements were estimated for barley, canola, sunflowers, dry edible beans, sugarbeets, and potatoes. Because of the truck volumes required to deliver fertilizer to fields in the spring, fertilizer requirements for each acre produced of each commodity were estimated using NDSU Extension Service crop budgets. Truck movements from fertilizer locations to crop production areas were modeled in a similar, but reverse direction, as those for crop shipments. Finally, because of the structure of the elevator industry in North Dakota, transshipments between elevators (i.e. satellite elevator to shuttle elevator) were also included in the traffic forecasts.

3.1.3. 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 2019. County level data is not sufficient for use in a traffic model as it is too aggregated to accurately assign traffic to individual roadways, especially at the county level. To further disaggregate this data, the United States Department of Agriculture's (USDA) Crop Data Layer (CDL) was utilized.

The CDL is a satellite image of land use in North Dakota, with individual crop types represented by different colors. Each pixel of the image represents a 30-meter by 30-meter area. Used in conjunction with GIS software packages, the CDL provides data regarding the total number of acres of each crop produced in each county subdivision. In this study, acreage data was aggregated to the county level and compared against known NASS data for accuracy.

Analysis using the CDL is precise with respect to geographic area, but is only a snapshot of production in time and does not provide production data (e.g., bushels or pounds harvested).

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

3.1.4. 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 1.16 million acres of CRP set to expire within the next 15 years, an increase in total acres is expected. However, spatial data is currently unavailable for the location of the acres set to expire by year. Consequently, the assumption made for the purpose of this study is that acres in production will remain at 2018 levels, which is the highest on record for the past 10 years.

3.1.5. 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 yield 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% yield 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.

3.1.6. Elevator and Processor Demands

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

Ethanol facility demands were estimated by obtaining the output capacity of ethanol for each facility and dividing the capacity by the conversion rate of 2.78 gallons of ethanol per bushel of corn. For processing facilities, annual capacities were obtained through news releases, website publications, or phone surveys of the facilities. Individual elevator and plant demands are based upon actual data in the base year of 2019. Because there is forecasted growth in each commodity's yield over the 20-year analysis period, to balance the model, an equal increase in the plant and elevator demand for the commodities was implemented for future year analysis.

3.2. Oil and Gas

3.2.1. Transportation Analysis Zones

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

3.2.2. Wells per Rig per Year

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

3.2.3. Well Forecasts

Because of uncertainty in present and future crude petroleum markets, three scenarios were estimated. Each of the scenarios forecasts the number of new wells drilled as a function of the number of active drilling rigs within the state. The baseline forecast scenario is equivalent to a 60-rig drilling level, representing 1,440 wells per year. As stated above, it is assumed that each rig can drill 20-24 new wells per year.

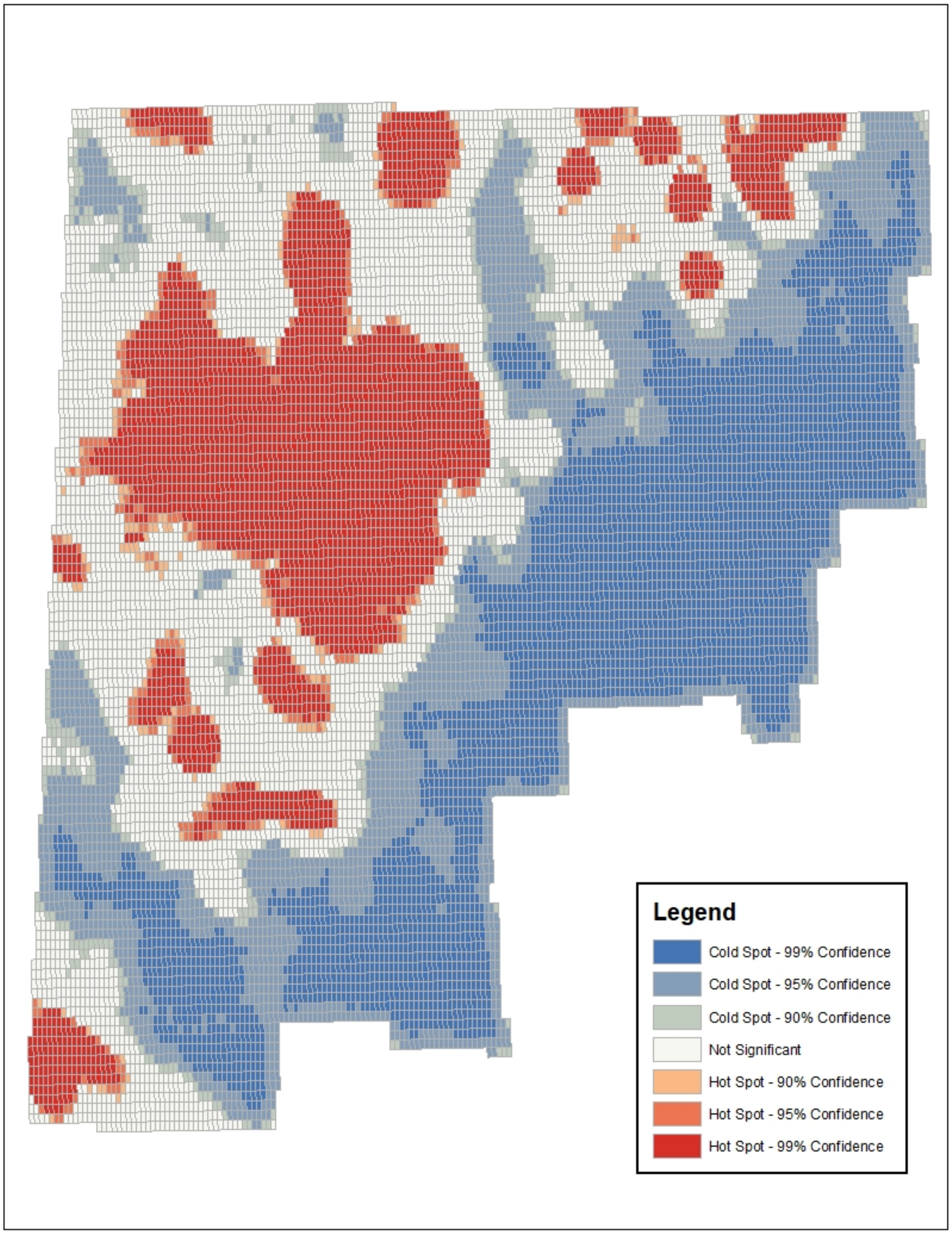
3.2.4. Spatial Forecasts

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

Figures 13 shows the clustering of existing wells in the base year which serves as the basis for locating future well drilling activities throughout the analysis period. Red areas represent significant clustering of existing wells, and blue areas represent a lack of clustering of oil development.

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

Figure 13. Hot Spot Map of Oilfield Spacing Units 2019



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

3.2.5. Initial Production Rates

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

3.2.6. Truck Volumes

Data on the number of trucks by type were compiled from input provided by the North Dakota Department of Transportation, and the Oil and Gas Division. As shown in Table 2, a total of 3,520 truck movements is estimated per well, with approximately half of them representing loaded trips.

Table 2. Drilling Related Truck Movements

Item	Number of Trucks	Inbound or Outbound
Sand	200	Inbound
Water (Fresh)	500-800*	Inbound
Water (Waste)	300	Outbound
Tanks and Equipment	460	Both
Total – Single Direction	1,760	
Total Truck Trips	3,020-3,520	

* Fresh water truck volumes decrease to nearly zero in areas with water pipeline availability

3.2.7. Mode Splits

At the time of the writing of this report, roughly 64% of outbound crude oil from well sites to either rail or pipeline transload locations is transported via gathering pipeline, with the remaining 35% transported by truck. Based on discussions with the Oil and Gas Division and the ND Pipeline Authority, forecast assumptions with regard to changes in the mode for outbound crude were made. The underlying assumption is that 2,400 miles of gathering pipeline will be built per year for the next 10 years. As a result, by 2024, 80% of outbound crude oil from well sites will be transported to transload locations via gathering pipelines and the remaining 20% will be transported via truck. It is assumed that this shift will occur in a linear fashion. The mode split by year is shown in Table 3.

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

Year	Percent Truck	Percent Pipeline
2019	35%	65%
2020	32%	61%
2021	29%	66%
2022	26%	71%
2023	23%	75%
2024	20%	80%
2025-2040	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 surface type, are provided as shown in Table 4.

Table 4. Miles Analyzed by Surface Type

Surface Type	Miles
Graded & Drained	8,276
Gravel	56,656
Paved	6,876
Trail	16,951
Unimproved	5,309
Total	**94,068**

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 (County Major Collector) system there is no distinction between county-owned non-CMC routes and township roads. To identify township roads apart from county non-CMCs, UGPTI and ND-LTAP conducted surveys of all 53 counties in North Dakota. The results were then attributed to the original network for identification purposes. In addition to non-CMC identification, UGPTI and ND-LTAP staff asked for information about other jurisdictional categories, but responses were not consistent on a statewide basis aside from the non-CMC designation.

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

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

Jurisdiction	Miles
Forest Service	250
Township and County Non-CMC	59,528
CMC (Federal Aid)	11,442
Tribal	483
Total	**71,704**

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

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

Jurisdiction	Miles
Forest Service	250
Township	47,139
CMC (Federal Aid)	11,442
County Non-CMC	12,390
Tribal	483
Total	**71,704**

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

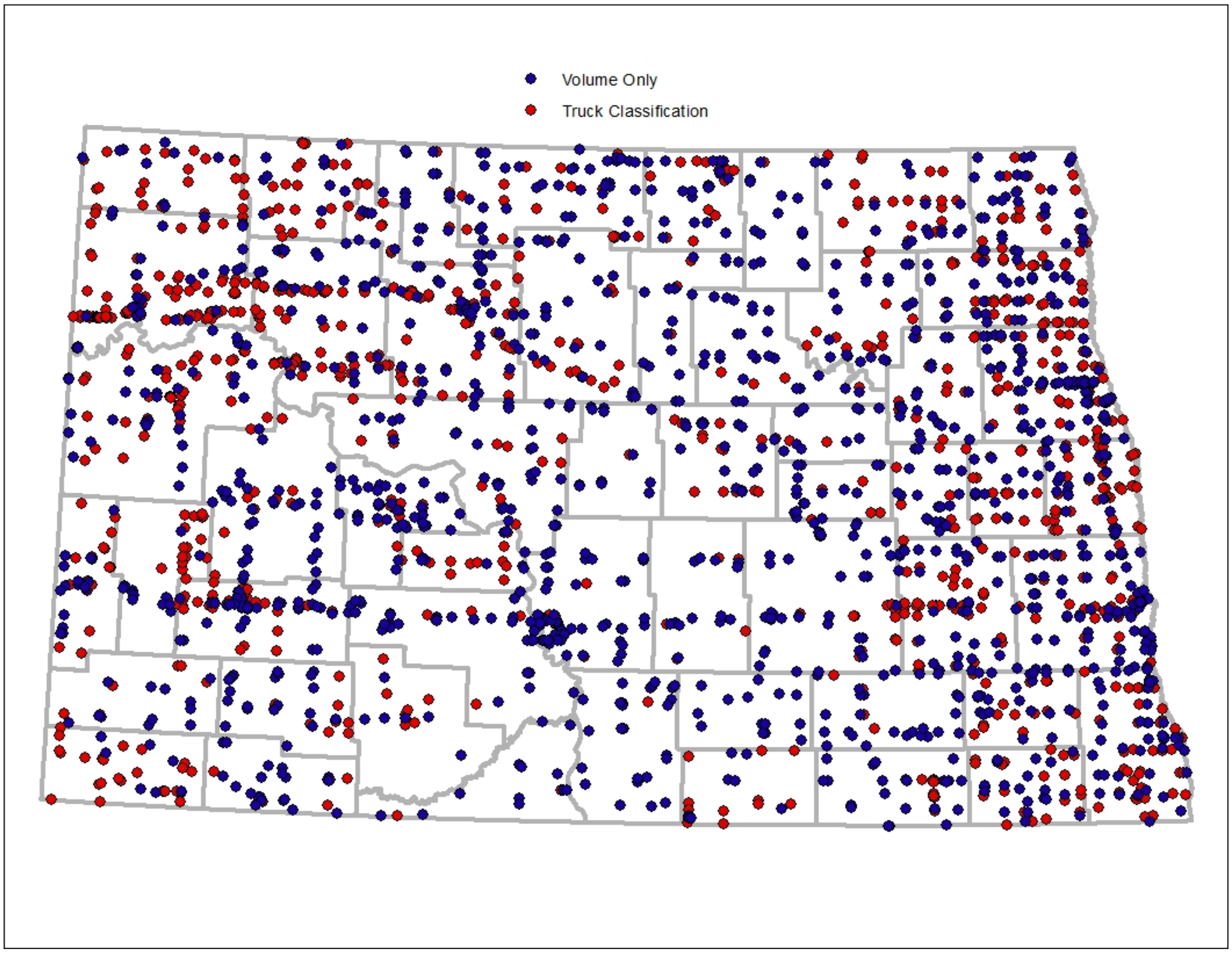
NDDOT collects traffic data on State and County Major Collectors on a 3-year cycle. In 2019 NDDOT counted the central part of the state and UGPTI requested that some additional county stations be added for NDDOT's part of the state. For the eastern 1/3 of the state, UGPTI used students from its Department of Transportation Support Center (DOTSC) to collect traffic data at approximately 200 county road locations. These sites were used in addition to the NDDOT county counts from previous years. For the western 1/3 of the state, UGPTI contracted with a traffic counting consultant to count more than 200 county road locations. Again, these counts were used in conjunction with, and to update, NDDOT county counts from previous years. Figure 14 depicts the locations of county and township traffic data collection.

5.2. Traffic Data Processing

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

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

Figure 14. Traffic Data Collection Sites



5.3. Traffic Model Development

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

5.3.1. Movement Types

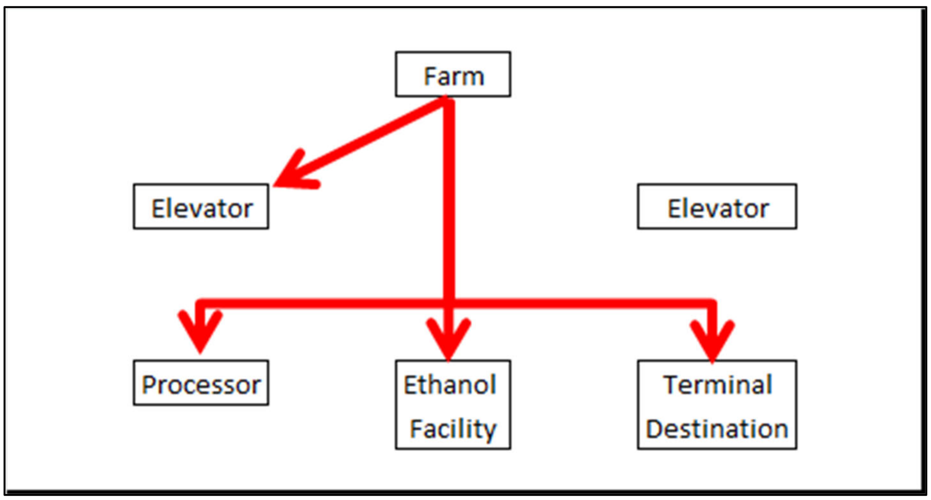
The travel demand model developed for this study consists of 18 individual submodels: 11 for agricultural movements and 7 for oil-related movements. Nine of the 11 agricultural submodels, represent individual commodities, with the remaining representing fertilizer and transshipment movements. Of the 7 oil related submodels, five relate to inputs to the drilling process and the remaining 2 represent the movement of outbound crude oil and salt water.

5.3.2. Distribution Networks - Agriculture

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

Figure 15 provides an overview of the movements from the farm to a variety of destinations. In this simplified diagram, the farm-to-elevator movement is shown, as well as farm-to-final destinations such as processors, ethanol facilities, or terminal destinations such as Minneapolis or Duluth. Each of these movements is effectively a truck movement because there is no rail access from individual farms.

Figure 15. Agricultural Distribution Network without Transshipments



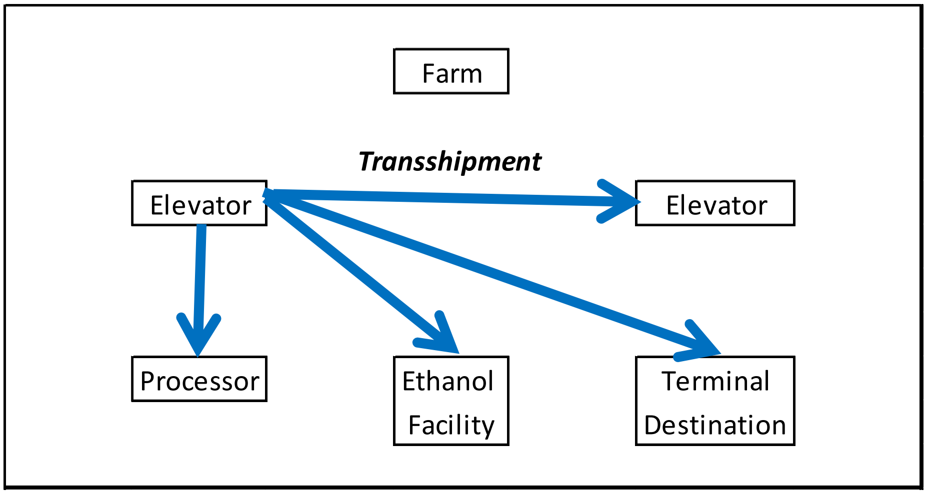
To take advantage of lower shipping rates at higher volumes, grain is commonly shipped between elevators for consolidation. Depending on the final destination of the grain from the elevator, the mode split between truck and rail varies. But as a general rule, as distance increases, truck transportation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

Figure 16 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, 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

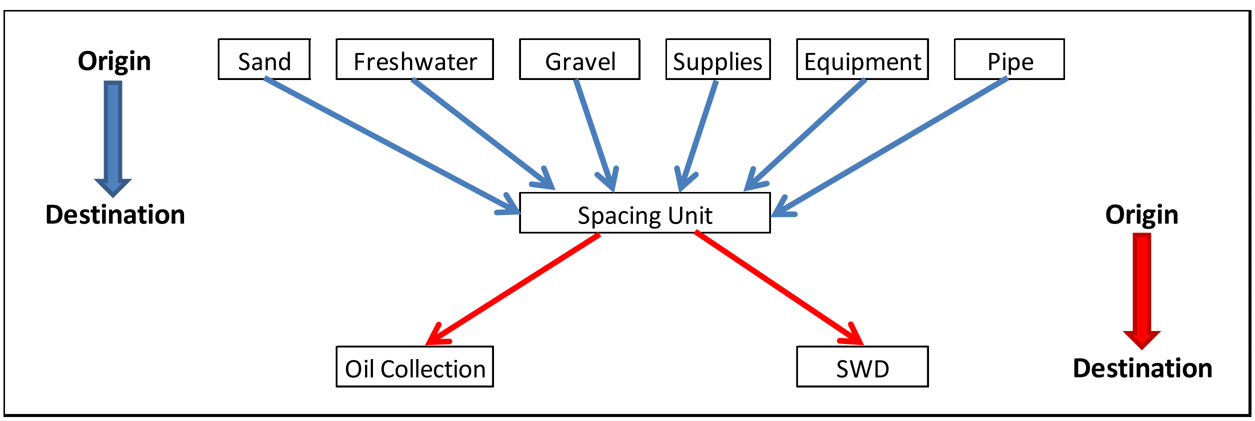
In contrast to the agricultural model where the base unit of production and related origin is the township, the oil model's base unit of production is the spacing unit, which functions as both an origin and destination as time progresses. Figure 17 provides a simplified diagram of the modeled oil-related 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 16. Transshipment Movements within an Agricultural Network



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

Figure 17. Oil Related Movement Network



5.3.4. Travel Demand 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 areas of production (origins), and attractions (destinations) are estimated. Distribution refers to the selection of flows between origins and destinations, and is generally made using a gravity model or linear programming model. Traffic assignment occurs once movements between origins and destinations have been selected, and the minimum-cost route between them is selected. The distinction between distribution and assignment is that distribution selects the origin and destination for individual trips generated, and assignment selects the method of connecting them. This is generally the final step in the FSM, but in the case of optimization models, traffic assignment for all possible destinations from origins is completed to generate arc cost data for the model.

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

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

Mode choice is the third step in the four-step model. This step was not directly included in the travel demand model for two reasons. First, the movements modeled were specifically truck-related movements. Second, the primary factor where mode split would have a significant impact on traffic volumes relates to gathering pipelines between well sites and oil transload facilities. Because assumptions were specified by the Oil and Gas Division and the North Dakota 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 the travel demand model. The cost selected for the purpose of routing is time. Each individual segment was assigned a travel speed based on posted speed or roadway class. Based on this speed, the individual travel time was calculated for each segment. The shortest path algorithm then selects the least-cost path between the origin and destination for each pair, aggregating the movements at the segment level.

5.3.5. Calibration Procedures

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

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

The final step in the calibration process was to utilize matrix estimation. This process 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

The unpaved road analysis has two primary components: traffic volumes and maintenance practices. Traffic volumes are estimated using the travel demand modeling process described in Section 5 of this report. Maintenance practices and corresponding costs were obtained through a survey of county road maintenance officials and commissioners.

