DEPARTMENT OF TRANSPORTATION

# Development of a Process for Quantifying the Benefits of Research

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**July 2017**

Research Project
Final Report 2017-13

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**Technical Report Documentation Page**

| 1. Report No. | 2. | 3. Recipients Accession No. |
|---|---|---|
| MN/RC 2017-13 | | |
| 4. Title and Subtitle<br>Development of a Process for Quantifying the Benefits of Research | | 5. Report Date<br>July 2017<br>6. |
| 7. Author(s)<br>Howard Preston and Jacqueline Dowds Bennett | | 8. Performing Organization Report No. |
| 9. Performing Organization Name and Address<br>CH2M Hill<br>1295 Northland Drive, Suite 200<br>Mendota Heights, MN 55120 | | 10. Project/Task/Work Unit No.<br>11. Contract (C) or Grant (G) No.<br>(C) 05794 |
| 12. Sponsoring Organization Name and Address<br>Minnesota Department of Transportation<br>Research Services & Library<br>395 John Ireland Boulevard, MS 330<br>St. Paul, Minnesota 55155-1899 | | 13. Type of Report and Period Covered<br>Final Report<br>14. Sponsoring Agency Code |

15. Supplementary Notes

http:// mndot.gov/research/reports/2017/201713.pdf

Related Materials:

- User guide: http:// mndot.gov/research/reports/2017/201713A.pdf
- Final presentation: http:// mndot.gov/research/reports/2017/201713B.pdf
- Spreadsheet tool: http:// mndot.gov/research/reports/2017/201713C.pdf

16. Abstract (Limit: 250 words)

MnDOT Research Services funds and administers approximately 180 transportation research projects annually at a cost of slightly more than $3 million. This project developed an easy-to-apply process for quantifying the potential benefits of research and comparing the monetary benefits of implemented research results with the cost of doing the research.

Researchers applied this process to a limited number of previously completed MnDOT research projects and determined that the potential three-year cost savings (approximately $69 million) of just 11 sample projects was enough to fund the cost of the entire research program for approximately seven years.

The ultimate outcome of this project is a guidance document and user tool for quantifying the benefits of research recommendations.

| 17. Document Analysis/Descriptors | | 18. Availability Statement | |
|---|---|---|---|
| benefit cost analysis, research, benefits | | No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312 | |
| 19. Security Class (this report) | 20. Security Class (this page) | 21. No. of Pages | 22. Price |
| Unclassified | Unclassified | 90 | |

# Development of a Process for Quantifying the Benefits of Research

## FINAL REPORT


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## July 2017


*Published by:*

Minnesota Department of Transportation
Research Services & Library
395 John Ireland Boulevard, MS 330
St. Paul, Minnesota 55155-1899

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ARTS | Automated Research Tracking System |
| CSAH | County State Aid Highway |
| $yd^3$ | cubic yard |
| DOT | department of transportation |
| FHWA | Federal Highway Administration |
| HMA | hot mix asphalt |
| K-TRAN | Kansas Transportation Research and New Developments |
| MnDOT | Minnesota Department of Transportation |
| MnROAD | MnDOT Office of Materials and Road Research |
| NCHRP | National Cooperative Highway Research Program |
| PCC | Portland cement concrete |
| PCSSS | Precast Composite Slab Span System |
| pdo | property damage only |
| PG | performance-grading |
| PI | principal investigator |
| SMART | Systematic Monitoring of Arterial Road Traffic Signals |
| STC | Southeast Transportation Consortium |
| TAP | Technical Advisory Panel |
| TPF | Transportation Pooled Funds |
| TRB | Transportation Research Board |

# EXECUTIVE SUMMARY

MnDOT's Research Services funds and administers approximately 180 projects annually at a cost of slightly more than $3 million (this value does not include projects that are supported by the National Cooperative Highway Research Program, Transportation Research Board or with funds pooled from participating states). These projects investigate ways to improve the design, construction, maintenance, management, environmental compatibility, quality of operations, and safety performance of highway systems through the implementation of innovations identified in the research. Previously, a variety of methods was used to evaluate research projects upon completion with a focus on leveraging the immediate potential benefits, raising the awareness of the research results, and encouraging both MnDOT and local highway agency staff to consider implementation of the key results.

