NDSU UPPER GREAT PLAINS TRANSPORTATION INSTITUTE

Economic Benefits of Investment in North Dakota's State Highway System: 2016 – 2035

Draft Final Report to North Dakota Department of Transportation

February 5, 2016

Introduction:

Over the last several biennia, Upper Great Plains Transportation Institute (UGPTI) has conducted several state highway and bridge needs studies for the North Dakota Department of Transportation (NDDOT). These studies have focused on the funding levels required to maintain and improve existing conditions on the state's highway system. Rather than estimate the total needs to maintain the system, this study estimates conditions as a result of existing funding levels, and through three additional scenarios; 100% increase in funding, 50% increase in funding, and 50% decrease in funding, to estimate the system-wide conditions and the resulting economic impact to the state. In addition, one scenario which reduces funding is also estimated to provide a description of what may happen under reduced federal funding. The study utilized three primary analysis tools: HERS-ST, REMI, and SAS. HERS-ST in conjunction with SAS was used to estimate system conditions under the baseline revenue and additional revenue scenarios. In addition, bridge deterioration was modeled using a program developed in SAS. The resulting highway and bridge conditions under the modeled scenarios as well as the investment levels were used to develop an economic analysis using the REMI software.

HERS-ST Methods:

The state version of the Highway Economics Requirements System was used to estimate the direct benefits of making highway infrastructure improvements and to forecast the performance of the highway system in future years. HERS-ST is widely used at the federal and state levels. The national HERS model was developed by USDOT in the early 1990s. It is used to help prepare biennial reports for Congress which describes the condition and status of the nation's highways. The national model is also used to estimate the investment levels necessary to improve highway conditions. The state version of HERS is frequently used by transportation departments to estimate highway needs and investment benefits.

HERS-ST estimates traveler, societal, and transportation agency benefits resulting from highway investments. Highway user benefits include reductions in vehicle operating costs, travel time costs and crash costs. Reductions in vehicle emissions are classified as societal benefits. Traveler and societal benefits are estimated by comparing the levels of vehicle, user, crash, and emissions costs that would occur as a result of improvement to levels without the improvement. HERS-ST also estimates the maintenance cost savings resulting from timely resurfacing improvements, as well as the residual value of investments that continue to provide traffic or structural capacity beyond the end of the analysis period.

HERS-ST Analysis Process:

HERS-ST Overview

HERS-ST uses the state Highway Performance Monitoring System (HPMS) sample. Starting from the first year, HERS-ST forecasts when a pavement or capacity related deficiency will occur based on pavement and travel conditions. Pavement-related deficiencies are identified by comparing a section's condition to NDDOT standards. Capacity related deficiencies are identified by comparing a section's volume-capacity ratio to congestion boundary values. When a pavement or capacity related deficiency is identified, HERS-ST assesses the benefits of simultaneously making other improvements, such as improving shoulders or alignment. When a pavement deficiency is identified, HERS-ST further determines if a capacity deficiency will occur on the same highway section, and in which funding period the capacity deficiency will occur. If it is economical to combine a capacity improvement (e.g., widening or adding lanes) with a pavement improvement (e.g., resurfacing or reconstruction) HERS-ST determines the optimal timing of the combined improvement.

Calibration

Several important steps have been taken to ensure that HERS-ST predicts realistic results for North Dakota. (1) The HPMS sample, which is based on federal highway classifications, has been restructured to fit NDDOT's priority classification system. This allows the specification of highway design standards and calibration factors for individual highway classes. (2) Where applicable, the default federal deficiency indicators and inputs used in HERS-ST have been replaced by North Dakota values after a review of model parameters by NDDOT. (3) Rates of pavement deterioration have been calibrated so that the pavement lives predicted by HERS-ST agree with NDDOT's resurfacing cycles. These cycles are: 20 years for flexible pavements and 30 years for concrete pavements. These calibration factors are based upon the 2014 HPMS data. (4) Adjustments have been made to normal resurfacing costs to account for anticipated reconstruction due to inadequate finished roadway widths.

HPMS Data

2014 HPMS data was obtained from NDDOT. This was the most recent year available using the format required by HERS-ST. As discussed above, the model was calibrated based upon the base 2014 traffic data presented in the 2014 HPMS dataset. This was done to reflect NDDOT resurfacing cycles prior to oil development. It is possible that resurfacing cycles may decrease on high volume roads, and calibration before additional traffic is added would allow this practice to be modeled. Once calibration was complete, the traffic modifications outlined above were implemented.

What HERS-ST does and does not estimate

HERS-ST estimates the cost of improving highways due to condition and capacity related deficiencies. The types of improvements modeled include: resurfacing, reconstruction, minor widening, major widening, and shoulder improvements. HERS-ST does not consider construction of climbing lanes, bridges, turn lane additions, reliever routes, underpasses and overpasses. As these improvements are included in total statewide needs, this analysis considers them separately.

Roadway Width

HERS-ST does not model reconstruction or sliver widening due to deficient finished roadway width. NDDOT does not currently have a data as to the finished width on individual segments. To calculate the incremental cost of width correction improvements, an analysis of the RIMS data was undertaken and methods were decided through discussions with NDDOT. The following formula was used to calculate finished width:

$$Roadway\ Width = GRADED\_WDT - \frac{(BaseDPTH + (1.25 * SURFACEDP)) * 4 * 2}{12}$$

Graded_WDT, BaseDPTH and SURFACEDP were taken directly from the RIMS database. SURFACEDP was multiplied by 1.25 to account for thickness increases due to patching. This is added to the base depth and multiplied by 4 to consider the slope ratio. This is multiplied by 2 to account for a 2 lane facility, and divided by 12 to convert to units measured in feet. Minimum thresholds were taken from the width deficiency parameters provided by NDDOT. Tables 1-3 present the results of the analysis.

Table 1. Miles currently below minimum roadway width thresholds

HPCS	Below Threshold	Above Threshold	% Below
Rural DIS CORR	0.22	147.04	0.1%
RURAL DIST COLLECTOR	39.65	1,398.83	2.7%
RURAL DIST CORRIDOR	5.61	2,120.72	2.5%
RURAL INTER CORRIDOR	50.57	1,712.94	2.8%
RURAL STATE CORRIDOR	147.51	1,496.65	8.9%

Table 2. Miles below minimum roadway width thresholds after 2 inch overlay

HPCS	Below Threshold	Above Threshold	% Below
Rural DIS CORR	0.22	147.04	0.2%
RURAL DIST COLLECTOR	144.50	1,293.99	10.0%
RURAL DIST CORRIDOR	205.62	1,970.73	9.4%
RURAL INTER CORRIDOR	57.67	1,705.93	3.3%
RURAL STATE CORRIDOR	284.93	1,358.89	17.3%

Table 3. Miles below minimum roadway width thresholds after 3 inch overlay

HPCS	Below Threshold	Above Threshold	% Below
Rural DIS CORR	26.42	120.84	17.94%
RURAL DIST COLLECTOR	235.20	1,203.30	16.35%
RURAL DIST CORRIDOR	442.16	1,734.18	20.32%
RURAL INTER CORRIDOR	91.01	1,672.60	5.16%
RURAL STATE CORRIDOR	468.57	1,175.25	28.51%

The impact of width deficiencies on improvement costs are presented below. Table 4 outlines the cost estimates provided by NDDOT for sliver widening by HPCS classification. These cost estimates represent the cost of widening only, and do not include the cost of a resurfacing improvement.

Table 4. Sliver Widening Costs by HPCS

HPCS	# of Lanes	Width Added	Cost per Mile
Interregional	4	4	$452,000
NHS	2	6	$483,000
State Corridor	2	6	$455,000
District Corridor	2	6	$440,000
District Collector	2	5	$393,000

The estimated incremental cost of sliver widening over the 20 year analysis period was $303 million. In the upcoming biennium, the estimated annual incremental cost of sliver widening was $15.15 million.

Geographic Analysis

Due to differences in improvement costs in the oil patch and outside of the oil patch, the state was divided into two regions. The region located within the oil patch utilized higher improvement costs which were derived from recent bid estimates and prepared by NDDOT. Outside of the oil patch, a lower, different set of cost estimates were used. The intent of running a dual analysis was to reflect actual construction costs which are incurred in different geographic areas of the state.