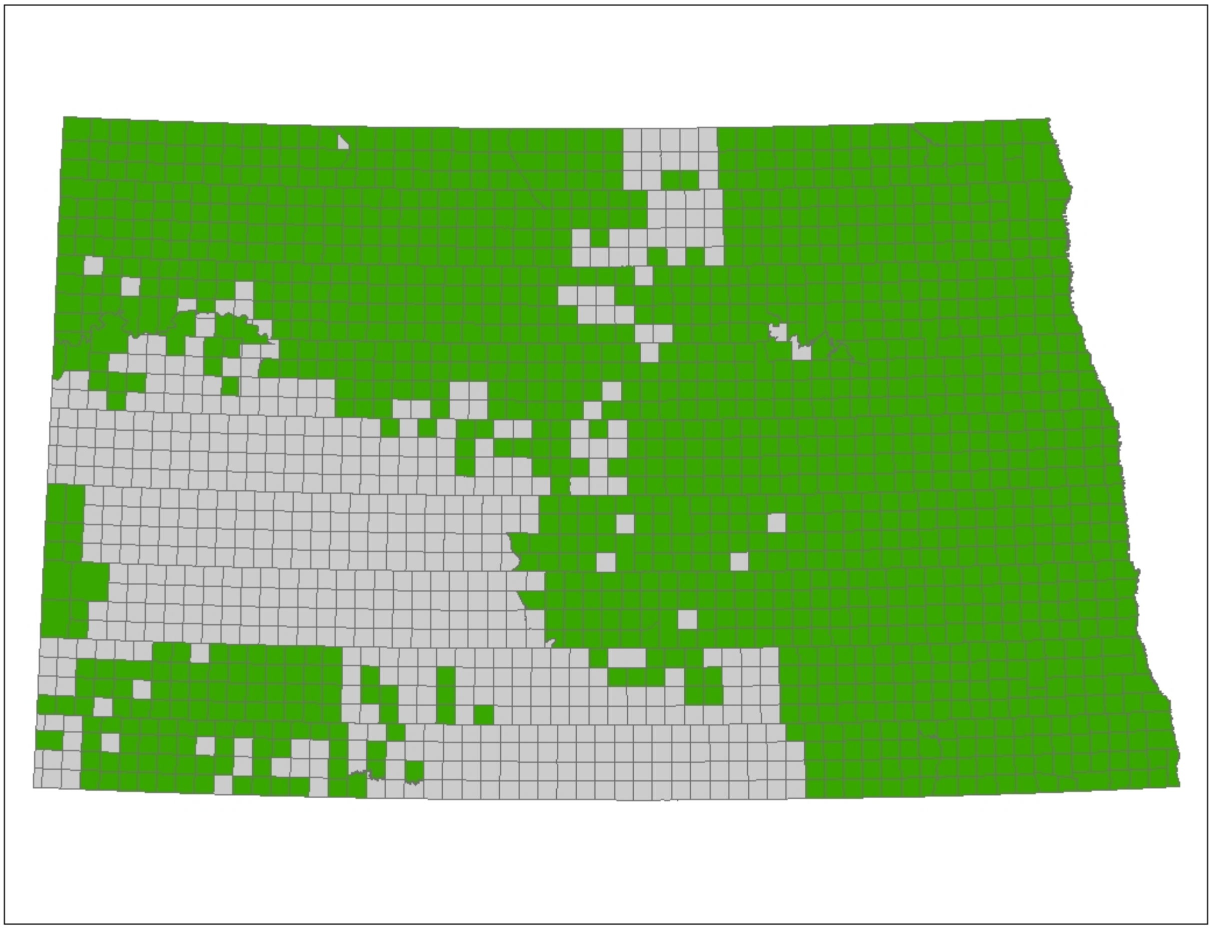
6.1. Costs and Practices Survey

Assessment of the funding needs to maintain and preserve unpaved county and local roads focuses on traffic levels and existing practices as reported by counties and townships in survey responses. Each county was analyzed separately, which allows the study to focus on county-level needs based upon existing practices and expectations. During the input process from the 2014 study, concern was expressed by policy-makers and county officials as to the homogeneity of costs and practices within regions, as well as the varied utilization of contractors for work within the counties. The survey was enhanced in 2016 and 2019 to collect additional information as to graveling practices, aggregate type, use of contractors, and reported traffic levels by county. The survey enhancements were developed with the assistance of a panel of county engineers and road superintendents. Survey training webinars were hosted to provide additional insights to all county and township survey respondents. This provided additional information as to the reason for regional discrepancies and allowed for consistency within regions where costs and practices are similar.

Because of variations in dedicated staff for roadway planning, separate surveys were designed for county and township officials. The county survey was mailed to all 53 counties in North Dakota and a 100% response rate was achieved. The township survey was mailed to all 1,333 organized townships (shown in Figure 18) with a 75% response rate. Unorganized township maintenance practices were derived from responses of organized townships within the same county or through county survey responses.

The survey was designed to obtain information on maintenance practices for unpaved roads as well as the costs that are faced by each county and local entity. The full survey can be found in Appendix A of this report.

Figure 18. Organized Townships in North Dakota



Since the last study, there have been dramatic changes in maintenance practices of unpaved roads that are intended to preserve the resources applied to the roads. These preservation techniques are evolving across the nation and North Dakota. The new techniques may slightly increase initial costs but will reduce costs over time through reduced blading and gravel overlay frequency. The goal of the new gravel techniques is to preserve the gravel on the roadway rather than let it be blown away as dust or have it roll into the adjacent ditches. At the time of this report, many counties were in the process of changing or had changed their gravel bidding and testing practices to ensure that higher quality and lower maintenance gravel was being purchased. The Federal Highway Administration (FHWA) and the Department of Defense (DOD) were also adding specification and testing requirements to missile road graveling projects administered by NDDOT.

6.1.1. Aggregate Description

The type and quality of aggregate used on unpaved roads has an impact on the cost and amount of maintenance required to maintain a road in acceptable condition. The survey utilized the following types of aggregate: gravel or scoria. In addition to aggregate type, respondents were asked whether their aggregate is pit run, screened, crushed material or if gravel purchases include specification and testing.

Figure 19. Survey Responses to Gravel Specifications

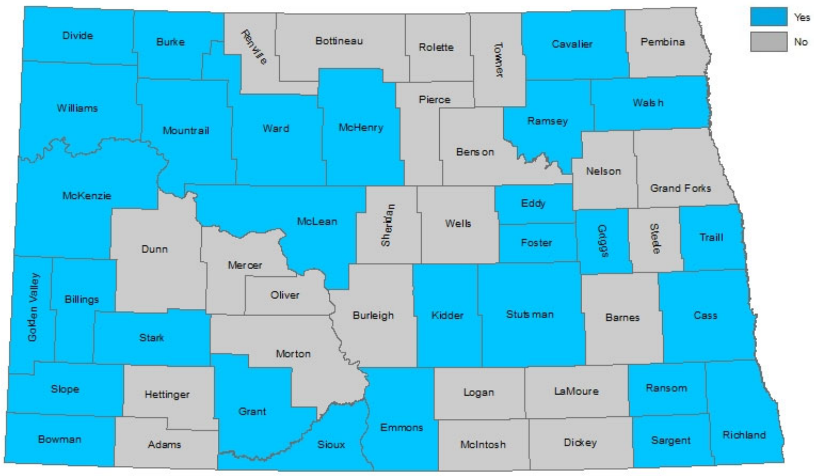
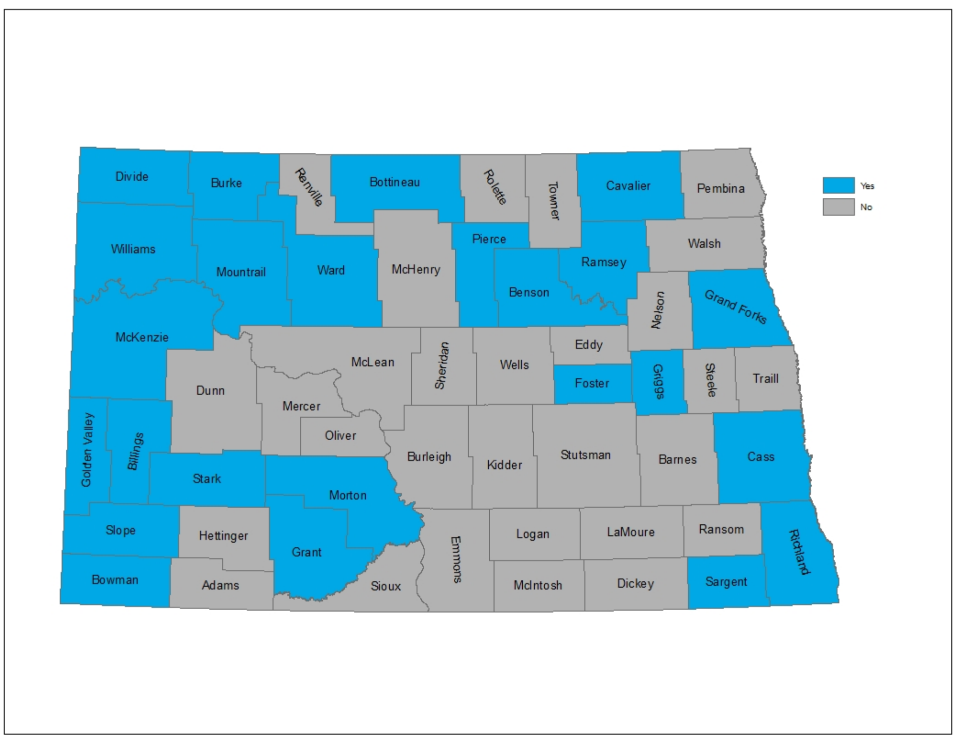


Figure 20. Survey Responses to Gravel Testing



6.1.2. Placement Practices

There are several common methods of applying a gravel overlay including truck drop and blading, windrowing and equalizing, watering rolling and compaction or a combination of any of the three. In addition, counties were asked for practices listed other than the most common placement techniques. Each of these techniques come at a different cost and the responses in this section of the survey help to reconcile reported placement costs in the cost section of the survey.

6.1.3. County vs. Contractor Work

In previous iterations of this study, significant variations in costs were observed and weren't readily explained by geographic aggregate and labor prices. Further conversations with county officials revealed that many of these cost differences could be explained by whether a county utilizes their own staff and equipment or contractors for gravel acquisition and maintenance activities. County officials were asked whether county staff or contractors were utilized for crushing, hauling, placement, blading, dust control and base stabilization.

6.1.4. Costs

Depending on the region within the state, the survey indicated that there were significant variations in component costs. From region-to-region, aggregate availability and quality varies significantly and the resulting cost per yard and trucking cost from gravel pits to roads varies accordingly. County officials were asked for cost estimates for the following categories:

- Cost per cubic yard
- Trucking cost from gravel origin
- Trucking distance
- Truck payload
- Placement costs
- Blading cost
- Dust suppressant cost
- Base stabilization cost

To represent regional variations in aggregate price and availability, Figures 21 and 22 show the unit price of aggregate per cubic yard and the average trucking distance for aggregate respectively. As Figure 21 shows, there are regional variations in aggregate prices with the highest per-yard costs in the western portion of the state and the lowest prices in the southeast and northeast part of the state. One outlier in eastern North Dakota is Traill County which reported the combined aggregate and hauling cost.

Figure 22 shows the average hauling distance from aggregate sources to improved roads. This map serves as a representative of aggregate availability. In counties having numerous sources of aggregate, the hauling distance is expected to be very short. In other counties with scarce aggregate resources, the hauling distance may be from one end of the county to the other, or even from outside of the county. The largest haul distances can be found in the Red River Valley because of low aggregate availability. As with Figure 21, Traill County is an outlier as it reported aggregate cost and hauling in one combined figure.

Figure 21. Aggregate Cost per Cubic Yard ($2020)

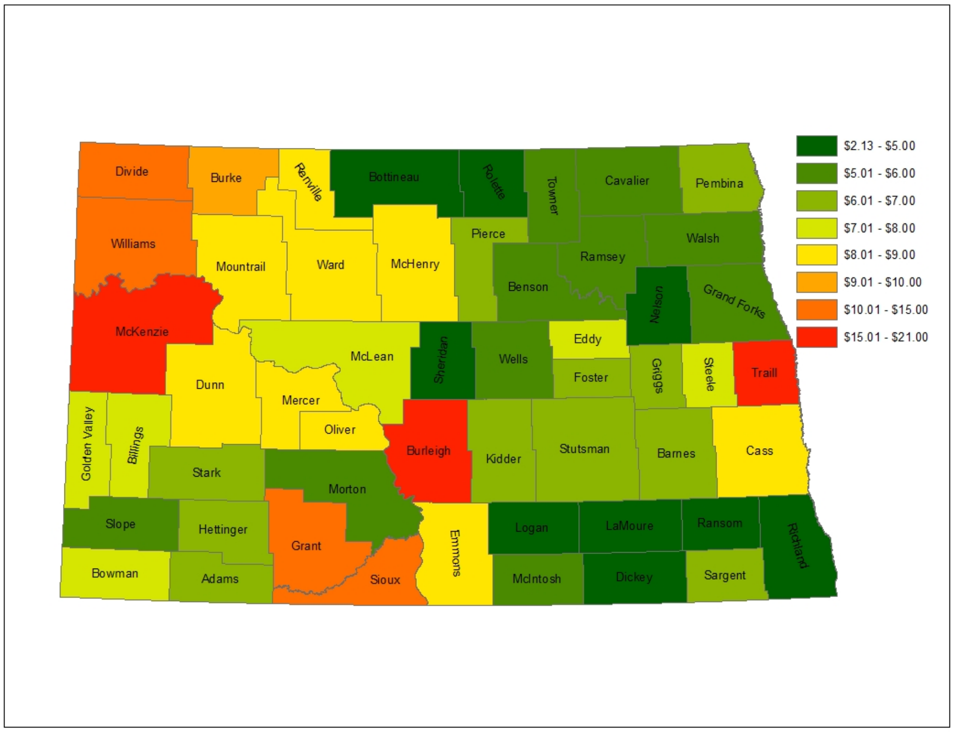
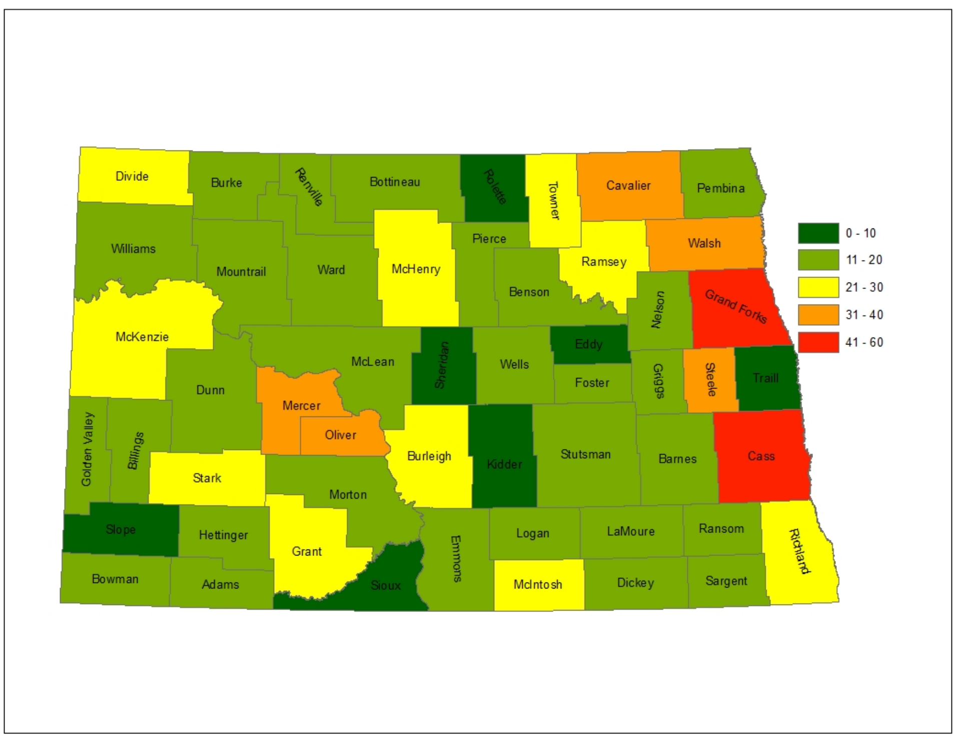


Figure 22. Aggregate Trucking Distance



6.1.5. Practices by Traffic Level

Routine maintenance practices utilized by county and township officials for unpaved roads include blading and regraveling. The frequency and type of these practices vary based on the traffic levels on the road being maintained. For example, a high-volume gravel road requires more frequent blading and gravel overlays. Moreover, the gravel overlay would be thicker on a high-volume road than on a low-volume road. In addition to routine maintenance practices, many counties use dust suppressants or base stabilizations on highvolume roads to help preserve the road condition and mitigate impacts to citizens.

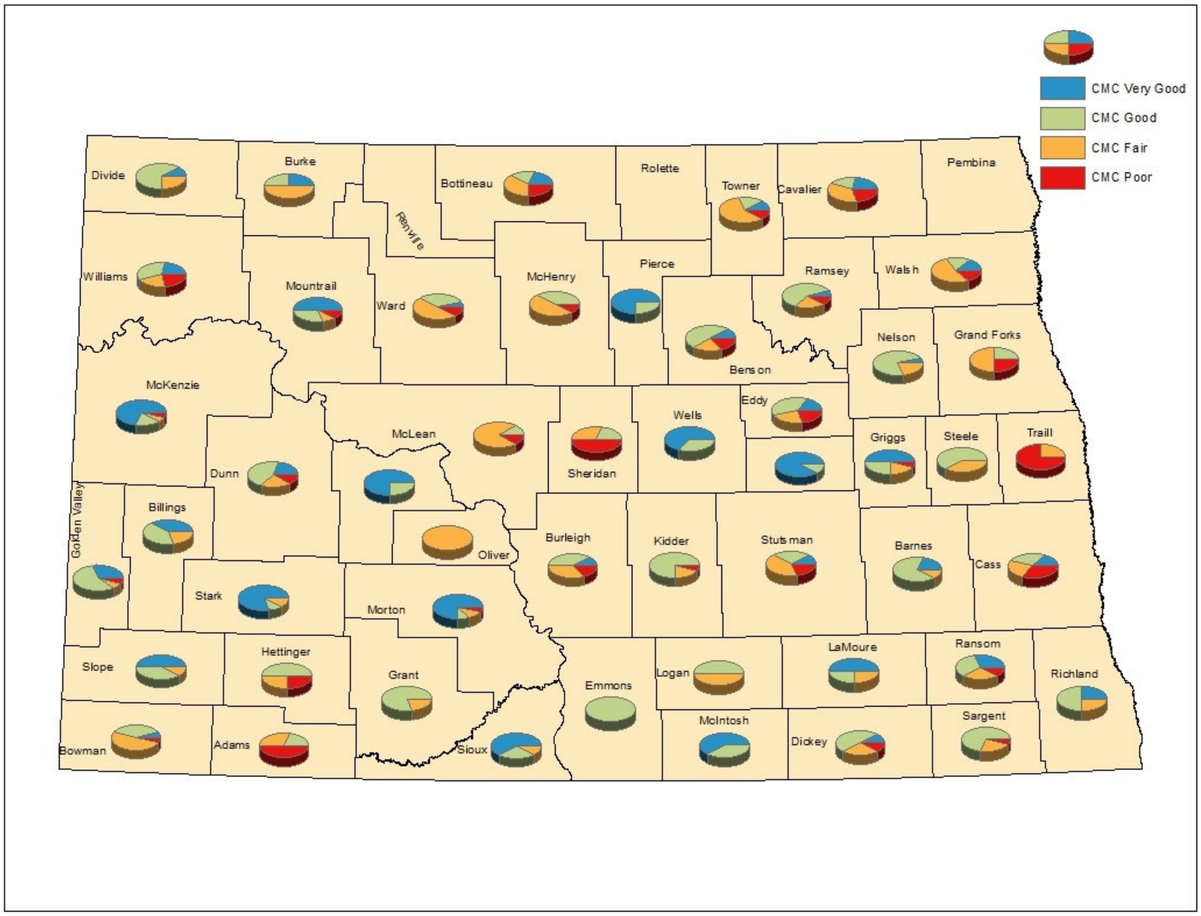
To assess how counties are maintaining their roads under different traffic categories, respondents were first asked to define what comprises a high-, medium- or low-volume road. There is also significant variation in traffic levels across the state; one county's high-volume road may be another county's low-volume road at the same traffic level. Following the question regarding the definition of traffic volumes, the county representatives were asked to provide blading and overlay frequencies at each traffic level. In addition, the overlay thickness and utilization of dust suppressant and base stabilization were established.

6.1.6. Road Condition

County representatives were asked to rate their unpaved road system condition as very good, good, fair or poor. This evaluation is subjective in nature and is difficult to objectively measure on a statewide basis. The respondents were asked to rate CMC and non-CMC roads separately as it was assumed that CMC roads would be in better condition because of the availability of additional funding sources.

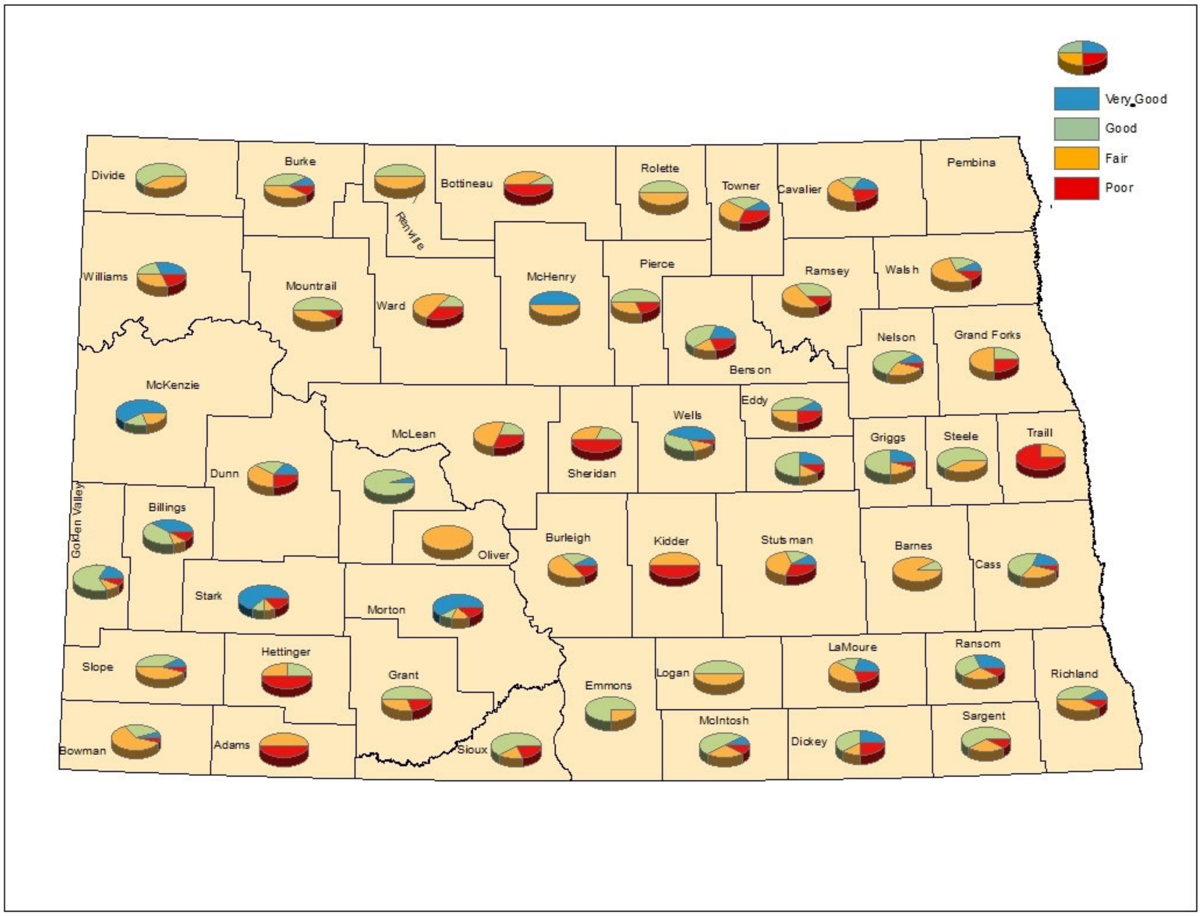
Figure 23 shows the reported conditions as a percentage of the CMC system. Only counties that fully reported conditions are shown in the map.

Figure 23. Reported Unpaved Road Conditions – CMC Routes



The information presented in Figure 24 is the reported condition data for non-CMC routes as a percentage of the non-CMC system. As discussed above, the average condition ratings for non-CMC routes were in the lower condition categories compared to the CMC routes.