Research Services envisions that an understanding of the benefits of research recommendations implemented statewide for previously supported projects as compared to research cost would help raise awareness of the value of the research and support implementation efforts for future research recommendations. Furthermore, this understanding will help Research Services improve its selection process for new projects. Before moving forward with this approach, Research Services determined it was necessary to develop a uniform approach to quantifying benefits in more absolute terms such as the dollar value of particular ideas (i.e. the reduction in labor or material costs). The objective of this project is to develop an easy-to-apply process for quantifying benefits and then to apply the process to a limited number of previous research projects selected by MnDOT technical experts as part of a pilot study. The ultimate outcome of this project is a guidance document and user tool for quantifying the benefits of research recommendations.

To review current practices for identifying and quantifying the benefits of research, a literature review was conducted of documents recommended by Research Services and MnDOT technical experts were interviewed. The review of approximately a dozen reports suggested that the evaluation methodology should not be too long or complex and flexible. These reports also suggested that very few states have developed and adopted formal guidelines for assessing the benefits of research. Those that have promote the practice of starting the determination of research benefits early in the research effort. ***The MnDOT technical experts suggested benefit quantification should be an integral part of the entire research process and should be coordinated with MnDOT's Office of Transportation System Management. The experts also acknowledged that many projects support and/or improve MnDOT practices and policies, but would not produce quantifiable benefits. Ideas that were incorporated into the benefit estimation process include: inclusion of the ten MnDOT benefit categories for research; the notion of focusing efforts to quantify benefits on only a few, select projects*** that were identified as likely having benefits; and adopting MnDOT values for user and safety benefits.

Following the review of current practices, a seven-step process was approved for use in the pilot study. The process includes the following steps:

1. Determine Benefit Category
2. Build/Apply the Benefit Estimation Tool

3. Collect Input Data
4. Document Extent of Actual/Probable Implementation
5. Populate Benefit Estimation Tool
6. Determine/Quantify Benefit
7. Compare Benefit to Cost

The benefit estimation tool (an Excel spreadsheet) evolved into six separate tools when it was determined through the course of the study that the computation process would be somewhat different and require different input based on the category of the benefit. The selected benefit categories include:

- Construction Saving
- Decreased Engineering/Administrative Costs
- Decreased Lifecycle Costs
- Environmental Aspects
- Increased Lifecycle
- Operation and Maintenance Savings
- Safety (Crash Reduction)
- User Benefit
- Risk Management

Based on literature review findings, it was determined that the tool would be set to compute the present value of three years of annual benefits (to reduce the possibility of the outcome being overly influenced by one unusual year) using a 2 percent interest rate based on consistency with the approach used in other DOT's and with the practices of MnDOT's Office of Investment Management. Ten-year benefits were also estimated to demonstrate the ongoing value of the recommendations over time.

Input data was collected for eleven research projects selected by MnDOT technical experts based on their opinion about which projects would be most likely to produce benefits that could be quantified. The research projects selected for the pilot study are:

- Assessment and Recommendation for Operation of Standard Sumps as Best Management Practices for Stormwater Treatment
- Economic and Environmental Costs and Benefits of Living Snow Fences: Safety, Mobility, and Transportation Authority Benefits, Farmer Costs, and Carbon Benefits
- Effects of Signing and Lane Markings on the Safety of a Two-Lane Roundabout
- Full-Depth Precast Concrete Bridge Deck System (Phase II)

- Improving Weigh-In-Motion Sensor Accuracy Between Calibrations
- Investigation of Low-Temperature Cracking in Asphalt Pavements (Phase II)
- Load and Resistance Factor Design (LRFD) Pile Driving Project (Phase II)
- Putting Research into Practice: Snowplow Calibration Guides for MnDOT and Local Governments
- Recycled Unbound Materials
- Systematic Monitoring of Arterial Road Traffic Signals (SMART) Signal
- Traffic Sign Life Expectancy
- Traffic Sign Maintenance/Management Handbook

Initially it was determined that none of these projects had reported benefits consistent with the adopted performance measures – the present value of three years worth of identified annual benefits and that the effort to obtain the necessary input data would involve reviewing the reports to obtain the data to be entered into the tool. In fact this turned out to be the case for only two of the projects.