Analysis Funding Periods

HERS-ST is designed to operate under multiple funding periods throughout the analysis period. The base funding period scheme is set at five four-year funding periods for a total analysis period of 20 years. Prior discussions as to the desired timeframe for outputs resulted in a request to run the analysis by biennium which would consist of ten 2-year funding periods. The two-year period is outside of the HERS-ST programming and benefit-cost logic. Initial attempts at analysis using two-year funding periods were promising, but further inspection of the results indicate that the HERS-ST timing of the improvements were flawed. For this reason, four 5-year funding periods were used. Results were distributed among individual years within funding periods based upon the known project dates if available, otherwise distribution occurred as HERS-ST dictated.

HERS-ST Results

The results of the HERS-ST analysis are presented in Table 5 below. These costs include preliminary engineering, construction engineering, ROW, utilities, wetlands, cultural mitigation, and haul roads. The base column shows the initial improvement costs in 2015 dollars estimated by HERS-ST. It should be noted that these estimates include projects specified in the improvements file which were discussed above, as they were specified during the HERS-ST analysis. Each column represents one of the four scenarios that are being estimated: 100% increase, 50% increase, Actual funding levels, and 50% decrease in funding levels.

Table 5. Funding levels for four funding scenarios ($2015)

	100%	50%	Actual	-50%
Total	$11,994	$8,864	$5,993	$2,986
FP1	$2,388	$1,793	$1,179	$597
FP2	$2,367	$1,791	$1,215	$602
FP3	$2,329	$1,814	$1,183	$596
FP4	$2,457	$1,798	$1,191	$599
FP5	$2,349	$1,666	$1,223	$590

As shown in Table 5, if current funding levels would continue for the next 20 years, a total of roughly $6 billion would be available to maintain and improve North Dakota's state highway system. If the funding level were increased by 50% and 100%, $8.86 billion and $12 billion would be available. Under each of these scenarios, the ability of timely improvements differs, as do the resulting improvement types and pavement conditions. It should be noted that due to the budget constraints on the actual and scenario funding levels by funding period, there is little variation in expenditure from funding period to funding period. This restriction does not allow HERS-ST to address potential backlog issues in the early funding periods.

Figures 1-3 present the lane miles improved under each funding scenario. Figure 1 shows the total lane-miles that would be improved by funding period under each scenario. As expected, there is a direct correlation between funding levels and lane-miles improved. In all four scenarios, there is an increase in improvements in funding period 4. This represents 16 years into the future and reflects the 20 year life of pavements which were recently improved.

Figure 1. Lane-Miles Improved by Scenario and Funding Period

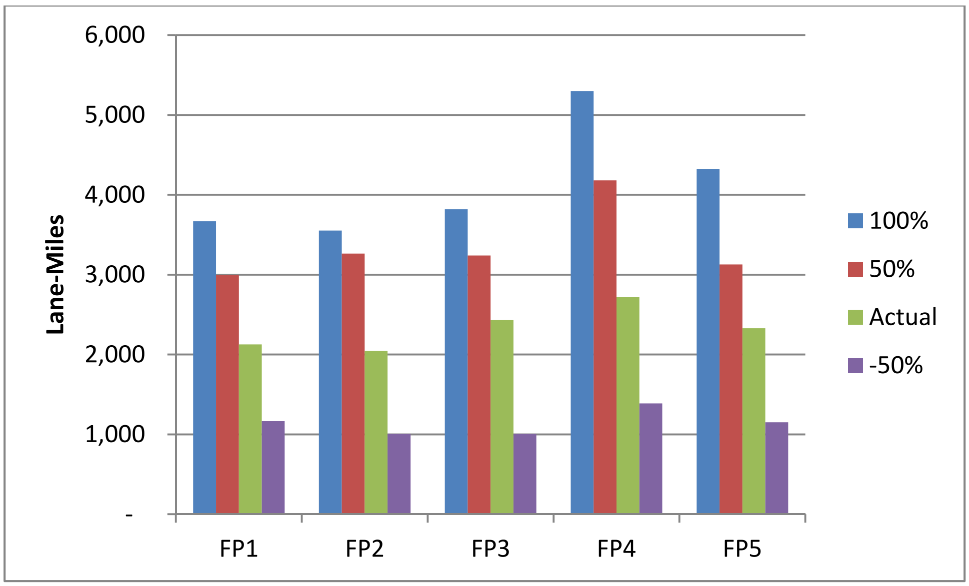


Figure 2 provides information on the lane-miles which were resurfaced under each funding scenario, by funding period. It is expected that as funding levels decrease, the opportunity for timely improvements to avoid higher cost reconstruction improvement decrease.

Figure 2. Lane-miles Resurfaced by Funding Period and Scenario

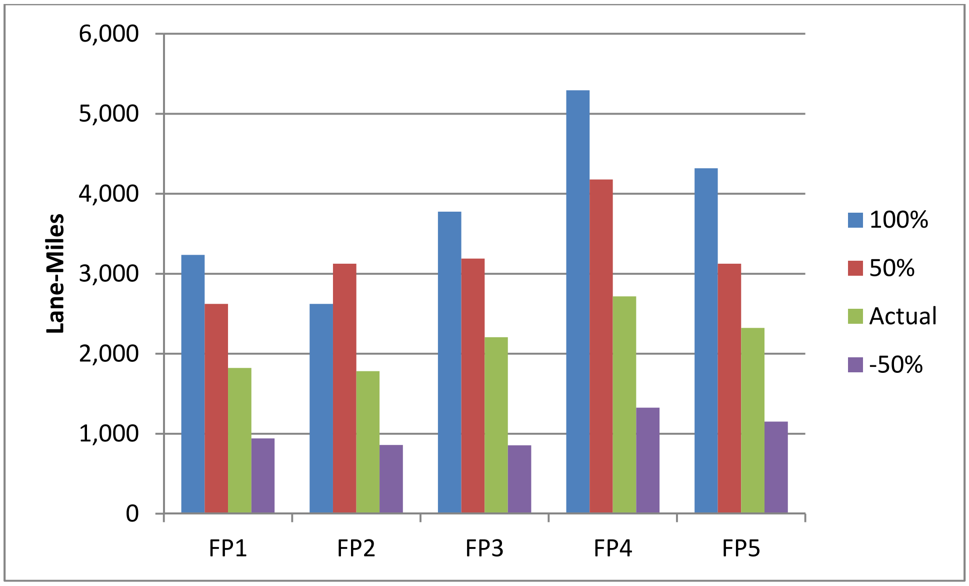
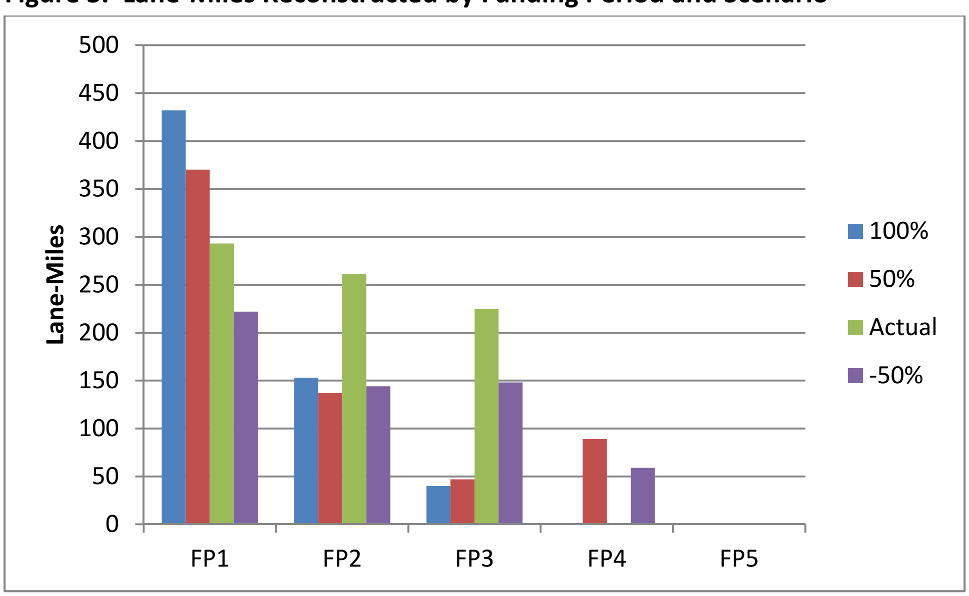