Figure 24. Reported Unpaved Road Conditions – Non-CMC Routes



6.2. Analysis Procedures

6.2.1. Traffic Classification

Within each county, unpaved roads were classified by daily truck estimates. Classification ranges are shown in Table 7. Each category represents a differing traffic level leading to differing maintenance needs. Note that the 25-50 range represents the baseline traffic level. A 2007 survey prior to significant oil development reported an average of 20 trucks per day on local roads and 22 on County Major Collector (CMC) routes. Traffic counts taken across the state for the purpose of this study indicate that these estimates have increased slightly statewide, and greatly in areas of oil development or in proximity to new shuttle train facilities. In the UGPTI conditions and practices questionnaire, counties were asked to provide maintenance practices on an average mile of gravel road classified by three traffic ranges (low, medium, high). Counties were asked to define their own range thresholds for these classifications. The surveys are presented in Appendix A and the spatial distribution of county traffic volume thresholds is shown in Appendix D, Fig. D.7 and D.8.

Table 7: Unpaved Road Classification

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

6.2.2. Improvement Types

Survey questions asked county and township officials to provide the improvement and maintenance cycles for gravel roads within their jurisdictions. The county surveys asked officials to provide these cycles separately for each of the three traffic volume categories. Improvement types included: 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 that an asphalt surface is the most 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 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. According to interviews with county road supervisors, stabilization has been used on on a few county roads in North Dakota. Recent trials have yielded mixed results, with some positive cases resulting in reduced maintenance costs. However, the longevity of these types of treatments are unknown, particularly with regard to performance under North Dakota's freeze/thaw cycles.

The goal of stabilization is to add structure, minimize use of new aggregate or preserve existing aggregate, reduce susceptibility to moisture, and provide a base upon which to apply an armor coat. Cost estimates reported in the county surveys list Base One treatments at $4,500-12,000 per mile, Permazyme treatments at $12,000-$15,000 per mile, and concrete stabilization ranging from $108,000 to $220,000 per mile. As mentioned previously, the life of these treatments are unknown, as historical performance data is unavailable. If Base One application would occur annually, Permazyme biennially, and concrete stabilization once per decade, the cost per year would be equal. Compared to a statewide annual average regraveling cost of roughly $5,000 per mile for average roads, the cost of stabilization is approximately equivalent to doubling the graveling and blading frequency. For this reason, the cost of increased gravel application and blading frequency is used as a proxy for these intermediate improvements where direct observations were not provided.

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

Table 8: Improvement Types for Unpaved Roads by Traffic Category

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

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

6.2.3. Projected Investment Needs

The projected costs by time period, region, and functional class for the three oil drilling scenarios (30, 60, 90 rigs) are summarized in Tables 9-11. The total projected statewide need during the 20-year analysis period is $6.13 billion.

Table 9: Summary of Unpaved Road Investment and Maintenance Needs for Counties and Townships in North Dakota (Millions of 2020 Dollars)

Period	Statewide
2021-22	$ 611.08
2023-24	$ 602.19
2025-26	$ 616.21
2027-28	$ 615.89
2029-30	$ 602.76
2031-40	$ 3,008.07
2021-40	**$ 6,056.34**

The estimated needs are shown by jurisdiction for the 2021-22 biennium in Table 10. To clarify, both county and township roads are included in the county jurisdiction row entitled Non-CMC/Twp. This category combines both roads in unorganized townships and township roads for which the county assumes maintenance responsibility. Per the survey of townships, an estimated 453 roads in organized townships are maintained by the counties in which they are located. Similarly, the investment needs are shown by jurisdiction for the entire analysis period in Table 11.

Table 10: Unpaved Road Investments Needs, by Jurisdiction (2021-2022)

Jurisdiction and/or Maintenance Resp.	Needs (Millions)	Percent of Needs
County	$ 395.86	65%
Township	$ 203.00	33%
Tribal	$ 12.22	2%
Total	**$ 611.08**	**100%**

Table 11: Unpaved Road Investment Needs, by Jurisdiction (2021-2040)

Jurisdiction and/or Maintenance Resp.	Needs (Millions)	Percent of Needs
County	$3,794.97	65%
Township	$2,038.41	33%
Tribal	$ 122.72	2%
Total	**$6,056.34**	**100%**

Table 12 presents the unpaved road needs by county for the analysis period by biennium for the first 10 years, as well as the last 10 years of the study period.

Table 12: Unpaved Road Needs by County (2020 $Million)

County	**2021-22**	**2023-24**	**2025-26**	**2027-28**	**2029-30**	**2031-40**
Adams	$ 5.33	$ 5.34	$ 5.34	$ 5.34	$ 5.35	$ 27.35
Barnes	$ 13.23	$ 13.23	$ 13.23	$ 13.23	$ 13.23	$ 66.22
Benson	$ 7.84	$ 7.84	$ 7.84	$ 7.84	$ 7.84	$ 39.22
Billings	$ 8.42	$ 7.70	$ 9.42	$ 8.67	$ 7.23	$ 35.72
Bottineau	$ 10.71	$ 10.64	$ 10.64	$ 10.70	$ 10.70	$ 53.49
Bowman	$ 7.57	$ 7.61	$ 7.64	$ 7.61	$ 7.54	$ 37.69
Burke	$ 12.88	$ 12.81	$ 12.81	$ 12.81	$ 12.83	$ 64.17
Burleigh	$ 15.89	$ 15.90	$ 15.95	$ 15.98	$ 15.98	$ 79.90
Cass	$ 28.00	$ 28.03	$ 28.16	$ 28.28	$ 28.39	$ 142.57

County	2021-22	2023-24	2025-26	2027-28	2029-30	2031-40
Cavalier	$ 11.67	$ 11.67	$ 11.72	$ 11.74	$ 11.74	$ 58.72
Dickey	$ 7.41	$ 7.41	$ 7.41	$ 7.41	$ 7.41	$ 37.03
Divide	$ 15.36	$ 15.17	$ 15.43	$ 15.54	$ 15.29	$ 76.45
Dunn	$ 29.70	$ 28.23	$ 30.45	$ 30.91	$ 27.86	$ 140.48
Eddy	$ 3.57	$ 3.58	$ 3.58	$ 3.58	$ 3.58	$ 17.90
Emmons	$ 7.75	$ 7.75	$ 7.75	$ 7.75	$ 7.75	$ 38.77
Foster	$ 4.86	$ 4.86	$ 4.86	$ 4.86	$ 4.86	$ 24.32
Golden Valley	$ 8.48	$ 8.89	$ 8.60	$ 8.55	$ 8.42	$ 42.08
Grand Forks	$ 24.15	$ 24.23	$ 24.23	$ 24.23	$ 24.25	$ 121.81
Grant	$ 12.53	$ 12.53	$ 12.53	$ 12.53	$ 12.53	$ 62.64
Griggs	$ 4.62	$ 4.62	$ 4.62	$ 4.62	$ 4.67	$ 23.40
Hettinger	$ 6.71	$ 6.71	$ 6.71	$ 6.71	$ 6.71	$ 33.57
Kidder	$ 7.06	$ 7.06	$ 7.06	$ 7.06	$ 7.06	$ 35.28
LaMoure	$ 10.50	$ 10.50	$ 10.50	$ 10.50	$ 10.50	$ 52.50
Logan	$ 4.92	$ 4.92	$ 4.92	$ 4.92	$ 4.92	$ 24.59
McHenry	$ 11.61	$ 11.64	$ 11.64	$ 11.64	$ 11.68	$ 58.42
McIntosh	$ 4.77	$ 4.77	$ 4.77	$ 4.77	$ 4.77	$ 23.87
McKenzie	$ 45.94	$ 42.65	$ 46.45	$ 46.24	$ 43.56	$ 208.93
McLean	$ 16.73	$ 16.73	$ 16.74	$ 16.75	$ 16.76	$ 84.01
Mercer	$ 8.98	$ 8.98	$ 8.98	$ 8.95	$ 8.95	$ 44.73
Morton	$ 10.65	$ 10.65	$ 10.65	$ 10.65	$ 10.65	$ 53.26
Mountrail	$ 21.83	$ 19.28	$ 23.10	$ 23.16	$ 19.53	$ 96.56
Nelson	$ 5.90	$ 5.90	$ 5.90	$ 5.92	$ 5.92	$ 29.58
Oliver	$ 3.31	$ 3.28	$ 3.28	$ 3.28	$ 3.28	$ 16.11
Pembina	$ 8.14	$ 8.17	$ 8.17	$ 8.17	$ 8.17	$ 40.94
Pierce	$ 9.74	$ 9.74	$ 9.74	$ 9.74	$ 9.74	$ 48.69
Ramsey	$ 6.31	$ 6.32	$ 6.32	$ 6.32	$ 6.32	$ 31.62
Ransom	$ 6.51	$ 6.54	$ 6.54	$ 6.54	$ 6.55	$ 32.75
Renville	$ 6.66	$ 6.66	$ 6.66	$ 6.66	$ 6.66	$ 33.31
Richland	$ 18.63	$ 18.63	$ 18.63	$ 18.64	$ 18.65	$ 93.35
Rolette	$ 5.14	$ 5.14	$ 5.14	$ 5.14	$ 5.14	$ 25.70
Sargent	$ 5.24	$ 5.24	$ 5.24	$ 5.24	$ 5.24	$ 26.22
Sheridan	$ 5.44	$ 5.44	$ 5.44	$ 5.44	$ 5.44	$ 27.18
Sioux	$ 6.10	$ 6.10	$ 6.10	$ 6.10	$ 6.10	$ 30.60

County	2021-22	2023-24	2025-26	2027-28	2029-30	2031-40
Slope	$ 5.97	$ 5.97	$ 5.97	$ 5.83	$ 5.78	$ 28.88
Stark	$ 17.04	$ 17.00	$ 17.17	$ 16.93	$ 16.79	$ 83.94
Steele	$ 7.93	$ 7.93	$ 7.95	$ 7.95	$ 7.95	$ 39.75
Stutsman	$ 13.69	$ 13.69	$ 13.70	$ 13.71	$ 13.73	$ 68.69
Towner	$ 7.52	$ 7.52	$ 7.52	$ 7.52	$ 7.52	$ 37.62
Traill	$ 8.35	$ 8.37	$ 8.48	$ 8.50	$ 8.52	$ 42.71
Walsh	$ 18.47	$ 18.47	$ 18.69	$ 18.71	$ 18.71	$ 93.82
Ward	$ 21.19	$ 21.36	$ 21.49	$ 21.59	$ 21.48	$ 107.49
Wells	$ 8.47	$ 8.47	$ 8.47	$ 8.47	$ 8.47	$ 42.33
Williams	$ 25.69	$ 24.32	$ 25.92	$ 25.98	$ 24.07	$ 121.18
Total	$ 611.08	$ 602.19	$ 616.21	$ 615.89	$ 602.76	$ 3,008.07

7. Paved Road Analysis

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

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

More than 5,500 miles of paved county and local roads (exclusive of city streets) are traveled by agricultural and oil-related traffic and other highway users. Some of these roads are under the jurisdiction of governments or agencies other than counties, such as townships, municipal governments, the Bureau of Indian Affairs (BIA), and the Forest Service. City streets and Forest Service roads are excluded from the study.[1] BIA and tribal roads are included, but the results are presented separately from county and township roads.

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

7.1. Truck Axle Weights

American Association of State Highway Transportation Officials (AASHTO) pavement design equations were used to analyze paved road impacts. These same equations are used by most state transportation departments. The equations are expressed in equivalent single axle loads (ESALs). In this form of measurement, the weights of various axle configurations (e.g., single, tandem, and tridem axles) are converted to a uniform measure of pavement impact. With this concept, the service life of a road can be expressed in ESALs instead of truck trips.

An ESAL factor for a specific axle represents the impact of that axle in comparison to an 18,000-pound single axle. The effects are nonlinear. For example, a 16,000-pound single axle followed by a 20,000-pound single axle generates a total of 2.19 ESALs, as compared to 2.0 ESALs for the passage of two 18,000-pound single axles.[2] An increase in a single-axle load from 18,000 to 22,000 pounds more than doubles the pavement impact, increasing the ESAL factor from 1.0 to

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

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

2.44. Because of these nonlinear relationships, even modest illegal overloads (e.g. 22,000 pounds on a single axle) can significantly reduce pavement life.

7.2. Trucks Used to Haul Oil Products and Inputs

The forecasted trips for each type of load moving to and from well sites were shown in Table 3. The characteristics of these trips are depicted in Table 13. 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 13. These vehicles (which exceed the maximum vehicle weight limit) travel under special permits. In comparison, a truck used to transport sand while complying with Bridge Formula B weighs 76,000 pounds and generates an ESAL factor of 2.24. Nevertheless, based on enforcement data from the North Dakota Highway Patrol and results of special studies at truck weigh stations, it has been estimated that 25% of these trucks are overloaded. The typical overloaded vehicle weighs 90,000 pounds with an ESAL factor of 3.78 (instead of 2.24).

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

Table 13: 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

7.3. 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 14, 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 14: 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.

7.4. Surface Conditions

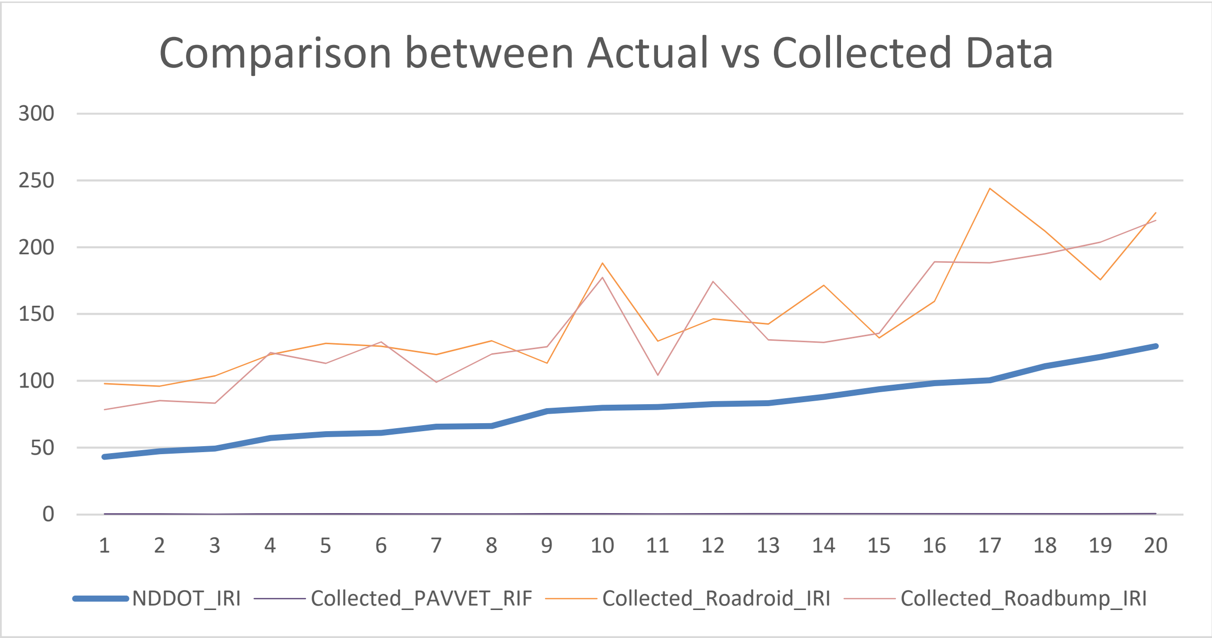
Pavement data has been collected using three different tools namely PAVVET (Performance Analysis Via Vehicle Electronic Telemetry), Roadroid, and Roadbump. PAVVET is an in-house tool of UGPTI which is in the process of developing a scalable and affordable technique to measure the ride quality and that uses data freely available from a smartphone sensors. It provides the Road Impact Factor (RIF) values. According to the PAVVET prospectus, this is an improved index of roughness characterization from smartphone sensors mounted in vehicles irrespective of speed. Roadroid is designed by a Swedish civil engineering company with a vision to create an international road quality standard that helps to make the road quality better and more sustainable in a global perspective (Forslöf, 2012). It presents the final output in two forms of IRI: Calculated IRI (cIRI) and Estimated IRI (eIRI). The cIRI value is measured based on the quarter car simulation formula; while the eIRI value is determined based on the correlation developed based on peak and root mean square (RMS) vibration analysis. Another tool, Roadbump Pro is a production of Grimmer Software that also serves the same purpose of acquiring road roughness data and delivers both IRI value with corresponding PSR value. The data collection took place within a strictly maintained vehicle speed of 55 mph. All three tools use the GPS and accelerometer of a smartphone to measure the road roughness. There is another tool used namely RIC (Roadway Image Capture) which collects the image of the driven road and uploads those images to the GRIT server. These images have been used for subjective rating

(PSRcondition) of the road sections. The images were also used to verify surface type for roadways with out-of-date or unavailable information.

Pavement data was collected from more than 5,680 miles of paved county roads from all over North Dakota during the summer of 2019. Each smartphone app was required to go through different calibration processes and their output format was in different formats. For example, the Roadbump tool provided the average IRI and PSR for every 0.5 miles of driving distance. In a normal setting, this tool expands the IRI results to achieve the most accurate results. Unlike the Roadbump, Roadroid generates two types of IRI values (cIRI and eIRI) with no PSR conversion. Usually, the eIRI values are always lower than cIRI values, because cIRI values using the quarter car formula and a smothering filter when the eIRI values are using a linear conversion formula from the calculated values. eIRI picks up more of the texture of the road and has a speed compensator for paved roads. On the other hand, PAVVET provides the Roadway Impact Factor (RIF) values. All these tools generate data based on the calibration of the specific tool; consequently the data obtained does not initially correlate directly with the sophisticated precision laser profile measurements from a Class I profiler. However, to get complementing representative data, a regression analysis is performed to find the correlation between the collected data and data collected on the same segments with a Class I laser based profiler (NDDOT Pathway Van).

For this analysis, pavement roughness data was collected in the same manner over the state road network from the southwestern part of North Dakota. The NDDOT has the data collected for those state road sections using a Class I profiler which collects the longitudinal profile of the pavement surface for both wheel paths. With the similar road roughness (IRI) from the NDDOT data, 20 road sections were identified from the entire route. Then the average output measurement from different tools was used as the independent variable of the analysis. In the same manner, the average value of the Class I profiler is calculated (IRI_Average) for those sections to be considered as the dependent variable for the estimation. The collected data is represented in Figure 25.

Figure 25: Comparison between Actual NDDOT and Collected IRI from different tools



Based on Figure 25, it is evident that all the collected data from the different tools need calibration to denote the precision profile measurement for a road section. The RIF value from PAVVET cannot be represented as it is a different unit of measurement than IRI. The other two tools measured the road roughness with a higher threshold than the DOT profiler and do not follow any specific pattern. Therefore, it is recommended to use more than one equation for different ranges of IRI reading.

Regression for both linear and quadratic (second-order) models has been attempted for all types of IRI values. In the analysis, with the model equation, the standard deviation (SD) and the coefficient of determination are (R-sq) also presented in the following table.

Table 15: Regression model to estimate the correlation for various tools

Tool	Dependent value	Model Type	Equation	SD	R-sq value (%)
Roadroid	Calc_iri	Linear	IRI_Averag= 10.97 + 0.4621 * Calc_iri	13.45	69.2
		Quadratic	IRI_Averag= -82.57+1.678 * Calc_iri-0.00366*(Calc_iri)2	12.04	76.72
	Est_iri	Linear	IRI_Averag= 4.86+0.6773* Est_iri	14.94	61.98
		Quadratic	IRI_Averag= -115.4 + 2.756* Est_iri- 0.00846*(Est_iri)2	13.10	72.38
Roadbump	IRIAvg	Linear	IRI_Averag = 7.58 + 0.5330 * IRIAvg	13.98	66.72
		Quadratic 1	IRI_Averag= -13.3+ 0.913 * IRIAvg-0.001449*$(IRIAvg)^2$	19.53	50.45
		Quadratic 2	IRI_Averag =-65.82+ 1.990 * IRIAvg-0.006836*$(IRIAvg)^2$	16.09	27.64
PAVVET	RIF	Linear	IRI_Averag= 20.9 + 161.6 * RIF	17.02	50.68

For various tools, the prepared models with a linear relationship have the R-square value from 62% to 70% (Table 15). If we consider a polynomial relationship between the variable, it may rise to 76.76%. Although this is a moderate correlation, the sample size is very small with only 20 values and may require more statistical analysis. Also, no correlation can be found for the quadratic model of Roadbump in the initial result. Therefore, more in-depth analysis has been done for similar Roadbump data reading across the state road which results in additional quadratic equations with an R-square value between 27.64% and 50.45%.

The application of all those equations were used separately for each IRI values from different tools and applied on the entire state road sections. Based on the validation result, different equations have been identified for the different range of readings made by a tool for a road section. All correlated data with the actual reading from Class I profiler is presented in the Figure 26.

Figure 26: Comparison between Actual NDDOT and Correlated IRI from different tools

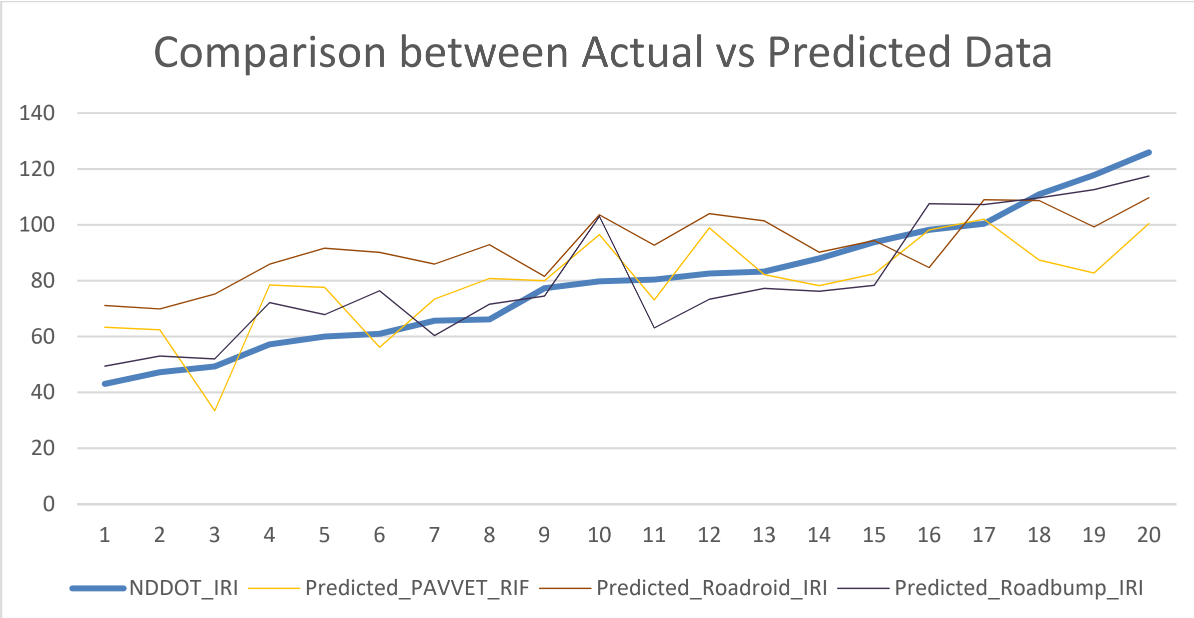


Figure 26 shows good correlation of the final IRI of all three devices. There are some small variations which may occur because differences of accelerometer-based devices and laser-based devices. For example, the 10th and 11th section of the above graph have consecutive higher and lower IRI values from each tool used than from the actual data collected by Class I profiler. This can happen for the following reasons:

- Presence of grade elevation on the road sections in question.
- Presence of road patches
- The difference in texture in the same road section

The data from Roadbump follows the actual IRI data trend line somewhat closer than the data from the other tools. Consequently, this study is using those values for most of the North Dakota road sections. If there is no data available from Roadbump, the maximum value from the other two tools were considered for a section. Thus, an entire dataset has been created on the GRIT server for IRI values from the three different apps. The pavement data is then spatially joined with the GRIT road sections based on data availability within 100 feet of a paved road. The average of those points allocated to each road segment was considered as the IRI for the entire road section. About 60 miles of road roughness data could not be collected as those are mostly short segments (less than 0.05 miles) inside cities or townships or the road section was under construction. For those sections, the pavement condition is calculated using the pavement age information provided by the local agencies in GRIT while considering standard low pavement performance measures.