This level of effort was unexpected and greatly added to the timeline for completion. Ultimately, enough data was obtained for all but one project. However, in several cases, this involved generating substitutes for actual data using estimation and speculation based on information from sources with varying degrees of reliability. This led to assigning a level of confidence to the output – high if the necessary data existed and were from either MnDOT or local agency sources that were considered reliable and low if the data did not exist and substitutes for real data had to be estimated from unreliable sources.

For the eleven projects where input data was obtained or estimated, the tool computed results of present value ranging from $0 to $30.7 million (Table ES-1) per project over a three-year benefit time frame. Table ES-1 includes a level of confidence in the results. A rating of 1 was assigned if the necessary data existed and was from either MnDOT or local agency sources that were considered reliable. A rating of 2 was assigned if there was a lack of data in the report, the dataset was small and/or a few assumptions were required to be made. A rating of 3 was assigned if the data did not exist and substitutes for real data had to be estimated from unreliable sources.

Results for six of the projects were considered to have a high level of confidence. In addition, seven of the projects were determined to have benefits greater than the cost to produce the research and develop the recommendations. For example, the potential savings associated with the storm water baffle, low-temperature asphalt mixture, and traffic sign research projects collectively exceed three years' of Research Service's annual budget for all research (approximately $10 million), justifying the continuing existence of the research program.  Furthermore, the potential three-year cost savings for all 11 of these sample projects (approximately $69 million) would fund the entire research program for approximately 7 years.

The results of this pilot effort support a conclusion that the overall value of MnDOT’s research program can be demonstrated by focusing on a select few projects for which data is available to conclusively prove that a high benefit/large cost savings can be achieved by implementing research recommendations. Thus, a representative sampling of projects is sufficient to demonstrate a benefit to the state’s citizens in the form of dollars saved compared to expenditures in support of the research program.

Table ES-1. Summary of Quantitative Benefits for Selected Research Projects for Three- and Ten- Year Time Periods

| Research Project | Project Number | Research Area | Report Number | Project Cost | Net Present Value of Benefits | | | | Savings-Cost of Research Ratio | | Confidence Level |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Actual | Estimated | Calculated Value | | | | |
| | | | | | | | 3-Year | 10-Year | 3-Year | 10-Year | |
| Assessment and Recommendation for Operation of Standard Sumps as Best Management Practices for Stormwater Treatment | 2008-005 | Environmental Stewardship | 2012-13 | $257,000 | | ✓ | $8.5M | $26.4M | 33.1 | 102.7 | 3 |
| Economic and Environmental Costs and Benefits of Living Snow Fences: Safety, Mobility, and Transportation Authority Benefits, Farmer Costs, and Carbon Benefits | 2009-035 | Maintenance | 2012-03 | $99,000 | | ✓ | $141K | $440K | 1.4 | 4.4 | 3 |
| Effects of Signing and Lane Markings on the Safety of a Two-Lane Roundabout | 2013-053 | Traffic Safety | 2014-04 | $124,920 | ✓ | | $0 | $0 | 0.0 | 0.0 | 2 |
| Full-Depth Precast Concrete Bridge Deck System (Phase II) | 2009-017 | Bridge and Structures | 2012-30 | $165,000 | | ✓ | $29K | $91K | 0.2 | 0.6 | 2 |
| Improving Weigh-In-Motion Sensor Accuracy Between Calibrations | 2015-18 | Materials and Road Research | 2015-18TS | $95,000 | | ✓ | $80K | $249K | 0.8 | 2.6 | 1 |
| Investigation of Low Temperature Cracking in Asphalt Pavements (Phase II) | TPF-5(132) | Materials and Road Research | 2012-23 | $475,000 | ✓ | | $6.6M | $20.8M | 13.9 | 43.8 | 1 |
| Load and Resistance Factor Design (LRFD) Pile Driving Project (Phase II) | 2007-030 | Bridge and Structures | 2014-16 | $160,000 | | | Could not compute | | Could not compute | | 4 |
| Putting Research into Practice: Snowplow Calibration Guides for MnDOT and Local Governments | 2008-104 | Maintenance | 2009RIC08 | $88,705 | ✓ | | $400K | $1.2M | 4.5 | 13.5 | 1 |
| Recycled Unbound Materials | TPF-5(129) | Materials and Road Research | 2012-35 | $349,910 | ✓ | | $2.3M | $7.3M | 6.6 | 20.9 | 1 |
| SMART Signal | Unknown | Traffic Operations | Unknown | $239,000 | | ✓ | $155K | $155K | 0.6 | 0.6 | 3 |
| Traffic Sign Life Expectancy | 2012-063 | Traffic Safety | 2014-20 | $37,722 | | ✓ | $19.7M | $62.5M | 522.2 | 1656.9 | 1 |
| Traffic Sign Maintenance/ Management Handbook | 2013-052 | Traffic Safety | 2014RIC20 | $49,891 | | ✓ | $30.7M | $95.6M | 615.3 | 1916.2 | 1 |