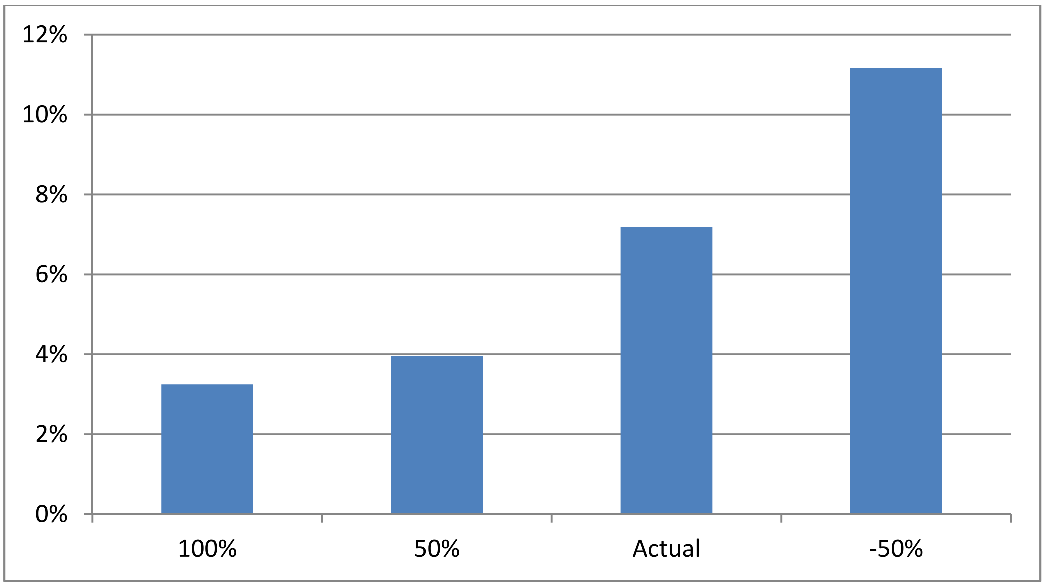
Figure 3 shows the lane-miles which were reconstructed by funding period for each scenario. It should be noted that each of the four funding scenarios reconstruct significant mileage in the first funding period, representing a backlog of improvements. Under the 100% increase scenario, these backlog miles are eliminated by funding period 3. Under the 50% increase scenario a similar pattern occurs, but reconstruction ends in funding period 4. Under the actual funding scenario a similar pattern to the 100% increase occurs, but reconstruction improvements, due to the funding constraints, are spread almost evenly between the first three funding periods.

Figure 3. Lane-Miles Reconstructed by Funding Period and Scenario



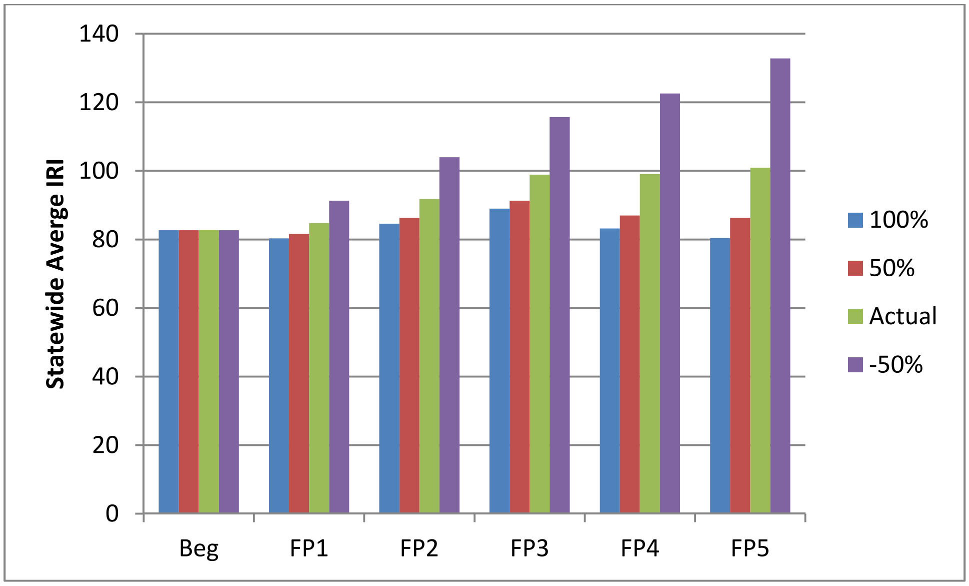
The impact of funding constraints on timeliness of improvements is illustrated in Figure 4. Due to the rate of pavement deterioration midway through the pavement life cycle, a timely improvement can restore pavement condition using a resurfacing improvement. However, if this improvement is postponed, the pavement may deteriorate to a point at which reconstruction is the only viable option. As Figure 4 shows, the funding constraints increase the percentage of miles which require reconstruction improvements.

Figure 4. Percentage of Total Improvements – Reconstruction



The overall system condition deteriorates as funding levels decrease. Figure 5 reports the average IRI for the entire system by funding period and scenario. The initial statewide average IRI is 82.9. Under the 100% increase scenario, this level is maintained throughout the entire analysis period. The 50% increase scenario shows a slight increase in IRI over the 20 year period. The actual and 50% decrease scenarios indicate that statewide average IRI will increase over the analysis period.

Figure 5. Average IRI by Funding Period and Scenario



HERS-ST Study Limitations

Due to the limitations of the HERS-ST framework, corridor planning is not taken into account when capacity improvements are implemented. These improvements are a result of volume capacity ratio deficiencies during the analysis period, and only correspond to sections where this deficiency occurs. This study does not expressly consider implementation of a concrete overlay improvement type to sections included in the analysis. It is possible that the improvements implemented using the improvements file in the first funding period may include this type of improvement, but in the remaining funding periods, HERS-ST does not consider implementation of a concrete overlay improvement. It is understood that due to the significant cost increase of this type of improvement over a typical overlay that specific engineering analysis is required on a segment basis.

HERS –ST Summary

This study outlines the 20 year needs for improvement and maintenance of North Dakota state highways through multiple analysis methods. HERS-ST was used to estimate improvement needs to improve and maintain highway based upon surface condition and capacity considerations, among other considerations. Finished width deficiencies were estimated based upon graded width overlay thickness and patching.

Bridge Analysis Process:

Bridge Data and Overview

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 state bridge). These databases were combined and spatially merged with a shapefile of the state road centerlines which are the focus of the 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 722 NBI (2014) state non-culvert structures. This dataset represents the basis for this study's needs analysis.

The condition assessment scales are used in the National Bridge Inventory. In the scale, a brand-new bridge component deteriorates from excellent condition (9) to failure (0) 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 overall sufficiency is expressed as a sufficiency rating (SR) in NBI, 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. 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.

Bridge Deterioration Model

From a past regional study that studied bridge deterioration of specific components like deck, superstructure and substructure, a set of empirical regression models developed by UGPTI were used to predict component deterioration. In reality, there is not much deterioration in these components for such a short window and 20 years is a short window for bridges. The deteriorations models show on average about 1 score change in about 13 years for a bridge at an earlier age.

The multivariate component deterioration models include four effects: bridge type, average daily traffic, reconstruction history, and bridge jurisdiction or location. For the deck model, the effect of deicing salt is also captured by introducing a maintenance authorization effect. Bridge age is the independent variable used in the models and is calculated as 2015 minus the year of original construction or reconstruction year. A polynomial function between bridge rating and age was adopted. The hypothesis is based on two suppositions. First, the rate of loss may be modest and nearly linear until a bridge's condition deteriorates to fair, at which point more maintenance and repairs are implemented to keep the bridge in acceptable condition. These improvements may slow down the deterioration rate with time. Second, once the bridge is in serious condition it may continue in light service for some time under close scrutiny via posting (e.g., limiting the traffic loads). Age and age-squared are the quantitative independent continuous variables in this study.

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

Bridge 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 structural rehabilitation. Bridge replacement is separated into three subcategories based the type of structure which will replace the existing bridge:

1. Bridge with 60-foot span length
2. Single barrel reinforced concrete box culvert
3. Multiple barrel reinforced concrete box culvert

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 such as desk penetrations seals, sweeping, crack sealing. 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 bridge painting on maintenance-eligible bridges with steel super structure. The bridge painting allocation recognizes the need for maintenance to combat chloride-induced corrosion and rusting of structural steel (and resulting loss of service life) for steel bridges.

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 A.

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 or no action. 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.

Bridge Cost Models

Preventive maintenance cost estimates used an annual unit cost of $0.24 per square foot deck area. This value represents a typical annualized cost of maintenance as derived from other state DOT preventive maintenance expenditures outlined in individual state needs studies and in NCHRP 20-68A Scan 07-05 Best Practices In Bridge Management Decision-Making (2009). Deck square footage costs are estimated for sweeping, crack sealing and deck penetrant applications on a 5 year basis. The deck sealant is intended to provide reinforcing steel corrosion protection as result of chloride based anti-icing procedures. An additional $0.05 per square foot for annual deck washing was allowed for deck washing on bridges. Bridge painting was also summarized based on painting (new paint) every 25 years. The unit cost is additional $0.56/sf of painted area/yr.