All the IRI value is expressed in inches per mile and converted into PSR rating based on the Minnesota survey panel model. The model proposes two equations for bituminous and concrete pavements by using subjective feedback from 32 citizens who drove on the 120 pre-selected test sections on the state's highway system. Drivers reported their driving experience within the range of 0 (very poor) to 5 (very good) with poor, fair, and good grades between them. This value was then used with the AASTHO 93 pavement design equation. The following formulas were used for this conversion:

- IRI to PSR is converted using the Minnesota survey panel equation (MnDOT, 2003):

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

- Combined ride and condition values of PSR with the following equation:

$$PSR_{combined} = \sqrt{PSR_{ride} * PSR_{condition}})$$

The $PSR_{condition}$ used in the equation is the subjective 0 to 5 scale rating of cracking and surface deterioration of the road sections. Approximately 5,287 miles of road sections were rated for condition by researchers using the RIC images from GRIT. The images were also accessed for any roadway information during the analysis of the rating.

The results of the combined condition and ride PSR assessment are summarized in Table 16. About 38% of paved county and township road miles are in good condition. Another 50% of paved road miles are in fair condition and should be considered for improvements within the next 10 years or so. The last 11% is in poor condition which are likely in need of immediate improvement. Road condition ratings for each county are shown in Appendix C.

Table 16: Conditions of Paved County and Township Roads in North Dakota in 2020 Condition Miles

Conditions	Miles- 2019	Percent- 2019	Percent- 2015
Good	2162.21	38%	44%
Fair	2844.86	50%	47%
Poor	675.12	12%	9%
	5682.19	100%	100%

7.5. Structural Conditions

The capability of pavement to accommodate heavy truck traffic is reflected in its structural rating, which is measured through the structural number (SN). The structural number is a function of the thickness and material composition of the surface, base, and sub-base layers. The surface (top) layer is typically composed of asphalt while the sub-base (bottom) layer is comprised of aggregate material. The base (intermediate) layers consist of the original or older surface layers that have been overlaid or resurfaced. Roads that have not yet been resurfaced or have recently been reconstructed may have only surface and aggregate sub-base layers. County officials have access to update these layer thickness data on GRIT. For the analysis in this study, those updated layer thickness values are primarily selected from the GRIT inventory. If there is no data available on GRIT, then those gaps can be filled with the data collected via non-destructive testing (NDT) data collected in 2015. The details of NDT are provided in Appendix H. For any additional missing data, the analysis use default values based on the region and pavement rating. For calculating the resilient modulus, the same approach is adopted where initially the subgrade strength information updated by county is used. If there is no data entered, the elastic modulus provided by NDT or the default values were used for further calculation.

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 existing pavement's structural number is calculated using the depth of different layers in the pavement with the respective structural coefficients. 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.

7.6. Types of Improvement

Five types of road improvements are analyzed in this study: (1) reconstruction, (2) mine and blend, (3) resurfacing, (4) resurfacing with widening, and (5) breaking and seating concrete pavements with an asphalt overlay. If a pavement is not too badly deteriorated, normal resurfacing is a cost-effective method of restoring structural capacity. In this type of improvement, a new asphalt layer is placed on top of the existing pavement. The thickness of the layer may vary. However, it may be as thick as six to seven inches. For roads without extensive truck traffic, a relatively thin overlay (e.g. two to three inches) may be sufficient.

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 by overlays, a cross-sectional in-slope must be maintained. As a result, the useable width may decline or the in-slope may become steeper and not meet design standards. For narrower roads, this may result in reduced lane and shoulder widths and/or the elimination of shoulders. 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.

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

7.7. 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 forecasted traffic.[3] The PSR of each road segment is predicted year by year, starting from its current value and 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 the 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 the less expensive mine and blend treatment. Otherwise, the road segment will be selected for full reconstruction.

If a pavement is still above the poor condition and has not yet dropped below the reconstruction PSR, it is slated for resurfacing and/or widening. This is considered the ideal time for a lower cost surfacing improvement in order to avoid the much higher reconstruction costs. 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 the section corresponding to a 20-year design life, based on forecasted traffic
SN_{Old}	=	Estimated structural contribution of existing layers, based on the projected condition at the time of improvement
I	=	Inches of new asphalt surface layer required for the new structural number
0.40	=	Structural coefficient of asphalt surface layer

If the width is deficient and the projected overlay thickness is greater than 2 inches, treatment is determined based on the condition of the pavement's unbound base layer. If the 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 a 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.

[3] 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.

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 the NDDOT Local Government Division. The four major oil-producing counties (Dunn, McKenzie, Mountrail, and Williams) currently allow a maximum sliver widening 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.

7.8. Preservation Maintenance

As mentioned earlier in the report, there has been an evolution in asset management in the area of preservation. Of the three preservation areas, pavement, gravel, and bridge, pavement preservation is the most mature and accepted and regularly practiced concept. Pavement preservation techniques include timely crack sealing, seal coats, and timely overlays that are intended to prevent the pavement from rarely, if ever needing to be reconstructed. Reconstruction can cost as much as six times the cost of an overlay. Although pavement preservation is generally accepted, it is not practiced uniformly due to budgetary constraints. This study provides and includes the cost of timely pavement preservation techniques even if the techniques are not uniformly applied across the jurisdictions included in this study. 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 17 have been derived from a South Dakota Department of Transportation study and unpublished UGPTI research. Costs have been updated to 2020 levels and annualized based on the FHWA Construction Cost Index changes from 2016. 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 micro-surfacing treatments in those counties.

Table 17: Routine Maintenance Cost Factors for Paved Roads by Traffic Level (Millions of 2020 Dollars)

AADTT Truck Traffic	Region	Annualized Cost of Road Maintenance Activities				
		Chip Seal	Crack Sealing	Contract Patching	Microsurfacing	Total
0-500	All	$5,650	$1,211	$3,229	-	**$10,090**
>500	All	$3,766	$1,615	$6,457	$12,915	**$24,573**

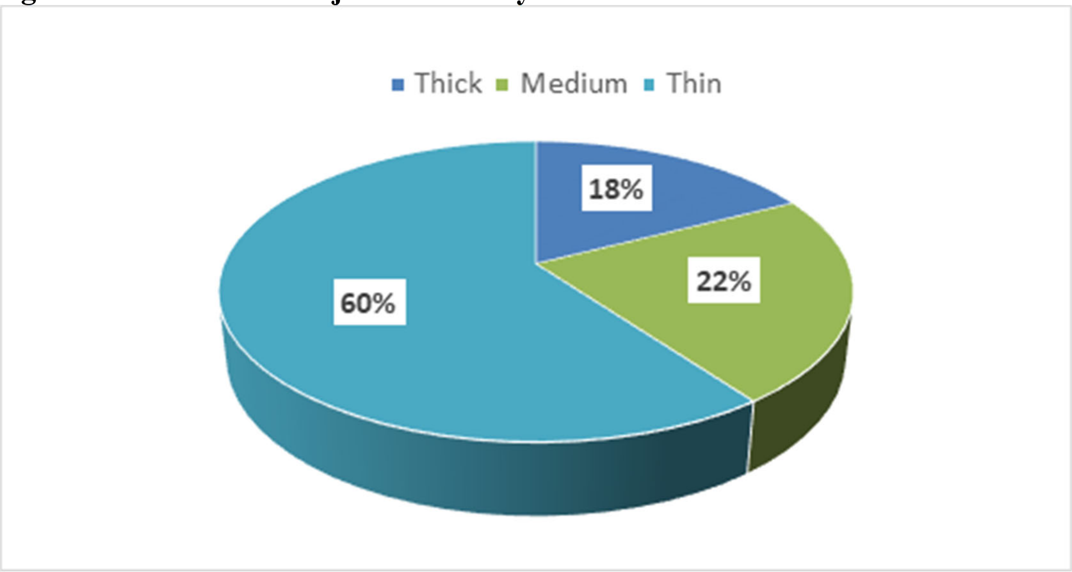
7.9. Forecasted Improvement Needs

7.9.1. Required Overlay Thickness

As noted earlier, the projected thickness of an overlay is a function of truck traffic and 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), medium (between 2 and 4 inches), and thick (≥ 4 inches). As shown in Figure 27, 18% of the the state's paved road miles are expected to need thick overlays or major rehabilitation. Another 22% will require medium overlays and thin overlays will suffice for the remaining 60%.

Figure 27: Statewide Projected Overlay Thickness

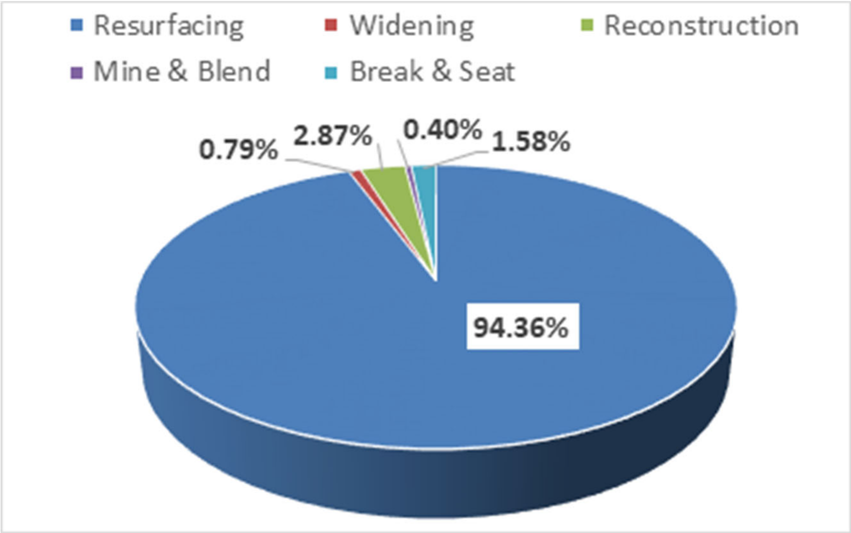


7.9.2. Miles Improved

As shown in Figure 28, approximately 3% miles of the paved roads in the state must receive major rehabilitation (reconstruction or mine and blend treatment) because of their poor condition and heavy traffic that will cause existing pavements to deteriorate very quickly. Only 0.8% of road miles must be widened when they are resurfaced while 1.6% of miles are concrete and will need a break and seat project.

Overall, the analysis shows that most of the miles 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 may need to be widened in the future, beyond this study's time frame.

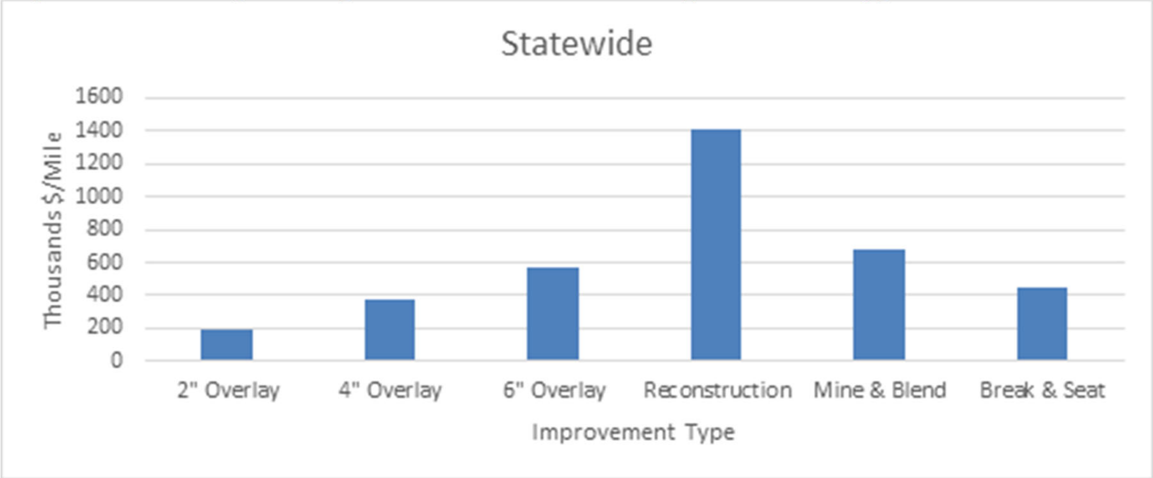
Figure 28: Percent of Paved Road Miles by Improvement Type



7.9.3. Improvement Costs per Mile

Construction costs have experienced steady incremental increases over the last several years. In the previous study, the cost was reported for five categories of improvement types based on NDDOT bid information and plan documents. According to the latest FHWA National Highway Construction Cost Index, there was an average increase of 3.25% per year from 2015 to 2019 for various types of construction projects. With this information, the resurfacing cost of each project was determined to be $3,943 per inch foot width statewide. Therefore, a two-inch overlay costs roughly $189,300 per mile for a 24-foot roadway (Figure 29). A four-inch overlay costs roughly $379,000 per mile, while a six-inch overlay results in a cost of $568,000 per mile[4].

Figure 29. Average Cost per Mile for Different Improvement Type



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

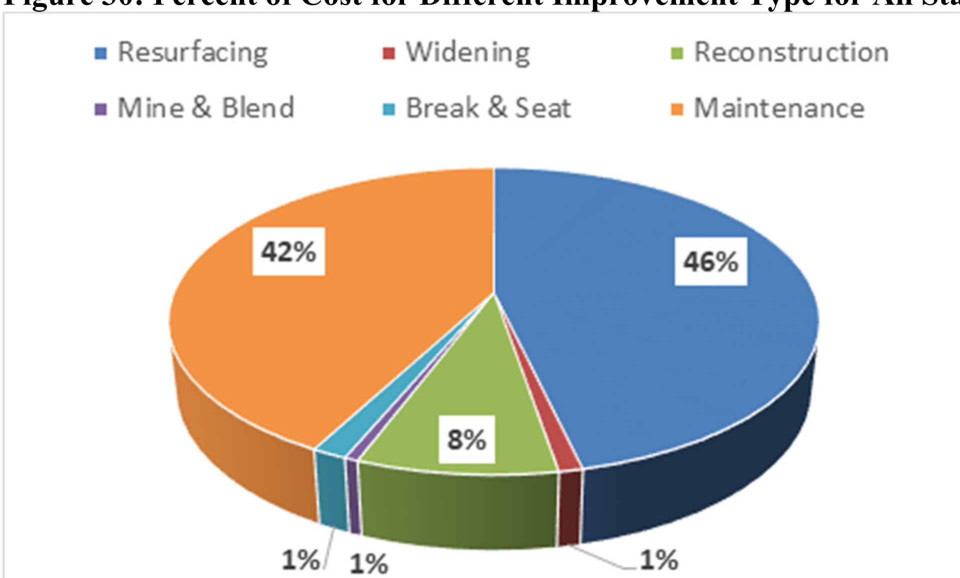
Major rehabilitation costs are estimated using NDDOT unit cost data, which has also been normalized statewide. Reconstruction cost due to weak or failed subgrade is estimated at $1,412,500 per mile statewide. A mine and blend treatment is expected to cost roughly $678,000 per mile. Break and seat treatments are expected to cost approximately $452,000 per mile. Segments selected for sliver widening are assigned a widening cost of $87,575 per added foot width (in addition to overlay cost).

The results of the analysis are summarized in Tables 18-20. These tables show the projected improvements and costs (including maintenance costs) for each biennium during the next 10 years, a projected subtotal for the 2021-2030 period, and another subtotal for 2031-2040. Similar information is shown for oil- and gas-producing counties. The values in oil and gas tables are included in the statewide tables. Finally, Table 20 is the summary of total statewide costs for pavement preservation. Appendix D.2 describes total paved road needs by county.

As shown in Table 18, approximately 160 miles of paved county and township roads in North Dakota must be reconstructed or reclaimed because of poor conditions, high traffic loads, or deficient width. Only 45 miles are candidates for widening. The remaining miles will need resurfacing during the next 20 years. On those roads, there are almost 90 miles which must be considered for breaking and seating while 22.7 miles need to go through a mine and blend treatment. 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 the traffic level.

The estimated cost for all county and township roads is approximately $2,669 million or $113.4 million per year. About 8% of the expected cost is due to major rehabilitation (Figure 30). Only 1% is attributable to each minor rehabilitation improvement like break and seat, mine and blend, and widening. Resurfacing accounts for 46% based on traffic. The remaining costs are linked to routine maintenance.

Figure 30: Percent of Cost for Different Improvement Type for All Statewide Roads



As shown in Table 19, about $1,077 million (or 40%) of the projected statewide need can be traced to oil- and gas-producing counties. Thirty-eight percent of the mine and blend cost and 68% of the major rehabilitation costs are attributable to this region. In addition, as shown in Table 19, the need for reconstruction is greater during the early years of the analysis period, with more than 76% of the reconstruction costs needed during the first decade. About 39% of the total statewide resurfacing cost should be allocated for the oil county. But it is very significant that between 2023 and 2026, all widening in the oil patch will be needed.

The weighted-average cost for the predicted resurfacing improvements is roughly $218,000 per mile. The average routine maintenance cost is approximately $9,917 per mile per year. For roads that do not require major rehabilitation or widening, the annualized cost per mile is roughly $11,365 per year. Once deferred investment needs have been taken care of and regular preservation maintenance is practiced on all segments, annualized costs should stabilize near this level.

Table 18: Summary Statewide of Forecasted Improvements and Costs for Paved County and Township Roads (Millions of 2020 Dollars)

Period	Resurfacing		Widening		Reconstruction		Mine & Blend		Break & Seat		Maintenance Cost	Total Cost
	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost		
2021-2022	809.7	$224.50	18.5	$10.70	10.2	$14.40	16	$10.90	23	$9.60	$118.50	$388.50
2023-2024	730.1	$192.30	21.7	$13.30	47.6	$66.80	0.3	$0.20	36.2	$15.90	$118.50	$407.00
2025-2026	583.3	$131.00	3.7	$2.10	30	$42.30	0.4	$0.30	23	$10.40	$118.50	$304.60
2027-2028	419.8	$88.50	0	$0.00	42.8	$54.30	1.9	$1.30	4	$1.80	$118.60	$264.50
2029-2030	455.6	$103.00	0	$0.00	0.3	$0.40	0	$0.00	0.3	$0.10	$118.60	$222.20
2021-2030	**2998.5**	**$739.30**	**43.9**	**$26.10**	**130.9**	**$178.20**	**18.6**	**$12.70**	**86.5**	**$37.80**	**$592.70**	**$1,586.80**
2031-2040	**2,363.3**	**$497.50**	**1**	**$0.70**	**31.9**	**$45.10**	**4**	**$2.70**	**3.5**	**$1.60**	**$534.20**	**$1,081.80**

Table 19: Summary of Forecasted Improvements and Costs for Paved County and Township Roads in Oil and Gas Producing Counties (Millions of 2020 Dollars)

Period	Resurfacing		Widening		Reconstruction		Mine & Blend		Break & Seat		Maintenance Cost	Total Cost
	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost	Miles	Cost		
2021-2022	237.3	$66.70	0	$0.00	0.2	$0.30	5.3	$3.60	3.8	$0.90	$45.10	$116.50
2023-2024	250.8	$76.20	7.3	$4.00	32.2	$45.50	0	$0.00	2.1	$0.50	$45.10	$171.20
2025-2026	198.5	$48.90	3.4	$1.60	17.8	$25.10	0.4	$0.30	0	$0.00	$45.10	$121.10
2027-2028	108.8	$29.20	0	$0.00	31.4	$44.30	0	$0.00	0	$0.00	$45.30	$118.80
2029-2030	173.2	$44.00	0	$0.00	0.3	$0.40	0	$0.00	0	$0.00	$45.30	$89.70
2021-2030	**968.6**	**$265.0**	**10.7**	**$5.60**	**81.9**	**$115.6**	**5.7**	**$3.90**	**5.9**	**$1.40**	**$225.90**	**$617.30**
2031-2040	**975.4**	**$216.3**	**0**	**$0.00**	**25.9**	**$36.60**	**3**	**$2.00**	**1**	**$0.50**	**$204.10**	**$459.50**

Table 20: Summary of Projected Pavement Investment Needs for County and Township Roads (Millions of 2020 Dollars)

Period	Paved
2021-2022	$388.50
2023-2024	$407.00
2025-2026	$304.60
2027-2028	$264.50
2029-2030	$222.20
2031-2040	$1,081.80

7.9.4. Indian Reservation Roads

Thus far, only county and township roads, excluding Indian Reservation Roads, have been presented. However, some of the roads utilized by agricultural and oil-related traffic are under the jurisdiction of the Bureau of Indian Affairs (BIA) and Native American tribal governments. These roads are included in the travel demand network and traffic predictions and investment forecasts are developed for them as well. However, the results are presented separately here because funding for Indian Reservation Roads is appropriated and distributed differently than funding for county and township roads.

The same methods and assumptions used to analyze county and township roads are used to analyze tribal roads. The results of the paved road analysis are summarized in Table 21, which shows the forecasted improvements and costs for all tribal road segments and specifically for those routes in oil-producing regions. Altogether, 184.4 miles of paved IRR (Indian Reservation Roads) are captured in the analysis. Almost 65% of these miles only need resurfacing and just 5% will require reconstruction due to poor condition or poor subgrade. The forecasted improvements are shown by funding period for paved and unpaved roads in Table 18.

Table 21: Summary of Indian Reservation Paved Road Investment Analysis

Projected Improvement or Cost	Total: North Dakota
Miles Resurfaced	119.4
Resurfacing Cost (Million$)	$26.4
Miles Widened	0
Widening Cost (Million$)	$0.00
Miles Reconstructed	8.8
Reconstruction Cost (Million$)	$12.50
Miles Reclaimed	4.9
Mine & Blend Cost (Million$)	$3.40
Miles Break & Seat	51.4
Break & Seat Cost (Million$)	$23.20
Maintenance Cost (Million$)	$35.30
Total Cost (Million$)	$100.80

8. Bridge Analysis

8.1. Introduction

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

This study expands 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.

8.2. 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 bridges). 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 2,261 NBI (2019) rural non-culvert structures which are county- or township-owned and currently open to traffic. This dataset represents the basis for this study's needs analysis.

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

To support statistical significance, a complete NBI (2019) North Dakota bridge population dataset was used to develop the bridge condition forecasting models which will be explained in greater detail later.