Notes:
1: High level of confidence in the benefit estimation. This level of confidence was assigned if the data used in the estimation effort was either contained in the research report or obtained from a credible source.
2: Medium level of confidence in the benefit estimation. This level of confidence was assigned for one or more of the following reasons: a lack of data in the report, a small dataset, and/or the requirement to make a few assumptions.
3: Low level of confidence in the benefit estimation. This level of confidence was assigned for one or more of the following reasons: a lack of data in the report, inability to find relevant data from a credible source, a small dataset, or the requirement to make several assumptions.
4: Benefits could not be computed.

The pilot effort also identified a number of recommendations to modify the research process that would reinforce the importance of addressing benefits and including the necessary data in the project documents to support the computation of benefits:

- Select a representative sampling of projects to justify the research program. There is no reasonably objective means to estimate the benefits of the entire research program.
- Instill identification and quantification of benefits into all phases of research:
  - Emphasize the importance of addressing benefits from the beginning – make discussing potential benefits of research a key part of the project selection process. Include a benefits discussion along with an overview of the quantification process in the agenda for the first Technical Advisory Panel (TAP) meeting.
  - Conduct a pre-proposal webinar during the selection process and use that opportunity to make all participants aware that the selection process will include an evaluation of the potential benefits discussion included in the proposal.
  - Require research proposals to include scope to develop a plan for identifying data for quantifying potential benefits.
  - Conduct a post-proposal workshop with the selected university researchers shortly after notification to proceed. The objective would be to reinforce the requirement to include information about potential benefits, identifying approaches for quantifying benefits in their reports, and inviting their thoughts about how to generate the information and incorporate it into their reports. One way to encourage researchers' participation in this workshop would be to make it a separate task in their contract, which means they would be paid to attend.
  - Require that research reports include a discussion of potential benefits and to provide either actual or estimated data for the existing or before condition to serve as a basis for comparison once the recommendations are implemented. This discussion should include a realistic timeframe and level of deployment.
  - Require that research reports include evaluation and benefit quantification plans that have collectable data elements into research reports.
  - Encourage investigators and MnDOT staff to collaborate in benefit identification.
- Recognize that quantitative benefits should not be the sole deciding factor in the research proposal selection process. Research recommendations could provide value for modifying practices or policies.
- Assign the responsibility to quantify benefits to the Research Services staff assigned to each project and hold them accountable for computing the value of the benefits using the tool provided as part of this pilot effort and reporting the results to MnDOT management.
- Follow a consistent process to estimate research benefits.

# CHAPTER 1: INTRODUCTION

The Minnesota Department of Transportation's (MnDOT) Research Services administers approximately 180 projects annually that are intended to improve the design, construction, maintenance, management, environmental compatibility, quality of operations, and safety performance of transportation systems through research and implementation of innovations. Many of these projects support and/or improve MnDOT practices and policies. Previously, a variety of methods were used to evaluate research projects following completion. These methods focused on leveraging the immediate potential benefits, raising the awareness of the research, and encouraging state Research Services' staff and other highway agencies to consider implementation of the key results.

Research Services is undertaking a more detailed process of evaluation that includes quantifying the benefits of research projects in more absolute terms, such as the dollar value of particular ideas when implemented across the state's transportation system compared to the cost of conducting the research. The dollar value could be represented by the labor savings realized from an improved design or construction technique or the labor and material savings realized by increasing the lifecycle of traffic signs or pavement. Monetary savings can also be gained for the public by reducing traffic crashes and for MnDOT by reducing fines through modifications to construction or maintenance practices.