Similar unit costs are used as were used in the Legislative Assessment of ND County & Local Road Needs 2014-2015. Replacement costs were estimated by developing unit costs from recent (2009-2014) NDDOT bid reports and plan documents. Costs were adjusted to reflect 2015 dollars. The type of replacement structure was based on the criteria described in the Improvement Selection Model section of this chapter. To generalize widening and rehabilitation projects, 50% and 45% of replacement cost are used respectively.

Replacement costs were estimated by developing unit costs from recent (2009-2014) NDDOT bid reports and plan documents. Costs were adjusted to reflect 2015 dollars. The type of replacement structure was based on the criteria described in the Improvement Selection Model section of this chapter.

Unit replacement costs in oil-impacted and non-impacted counties were $275 per square foot and $250 per square foot deck area, respectively. All costs include preliminary engineering and construction engineering costs. Preliminary engineering costs are assumed to add an additional 10% to the bid price, while construction engineering adds approximately 15% of the bid price.

The cost assumptions are for typical approach work that accompanies a bridge replacement. Typically Bridge division estimates from the beginning to the end of the bridge while approach work is part of the grading costs. It was included because grading costs as an actual cost isn't predictable through any other part of this study.

A deficient bridge which is less than 40 feet long is assumed to be replaced by a culvert structure costing $400,000. A deficient bridge between 40 and 50 feet in length is assumed to be replaced by a culvert structure costing $600,000. Costs for bridges longer than 50 feet are calculated using the square footage of the deck and an average replacement unit cost.

Summary of Findings – Bridge Analysis

Estimated statewide improvement and preventive maintenance needs for the study period, 2016-2033, is $637 million. Most of the improvement needs are determined by the study's improvement model to be backlog needs, occurring during the first study biennium. $163.1 million in the first Biennium with backlog and preventive maintenance and $15.3 million in second Biennium with preventive maintenance are estimated. Bridge replacements were generally assumed to occur in the first biennium. Bridge rehabilitation and widening projects are typically performed with major pavement rehabilitation or re-grading projects. Costs for rehabilitation or widening were distributed equally throughout the 20 year study period to simulate matching up with major pavement projects. Complete bridge needs forecasts by 10 biennium periods are shown in Table 2.

Table 2. Summation of Bridge Needs

	Widening		Replacement		Structural Rehab		Preventive Mtce		Total Bridges	Total cost	Total Cost
Biennium	Bridges	Costs	Bridges	Costs	Bridges	Costs	Bridges	Costs	W/O PM	W/O PM	With PM
16-17	**5**	**$4,538,829**	**46**	**$149,937,108**	**22.3**	**$21,613,690**	**1409**	**$13,153,798**	**73.3**	**$273,404,627**	**$286,558,425**
18-19	**5**	**$4,538,829**	**0**	**$0**	**22.3**	**$21,613,690**	**1410**	**$15,287,182**	**27.3**	**$26,152,519**	**$41,439,701**
20-21	5	$4,538,829	0	$0	22.3	$21,613,690	1410	$15,271,501	27.3	$26,152,519	$41,424,020
22-23	5	$4,538,829	0	$0	22.3	$21,613,690	1402	$15,253,733	27.3	$26,152,519	$41,406,252
24-25	5	$4,538,829	1	$619,367	22.3	$21,613,690	1398	$15,307,598	28.3	$26,771,886	$42,079,485
26-27	5	$4,538,829	0	$0	22.3	$21,613,690	1396	$15,095,461	27.3	$26,152,519	$41,247,980
28-29	5	$4,538,829	0	$0	22.3	$21,613,690	1390	$15,159,165	27.3	$26,152,519	$41,311,684
30-31	5	$4,538,829	2	$6,698,000	22.3	$21,613,690	1396	$15,052,427	29.3	$32,850,519	$47,902,946
32-33	5	$4,538,829	1	$2,247,643	22.3	$21,613,690	2107	$22,956,779	28.3	$28,400,162	$51,356,941
Total	**45**	**$40,849,463**	**50**	**$159,502,119**	**200.7**	**$194,523,208**	**13318**	**$142,537,644**	**268.7**	**$492,189,790**	**$634,727,434**

Due to the even level of funding estimated for pavement rehabilitation and width correction, this study assumes an even replacement and maintenance of bridges over the 20 year analysis period. For this reason, an estimate of $31.73 million annual bridge replacement and maintenance funding level is used in the REMI analysis in conjunction with the HERS-ST funding levels and widening cost estimates.

REMI/HERS Integration

The goal of the analysis is to quantify the economic benefits of the highway improvements recommended by HERS-ST for the state of North Dakota. In order to accomplish this, we must rectify the conflicting goals of HERS-ST and REMI.

HERS-ST:

The HERS-ST program uses a variable length BCA, depending on specific segment conditions. For example, in the base period, if the section condition is in the unacceptable range, the benefit-cost-analysis ends in the following period. If the section condition is above the thresholds then the BCA extends to the future period when it is no longer acceptable. The length of the BCA varies for each situation.

The base case in HERS-ST is not constant. In some cases, the analysis is no-build versus build. In other cases it is build now versus build later. The complexity of the HERS-ST analysis process renders it nearly impossible to mimic in REMI.

HERS-ST optimizes the state's highway budget through prioritization of projects based on benefit-cost analysis. In any given period, there may be a number of highway segments that would warrant improvements due to high return on investment. HERS-ST chooses those improvements with the greatest benefit-cost ratio for improvements to maximize the overall impact of the funding.

REMI:

REMI assesses the economic impacts of the spending and the impacts of the change in highway user costs. The base case for the REMI analysis would be that no highway projects are implemented and that maintenance cost would increase due to pavement deterioration. The project case is the HERS-ST recommended improvements are made, maintenance cost decreases, and the user benefits are realized. The time frame of this analysis would be each four year funding period, as the highway conditions at the beginning of the latter periods reflect HERS-ST improvements in the prior period, so the base case of no-build maintenance cost are unavailable. However, by using the four-year analysis period, the economic effects of the policy by funding period can be obtained. For example: in the first funding period, the REMI base case would be no improvements in the first funding period thus allowing deterioration from the initial conditions, and the project case would be that the HERS-ST improvements are made. In the second funding period, the base case would be no improvements during the second funding period, allowing the pavement to deteriorate from the starting conditions at the beginning of the second funding period. In essence, the funding periods are analyzed independently of each other.

REMI Structure:

REMI, like HERS-ST has baseline conditions upon which future forecasts are based. In HERS-ST, the baseline conditions primarily deal with pavement and traffic conditions. From these baseline values, the future pavement condition is estimated for the purpose of identifying candidate improvements. In the REMI model, the baseline values are called the "Standard Regional Control" and include large amounts of industry and economic data from various government sources. As time progresses in the analysis, REMI produces a forecast based upon these baseline values to estimate how the economy would grow without any external shocks. The alternative forecast includes the effects of these economic shocks and the difference between the two is calculated.

Baseline:

The Standard Regional Control must be modified to quantify the full economic impact of the HERS-ST recommended improvements. The baseline value for construction sales represents the total amount of construction in the state, including highway construction. The base case states that we have no improvements, and no highway construction expenditures except highway maintenance. To represent this in the baseline value, the total highway construction and maintenance for the base year will be subtracted from the construction sales value in the base case. The baseline variable would then accurately represent zero highway construction.

This method raises a question – how is the increased maintenance cost reflected in the base case? In the HERS-ST output, the average annual maintenance cost under the build scenario is given. There is also an estimate of the maintenance cost savings in the final period as a result of the improvements. The baseline maintenance cost for the final year in the five year period could be obtained by summing the estimated maintenance cost after improvements are implemented and the maintenance cost saved in the last year as a result of the improvements. Baseline maintenance = maintenance cost after improvements + maintenance cost savings as a result of improvements. This number should approximate the increased maintenance cost as a result of pavement deterioration.

Notes:

If the base case involves no improvements, as mentioned above, the highway condition and performance would decrease, causing higher user costs. There are two options to deal with this in the analysis. The first option is to run a separate base HERS-ST budget constrained analysis, with the budget being zero. This would cause HERS-ST to make no improvements over the analysis period, and the increased user costs as a result of deterioration would be given in the output. The second option would be to ignore the increased user costs over each funding period.