8.2.1. Condition of County and Township Bridges

Table 22 summarizes the age distribution of county- and township-owned bridges in North Dakota based on the 2019 NBI, which was the most recent data available at the time of this report. Forty-five percent of bridges in the data set are older than 50 years. Another 35% are between 30 and 50 years of age. A total of 371 bridges (15%) were built more than 75 years ago. Although 50 years was historically considered the design life of many bridges, service lives can be extended through diligent maintenance and rehabilitation.

Table 22: Age distribution of county-, township-, and city-owned bridges in North Dakota

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

The condition assessment scale used in the National Bridge Inventory is shown in Table 23. 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 24, and in an alternative format in Table 25.

Table 23: 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 24: 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	84	3.72%	112	4.95%	96	4.25%
8	329	14.55%	604	26.71%	462	20.43%
7	502	22.20%	669	29.59%	587	25.96%
6	391	17.29%	454	20.08%	433	19.15%
5	213	9.42%	280	12.38%	409	18.09%
4	60	2.65%	112	4.95%	205	9.07%
3	6	0.27%	24	1.06%	59	2.61%
2	1	0.04%	1	0.04%	5	0.22%
1	0	0.00%	1	0.04%	1	0.04%
NA	675	29.85%	4	0.18%	4	0.18%

Table 25: Component Ratings [alternative format]

Component Ratings	Deck		Superstructure		Substructure	
	Bridges	Percent	Bridges	Percent	Bridges	Percent
Good (7-9)	915	58%	1385	61%	1145	51%
Fair (5-6)	604	38%	734	33%	842	37%
Poor (0-4)	67	4%	138	6%	270	12%

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

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

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

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

It can be helpful to consider a bridge's status in terms of its impact on the roadway network. If the width of a bridge is insufficient to carry modern traffic volume and trucks, 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.

8.2.2. 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. This effort identified 175 bridges as existing on minimum maintenance roads.

8.3. Methodology

8.3.1. Deterioration Model

In 2009, UGPTI developed a set of empirical models to forecast component (deck, superstructure and substructure) deterioration rates for bridges nationwide. UGPTI has since developed regional empirical regression models with a focus on North Dakota. These updated models are based on the 3,110 North Dakota bridges in the 2019 NBI database. They were validated using the updated 2019 NBI database.

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

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

Bridge age is the independent variable used in the models and is calculated as 2019 minus the year of original construction or reconstruction year. A polynomial function between bridge rating and age was adopted. The hypothesis is based on two suppositions. First, the rate of loss may be modest and nearly linear until a bridge's condition deteriorates to fair, at which point more maintenance and repairs must be implemented to keep the bridge in acceptable condition. These improvements may slow down the deterioration rate with time. Second, once the bridge is in serious condition it may continue in light service for some time under close scrutiny via posting (e.g., limiting the traffic loads). Age and age-squared are the quantitative independent continuous variables in this study.

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

The detailed model statistics are attached in Appendix E.

Forecasted component ratings were used to calculate bridge sufficiency rating. However, the sufficiency rating equation includes several other elements in addition to deck, superstructure and substructure condition. The detailed sufficiency rating formula is documented in NBI coding guide in Appendix F. Other elements included in the sufficiency rating equation are shown in Table 26.

Table 26: Other factors that affect sufficiency rating

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

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

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

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

8.3.2. Improvement Selection Model

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

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

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

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

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

An additional forecasted preventive maintenance need was included for deck washing on maintenance-eligible bridges within five miles of municipalities with populations 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 the preventive maintenance state but did not yet warrant total replacement. A number of exclusionary factors were applied to bridges for which it was determined that rehabilitation would be either undesirable or impossible. These included unknown foundation, poor substructure condition, and timber superstructure. Finally, to facilitate the movement of modern commercial traffic, bridges were assigned rehabilitative deck widening treatments if their deck width was less than 20 feet. This study recognizes that, in general, county and local agencies do not currently practice rehabilitation. However, bridge forecasts include rehabilitation to demonstrate the possibility of reduced lifecycle cost if effective treatment plans were to be adopted.

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

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

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 (≤20 feet). Removal of load postings was a priority, so bridges on CMC routes with operating ratings of less than a standard HS-20 load were sent to replacement state regardless of other condition criteria.

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

8.3.3. Cost Model

As mentioned earlier in the report, there has been an evolution in asset management in the area of preservation. Bridge preservation techniques include timely crack sealing, deck washing, deck seal coats and expansion joint maintenance that are intended to prevent the deck and substructure from rarely, if ever being reconstructed. Although bridge preservation is generally accepted, it is not practiced uniformly due to budgetary constraints. This study includes the cost of timely bridge preservation techniques even if the techniques are not uniformly applied across the jurisdictions of this study.

Preventive maintenance cost estimates used an annual unit cost of $0.25 per square foot of deck area. These values represent 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 $0.04 per square foot for annual deck washing was allowed for deck washing on bridges within five miles of municipalities with populations 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 (2018-19) NDDOT bid reports and plan documents. Unit costs reflect 2018 dollars, and the final costs estimated were adjusted to reflect 2019 dollars. The type of replacement structure was based on the criteria described in the Improvement Selection Model section of this chapter.

A deficient bridge less than 40 feet long is assumed to be replaced by a culvert structure costing $450,000. A deficient bridge between 40 and 50 feet in length is assumed to be replaced by a culvert structure costing $750,000. Costs for bridges longer than 50 feet are calculated using the square footage of the deck and an average replacement unit cost. Unit replacement costs were $295 per square foot of deck area. All costs include preliminary engineering and construction engineering costs. Preliminary engineering costs are assumed to add an additional 10% to the bid price, while construction engineering adds approximately 15% of the bid price.

8.4. Results

8.4.1. Estimated Needs by County

Estimated statewide bridge improvement and preventive maintenance needs for the study period, 2021-2040 are $498 million in 2020 dollars. The forecasts of needs specific to each county are shown in Table 27.

Table 27: Total County and Township Bridge Needs by County, in 2020 Dollars.

County	Rehabilitation and Replacement		Preventive Maintenance Cost	Total Cost
	Bridges	Cost		
Adams	6	$5,260,590.33	$295,153.75	$5,555,744.08
Barnes	3	$1,350,000.00	$397,502.52	$1,747,502.52
Benson	0	$0.00	$64,446.09	$64,446.09
Billings	2	$1,203,733.12	$208,008.99	$1,411,742.10
Bottineau	47	$37,089,561.83	$554,709.14	$37,644,270.98
Bowman	1	$450,000.00	$161,308.60	$611,308.60
Burke	4	$1,800,000.00	$39,067.68	$1,839,067.68
Burleigh	5	$4,168,124.87	$414,403.66	$4,582,528.53
Cass	25	$19,249,751.28	$2,768,946.20	$22,018,697.48
Cavalier	10	$5,328,887.56	$99,090.92	$5,427,978.47
Dickey	0	$0.00	$415,741.78	$415,741.78
Divide	2	$900,000.00	$55,594.40	$955,594.40
Dunn	4	$2,694,787.61	$306,679.39	$3,001,467.00
Eddy	1	$978,887.56	$222,094.20	$1,200,981.76
Emmons	2	$2,263,216.26	$291,996.63	$2,555,212.89
Foster	2	$990,573.67	$93,592.20	$1,084,165.87
Golden Valley	3	$2,149,510.82	$109,857.52	$2,259,368.35
Grand Forks	52	$33,989,404.09	$1,620,636.98	$35,610,041.07
Grant	12	$10,257,228.56	$420,033.42	$10,677,261.98
Griggs	1	$1,636,773.15	$173,762.28	$1,810,535.43
Hettinger	26	$19,320,382.47	$394,008.29	$19,714,390.75
Kidder	0	$0.00	$0.00	$0.00
LaMoure	7	$9,328,887.44	$428,898.09	$9,757,785.54
Logan	2	$900,000.00	$67,104.39	$967,104.39
McHenry	36	$25,492,101.03	$488,705.83	$25,980,806.86
McIntosh	0	$0.00	$16,172.65	$16,172.65
McKenzie	12	$7,331,613.37	$480,729.26	$7,812,342.63
McLean	5	$2,779,010.82	$304,790.03	$3,083,800.86
Mercer	3	$1,650,000.00	$476,584.27	$2,126,584.27

County	Rehabilitation and Replacement		Preventive Maintenance Cost	Total Cost
	Bridges	Cost		
Morton	60	$41,165,815.66	$1,050,553.57	$42,216,369.23
Mountrail	2	$900,000.00	$173,780.24	$1,073,780.24
Nelson	2	$2,070,711.34	$242,852.33	$2,313,563.67
Oliver	0	$0.00	$153,373.26	$153,373.26
Pembina	28	$21,855,149.07	$890,186.16	$22,745,335.23
Pierce	1	$450,000.00	$3,306.41	$453,306.41
Ramsey	10	$5,780,538.48	$154,627.18	$5,935,165.65
Ransom	5	$10,268,212.83	$468,267.46	$10,736,480.29
Renville	2	$2,244,787.61	$187,056.48	$2,431,844.09
Richland	36	$28,652,638.75	$1,422,757.30	$30,075,396.04
Rolette	1	$450,000.00	$37,006.44	$487,006.44
Sargent	5	$2,763,166.32	$32,310.10	$2,795,476.42
Sheridan	0	$0.00	$0.00	$0.00
Sioux	0	$0.00	$104,948.80	$104,948.80
Slope	1	$450,000.00	$158,223.17	$608,223.17
Stark	28	$18,826,411.46	$651,342.61	$19,477,754.07
Steele	18	$10,057,935.53	$468,810.31	$10,526,745.85
Stutsman	3	$2,770,499.63	$338,602.26	$3,109,101.89
Towner	9	$5,250,000.00	$62,460.69	$5,312,460.69
Traill	48	$59,415,090.58	$1,359,219.08	$60,774,309.66
Walsh	60	$42,279,079.19	$1,227,129.33	$43,506,208.51
Ward	14	$11,710,658.67	$417,715.82	$12,128,374.50
Wells	2	$877,256.41	$270,382.19	$1,147,638.60
Williams	18	$10,563,113.70	$198,792.11	$10,761,905.81
Statewide	626	$477,364,091.07	$21,443,322.48	$498,807,413.55

8.4.2. Summation of Bridge Needs for the Study Period

Estimated statewide improvement and preventive maintenance needs for the study period, 2021-2040 are $498 million in 2020 dollars. 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. This distribution of needs provides a credible number per biennium that could be achieved by the bridge construction industry. These forecasts are shown in Table 28.

Table 28: Statewide Summary of Forecasted Needs for County and Township Bridges ($000)

	Rehabilitation		Replacement		Improved Bridges	Maintenance Cost	Total Cost
Period	Bridges	Cost	Bridges	Cost			
Backlog							
2021-2022	1	$224.85	120	$92,018.59	121	$2,144.63	$94,388.06
2023-2024	1	$240.57	120	$92,018.59	121	$2,144.63	$94,403.79
2025-2026	1	$580.94	120	$92,018.59	121	$2,144.63	$94,744.15
2027-2028	1	$465.84	120	$92,018.59	121	$2,144.63	$94,629 .06
2029-2030	1	$312.09	120	$92,018.59	121	$2,144.63	$94,475.31
2031-2040	1	$427.26	20	$15,019.61	21	$10,720.17	$26,167 .04
2021-2040	6	$2,251.55	620	$475,112.54	626	$21,443.32	$498,807.41

9. Summary and Conclusions

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

The combined needs estimates by biennium are presented in Table 29.

Table 29 Statewide Summary of Forecasted Needs for County and Township Roads and Bridges

Period	Unpaved	Paved	Bridges	Total
2021-2022	$ 611.08	$ 388.46	$94.39	$ 1,093.93
2023-2024	$ 602.19	$ 406.97	$94.40	$ 1,103.56
2025-2026	$ 616.21	$ 304.56	$94.74	$ 1,015.51
2027-2028	$ 615.89	$ 264.53	$94.63	$ 975.05
2029-2030	$ 602.76	$ 222.20	$94.48	$ 919.44

2031-2040	$ 3,008.07	$ 1,081.77	$26.17	$ 4,116.1
2021-2040	**$ 6,056.34**	**$ 2,668.49**	**$498.81**	**$ 9,223.64**

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: https://www.ugpti.org/downloads/road_needs/.

10. Appendix A: Cost and Practices Surveys

NDSU UPPER GREAT PLAINS TRANSPORTATION INSTITUTE

2019 COUNTY ROAD NEEDS STUDY SURVEY

Please return this survey in the enclosed envelope by **November 20, 2019**. Please direct any questions to Alan Dybing at 701.231.5988 or countytwp@ugpti.org.

County: ____

Contact: ____________________ ____________________ ____________________
Name Phone Email

Preparer: ______________________ Date Prepared: ______________________

Aggregate Description

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

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

Placement Practices

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

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

1

Operational Tasks

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

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

Gravel Road Costs

Please report costs for gravel for county roads in the table below. The table asks for unit costs for graveling, maintaining, and operating gravel roads. If you are quoting contractor prices, please circle "yes" in the right hand column.

Gravel/Scoria Cost			
Average Gravel/Scoria Cost (crushing & royalties at the pit)		❑ Per cu. yard ❑ Per Ton	Is this Contractor Price? (yes/no)
Trucking Cost from Gravel Origin		❑ Per loaded mile ❑ Per cu. yard ❑ Per Ton	Is this Contractor Price? (yes/no)
Average trucking distance for aggregate		❑ Miles one-way ❑ Miles roundtrip	
Truck Payload		❑ Cu. Yards ❑ Tons	
Placement Costs		Per Mile	Is this Contractor Price? (yes/no)
Blading Cost		Annual cost per mile	Is this Contractor Price? (yes/no)
Dust Suppressant Costs		Per mile	Is this Contractor Price? (yes/no)
Base Stabilization Cost		Per mile	Is this Contractor Price? (yes/no)

2

Gravel Road Practices

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

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

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

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

____

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

____

Gravel Road Condition

This section asks for information regarding gravel road conditions and is broken into two separate categories: Federal Aid, and Non-Federal Aid. Please provide a rough estimate of the percentage of unpaved roads by condition for these two categories.

Condition	% Federal Aid Roads (CMC)	% Non-Federal Aid Roads (non-CMC)
Very Good		
Good		
Fair		
Poor		
Total	**100%**	**100%**

Gravel Materials Specifications

Please attach a sample specification and sample gradation, or state materials specification number. If materials used on CMC routes differ from non-CMC routes, please provide sample specifications and gradation by system type, if available.

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

NDSU UPPER GREAT PLAINS TRANSPORTATION INSTITUTE

2019 TOWNSHIP ROAD NEEDS STUDY SURVEY

Please return this survey in the enclosed envelope by **November 20, 2019**. Please direct any questions to Alan Dybing at 701.231.5988 or countytwp@ugpti.org.

Township: ______________________ County: ______________________

Contact: ______________ ______________ ______________

Name Phone Email

Preparer: ______________________ Date Prepared: ______________

Gravel Costs

Please report costs for gravel for township roads in either of the tables below. If information on cost breakouts is available, please use Table 1. If breakouts are not known, enter the information in the Table 2.

1. Cost Breakouts (If known)		
Average Gravel/Scoria Cost (crushing & royalties)		❑Per cu. yard ❑ Per Ton
Trucking Cost from Gravel Origin		❑Per loaded mile ❑Per cu. yard
Placement Costs		Per mile
Blading Cost		Annual cost per mile
Dust Suppressant Costs (If applicable)		Per mile

2. Total Cost (if cost breakouts are not known)		
Total Cost	$	❑ Per cu. yard ❑ Per Ton ❑ Annual cost per mile

Average Gravel/Scoria Overlay Thickness ______________ ❑Cu. Yard/mile

❑Inches

❑Tons/mile

Road Maintenance Practices

Who performs road maintenance in your township?

Blading Frequency

- ❑ County Maintained
- ❑ Township Contracted
- ❑ Township Staff

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) ____________________

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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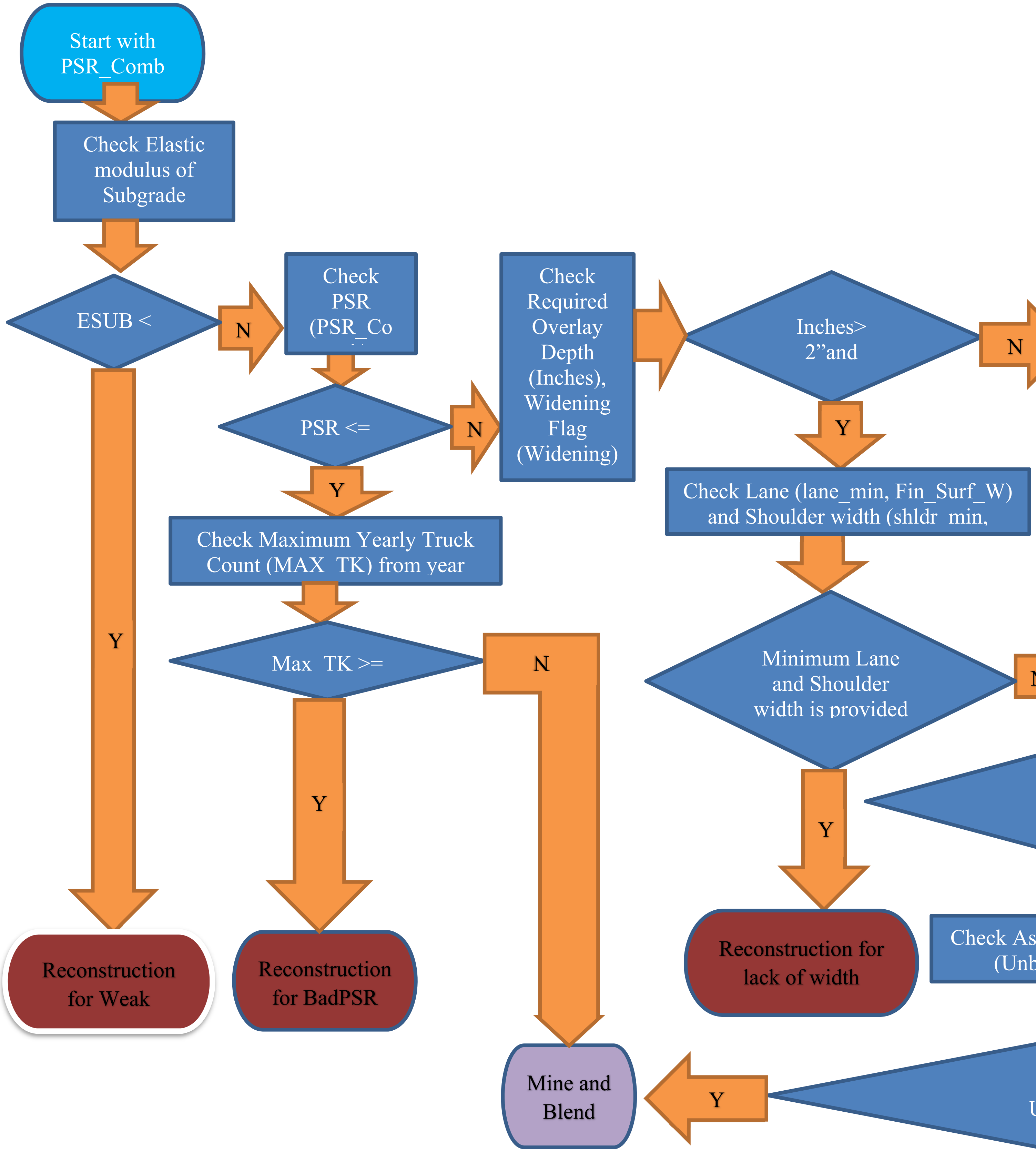
11. Appendix B: Flowchart for Road Improvement



12. Appendix C: Paved Road Conditions, by County - Surveyed in 2019

County	Condition	Miles	Percent
Adams	Fair	7.4411713	70%
	Poor	3.1264516	30%
Barnes	Good	53.846665	25%
	Fair	134.43801	62%
	Poor	26.925399	13%
Benson	Good	3.4992701	6%
	Fair	49.634557	80%
	Poor	8.7442196	14%
Billings	Good	9.3302288	59%
	Fair	4.7620625	30%
	Poor	1.7897909	11%
Bottineau	Good	118.14002	58%
	Fair	84.740726	42%
Bowman	Good	52.561459	36%
	Fair	76.456959	53%
	Poor	15.50879	11%
Burke	Good	30.258385	64%
	Fair	16.841423	36%
Burleigh	Good	120.06898	43%
	Fair	103.13722	37%
	Poor	55.76338	20%
Cass	Good	166.28988	52%
	Fair	152.8789	47%
	Poor	0.6452514	1%
Cavalier	Good	8.1693976	13%
	Fair	55.451451	86%
	Poor	0.4726955	1%
Dickey	Good	24.572786	32%
	Fair	52.175759	67%
	Poor	0.5760469	1%
Divide	Good	58.686299	80%
	Fair	14.533105	20%

County	Condition	Miles	Percent
Dunn	Good	9.6235451	17%
	Fair	46.024928	83%
Eddy	Good	7.3035268	12%
	Fair	34.302506	56%
	Poor	19.19357	32%
Emmons	Good	5.8892718	46%
	Fair	6.8863419	54%
Fort Berthold	Good	29.291583	64%
	Fair	3.0018944	6%
	Poor	13.782514	30%
Foster	Good	15.722729	18%
	Fair	47.307302	52%
	Poor	27.606081	30%
Golden Valley	Good	7.1530267	31%
	Fair	12.612193	55%
	Poor	3.3117283	14%
Grand Forks	Good	113.1161	42%
	Fair	133.35751	50%
	Poor	22.371842	8%
Griggs	Good	3.8646754	10%
	Fair	34.6938	90%
Hettinger	Fair	16.87831	100%
Kidder	Good	27.521868	56%
	Fair	18.710592	37%
	Poor	3.2745176	7%
LaMoure	Good	38.68946	27%
	Fair	106.55785	73%
Logan	Fair	6.6562333	100%
McHenry	Good	6.8312185	8%
	Fair	45.830341	50%
	Poor	38.426975	42%
McIntosh	Good	22.867558	27%
	Fair	46.646421	55%

County	Condition	Miles	Percent
	Poor	15.428967	18%
McKenzie	Good	120.83336	57%
	Fair	87.340841	41%
	Poor	5.3407983	3%
McLean	Good	28.925666	21%
	Fair	67.542357	50%
	Poor	39.138131	29%
Mercer	Good	15.363043	15%
	Fair	86.246918	85%
Morton	Good	22.807477	28%
	Fair	57.106021	69%
	Poor	2.6373604	3%
Mountrail	Good	114.20887	75%
	Fair	33.641771	22%
	Poor	4.3515352	3%
Nelson	Good	32.902745	40%
	Fair	13.225921	16%
	Poor	35.545345	44%
Oliver	Fair	10.57139	44%
	Poor	13.432543	56%
Pembina	Good	60.840346	35%
	Fair	110.72535	65%
Pierce	Good	6.9407126	63%
	Fair	4.0838361	37%
Ramsey	Good	42.107454	37%
	Fair	70.19588	63%
Ransom	Good	15.78572	28%
	Fair	40.358269	72%
Renville	Good	31.569409	41%
	Fair	44.743339	58%
	Poor	0.3441295	1%
Richland	Good	94.414004	39%
	Fair	137.48572	57%