The objective of this project is to develop an easy-to-apply process for quantifying benefits and then apply the process to a limited number of previous research projects as part of a pilot study. The ultimate outcome of this project is a guidance document and user tool for quantifying the benefits of research recommendations. This effort acknowledges that research-generated recommendations will likely have qualitative benefits that cannot be captured solely in economic terms through a process that calculates monetary benefit. The value of some recommendations generated by research projects would be realized by improvements to processes and procedures. Other qualitative benefits could be in the form of user benefits such as reduced travel time or the environmental benefits of less sediment in the waterways.

This report is organized into the following five chapters that represent the individual tasks performed to develop the benefit quantification process for research efforts and associated training materials:

Chapter 1 introduces the objective and purpose of the project.

Chapter 2 summarizes the literature review, which concluded with the decision to follow a similar process to that used by the Kansas Department of Transportation to quantify benefits.

Chapter 3 details the development and refinement of a step-by-step process for estimating potential research project benefits. The process provides a justifiable means to estimate monetary benefits and perform a traditional benefit-cost analysis to assess viability.

Chapter 4 presents the results of applying the quantification process to eleven selected research projects and discusses the broader benefits of the state's research program.

Chapter 5, the final section, introduces the user's guide and training materials developed to assist researchers with the application of the benefit quantification process.

# CHAPTER 2: REVIEW OF CURRENT PRACTICES

To review current practices for identifying and quantifying the benefits of research, a literature review was conducted of documents recommended by Research Services and MnDOT technical experts were interviewed. The results of these efforts determined that there is currently no uniform methodology or preference for conducting a research benefit analysis. The information gained during the review provided the basis for developing the research benefit quantification process. This chapter summarizes the process of this review.

Relevant Documents. Approximately a dozen reports related to quantifying research benefits were identified and reviewed. The following provides an overview of the three most relevant documents and the key points contained in each:

- Guidelines for Estimating the Triennial Benefits of Kansas Transportation Research and New Developments (K-TRAN) Research Projects – Report No. KS-03-9
  - In a 12-year period, K-TRAN funded more than 200 research projects at a cost of $7.3 million.
  - Research project monitors developed estimates of monetary benefits for 25 implemented projects and computed a Benefit:Cost ratio greater than 37:1.
  - The estimated benefits for the entire research program was extrapolated and determined to be approximately 15:1.
  - The suggested process for determining research benefits started early in the process and required the principal investigator (PI) to perform an initial subjective assessment of potential benefits, using a checklist of 10 benefit categories. These included:
  1. Construction Cost Savings
  2. Operation and Maintenance Savings
  3. Increase Life Cycle
  4. Decrease Life Cycle Costs
  5. Safety
  6. Decrease Administrative Costs
  7. Environmental Aspects
  8. Technology
  9. User Benefits
  10. Impact on Agency Policy
  - The suggested process also includes the PI assigning its project a value between 1 and 10, which represented an assessment of the ability to identify and quantify benefits – a value of 1 represented No Benefit, a value of 5 represented potential benefits but no ability to quantify, and 10 represented certain benefits and the ability to quantify.
  - The process requires researchers to attempt to quantify monetary benefits and, if possible, to also compute a Benefit:Cost ratio. If it is determined that it is not possible to compute actual benefits, the results of the subjective assessment are considered to represent the best possible outcome.

   - It should be noted that the report did not include any explanation of exactly how benefits for the example projects were actually computed.

- Southeast Transportation Consortium Synthesis of Best Practices for Determining Value of Research Results – Final Report 512

The synthesis identified 12 research impact areas, the 10 identified in the Kansas report plus customer satisfaction and system reliability.

The synthesis found that none of the consortium states have developed and adopted formal guidelines for assessing the benefits of research and that there have been few attempts to quantify benefits that are hard to put a monetary value on.

A suggested evaluation methodology should not be too long or complex, which could discourage its use. Flexibility is the key – the process should have multiple classifications, measures, and methods.

It was also noted that there is a need to train researchers and department of transportation (DOT) staff and to communicate the findings, including reinforcing the value of conducting research.

- Best Practice Guide for Quantifying the Benefits of MnDOT Research

The key findings and the suggested best practice approach to quantifying benefits was based on an overview of efforts made in four states – Utah, Missouri, Florida and Louisiana.

Key findings included focusing efforts to quantify benefits only on select projects that were identified as likely having benefits (projects documenting user benefits, safety benefits, reduced construction and maintenance costs, etc.) and that the methods and calculations were customized for individual projects.