The tradeoff between the two options is whether to overstate or understate the benefits of highway improvements. The first option would allow the highways to deteriorate to an unrealistic condition, while the second option would understate the benefits by not including the decreased highway performance. The second option is a more attractive option because the results would not be overstating the benefits. This more conservative approach could be presented as such, with a note stating that the benefits may be higher due to the omission of the increased user costs in the base. Conversely, the first option must be presented as a potential overstatement of the benefits which would take away from the validity of the results.

HERS inputs and use in REMI:

The inputs for REMI from the HERS-ST output which are of interest are:

- operating costs
- safety costs
- emissions benefits/costs
- construction costs
- changes in travel time

However, some adjustment to the raw HERS-ST output is necessary for the figures to be used as inputs to REMI.

The HERS-ST software analyzes highway improvements based upon an analysis period set by the user. For example, the HERS-ST analysis performed for the NDDOT was done over a 20-year planning horizon consisting of four five-year funding periods. The REMI program performs the analysis based on an annual basis. The inputs for construction costs, operating costs, safety costs, and emissions costs are derived simply through calculating an annualized figure.

Calculation of the commuting costs, transportation costs, and accessibility cost inputs to REMI from the commuting times and transportation costs output from HERS-ST requires conversion of units. The commuting cost input is determined by the traffic delay time variable in HERS. The original value is in hours per 1000 miles, but REMI requires it to be entered as delay time as a percentage over the eight-hour workday.

$$\frac{CT_{avg}}{2} \times AvgSpeed \times \frac{\Delta CT_{avg}}{1{,}000mi.} = CT_{saved}$$

From this, the Commuting Time saved in hours is divided by and eight hour work day. To obtain the percentage change in commuting time, the commuting time saved during the work day is divided by the total commuting time. The average commuting time and the total commuting time are census figures and provided with the model.

Commuting costs should decay back to 1.0 because the reduction in commuting costs increases the commuting quantity demanded (induced demand?). "This effect manifests over time as new migrants or moving residents buy or build houses further from the place of work, thus eliminating the initial benefit of reduced commuting time. Labor-market effects take 7-15 years to clear, so it is reasonable to model the commuting benefit as decaying in a straight line over 10-15 years."

To calculate transportation costs, the change in the travel time cost from the beginning of the funding period is divided by the total travel time cost at the beginning of the period to represent the percentage change in travel time costs.

$$\frac{TT_{saved}}{TT_{total}} \times 100 = \%\Delta TT$$

Accessibility Costs:

The transportation cost is used to approximate accessibility costs. The rationale is that accessibility cost impacts will have a minimum of zero, but will not exceed the transportation cost. These inputs are used in the transportation cost matrix in Policy Insight. Note: See above about the changes necessary to input the commuting cost.

Construction Costs:

Construction costs are incurred by the government for maintenance and repair of the highway and listed by improvement type. This is calculated by dividing the total initial improvement costs by the number of years in the funding period to obtain the improvement costs, and sum with annual maintenance costs.

Operating costs:

Annual changes in operating costs are calculated by multiplying the change in operating costs per 1,000 VMT by the actual VMT.

Safety Costs:

Safety costs are calculated in the same manner as operating costs.

Emissions Costs:

Emissions costs are calculated in the same manner as operating costs.

HERS-ST Outputs	**REMI Policy Insight Variables**
Construction Costs	Construction Sales
Operating Costs	Non-Pecuniary Aspects
Safety Costs and Benefits	Non-Pecuniary Aspects
Emissions Costs	Non-Pecuniary Aspects
Commuting Times	Transportation Cost Matrix-Commuting Costs
Transportation Costs	Transportation Cost Matrix-Transportation Costs
Transportation Costs	Transportation Cost Matrix-Accessibility Costs

REMI Results

As previously discussed, changes in highway funding levels not only change the amount of dollars which flow into the construction industry, the funding levels influence costs for all users who utilize the state's highway system.

Figures 6-10 below present five different economic measures to describe the impact of the investment scenarios. Each of these graphs present the change from present funding levels, that is if funding is increased or decreased, the graph shows what the difference in the economic measure would be. For example, in Figure 6 below, the change in GDP for the actual funding scenario is zero, as it is what the other scenarios are compared against. For this reason, the economic gains in the latter years of the analysis may seem large. However, they are in comparison to the actual funding scenario which would see a decrease in system performance over the 20 year horizon.

Figure 6 presents the state Gross Domestic Product (GDP) for each of the funding scenarios. Much of the initial benefit from the 100% and 50% increases are a direct result of additional highway spending. As time progresses in the estimates, the impact of deterioration of the highway system resulting in increased user costs widens the gap beyond simple construction spending. As user costs increase, they increase not only for motorists, but the industries which utilize the highway system for delivering products and sourcing inputs within and outside North Dakota.

Figure 6. Change in State GDP under Four Funding Scenarios

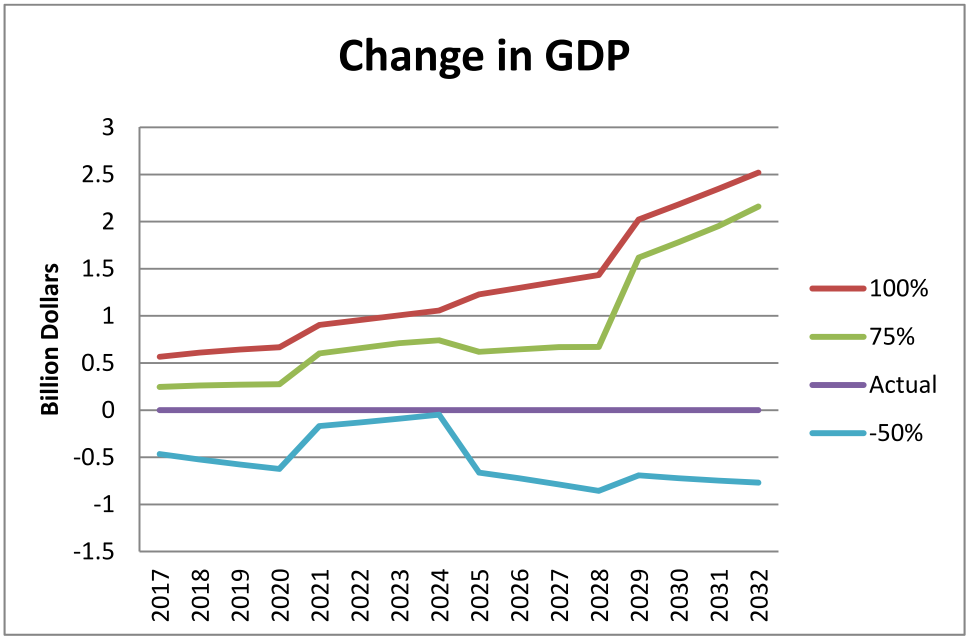


Figure 7 presents the change in Total Employment under the four funding scenarios. As with Figure 6, the initial increases can be directly attributed to the increase in construction spending.