County	Condition	Miles	Percent
	Poor	8.646211	4%
Rolette	Good	22.11636	49%
	Fair	23.177325	51%
Sargent	Good	26.239541	30%
	Fair	53.174532	61%
	Poor	7.9658893	9%
Sheridan	Good	20.317956	97%
	Fair	0.5672106	3%
Slope	Good	1.3440617	100%
Spirit Lake	Good	1.6905807	5%
	Fair	15.895846	45%
	Poor	17.926071	50%
Standing Rock	Fair	23.890557	75%
	Poor	7.8441643	25%
Stark	Good	97.545025	97%
	Fair	3.0461485	3%
Steele	Good	42.888832	59%
	Fair	19.953258	28%
	Poor	9.6209759	13%
Stutsman	Good	112.93745	48%
	Fair	94.035984	40%
	Poor	29.606603	13%
Traill	Good	41.266629	29%
	Fair	84.061071	58%
	Poor	18.577052	13%
Turtle Mountain	Fair	49.101787	69%
	Poor	22.054799	31%
Walsh	Good	49.374755	29%
	Fair	103.05859	60%
	Poor	20.474997	12%
Ward	Good	142.42592	46%
	Fair	142.13987	46%
	Poor	24.657366	8%

County	Condition	Miles	Percent
Wells	Good	18.2205	17%
	Fair	44.460253	43%
	Poor	41.167104	40%
Williams	Good	65.843917	23%
	Fair	113.07294	39%
	Poor	108.84203	38%

13. 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 2020 Dollars)

County	2021-2022	2023-2024	2025-2026	2027-2028	2029-2030	2031-2041	2021-2040	2021-2022
Adams	$ 5.33	$ 5.34	$ 5.34	$ 5.34	$ 5.35	$ 27.35	$ 54.06	$ 5.33
Barnes	$ 13.23	$ 13.23	$ 13.23	$ 13.23	$ 13.23	$ 66.22	$ 132.37	$ 13.23
Benson	$ 7.84	$ 7.84	$ 7.84	$ 7.84	$ 7.84	$ 39.22	$ 78.44	$ 7.84
Billings	$ 8.42	$ 7.70	$ 9.42	$ 8.67	$ 7.23	$ 35.72	$ 77.16	$ 8.42
Bottineau	$ 10.71	$ 10.64	$ 10.64	$ 10.70	$ 10.70	$ 53.49	$ 106.88	$ 10.71
Bowman	$ 7.57	$ 7.61	$ 7.64	$ 7.61	$ 7.54	$ 37.69	$ 75.64	$ 7.57
Burke	$ 12.88	$ 12.81	$ 12.81	$ 12.81	$ 12.83	$ 64.17	$ 128.31	$ 12.88
Burleigh	$ 15.89	$ 15.90	$ 15.95	$ 15.98	$ 15.98	$ 79.90	$ 159.60	$ 15.89
Cass	$ 28.00	$ 28.03	$ 28.16	$ 28.28	$ 28.39	$ 142.57	$ 283.43	$ 28.00
Cavalier	$ 11.67	$ 11.67	$ 11.72	$ 11.74	$ 11.74	$ 58.72	$ 117.26	$ 11.67
Dickey	$ 7.41	$ 7.41	$ 7.41	$ 7.41	$ 7.41	$ 37.03	$ 74.06	$ 7.41
Divide	$ 15.36	$ 15.17	$ 15.43	$ 15.54	$ 15.29	$ 76.45	$ 153.24	$ 15.36
Dunn	$ 29.70	$ 28.23	$ 30.45	$ 30.91	$ 27.86	$ 140.48	$ 287.63	$ 29.70
Eddy	$ 3.57	$ 3.58	$ 3.58	$ 3.58	$ 3.58	$ 17.90	$ 35.78	$ 3.57
Emmons	$ 7.75	$ 7.75	$ 7.75	$ 7.75	$ 7.75	$ 38.77	$ 77.55	$ 7.75
Foster	$ 4.86	$ 4.86	$ 4.86	$ 4.86	$ 4.86	$ 24.32	$ 48.64	$ 4.86
Golden Valley	$ 8.48	$ 8.89	$ 8.60	$ 8.55	$ 8.42	$ 42.08	$ 85.03	$ 8.48
Grand Forks	$ 24.15	$ 24.23	$ 24.23	$ 24.23	$ 24.25	$ 121.81	$ 242.91	$ 24.15
Grant	$ 12.53	$ 12.53	$ 12.53	$ 12.53	$ 12.53	$ 62.64	$ 125.27	$ 12.53
Griggs	$ 4.62	$ 4.62	$ 4.62	$ 4.62	$ 4.67	$ 23.40	$ 46.52	$ 4.62
Hettinger	$ 6.71	$ 6.71	$ 6.71	$ 6.71	$ 6.71	$ 33.57	$ 67.12	$ 6.71
Kidder	$ 7.06	$ 7.06	$ 7.06	$ 7.06	$ 7.06	$ 35.28	$ 70.55	$ 7.06
LaMoure	$ 10.50	$ 10.50	$ 10.50	$ 10.50	$ 10.50	$ 52.50	$ 105.00	$ 10.50
Logan	$ 4.92	$ 4.92	$ 4.92	$ 4.92	$ 4.92	$ 24.59	$ 49.18	$ 4.92
McHenry	$ 11.61	$ 11.64	$ 11.64	$ 11.64	$ 11.68	$ 58.42	$ 116.64	$ 11.61
McIntosh	$ 4.77	$ 4.77	$ 4.77	$ 4.77	$ 4.77	$ 23.87	$ 47.74	$ 4.77
McKenzie	$ 45.94	$ 42.65	$ 46.45	$ 46.24	$ 43.56	$ 208.93	$ 433.77	$ 45.94
McLean	$ 16.73	$ 16.73	$ 16.74	$ 16.75	$ 16.76	$ 84.01	$ 167.72	$ 16.73
Mercer	$ 8.98	$ 8.98	$ 8.98	$ 8.95	$ 8.95	$ 44.73	$ 89.54	$ 8.98
Morton	$ 10.65	$ 10.65	$ 10.65	$ 10.65	$ 10.65	$ 53.26	$ 106.51	$ 10.65
Mountrail	$ 21.83	$ 19.28	$ 23.10	$ 23.16	$ 19.53	$ 96.56	$ 203.45	$ 21.83
Nelson	$ 5.90	$ 5.90	$ 5.90	$ 5.92	$ 5.92	$ 29.58	$ 59.10	$ 5.90
Oliver	$ 3.31	$ 3.28	$ 3.28	$ 3.28	$ 3.28	$ 16.11	$ 32.54	$ 3.31

Table D.1: County and Township Unpaved Road Investment Needs by County and Period (Millions of 2020 Dollars)								
County	**2021-2022**	**2023-2024**	**2025-2026**	**2027-2028**	**2029-2030**	**2031-2041**	**2021-2040**	**2021-2022**
Pembina	$ 8.14	$ 8.17	$ 8.17	$ 8.17	$ 8.17	$ 40.94	$ 81.77	$ 8.14
Pierce	$ 9.74	$ 9.74	$ 9.74	$ 9.74	$ 9.74	$ 48.69	$ 97.37	$ 9.74
Ramsey	$ 6.31	$ 6.32	$ 6.32	$ 6.32	$ 6.32	$ 31.62	$ 63.20	$ 6.31
Ransom	$ 6.51	$ 6.54	$ 6.54	$ 6.54	$ 6.55	$ 32.75	$ 65.43	$ 6.51
Renville	$ 6.66	$ 6.66	$ 6.66	$ 6.66	$ 6.66	$ 33.31	$ 66.62	$ 6.66
Richland	$ 18.63	$ 18.63	$ 18.63	$ 18.64	$ 18.65	$ 93.35	$ 186.53	$ 18.63
Rolette	$ 5.14	$ 5.14	$ 5.14	$ 5.14	$ 5.14	$ 25.70	$ 51.40	$ 5.14
Sargent	$ 5.24	$ 5.24	$ 5.24	$ 5.24	$ 5.24	$ 26.22	$ 52.45	$ 5.24
Sheridan	$ 5.44	$ 5.44	$ 5.44	$ 5.44	$ 5.44	$ 27.18	$ 54.36	$ 5.44
Sioux	$ 6.10	$ 6.10	$ 6.10	$ 6.10	$ 6.10	$ 30.60	$ 61.08	$ 6.10
Slope	$ 5.97	$ 5.97	$ 5.97	$ 5.83	$ 5.78	$ 28.88	$ 58.38	$ 5.97
Stark	$ 17.04	$ 17.00	$ 17.17	$ 16.93	$ 16.79	$ 83.94	$ 168.86	$ 17.04
Steele	$ 7.93	$ 7.93	$ 7.95	$ 7.95	$ 7.95	$ 39.75	$ 79.45	$ 7.93
Stutsman	$ 13.69	$ 13.69	$ 13.70	$ 13.71	$ 13.73	$ 68.69	$ 137.21	$ 13.69
Towner	$ 7.52	$ 7.52	$ 7.52	$ 7.52	$ 7.52	$ 37.62	$ 75.23	$ 7.52
Traill	$ 8.35	$ 8.37	$ 8.48	$ 8.50	$ 8.52	$ 42.71	$ 84.93	$ 8.35
Walsh	$ 18.47	$ 18.47	$ 18.69	$ 18.71	$ 18.71	$ 93.82	$ 186.86	$ 18.47
Ward	$ 21.19	$ 21.36	$ 21.49	$ 21.59	$ 21.48	$ 107.49	$ 214.60	$ 21.19
Wells	$ 8.47	$ 8.47	$ 8.47	$ 8.47	$ 8.47	$ 42.33	$ 84.65	$ 8.47
Williams	$ 25.69	$ 24.32	$ 25.92	$ 25.98	$ 24.07	$ 121.18	$ 247.15	$ 25.69
Total	$ 611.08	$ 602.19	$ 616.21	$ 615.89	$ 602.76	$ 3,008.07	$ 6,056.34	$ 611.08

Table D.2: County and Township Paved Road Investment Needs by County and Period (Millions of 2020 Dollars)								
County	**Miles Resurfaced**	**Miles Widened**	**Miles Reconstructed**	**Miles Mine & Blend**	**Miles Break & Seat**	**Total Miles Improved**	**Total Cost (Million$)**	**Annual Cost per Mile**
Adams	10.5676	0.0	0.0	0.0	0.0000	10.6	$4.25	$20,097.71
Barnes	215.2101	0.0	0.0	0.0	0.0000	215.2	$88.17	$20,483.71
Benson	61.8780	0.0	0.0	0.0	0.0000	61.9	$25.20	$20,365.50
Billings	15.8821	0.0	0.0	0.0	0.0000	15.9	$6.23	$19,624.37
Bottineau	202.8807	0.0	0.0	0.0	0.0000	202.9	$88.70	$21,860.34
Bowman	144.5272	0.0	0.0	0.0	0.0000	144.5	$64.54	$22,328.83
Burke	47.0998	0.0	0.0	0.0	0.0000	47.1	$18.87	$20,027.77
Burleigh	259.8759	9.8	8.6	0.6	0.0000	279.0	$134.71	$24,143.55
Cass	279.7377	4.0	6.8	0.0	29.1894	319.8	$138.65	$21,676.17
Cavalier	63.6208	0.0	0.0	0.5	0.0000	64.1	$28.68	$22,375.80
Dickey	77.3246	0.0	0.0	0.0	0.0000	77.3	$32.17	$20,800.80
Divide	68.8818	0.0	4.3	0.0	0.0000	73.2	$38.19	$26,076.43
Dunn	55.6485	0.0	0.0	0.0	0.0000	55.6	$22.93	$20,601.60
Eddy	58.6405	0.0	0.0	2.2	0.0000	60.8	$24.50	$20,146.88
Emmons	12.7756	0.0	0.0	0.0	0.0000	12.8	$5.10	$19,976.42
Fort Berthold	32.2935	0.0	8.8	4.9	0.0000	46.1	$30.79	$33,410.19
Foster	86.6611	0.0	4.0	0.0	0.0000	90.6	$44.89	$24,765.06

Table D.2: County and Township Paved Road Investment Needs by County and Period (Millions of 2020 Dollars)								
County	**Miles Resurfaced**	**Miles Widened**	**Miles Reconstructed**	**Miles Mine & Blend**	**Miles Break & Seat**	**Total Miles Improved**	**Total Cost (Million$)**	**Annual Cost per Mile**
Golden Valley	23.0769	0.0	0.0	0.0	0.0000	23.1	$9.64	$20,891.68
Grand Forks	260.4531	0.0	3.9	4.5	0.0000	268.8	$111.45	$20,728.07
Griggs	38.5585	0.0	0.0	0.0	0.0000	38.6	$14.68	$19,040.39
Hettinger	16.8783	0.0	0.0	0.0	0.0000	16.9	$6.25	$18,522.97
Kidder	47.2651	0.0	0.0	2.2	0.0000	49.5	$20.43	$20,632.23
LaMoure	145.2473	0.0	0.0	0.0	0.0000	145.2	$58.13	$20,009.88
Logan	6.6562	0.0	0.0	0.0	0.0000	6.7	$2.47	$18,522.97
McHenry	91.0885	0.0	0.0	0.0	0.0000	91.1	$42.35	$23,248.17
McIntosh	84.9429	0.0	0.0	0.0	0.0000	84.9	$43.24	$25,451.60
McKenzie	198.6837	0.0	14.8	0.0	0.0000	213.5	$122.53	$28,692.87
McLean	123.1787	0.0	11.7	0.7	0.0000	135.6	$78.50	$28,945.25
Mercer	101.6100	0.0	0.0	0.0	0.0000	101.6	$43.50	$21,403.02
Morton	81.7419	0.8	0.0	0.0	0.0000	82.6	$34.84	$21,104.88
Mountrail	152.2022	0.0	0.0	0.0	0.0000	152.2	$67.54	$22,187.71
Nelson	81.6740	0.0	0.0	0.0	0.0000	81.7	$31.40	$19,221.46
Oliver	24.0039	0.0	0.0	0.0	0.0000	24.0	$8.89	$18,522.97
Pembina	171.5657	0.0	0.0	0.0	0.0000	171.6	$70.66	$20,591.29
Pierce	11.0245	0.0	0.0	0.0	0.0000	11.0	$4.08	$18,522.97

Table D.2: County and Township Paved Road Investment Needs by County and Period (Millions of 2020 Dollars)								
County	**Miles Resurfaced**	**Miles Widened**	**Miles Reconstructed**	**Miles Mine & Blend**	**Miles Break & Seat**	**Total Miles Improved**	**Total Cost (Million$)**	**Annual Cost per Mile**
Ramsey	112.3033	0.0	0.0	0.0	0.0000	112.3	$45.81	$20,396.40
Ransom	56.1440	0.0	0.0	0.0	0.0000	56.1	$25.01	$22,274.93
Renville	70.5780	0.0	6.1	0.0	0.0000	76.7	$40.26	$26,262.67
Richland	219.7502	12.5	8.3	0.0	0.0000	240.5	$118.32	$24,593.47
Rolette	45.2937	0.0	0.0	0.0	0.0000	45.3	$16.78	$18,522.97
Sargent	81.3561	0.0	6.0	0.0	0.0000	87.4	$42.28	$24,194.78
Sheridan	20.8852	0.0	0.0	0.0	0.0000	20.9	$8.28	$19,824.24
Slope	1.3441	0.0	0.0	0.0	0.0000	1.3	$0.50	$18,522.97
Spirit Lake	35.5125	0.0	0.0	0.0	0.0000	35.5	$13.81	$19,439.63
Standing Rock	31.7347	0.0	0.0	0.0	0.0000	31.7	$15.74	$24,793.78
Stark	91.0561	4.7	4.8	0.0	0.0000	100.6	$57.52	$28,590.07
Steele	72.4631	0.0	0.0	0.0	0.0000	72.5	$26.88	$18,546.58
Stutsman	232.6990	1.0	0.0	0.4	2.4769	236.6	$105.74	$22,348.61
Traill	129.2306	6.0	6.4	2.3	0.0000	143.9	$69.11	$24,010.72
Turtle Mountain	19.8412	0.0	0.0	0.0	51.3154	71.2	$40.38	$28,375.87
Walsh	166.9008	0.0	5.0	1.0	0.0000	172.9	$76.95	$22,250.99
Ward	284.4153	6.0	17.9	0.0	0.8869	309.2	$158.39	$25,611.45

Table D.2: County and Township Paved Road Investment Needs by County and Period (Millions of 2020 Dollars)								
County	**Miles Resurfaced**	**Miles Widened**	**Miles Reconstructed**	**Miles Mine & Blend**	**Miles Break & Seat**	**Total Miles Improved**	**Total Cost (Million$)**	**Annual Cost per Mile**
Wells	97.5431	0.0	6.0	0.3	0.0000	103.8	$53.81	$25,907.77
Williams	239.4286	0.0	39.2	3.0	6.1049	287.8	$185.78	$32,280.24

Table D.3: County and Township Paved Road Investment Needs by County and Period (Thousands of 2020 Dollars)							
County	**V2021_2022**	**V2023_2024**	**V2025_2026**	**V2027_2028**	**V2029_2030**	**V2031_2040**	**V2021_2040**
Adams	$1,105	$213	$213	$213	$213	$2,290	$4,248
Barnes	$14,476	$10,292	$7,910	$5,736	$8,767	$40,984	$88,166
Benson	$5,099	$2,406	$1,965	$1,249	$1,249	$13,236	$25,204
Billings	$1,097	$1,153	$321	$321	$321	$3,022	$6,234
Bottineau	$7,372	$27,406	$5,446	$8,148	$7,246	$33,084	$88,701
Bowman	$2,917	$3,628	$2,917	$2,917	$7,166	$44,999	$64,542
Burke	$950	$3,591	$2,138	$950	$950	$10,285	$18,866
Burleigh	$26,732	$28,968	$12,081	$7,418	$7,332	$52,174	$134,706
Cass	$14,810	$16,518	$18,453	$19,652	$10,866	$58,347	$138,647
Cavalier	$2,159	$5,273	$4,309	$2,189	$1,293	$13,459	$28,683
Dickey	$3,382	$8,906	$3,176	$3,525	$1,560	$11,618	$32,168
Divide	$1,478	$3,042	$2,601	$8,155	$7,052	$15,857	$38,186
Dunn	$1,123	$3,030	$2,188	$1,123	$1,123	$14,342	$22,929
Eddy	$8,426	$1,227	$2,716	$1,227	$4,075	$6,827	$24,498
Emmons	$258	$581	$354	$339	$1,940	$1,631	$5,104
Fort Berthold	$4,285	$13,407	$5,635	$2,347	$930	$4,184	$30,788
Foster	$18,560	$4,592	$5,917	$1,829	$1,829	$12,166	$44,892
Golden Valley	$760	$576	$466	$466	$466	$6,910	$9,642
Grand Forks	$15,175	$6,848	$14,628	$13,210	$6,300	$55,292	$111,453
Griggs	$778	$4,791	$1,731	$915	$778	$5,690	$14,683

Table D.3: County and Township Paved Road Investment Needs by County and Period (Thousands of 2020 Dollars)							
County	**V2021_2022**	**V2023_2024**	**V2025_2026**	**V2027_2028**	**V2029_2030**	**V2031_2040**	**V2021_2040**
Hettinger	$341	$341	$341	$341	$3,358	$1,533	$6,253
Kidder	$4,052	$2,444	$1,822	$1,918	$1,178	$9,014	$20,429
LaMoure	$5,191	$8,301	$11,605	$8,745	$4,904	$19,381	$58,128
Logan	$134	$1,324	$134	$134	$134	$604	$2,466
McHenry	$16,877	$5,213	$5,385	$1,838	$1,838	$11,202	$42,353
McIntosh	$15,332	$4,320	$5,879	$4,887	$2,616	$10,204	$43,239
McKenzie	$9,944	$9,235	$33,873	$20,939	$7,351	$41,184	$122,527
McLean	$21,732	$14,009	$19,503	$2,737	$4,354	$16,168	$78,503
Mercer	$3,594	$11,380	$2,639	$2,050	$5,407	$18,425	$43,495
Morton	$5,427	$6,184	$3,576	$2,033	$1,666	$15,957	$34,845
Mountrail	$5,420	$6,171	$3,661	$4,218	$6,724	$41,346	$67,540
Nelson	$6,361	$3,397	$3,203	$1,648	$1,648	$15,141	$31,398
Oliver	$1,074	$2,659	$484	$1,376	$1,119	$2,180	$8,892
Pembina	$6,219	$11,753	$9,274	$7,542	$7,005	$28,862	$70,655
Pierce	$222	$222	$222	$222	$222	$2,972	$4,084
Ramsey	$2,291	$4,766	$3,263	$5,768	$8,460	$21,264	$45,812
Ransom	$2,543	$2,573	$6,942	$2,710	$2,278	$7,967	$25,012
Renville	$1,677	$4,350	$4,157	$12,482	$6,983	$10,615	$40,264
Richland	$19,349	$19,034	$19,633	$9,971	$9,015	$41,315	$118,317
Rolette	$914	$914	$914	$914	$5,057	$8,066	$16,779
Sargent	$3,908	$3,323	$8,194	$3,666	$3,568	$19,624	$42,283

Table D.3: County and Township Paved Road Investment Needs by County and Period (Thousands of 2020 Dollars)							
County	**V2021_2022**	**V2023_2024**	**V2025_2026**	**V2027_2028**	**V2029_2030**	**V2031_2040**	**V2021_2040**
Sheridan	$421	$1,874	$1,495	$421	$421	$3,647	$8,281
Slope	$27	$27	$27	$27	$27	$362	$498
Spirit Lake	$3,596	$2,194	$2,110	$942	$1,439	$3,527	$13,807
Standing Rock	$8,355	$640	$640	$2,578	$640	$2,882	$15,736
Stark	$2,129	$2,916	$6,133	$16,729	$5,058	$24,554	$57,518
Steele	$3,216	$1,462	$2,724	$1,462	$5,909	$12,104	$26,879
Stutsman	$19,116	$21,484	$4,774	$6,411	$9,116	$44,844	$105,745
Traill	$13,270	$15,019	$5,662	$6,455	$5,452	$23,247	$69,105
Turtle Mountain	$7,613	$17,324	$5,577	$1,436	$1,971	$6,462	$40,383
Walsh	$5,500	$9,021	$8,583	$14,565	$7,011	$32,268	$76,948
Ward	$21,778	$22,964	$15,596	$8,196	$16,344	$73,515	$158,393
Wells	$26,512	$4,581	$2,988	$2,096	$2,096	$15,538	$53,809
Williams	$13,382	$39,102	$8,380	$25,143	$10,370	$89,402	$185,779

Table D.4: Estimated Improvement Needs for Unpaved Indian Reservation Roads by Reservation (Thousands of 2020 Dollars)							
County	**2021-2022**	**2023-2024**	**2025-2026**	**2027-2028**	**2029-2030**	**2031-2041**	**2021-2040**
Fort Berthold	$5,851.01	$5,765.92	$5,900.14	$5,897.01	$5,771.39	$29,566.81	$58,752.28
Spirit Lake	$191.74	$188.95	$193.35	$193.25	$189.13	$968.92	$1,925.34
Standing Rock	$5,534.32	$5,453.83	$5,580.79	$5,577.83	$5,459.00	$27,966.48	$55,572.26
Turtle Mountain	$644.55	$635.18	$649.96	$649.62	$635.78	$3,257.09	$6,472.17

Table D.5: Estimated Improvement Needs for Paved Indian Reservation Roads by Reservation (Thousands of 2020 Dollars)							
County	**2021-2022**	**2023-2024**	**2025-2026**	**2027-2028**	**2029-2030**	**2031-2040**	**2021-2040**
Fort Berthold	$4,285.08	$13,407.48	$5,634.74	$2,346.87	$929.81	$4,184.16	$30,788.15
Spirit Lake	$3,595.87	$2,193.53	$2,109.83	$942.14	$1,438.54	$3,527.08	$13,806.99
Standing Rock	$8,355.11	$640.41	$640.41	$2,578.31	$640.41	$2,881.83	$15,736.47
Turtle Mountain	$7,613.27	$17,324.05	$5,576.95	$1,435.94	$1,970.65	$6,461.73	$40,382.59

Table D.6 Estimated Bridge Improvement Needs by County (Thousands of 2020 Dollars)

County	Rehabilitation and Replacement		Preventive Maintenance Cost	Total Cost
	Bridges	Cost		
Adams	6	$5,260.59	$295.15	$5,555.74
Barnes	3	$1,350.00	$397.50	$1,747.50
Benson	0	$0.00	$64.45	$64.45
Billings	2	$1,203.73	$208.01	$1,411.74
Bottineau	47	$37,089.56	$554.71	$37,644.27
Bowman	1	$450.00	$161.31	$611.31
Burke	4	$1,800.00	$39.07	$1,839.07
Burleigh	5	$4,168.12	$414.40	$4,582.53
Cass	25	$19,249.75	$2,768.95	$22,018.70
Cavalier	10	$5,328.89	$99.09	$5,427.98
Dickey	0	$0.00	$415.74	$415.74
Divide	2	$900.00	$55.59	$955.59
Dunn	4	$2,694.79	$306.68	$3,001.47
Eddy	1	$978.89	$222.09	$1,200.98
Emmons	2	$2,263.22	$292.00	$2,555.21
Foster	2	$990.57	$93.59	$1,084.17
Golden Valley	3	$2,149.51	$109.86	$2,259.37
Grand Forks	52	$33,989.40	$1,620.64	$35,610.04
Grant	12	$10,257.23	$420.03	$10,677.26
Griggs	1	$1,636.77	$173.76	$1,810.54
Hettinger	26	$19,320.38	$394.01	$19,714.39
Kidder	0	$0.00	$0.00	$0.00
LaMoure	7	$9,328.89	$428.90	$9,757.79
Logan	2	$900.00	$67.10	$967.10
McHenry	36	$25,492.10	$488.71	$25,980.81
McIntosh	0	$0.00	$16.17	$16.17
McKenzie	12	$7,331.61	$480.73	$7,812.34
McLean	5	$2,779.01	$304.79	$3,083.80
Mercer	3	$1,650.00	$476.58	$2,126.58
Morton	60	$41,165.82	$1,050.55	$42,216.37
Mountrail	2	$900.00	$173.78	$1073.78
Nelson	2	$2,070.71	$242.85	$2,313.56

County	Rehabilitation and Replacement		Preventive Maintenance Cost	Total Cost
	Bridges	Cost		
Oliver	0	$0.00	$153.37	$153.37
Pembina	28	$21,855.15	$890.19	$22,745.34
Pierce	1	$450.00	$3.31	$453.31
Ramsey	10	$5,780.54	$154.63	$5,935.17
Ransom	5	$10,268.21	$468.27	$10,736.48
Renville	2	$2,244.79	$187.06	$2,431.84
Richland	36	$28,652.64	$1,422.76	$30,075.40
Rolette	1	$450.00	$37.01	$487.01
Sargent	5	$2,763.17	$32.31	$2,795.48
Sheridan	0	$0.00	$0.00	$0.00
Sioux	0	$0.00	$104.95	$104.95
Slope	1	$450.00	$158.22	$608.22
Stark	28	$18,826.41	$651.34	$19,477.75
Steele	18	$10,057.94	$468.81	$10,526.75
Stutsman	3	$2,770.50	$338.60	$3,109.10
Towner	9	$5,250.00	$62.46	$5,312.46
Traill	48	$59,415.09	$1,359.22	$60,774.31
Walsh	60	$42,279.08	$1,227.13	$43,506.21
Ward	14	$11,710.66	$417.72	$12,128.37
Wells	2	$877.26	$270.38	$1,147.64
Williams	18	$10,563.11	$198.79	$10,761.91
Statewide	626	$477,364.09	$21,443.32	$498,807.41

Table D.7: Statewide Summary of Forecasted Needs for County and Township Bridges ($000)

	Rehabilitation		Replacement		Improved Bridges	Maintenance Cost	Total Cost
Period	Bridges	Cost	Bridges	Cost			
Backlog							
2021-2022	1	$224.85	120	$92,018.59	121	$2,144.63	$94,388.06
2023-2024	1	$240.57	120	$92,018.59	121	$2,144.63	$94,403.79
2025-2026	1	$580.94	120	$92,018.59	121	$2,144.63	$94,744.15
2027-2028	1	$465.84	120	$92,018.59	121	$2,144.63	$94,629.06
2029-2030	1	$312.09	120	$92,018.59	121	$2,144.63	$94,475.31
2031-2040	1	$427.26	20	$15,019.61	21	$10,720.17	$26,167.04
2021-2040	6	$2,251.55	620	$475,112.54	626	$21,443.32	$498,807.41

Table D.8: Total Estimated Road and Bridge Investment Needs by County, 2021-2040 (Millions of 2020 Dollars)

County	Unpaved Road Needs	Paved Road Needs	Bridge Needs	Total Needs
Adams	$54.06	$ 4.25	$5.56	$63.87
Barnes	$132.37	$ 88.17	$1.75	$222.29
Benson	$78.44	$ 25.21	$0.06	$103.71
Billings	$77.16	$ 6.23	$1.41	$84.8
Bottineau	$106.88	$ 88.70	$37.64	$233.22
Bowman	$75.64	$ 64.54	$0.61	$140.79
Burke	$128.31	$ 18.87	$1.84	$149.02
Burleigh	$159.60	$ 134.70	$4.58	$298.88
Cass	$283.43	$ 138.65	$22.01	$444.09
Cavalier	$117.26	$ 28.68	$5.43	$151.37
Dickey	$74.06	$ 32.19	$0.42	$106.67
Divide	$153.24	$ 38.19	$0.96	$192.39

Table D.8: Total Estimated Road and Bridge Investment Needs by County, 2021-2040 (Millions of 2020 Dollars)				
County	**Unpaved Road Needs**	**Paved Road Needs**	**Bridge Needs**	**Total Needs**
Dunn	$287.63	$ 23.00	$3.00	$313.63
Eddy	$35.78	$ 24.50	$1.20	$61.48
Emmons	$77.55	$ 5.10	$2.56	$85.21
Foster	$48.64	$ 44.89	$1.08	$94.61
Golden Valley	$85.03	$ 9.64	$2.26	$96.93
Grand Forks	$242.91	$ 111.45	$35.61	$389.97
Grant	$125.27	$ 0.00	$10.67	$135.94
Griggs	$46.52	$ 14.68	$1.81	$63.01
Hettinger	$67.12	$ 6.25	$19.71	$93.08
Kidder	$70.55	$ 20.43	$0.00	$90.98
LaMoure	$105.00	$ 58.13	$9.76	$172.89
Logan	$49.18	$ 2.47	$0.97	$52.62
McHenry	$116.64	$ 42.23	$25.98	$184.85
McIntosh	$47.74	$ 43.19	$0.02	$90.95
McKenzie	$433.77	$ 122.53	$7.81	$564.11
McLean	$167.72	$ 78.50	$3.08	$249.30
Mercer	$89.54	$ 43.50	$2.13	$135.17
Morton	$106.51	$ 34.84	$42.22	$183.57
Mountrail	$203.45	$ 67.54	$ 1.07	$272.06
Nelson	$59.10	$31.40	$2.31	$92.81
Oliver	$32.54	$ 8.89	$ 0.15	$41.58
Pembina	$81.77	$ 70.66	$ 22.75	$175.18
Pierce	$97.37	$ 4.08	$ 0.45	$101.90
Ramsey	$63.20	$ 45.81	$ 5.94	$114.95
Ransom	$65.43	$ 25.01	$ 10.74	$101.18
Renville	$66.62	$ 40.26	$ 2.43	$109.31
Richland	$186.53	$ 118.32	$ 30.08	$334.93
Rolette	$51.40	$ 16.78	$ 0.49	$68.67
Sargent	$52.45	$ 42.28	$ 2.80	$97.53
Sheridan	$54.36	$ 8.28	$ 0.00	$62.64
Sioux	$61.08		$ 0.10	$61.18
Slope	$58.38	$ 0.50	$ 0.61	$59.49

Table D.8: Total Estimated Road and Bridge Investment Needs by County, 2021-2040 (Millions of 2020 Dollars)				
County	**Unpaved Road Needs**	**Paved Road Needs**	**Bridge Needs**	**Total Needs**
Stark	$168.86	$ 57.52	$ 19.48	$245.86
Steele	$79.45	$ 26.88	$ 10.53	$116.86
Stutsman	$137.21	$ 105.74	$ 3.11	$246.06
Towner	$75.23		$ 5.31	$80.54
Traill	$84.93	$ 69.11	$ 60.77	$214.81
Walsh	$186.86	$ 76.95	$ 43.51	$307.32
Ward	$214.60	$ 158.39	$ 12.13	$385.12
Wells	$84.65	$ 53.81	$ 1.15	$139.61
Williams	$247.15	$ 185.78	$ 10.76	$443.69
Total	$6,056.34	$ 2,567.70	498.81	$9202.58

14. Appendix E: Bridge Component Deterioration Models

Substructure Model

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

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

Superstructure Model

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

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

Deck Model

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

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

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

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

Entries are:

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

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 – Structural Condition; or
   - Item 71 – Waterway Adequacy[5]

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

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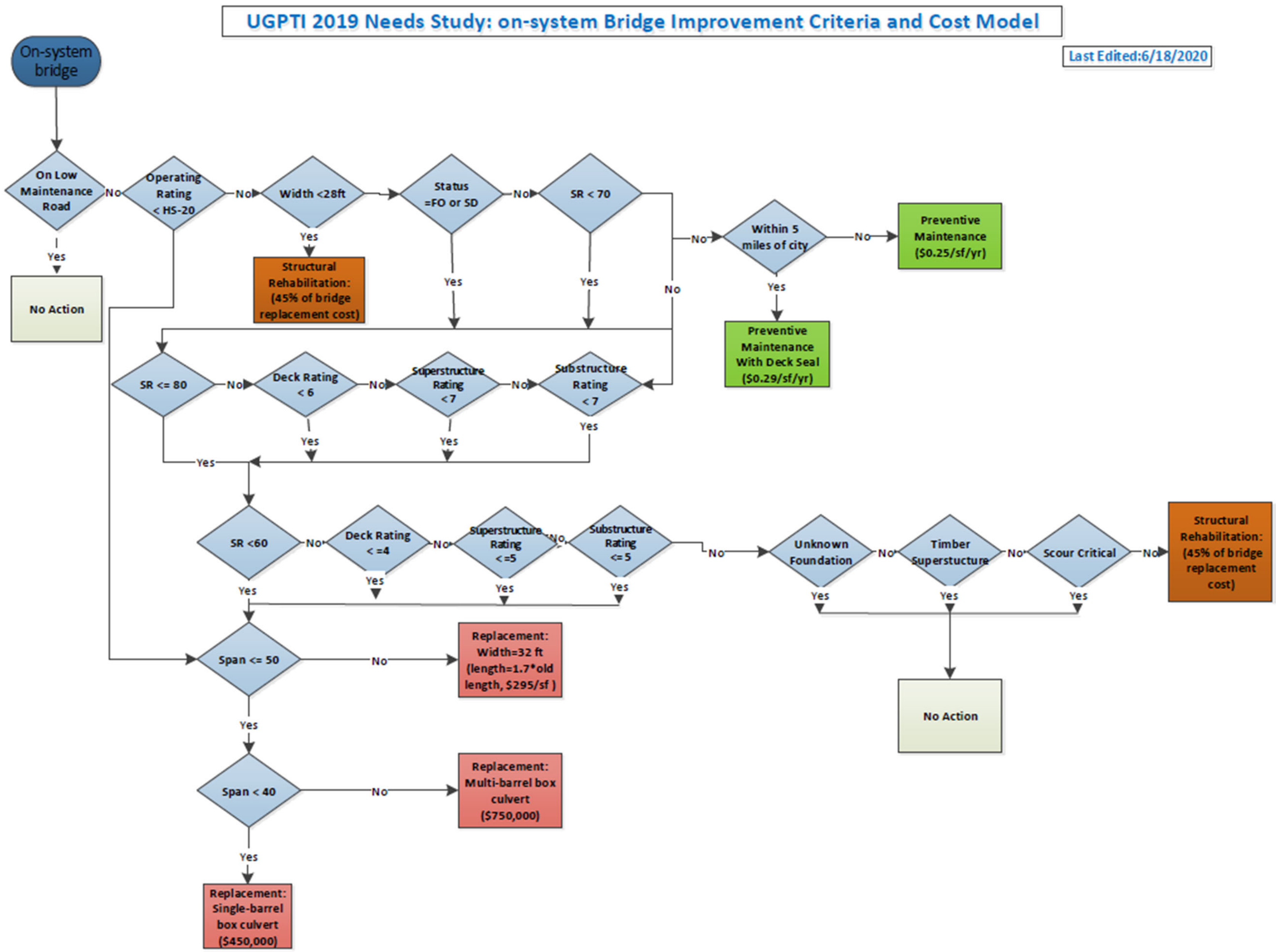
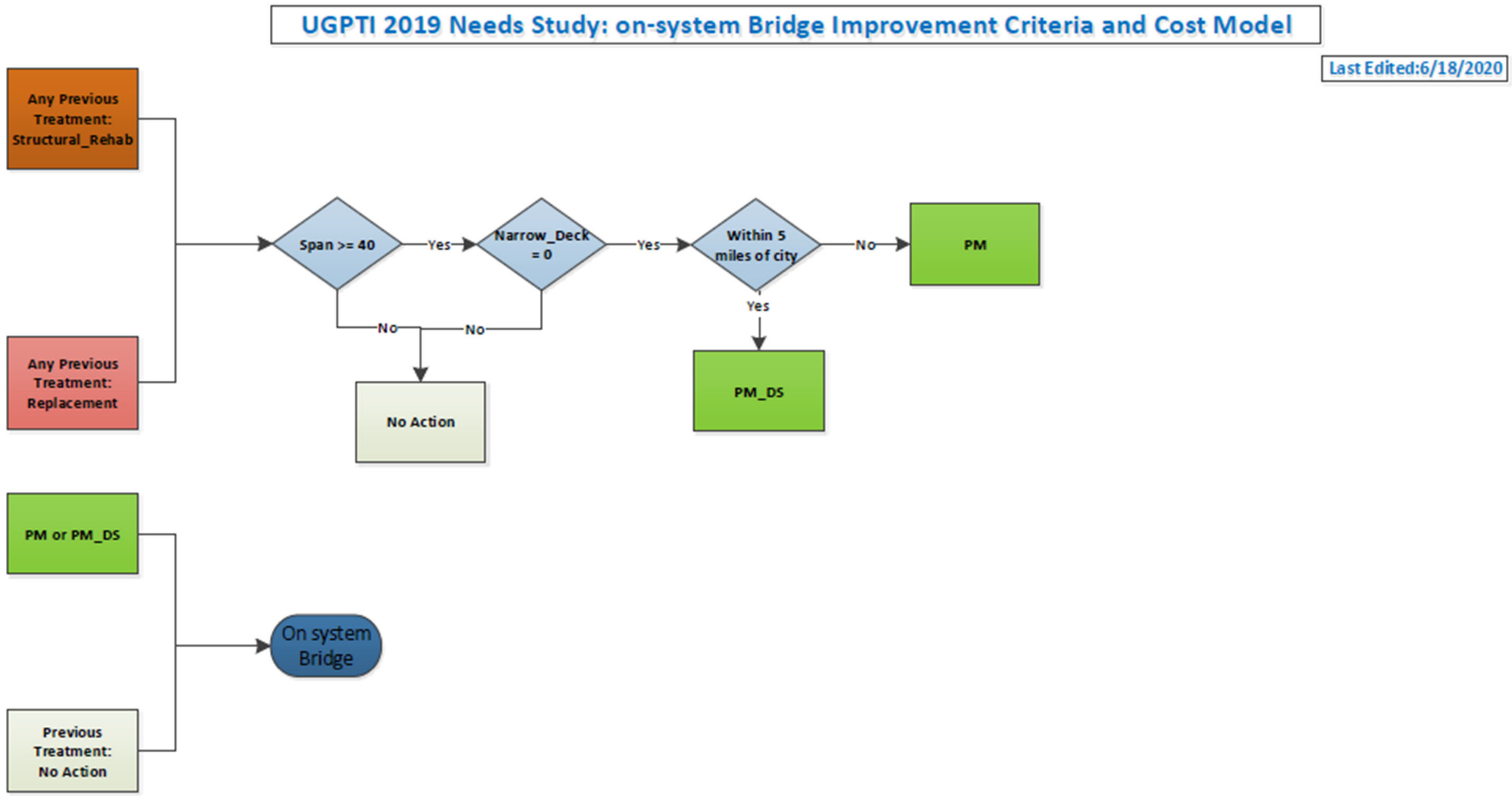
[1] Culvert and Retaining Walls (Item 62) applies only if the last two digits of Design Main (Item 42) are coded Frame or Culvert

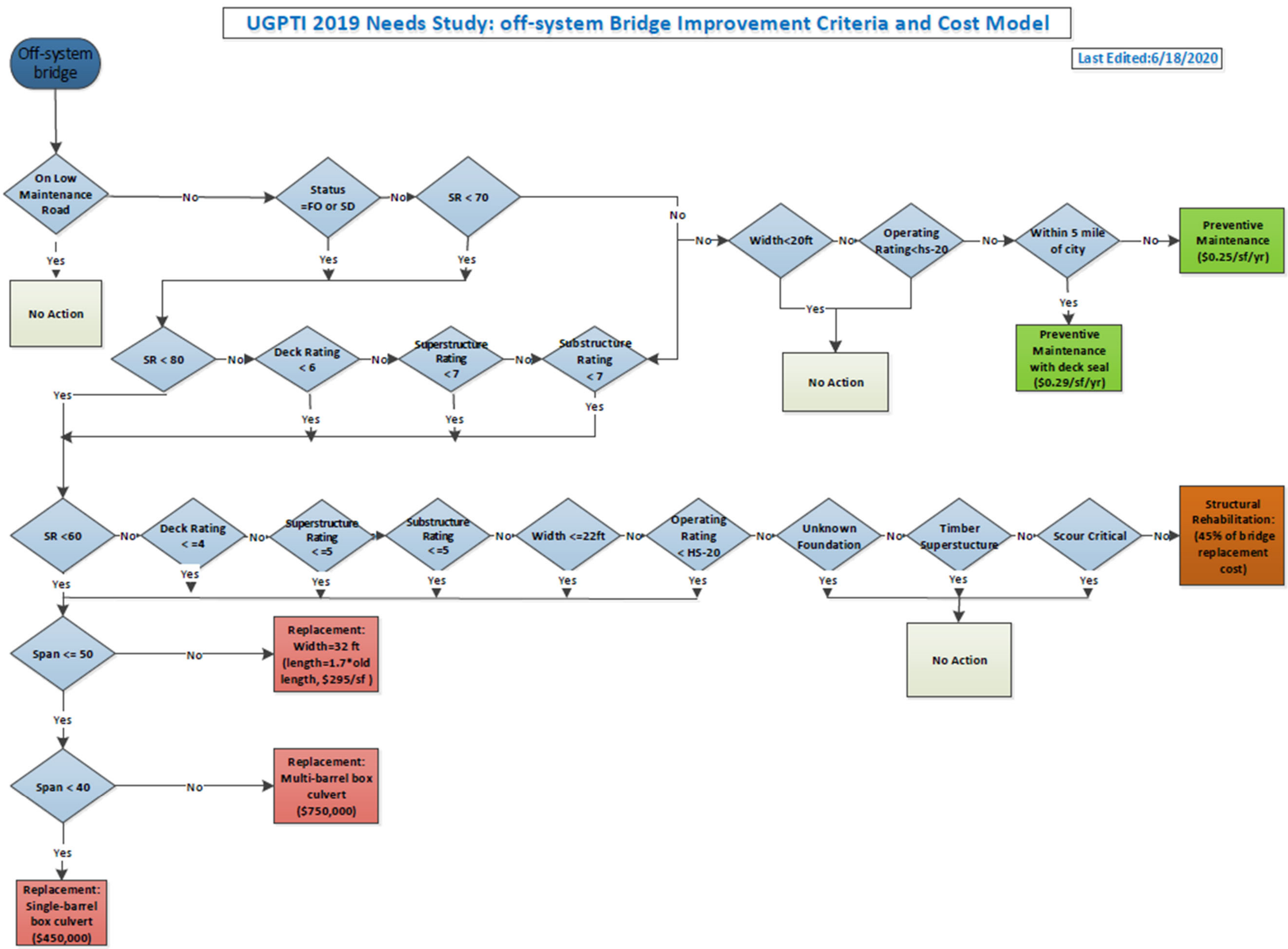
[2] Waterway Adequacy (Item 71) applies only if the last digit of Design Main (Item 42) is coded other (0), Waterway (5), Highway-Waterway (6), Railroad-Waterway (7), Hwy-Waterway-RR (8) or Relief for Waterway (9)

[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)