Figure 7. Change in Employment under Four Funding Scenarios

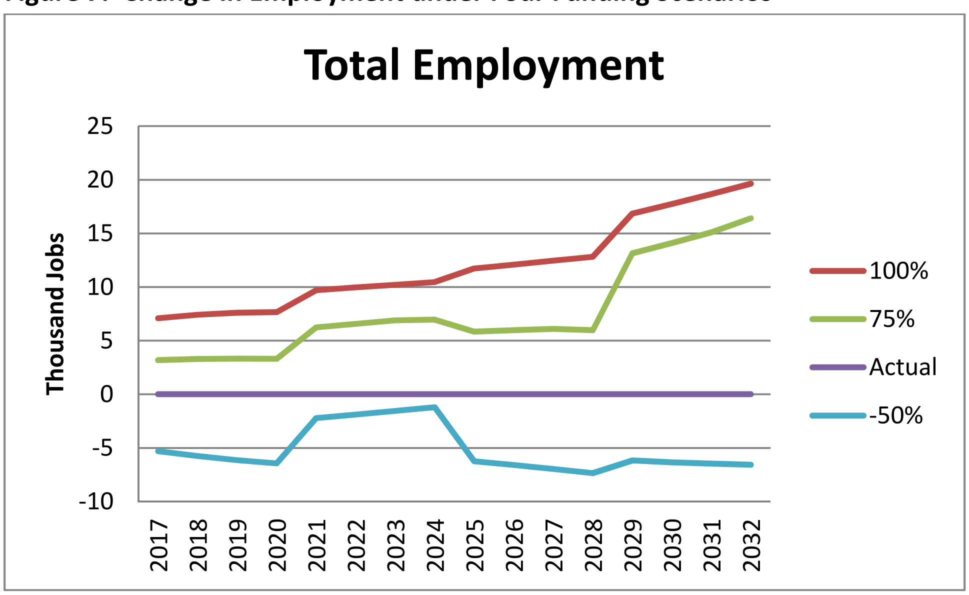
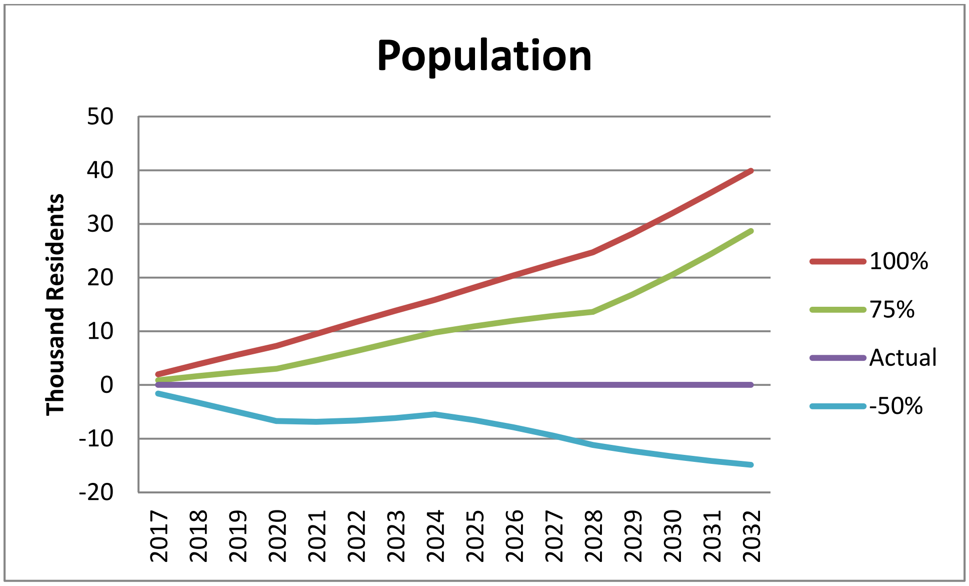


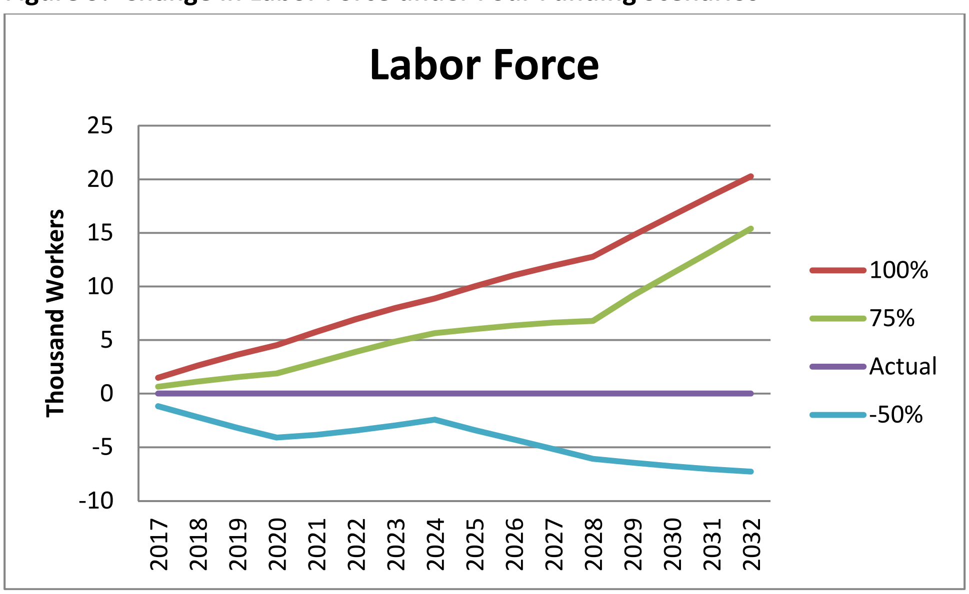
Figure 8 presents the change in state population under the four funding scenarios. The population increases estimated are a result of increasing economic activity requiring employment within the state of North Dakota. Under both the 100% and 75% scenarios a positive population growth change is shown as a result of the economic activity generated through highway investment and the resulting infrastructure's effect on user costs.

Figure 8. Change in Population under Four Funding Scenarios



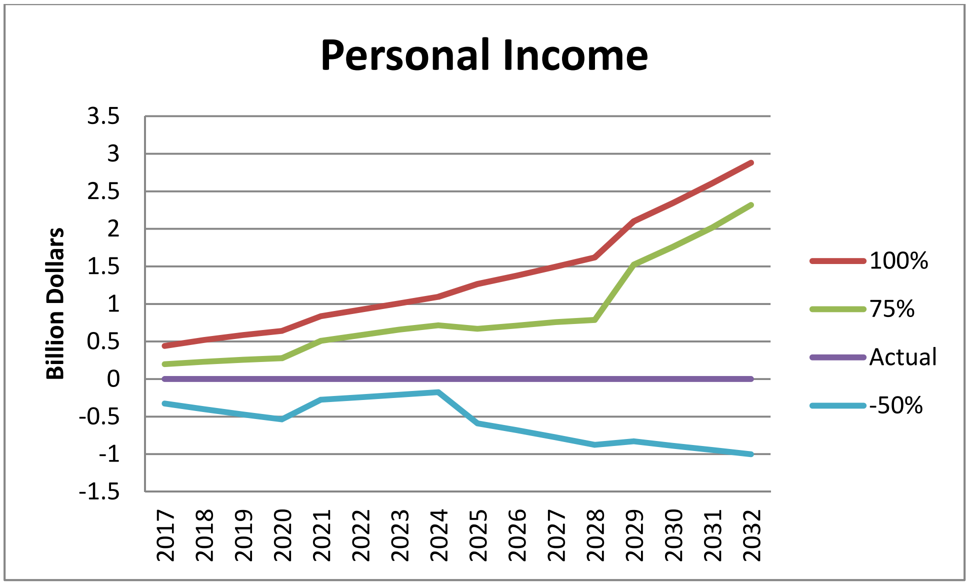
Of the growth in population shown in Figure 8, a proportion will enter the state's workforce. Figure 9 presents the change in the state's labor force under the four funding scenarios. Similar trends to the population forecasts are shown but at a lesser level due to the proportion of the state's population which is actively in the workforce.

Figure 9. Change in Labor Force under Four Funding Scenarios



Finally, Figure 10 shows the change in personal income under the four funding scenarios. Personal is the sum of all income sources to individuals and households. This amount is an indicator of available income to benefit industries within the state.

Figure 10. Change in Personal Income under Four Funding Scenarios



Conclusion/Summary/Future Studies:

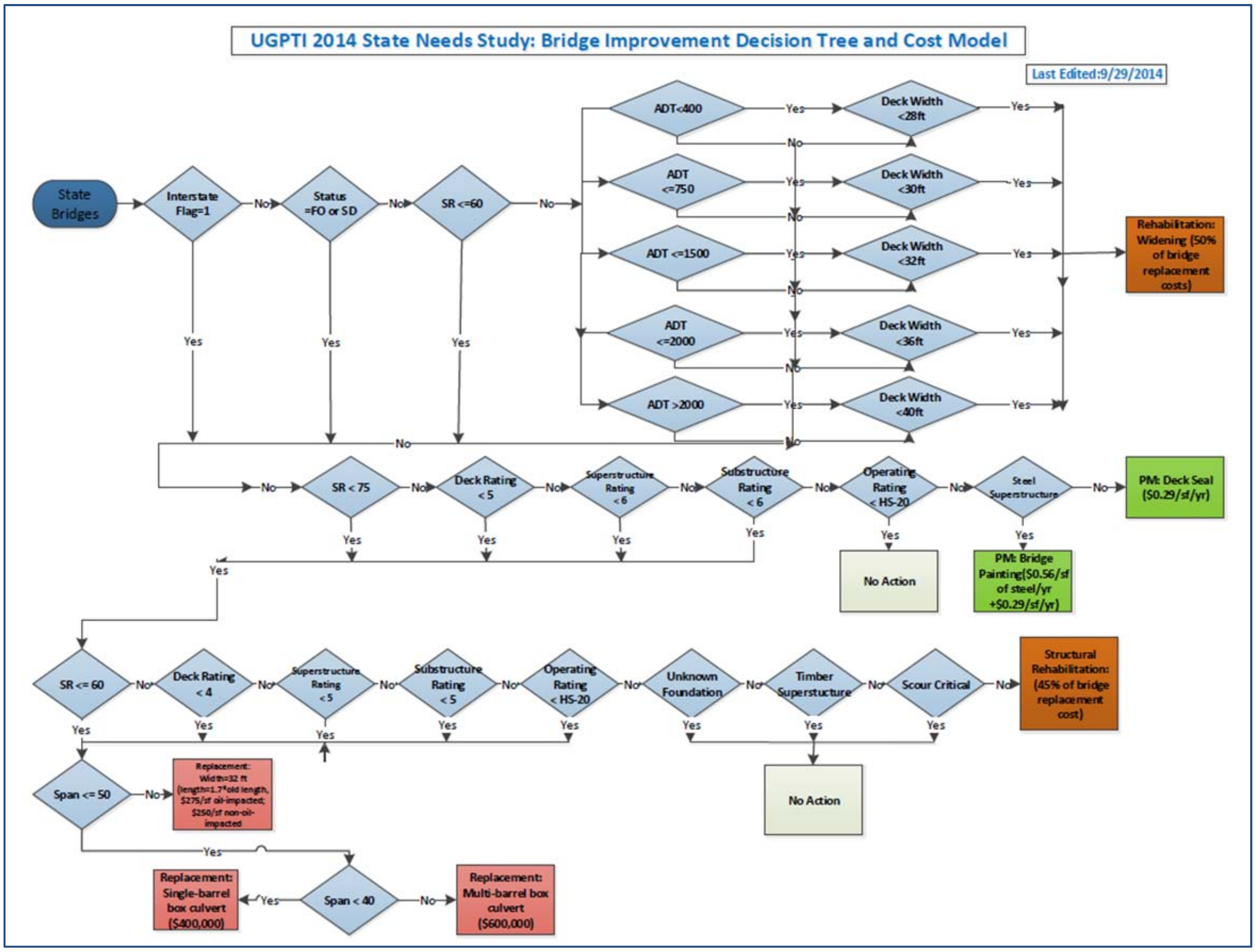
This study of the economic impact of different levels of highway funding has been completed using a combination of three analysis procedures. The HERS-ST module is an established FHWA method of predicting highway investment impacts on both rural and urban systems. Although the HPMS database has been updated to reflect new requirements at the FHWA level, the HERS-ST software has not, and significant up-front data processing was required to provide data that was usable in the HERS-ST software. Much of this work replicates the calculations that the previous HPMS submittal software was used to calculate. In addition, any requirements that could be made to HERS-ST to emulate NDDOT decision making were implemented.

In addition to highway improvement and maintenance, a bridge deterioration model developed in the 2014 State Needs Analysis was updated to the most current data including cost estimates. This, in conjunction with analysis of finished road width using the NDDOT RIMS database, most of the funding requirements influencing user costs on the state highways have been estimated.

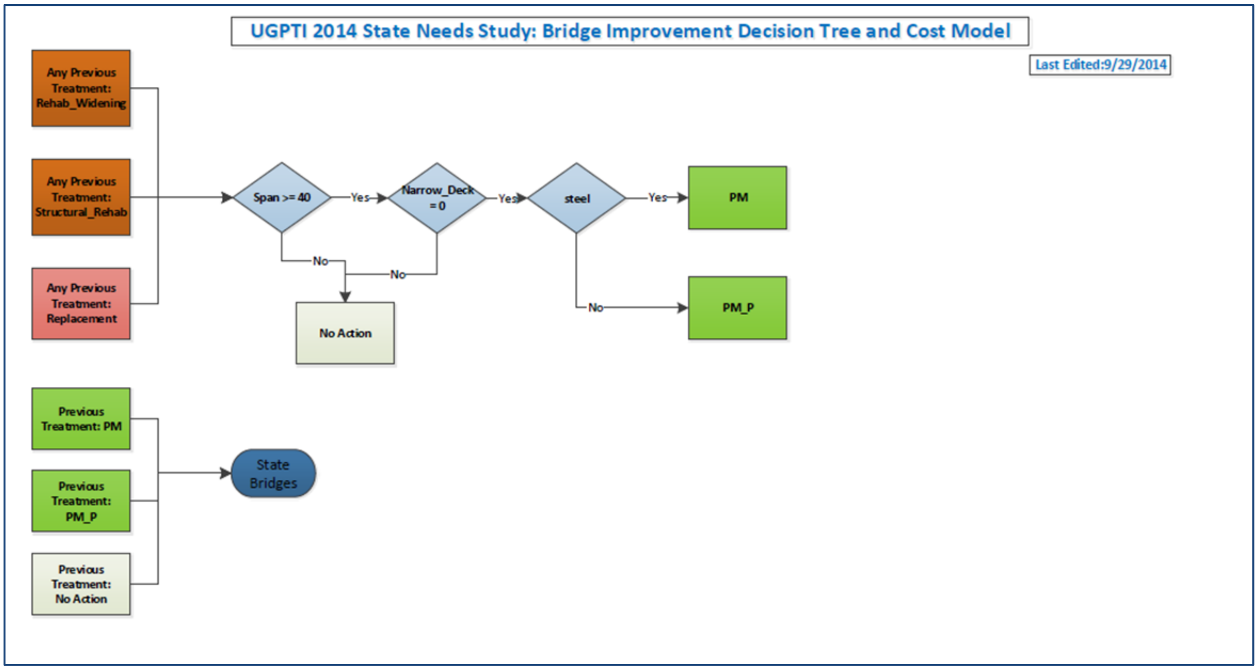
Because the objective of this study was to estimate the economic impact of investment in North Dakota's highways, the REMI software was used to estimate the regional economic impacts of each of the four funding scenarios. Pavement condition influences user costs, crash costs, and emissions costs which in turn influence the cost of travel for residents and businesses within the state. Using the user cost outputs from HERS-ST and the expenditures from HERS-ST, the bridge deterioration analysis, and the widening improvements, REMI estimated the change in multiple economic factors as a result of increases or decreases in highway funding.

Appendix A: Bridge Analysis Flow Charts

Bridge Improvement Decision Model Flowchart 1



Bridge Improvement Decision Model Flowchart 2



100% FUNDING SCENARIO compared to Standard Regional Control - Difference

Region = North Dakota

Browser

TranSight North Dakota v3.7.3 (Build 4015)

Category	Units	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Total Employment	Thousands (Jobs)	7.0917	7.4221	7.5962	7.6535	9.7082	9.9634	10.2113	10.4646	11.7232	12.0915	12.4635	12.8248	16.8503	17.7365	18.6688	19.6284	4.6446
Private Non-Farm Employment	Thousands (Jobs)	6.7678	6.8844	6.9036	6.8509	8.7077	8.8070	8.9268	9.0700	10.1733	10.4089	10.6626	10.9174	14.6182	15.2280	15.9090	16.6343	2.3579
Residence Adjusted Employment	Thousands	6.8375	7.1879	7.4282	7.5440	9.6039	9.9259	10.2375	10.5384	11.8203	12.2359	12.6462	13.0374	17.0556	18.0258	19.0398	20.0662	5.3737
Population	Thousands	1.9698	3.8365	5.6290	7.2919	9.5116	11.7092	13.8306	15.8669	18.1636	20.4081	22.5995	24.7258	28.1846	31.9264	35.8627	39.8854	37.8805
Labor Force	Thousands	1.4812	2.6097	3.6358	4.5234	5.7647	6.9397	7.9922	8.8840	10.0059	11.0429	11.9400	12.7723	14.7282	16.5937	18.4545	20.2796	16.9532
Gross Domestic Product	Billions of Fixed (2009)	0.5666	0.6106	0.6429	0.6660	0.9039	0.9554	1.0062	1.0569	1.2279	1.2963	1.3651	1.4338	2.0230	2.1818	2.3486	2.5196	0.4288
Output	Billions of Fixed (2009)	0.9555	1.0305	1.0859	1.1261	1.5348	1.6259	1.7154	1.8038	2.1007	2.2257	2.3503	2.4728	3.4873	3.7743	4.0740	4.3782	0.8472
Value Added	Billions of Fixed (2009)	0.5666	0.6106	0.6429	0.6660	0.9039	0.9554	1.0062	1.0569	1.2279	1.2963	1.3651	1.4338	2.0230	2.1818	2.3486	2.5196	0.4288
Personal Income	Billions of Current Dollars	0.4416	0.5195	0.5861	0.6412	0.8382	0.9234	1.0074	1.0945	1.2660	1.3763	1.4962	1.6192	2.1002	2.3436	2.6049	2.8809	1.3627
Disposable Personal Income	Billions of Current Dollars	0.3751	0.4401	0.4959	0.5438	0.7112	0.7849	0.8577	0.9336	1.0795	1.1744	1.2784	1.3854	1.7899	1.9985	2.2227	2.4595	1.2134
Real Disposable Personal	Billions of Fixed (2009)	0.3196	0.3650	0.4063	0.4390	0.5775	0.6343	0.6881	0.7410	0.8499	0.9148	0.9828	1.0484	1.3584	1.5124	1.6666	1.8171	0.8678
PCE-Price Index	2009=100 (Nation)	(0.0200)	(0.0096)	(0.0196)	(0.0306)	(0.0915)	(0.1318)	(0.1704)	(0.2033)	(0.2630)	(0.3077)	(0.3476)	(0.3813)	(0.5768)	(0.7102)	(0.8273)	(0.9237)	(0.4208)