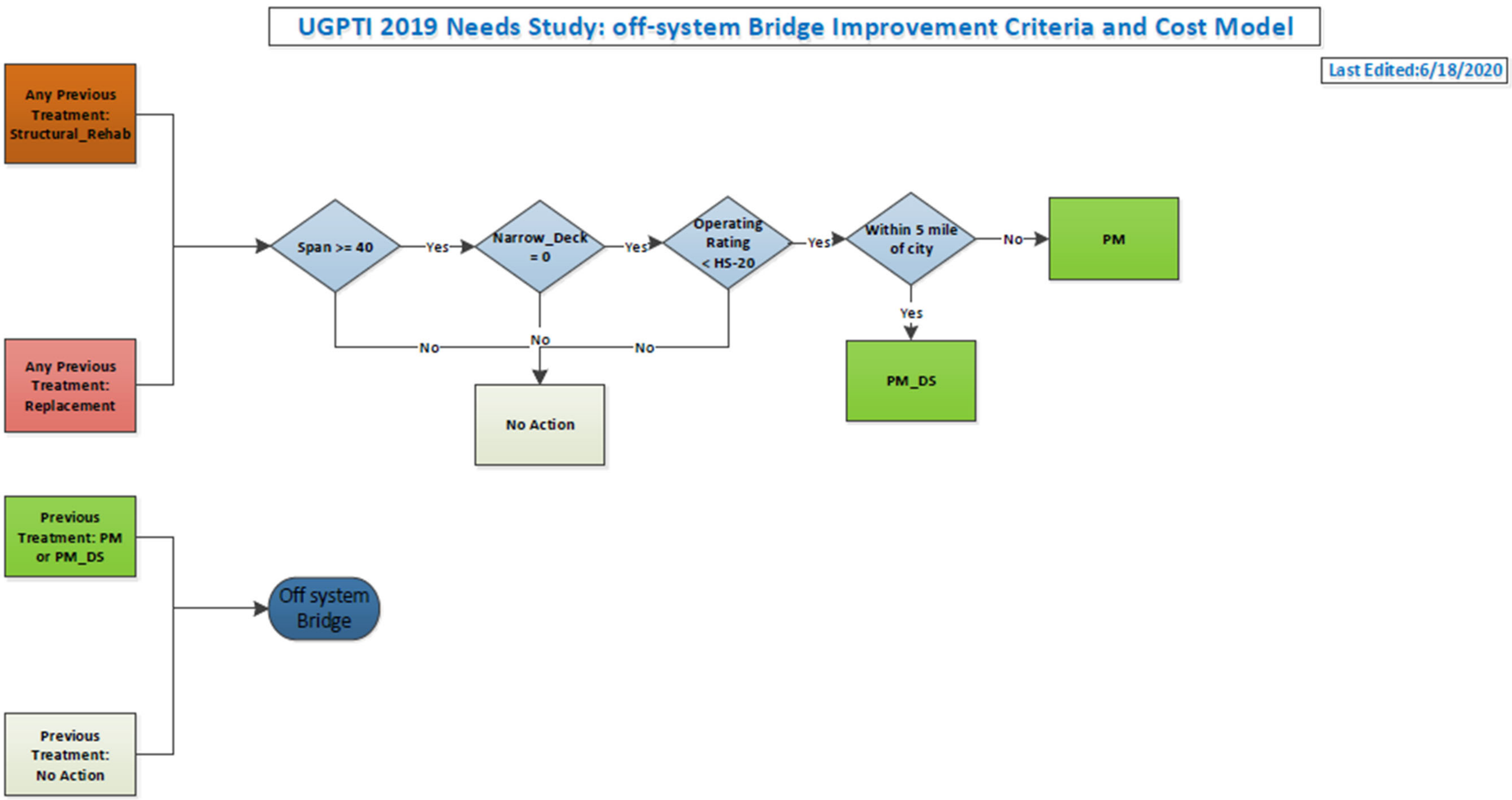
16. Appendix G: Bridge Improvement Decision Model Flowchart


UGPTI 2019 Needs Study: on-system Bridge Improvement Criteria and Cost Model
Last Edited:6/18/2020
On-system bridge
On Low Maintenance Road
Yes
No
No Action
Operating Rating < HS-20
Width <28ft
Yes
Structural Rehabilitation: (45% of bridge replacement cost)
Status =FO or SD
SR < 70
Within 5 miles of city
Preventive Maintenance ($0.25/sf/yr)
Preventive Maintenance With Deck Seal ($0.29/sf/yr)
SR <= 80
Deck Rating < 6
Superstructure Rating < 7
Substructure Rating < 7
SR <60
Deck Rating < =4
Superstructure Rating < =5
Substructure Rating <= 5
Unknown Foundation
Timber Superstucture
Scour Critical
Structural Rehabilitation: (45% of bridge replacement cost)
No Action
Span <= 50
Replacement: Width=32 ft (length=1.7*old length, $295/sf)
Span < 40
Replacement: Multi-barrel box culvert ($750,000)
Replacement: Single-barrel box culvert ($450,000)


UGPTI 2019 Needs Study: on-system Bridge Improvement Criteria and Cost Model
Last Edited:6/18/2020
Any Previous Treatment: Structural_Rehab
Any Previous Treatment: Replacement
Span >= 40
Yes
Narrow_Deck = 0
Yes
Within 5 miles of city
No
PM
Yes
PM_DS
No
No
No Action
PM or PM_DS
Previous Treatment: No Action
On system Bridge



UGPTI 2019 Needs Study: off-system Bridge Improvement Criteria and Cost Model
Last Edited:6/18/2020
Off-system bridge
On Low Maintenance Road
No
Yes
No Action
Status =FO or SD
SR < 70
Width<20ft
Operating Rating<hs-20
Within 5 mile of city
Preventive Maintenance ($0.25/sf/yr)
Preventive Maintenance with deck seal ($0.29/sf/yr)
No Action
SR < 80
Deck Rating < 6
Superstructure Rating <7
Substructure Rating < 7
SR <60
Deck Rating < =4
Superstructure Rating < =5
Substructure Rating < =5
Width <=22ft
Operating Rating < HS-20
Unknown Foundation
Timber Superstucture
Scour Critical
Structural Rehabilitation: (45% of bridge replacement cost)
No Action
Span <= 50
Replacement: Width=32 ft (length=1.7*old length, $295/sf)
Span < 40
Replacement: Multi-barrel box culvert ($750,000)
Replacement: Single-barrel box culvert ($450,000)


UGPTI 2019 Needs Study: off-system Bridge Improvement Criteria and Cost Model
Last Edited:6/18/2020
Any Previous Treatment: Structural_Rehab
Any Previous Treatment: Replacement
Span >= 40
Yes
Narrow_Deck = 0
Yes
Operating Rating < HS-20
Yes
Within 5 mile of city
No
PM
Yes
PM_DS
No
No
No
No Action
Previous Treatment: PM or PM_DS
Previous Treatment: No Action
Off system Bridge

17. Appendix H: Pavement Structural Data

17.1. Introduction

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

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

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

17.2. Methodology

17.2.1. Sampling Method

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

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

17.2.2. 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 of the selected test segments. Testing involved a vehicle-based GPR system traveling at highway speed. Test segments were located using GPS coordinates and scanned at continuous one-foot intervals.

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

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

17.2.3. Falling Weight Deflectometer (FWD)

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

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

Dynatest Consulting, Inc. (Dynatest) was contracted to conduct FWD testing and analysis of selected segments. Testing for the previous study was conducted in August and September 2013 and additional testing was completed in October 2015. Two different load levels (9,000 and 12,000 lbs.) were applied, with two replicates for each load. Tests were spaced at 0.25-mile intervals, resulting in over 35,000 deflection basins over the two separate testing sessions. Full test specifications are shown in Table H.1.

Table H.1. Falling Weight Deflectometer Test Specifications

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

Air and pavement surface temperature data were measured at each drop to allow normalization of back-calculated 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 back-calculate elastic moduli for each layer. The back-calculation process involved a cooperative, iterative effort by GPR and FWD consultants. Initially, the GPR layer thicknesses at FWD test locations were used as inputs for back calculation 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 back calculation, 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 back calculated layer moduli.

Infrasense and Dynatest used an iterative FWD/GPR calibration process which eliminated the need for pavement coring in GPR calibration. Initial back calculated 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 back calculation, or both. The result of this process was a database in which more than 89 percent of back calculated moduli fell within reasonable range.

17.3. Results

The inter-system quality control process described previously resulted in a database in which more than 89% of back calculated layer moduli fell within defined reasonable ranges as described in Table H.2. The remaining unreasonable deflection basins were removed from the results database.

Table H.2. Reasonable Layer Moduli Ranges

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

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

Tables H.3, H.4, H.5, and H.6 describe countywide, regional, and statewide pavement layer and moduli results. County averages are displayed for the 51 counties and all tribal areas with a tested roadway. A more detailed summary of nondestructive test results is available in Appendix B.

Table H.3. Nondestructive Test Results, Aggregated by Jurisdiction

County	Asphalt Concrete Thickness (in)	Granular Base Thickness (in)	Asphalt Concrete Modulus at 77°F (ksi)	Unbound Base Modulus (ksi)	Subgrade Modulus (ksi)
Adams	3.6	5.4	91.0	64.0	4.0
Barnes	7.2	4.5	315.2	34.5	7.4
Benson	5.5	4.0	223.4	67.1	8.4
Billings	10.4	8.7	411.0	90.0	8.0
Bottineau	7.1	3.5	270.0	44.3	8.3
Bowman	2.9	6.2	148.6	63.4	8.5
Burke	5.6	7.4	298.5	61.5	13.2
Burleigh	7.3	4.6	339.5	38.8	9.1
Cass	8.6	4.5	360.8	49.4	9.0
Cavalier	5.5	4.8	213.9	29.7	7.8
Dickey	5.9	4.8	272.3	47.6	6.2
Divide	4.9	6.5	338.0	63.5	8.7

County	Asphalt Concrete Thickness (in)	Granular Base Thickness (in)	Asphalt Concrete Modulus at 77°F (ksi)	Unbound Base Modulus (ksi)	Subgrade Modulus (ksi)
Dunn	5.9	12.7	306.1	76.7	11.7
Eddy	6.5	4.7	230.1	50.0	12.0
Emmons	4.2	3.8	436.6	45.5	12.0
Fort Berthold	5.5	1.9	170.7	32.6	8.6
Foster	5.0	3.3	122.9	42.7	7.0
Golden Valley	7.1	5.1	103.0	27.0	7.0
Grand Forks	7.6	4.5	353.3	40.2	7.6
Griggs	7.1	3.5	285.9	76.3	7.6
Hettinger	7.9	0.7	411.0	35.0	8.0
Kidder	6.8	3.6	312.0	91.2	10.0
LaMoure	5.7	2.8	528.2	32.7	8.7
Logan	9.4	0.0	N/A	N/A	N/A
McHenry	6.6	3.1	249.7	33.5	9.0
McIntosh	4.0	1.2	665.0	39.0	14.0
McKenzie	6.1	10.7	335.5	48.7	11.3
McLean	6.1	3.4	265.5	40.0	6.0
Mercer	6.7	4.4	185.4	24.3	7.0
Morton	8.0	7.0	578.0	62.1	10.7
Mountrail	6.5	12.3	329.9	43.1	12.3
Nelson	6.7	5.6	287.6	37.0	9.4
Oliver	5.7	8.0	316.1	32.5	8.0
Pembina	6.7	5.7	211.6	31.8	7.9
Pierce	7.6	4.7	244.4	40.5	9.5
Ramsey	5.9	5.2	265.6	67.8	7.9
Ransom	5.9	5.0	320.2	45.8	9.2
Renville	7.2	3.2	236.3	41.0	7.9
Richland	5.7	4.9	221.0	29.6	7.2
Rolette	8.7	1.9	293.8	49.4	8.3
Sargent	6.7	3.6	333.5	84.8	7.9
Sheridan	6.5	2.7	180.0	40.0	7.0
Spirit Lake	7.1	5.3	197.2	30.2	8.2
Standing Rock	4.0	3.2	235.0	55.0	7.0
Stark	4.2	6.3	263.3	29.4	8.9
Steele	7.0	5.0	280.6	38.3	8.3
Stutsman	5.7	5.8	190.4	37.0	8.3
Traill	7.1	4.7	203.1	38.1	6.8

County	Asphalt Concrete Thickness (in)	Granular Base Thickness (in)	Asphalt Concrete Modulus at 77°F (ksi)	Unbound Base Modulus (ksi)	Subgrade Modulus (ksi)
Turtle Mountain	8.8	0.0	N/A	N/A	N/A
Walsh	5.8	6.2	199.5	30.0	7.2
Ward	6.6	4.8	339.1	42.5	7.3
Wells	5.4	4.0	434.2	39.6	10.0
Williams	6.5	5.0	325.7	71.3	9.2

Table H.4. Nondestructive Test Results by Region

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

Table H.5. Typical Structure of County and Local Roads in North Dakota

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

Table H.6. Typical Layer Strengths of County and Local Roads in North Dakota

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

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

The results suggest a general trend in North Dakota's county and township roads of a thick combined asphalt layer, possibly the result of multiple thin-lift overlays throughout a long service life, with a relatively thin unbound base layer. The absence of a 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.

18. Appendix I: List of Abbreviations

ATR- Annual Traffic Recorders
AADT- Average Annual Daily Traffic
BBL- Barrel of Oil
BIA- Bureau of Indian Affairs
CDL- Crop Data Layer
CMC- County Major Collector
CRP- Conservation Reserve Program
DOD- Department of Defense
DOTSC- Department of Transportation Support Center
ESAL- Equivalent Single Axle Loads
FHWA- Federal Highway Administration
FO- Functionally Obsolete
FSM- Four Step Model
FWD- Falling Weight Deflectometer
GIS- Geographic Information System
GPR- Ground Penetrating Radar
GRIT- Geographic Roadway Inventory Tool
HB- House Bill
IRI- International Roughness Index
KIPS- Kilopounds
NASS- National Agricultural Statistics Service
NBI- National Bridge Inventory
NDDOT- North Dakota Department of Transportation
NDPSC- North Dakota Public Service Commission
NDT- Non Destructive Testing
PAVVET- Performance Analysis Via Vehicle Electronic Telemetry
PSR- Present Serviceability Index
R-Sq- Coefficient of Determination
RCBC- Reinforced Concrete Box Culverts
RIC- Roadway Image Capture
RIF- Road Impact Factor
RMS- Root Mean Square
SD- Standard Deviation/ Structurally Deficient
SN- Structural Number
SR- Sufficiency Rating
TAZ- Traffic Analysis Zones
TDM- Travel Demand Model
TWP- Township
UGPTI- Upper Great Plains Transportation Institute
USDA- United States Department of Agriculture

19. Appendix J: Reference

Forslöf, Lars (2012), "Roadroid – Smartphone Road Quality Monitoring", 19th ITS World Congress, Vienna, Austria.
Minnesota Department of Transportation. "An Overview of Mn/DOT's Pavement Condition Rating Procedures and Indices", Technical Report, 2003.

20. Comments Received and Action Taken

Through-out the study, enhanced outreach efforts were made in order to improve necessary study data and to keep stakeholders informed. UGPTI regularly sent status reports to legislators via and UGPTI Advisory Council and to local governments via UGPTI Local Technical Assistance Staff (LTAP).

Regarding gravel data, UGPTI staff worked with the Association of Counties to identify a panel of road managers from various counties to give advice toward an improved survey instrument. After developing the new survey instrument, a webinar was hosted by UGPTI LTAP to train county representatives in using the instrument. The webinar was recorded for later review.

The gravel survey instrument was sent to each county and information letters were also sent to the county auditor as well as the county commissioners. By the spring of 2020, all 53 counties had responded to this survey.

A similar survey was released to the association of townships at regional meetings. By the spring of 2020 approximate 650 townships had responded – nearly 50% of the organized townships.

The draft study was released for public comment on July 21, 2020 via a statewide webinar. An announcement was sent out via the North Dakota Association of Counties to inform stakeholders of the draft study availability. The North Dakota Legislature was alerted through an email announcement from the UGPTI Advisory Council chair. The study document was posted on the UGPTI website and an email link was provided for accepting comments. The comment period ended September October 12.

During the comment period, UGPTI received several comments via the email link. The summation of the comments and responses are shown on the following pages.

Various questions and comments were raised at the July 21, 2020 'Sharing the Vision for North Dakota's Transportation System' virtual meeting. Additional email questions were raised during the comment period. The comments and responses are shown in the following table:

Regional Meetings - UGPTI County Roads Needs study comments & feedback

Location	Comment
7-21-20 via email	This Table D.8 looks like there is a formula problem after Mountrail County – the totals don't reflect the individual components. **UGPTI Response**: The table does have an error and was corrected. The bridge numbers were posted incorrectly about 2/3 way through the list of the 53 counties.
7-28-20 via email	One of these numbers on page vi of the summary must be incorrect???? As shown in Table H, the combined estimate of infrastructure needs for all county and township roads is $8.8 billion over the next 20 years. Forty percent of this estimate relates to projected needs in the oil and gas producing counties of western North Dakota. Unpaved road funding needs comprise approximately 67% of the total. If averaged over the next 20 years, the annualized infrastructure need is equivalent to $440 million per year. The values shown in Tables H and I do not include the infrastructure needs of Forest Service roads or city streets within municipal areas. The infrastructure needs of Indian Reservation roads are presented separately in the report and detailed results are presented for county and township roads. **UGPTI Response**: This language was a carry-over from the 2016 report. The value narrative was indeed incorrect and the narrative was updated as follows: As shown in Tables H and I, the combined estimate of infrastructure needs for all county and township roads is $9.3 billion over the next 20 years. Unpaved road funding needs comprise approximately 66% of the total. If averaged over the next 20 years, the annualized infrastructure need is equivalent to $466 million per year. The values shown in Tables H and I do not include the infrastructure needs of Forest Service roads or city streets within municipal areas. The infrastructure needs of Indian Reservation roads are presented separately in the report and detailed results are presented for county and township roads.
7-29-20 via email	As a resident of Stark County and a former resident of Dunn County, I am somewhat familiar with the paved roads in both counties. Appendix C shows 97% of approximately 100 miles of paved roads in good condition, and 3% in fair condition in Stark County, and 17% of approximately 56 miles of paved roads in good condition, and 83% in fair condition in Dunn County. It appears something is out of kilter here. Please enlighten me. Richard Benz PE/PLS

	UGPTI Response: All paved county roads in these two counties were driven with a vehicle equipped to measure the roughness of the road which was then converted into a PSR score. We also collected video and did a quick condition survey of the road. These values were combined into a final 0 to 5 score and then compared against the age of the surface which the Counties provided through GRIT. In reviewing this data again for these counties, it appears to be in line as there are no sections of paved road older than 12 years that we could find. Pavements less than 12 years almost always fall into the good or fair range unless there was a significant increase in truck traffic. Most of the roads in Dunn County were very close to the line between good and fair which explains the higher % in the fair range. Thanks for taking the time to review the report and please let us know if you have any other questions.
9-21-20 via email	-Ramsey County does spec a class 13 gravel every time we bid a gravel project. The map has us the wrong color on the bidding process. Kevin Fieldsend **UGPTI Response:** We updated the map shown in figure 19.
9-21-20 via email	Please update Section 6.1.6. Roads Condition, Figures 23 & 24 with the attached information. Thank you and let me know if you have any questions. *Cindy Glover* McKenzie County Engineer's Office Permitting Specialist **UGPTI Response:** The maps that show conditions for unpaved CMCs and non-CMCs were updated to reflect Mckenzie County's gravel road condition response received 9-21-20.
10-12-20 via email	-Dear NDSU Upper Great Plains Transportation Institute and NDLTAP team, I am contacting you on behalf of Mountrail County Commissioners with our comments, questions and concerns regarding the draft Infrastructure Needs report. 1. **Page 37, table 12:** Can you please clarify from what source are you getting/verifying your miles from for paved and gravel roads. When referring to gravel miles are we strictly talking about "county" gravel roads or does your mileage include miles in Organized & Unorganized Townships? Is there any place within the report that is actually listing gravel miles?

2. **Page 58, table 21:** Are you referring to total miles on Reservation or total miles maintained on Reservation? If miles maintained, who is doing the maintenance.

3. **Page 94, BRIDGES:** There is only one bridge listed under Mountrail County. Our County definitely has more bridges that will need repairs or reconstruction in a near future. Why do we only have 1 bridge listed?

4. **Page 84:** Can you please be more specific on mileage. If we have mileage we can compare.

5. **Page 91**: can you please explain table D.3

6. **Page 87:** Please change 152.2 miles under Mountrail County to 165.82 miles. Why do we have 0 miles listed under reconstruction and 0 miles for mind and blend? Please see the attached pdf document ("Roadway Improvements Costs Worksheet") with project description and costs we have incurred on our (currently) PAVED roads since the 2011 legislative funding.

We appreciate your time and consideration in evaluating our comments and concerns. Please don't hesitate to contact me if you have any questions.

Thank you.

Jana Hennessy

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UGPTI responded to each item as follows:

Item 1. **Page 37, table 12**. **UGPTI response:** The source of the mileages is the NDDOT GIS Hub. Gravel roads of all jurisdictions are included in the study. Specific segment ownership information is obtained from two sources. First, the ND GIS Hub includes the CMC network. The county non-CMC and township road jurisdictions were obtained from a survey of county engineers and superintendents in conjunction with NDLTAP. The mileages used in Mountrail County are found below:

COUNTY	JURIS	SURFACE_TY	DISTANCE

Mountrail	CMC_RD	Gravel	201.34
Mountrail	COUNTY	Graded & Drained	6.22
Mountrail	COUNTY	Gravel	39.43
Mountrail	COUNTY	Trail	5.02
Mountrail	COUNTY	Unimproved	0.47
Mountrail	PRIVATE	Gravel	1.14
Mountrail	TRIBAL	Graded & Drained	0.39
Mountrail	TRIBAL	Gravel	15.46
Mountrail	TRIBAL	Trail	13.41
Mountrail	TRIBAL	Unimproved	1.04
Mountrail	TWP_RD	Graded & Drained	214.44
Mountrail	TWP_RD	Gravel	1,229.55
Mountrail	TWP_RD	Trail	456.50
Mountrail	TWP_RD	Unimproved	97.64

Item 2: **Page 58, table 21: UGPTI response:** Item 2: Page 58 Table 21 refers to the Total projected improvement cost for Indian Reservation paved roads across the State. These are the paved tribal roads entered into GRIT with Reservation ownership. Maintenance costs of these paved roads is listed in the table and is assumed to be by the tribal jurisdiction.

Item 3: **Page 94, BRIDGES: UGPTI response:** We reviewed the bridge listing for Mountrail county. We had initially identified one bridge need replacement and all other bridges longer than 20 feet in length were assigned annual preventive maintenance costs of $.25/year/SF. In review, we found 2 additional bridges that were scored as poor. Both of these bridges were missing a sufficiency rating and a deck score as the decks were covered with gravel and we assumed the bridge inspectors did not rate the decks since the surface of the deck was not visible. We used a component score of 4 or less for a replacement threshold and one of the 2 additional bridges met this threshold. The other bridge had component scores of 5 (31112070) so we did not deem it replacement eligible. We did add the 25 by 25-foot bridge (31113060) to the replacement list and assumed a single box replacement for $450,000. We likewise removed the annual preventive maintenance from the respective table column.

Item 4: **Page 84:** Can you please be more specific on mileage. If we have mileage, we can compare.
UGPTI response: Specific mileages are presented on page 84 as obtained in the table shown in response to question 1.

Item 5: **Page 91**: can you please explain table D.3. **UGPTI response:** Table D3 is the total county and township paved road investment needs for the next 20 years and is broken out by individual biennium for the first 10 years and combined for the last 10 years.

Item 6: **Page 87:** Please change 152.2 miles under Mountrail County to 165.82 miles. **UGPTI response:** The table with investment needs by improvement type on page 87 is based on the

	total paved mileage for each county that was entered or updated in GRIT as of June 2020. In order for paved roads to be considered in the pavement model the County must ensure any pavement improvements are updated in the GRIT program. If GRIT does not show a road as paved, the needs will be included under the gravel results of the Needs Study. Mountrail and many other counties are showing mostly surfacing projects over the next 20 years. This is mostly because the model is optimized to maintain the existing systems and to select less expensive surfacing projects if the pavement condition has not deteriorated to a point where more expensive reconstruction projects are required.