75% Scenario compared to Standard Regional Control - Difference

Region = North Dakota

Browser

TranSight North Dakota v3.7.3 (Build 4015)

Category	Units	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Total Employment	Thousands (Jobs)	3.1816	3.2903	3.3194	3.2958	6.2349	6.5651	6.8905	6.9552	5.8334	5.9657	6.0900	5.9749	13.1525	14.1033	15.0978	16.4177	3.7359
Private Non-Farm Employment	Thousands (Jobs)	3.0404	3.0596	3.0275	2.9631	5.7042	5.8798	6.0766	6.0398	4.9060	5.0147	5.1126	4.9816	11.7350	12.3514	13.0541	14.0948	1.9488
Residence Adjusted Employment	Thousands	3.0615	3.1763	3.2328	3.2327	6.1309	6.5167	6.9019	7.0223	5.9634	6.1081	6.2338	6.1253	13.1988	14.2465	15.3474	16.7453	4.3445
Population	Thousands	0.8639	1.6462	2.3683	3.0187	4.6131	6.3208	8.0706	9.7593	10.9314	11.9627	12.8723	13.6233	16.8411	20.4751	24.4388	28.6693	27.8204
Labor Force	Thousands	0.6540	1.1308	1.5493	1.8880	2.8922	3.9005	4.8550	5.6418	6.0184	6.3650	6.6230	6.7768	9.1152	11.2025	13.2816	15.4037	13.0653
Gross Domestic Product	Billions of Fixed (2009)	0.2459	0.2609	0.2698	0.2745	0.6024	0.6559	0.7098	0.7410	0.6189	0.6441	0.6680	0.6693	1.6185	1.7813	1.9528	2.1593	0.4007
Output	Billions of Fixed (2009)	0.4133	0.4379	0.4523	0.4598	1.0228	1.1184	1.2147	1.2730	1.0705	1.1172	1.1601	1.1645	2.7808	3.0746	3.3834	3.7485	0.7857
Value Added	Billions of Fixed (2009)	0.2459	0.2609	0.2698	0.2745	0.6024	0.6559	0.7098	0.7410	0.6189	0.6441	0.6680	0.6693	1.6185	1.7813	1.9528	2.1593	0.4007
Personal Income	Billions of Current Dollars	0.1986	0.2303	0.2559	0.2761	0.5092	0.5841	0.6592	0.7149	0.6686	0.7116	0.7588	0.7850	1.5229	1.7608	2.0159	2.3185	1.0472
Disposable Personal Income	Billions of Current Dollars	0.1687	0.1950	0.2165	0.2341	0.4307	0.4950	0.5596	0.6085	0.5719	0.6094	0.6510	0.6751	1.2904	1.4930	1.7109	1.9690	0.9266
Real Disposable Personal	Billions of Fixed (2009)	0.1412	0.1575	0.1715	0.1820	0.3535	0.4100	0.4645	0.5041	0.4663	0.4852	0.5055	0.5134	0.9866	1.1488	1.3122	1.4876	0.7010
PCE-Price Index	2009=100 (Nation)	0.0001	0.0113	0.0120	0.0113	(0.0688)	(0.1178)	(0.1646)	(0.2044)	(0.1946)	(0.1964)	(0.1958)	(0.1964)	(0.4428)	(0.5960)	(0.7363)	(0.8506)	(0.4489)

25% Scenario compared to Standard Regional Control - Difference

Region = North Dakota

Browser

TranSight North Dakota v3.7.3 (Build 4015)

Category	Units	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Total Employment	Thousands (Jobs)	(5.2981)	(5.7539)	(6.1380)	(6.4430)	(2.2183)	(1.8844)	(1.5406)	(1.1958)	(6.2473)	(6.5838)	(6.9573)	(7.3538)	(6.1688)	(6.3407)	(6.4693)	(6.5653)	(10.7097)
Private Non-Farm Employment	Thousands (Jobs)	(5.0332)	(5.2969)	(5.5255)	(5.7043)	(1.6310)	(1.4083)	(1.1579)	(0.8984)	(5.7178)	(5.8857)	(6.1193)	(6.3925)	(5.1964)	(5.3464)	(5.4522)	(5.5279)	(9.4223)
Residence Adjusted Employment	Thousands	(5.1379)	(5.6252)	(6.0719)	(6.4315)	(2.3413)	(1.9873)	(1.6046)	(1.2244)	(6.1572)	(6.5425)	(6.9793)	(7.4296)	(6.2991)	(6.4760)	(6.6025)	(6.6964)	(10.7905)
Population	Thousands	(1.5941)	(3.2618)	(4.9942)	(6.7257)	(6.8678)	(6.6497)	(6.1604)	(5.4694)	(6.5422)	(7.8840)	(9.4550)	(11.1607)	(12.3069)	(13.2996)	(14.1464)	(14.8729)	(17.0322)
Labor Force	Thousands	(1.1753)	(2.1898)	(3.1796)	(4.0980)	(3.8427)	(3.4431)	(2.9590)	(2.4234)	(3.3874)	(4.2713)	(5.1699)	(6.0742)	(6.4331)	(6.7713)	(7.0474)	(7.2694)	(8.7451)
Gross Domestic Product	Billions of Fixed (2009)	(0.4660)	(0.5233)	(0.5761)	(0.6229)	(0.1689)	(0.1309)	(0.0900)	(0.0479)	(0.6625)	(0.7224)	(0.7875)	(0.8560)	(0.6920)	(0.7220)	(0.7475)	(0.7695)	(1.3702)
Output	Billions of Fixed (2009)	(0.7935)	(0.8954)	(0.9902)	(1.0749)	(0.2974)	(0.2282)	(0.1527)	(0.0746)	(1.1184)	(1.2261)	(1.3440)	(1.4679)	(1.1915)	(1.2441)	(1.2876)	(1.3235)	(2.3417)
Value Added	Billions of Fixed (2009)	(0.4660)	(0.5233)	(0.5761)	(0.6229)	(0.1689)	(0.1309)	(0.0900)	(0.0479)	(0.6625)	(0.7224)	(0.7875)	(0.8560)	(0.6920)	(0.7220)	(0.7475)	(0.7695)	(1.3702)
Personal Income	Billions of Current Dollars	(0.3267)	(0.4005)	(0.4716)	(0.5371)	(0.2751)	(0.2436)	(0.2096)	(0.1744)	(0.5911)	(0.6789)	(0.7752)	(0.8758)	(0.8283)	(0.8879)	(0.9450)	(1.0007)	(1.4987)
Disposable Personal Income	Billions of Current Dollars	(0.2776)	(0.3396)	(0.3995)	(0.4562)	(0.2378)	(0.2121)	(0.1838)	(0.1542)	(0.5022)	(0.5763)	(0.6585)	(0.7448)	(0.7082)	(0.7601)	(0.8097)	(0.8579)	(1.2722)
Real Disposable Personal	Billions of Fixed (2009)	(0.2489)	(0.3037)	(0.3571)	(0.4041)	(0.1991)	(0.1602)	(0.1207)	(0.0838)	(0.3710)	(0.4395)	(0.5111)	(0.5797)	(0.5370)	(0.5584)	(0.5770)	(0.5944)	(0.8860)
PCE-Price Index	2009=100 (Nation)	0.0624	0.0892	0.1241	0.1547	0.0523	(0.0026)	(0.0551)	(0.0977)	0.0425	0.1235	0.2018	0.2670	0.2363	0.2257	0.2144	0.2057	0.3763