The best practice includes starting early (using both PI's and DOT technical staff), systematically tracking research projects through implementation and then documenting assumptions, calculations and the resulting Benefit:Cost ratio.

**Interview Questionnaire.** A questionnaire was developed for use in conversations conducted with MnDOT technical experts to determine how they used the results of research, ask if they previously made any effort to quantify benefits, and request their input relative to identifying a short list of projects based on the ability to quantify benefits that would be candidates for a detailed analysis. The questionnaire consisted of a paragraph that provided an overview of the project and the following nine questions:

1. Can you identify any examples of how you have used results of research to improve your work practices?
2. Are there particular research topics you are most interested in?
3. For research projects that you found to be beneficial, how did you determine there was a benefit? A subjective approach? An objective approach?
4. How do you expect to use this information (about benefits)?
5. Does your office have a process to identify benefits in travel time, safety, construction, maintenance, project delivery?
6. Does your office have established values for estimating travel time, crash cost, labor, maintenance, construction, etc.?
7. Do you have any suggestions about a specific approach to quantifying benefits of research?

8. Are there particular research projects that you suggest be used as an example for quantifying benefits? (See the provided list of previously published reports.)
9. Are you aware of any university researchers that have quantified the expected benefits of their completed research projects?

**Interviews with MnDOT Technical Experts.** The questionnaire was used to document the information provided during conversations with the technical experts selected by Research Services staff. The MnDOT technical staff who participated included:

- Traffic Safety – Sue Groth and Brad Estochen
- Bridge and Structures – Nancy Daubenberger and Paul Rowekamp
- Maintenance – Tom Peters, Bob Vasek, and Clark Moe
- Traffic Operations – Steve Misgen, Kevin Schwartz, Jim Kranig, and Brian Kary
- Environmental Stewardship – Lynn Clarkowski and Scott Bradley
- Materials and Road Research – Chris Kufner, Ben Worel, and Glenn Engstrom

Key comments provided during the conversations included:

- **Projects funded by Research Services added value by supporting and advancing their work, but it was expected that actually quantifying benefits would be challenging because many of the projects dealt with policy issues as opposed to items that could actually be monetized.**
- **Staff acknowledged that many projects supported and/or improved MnDOT practices and policies, but would not likely result in benefits that could be quantified.** Examples included confirming that current bridge design practices are consistent with national guidelines and that MnDOT's approach to marking the entries to high-occupancy toll lanes produces comparable safety and operational performance measures as Federal Highway Administration's (FHWA) guidelines.
- **Staff suggested having two subjective scales relating to the benefits of research** – the first assigning a subjective value to the project based on a range of no value to high value and the second scale assessing the ability to quantify benefits.
- **Identifying potential benefits of research should be an integral part of the entire research process.** It was noted that the Research Needs Statement already includes a requirement to identify potential benefits – the selection process could assign greater weight to the PI's response in their proposal. In addition, Research Services could require that all research reports include at least a minimal discussion of potential benefits, likely performance measures and a suggested analytical process for quantifying benefits.
- **Staff suggested a need to coordinate efforts to quantify benefits research with MnDOT's Office of Transportation System Management where efforts had been made to estimate the benefits associated with improvements to the State's Trunk Highway System.** (Note: CH2M HILL had a conversation with Deanna Belden and John Wilson and they provided links to tables of standard values for analyses of travel time and safety.)

**Benefits of MnROAD Phase-II Research Report.** The Minnesota Road Research Project (MnROAD) is an accelerated pavement test facility owned and operated by the Minnesota Department of Transportation. Transportation research is conducted at the facility to identify opportunities to achieve increases in performance and pavement life to reduce costs for maintenance, repairs, user delays, and congestion. This report summarizes the outcome of the 32 projects that were completed during

MnROAD Phase-II. The results include a discussion of the research costs and the process to quantify the monetary benefits of the project recommendations, which were based on material savings or enhanced performance. The MnROAD calculations estimate a combined monetary savings of over $10 million per year for the ten-year period starting in 2016 upon completion of Phase-II, for a total potential savings of $104 million. Based on a total cost to conduct the research projects of $28 million, the approximate benefit-cost ratio of the Phase-II projects is 3.8. The process varies from the benefit quantification process presented in this report in two ways: it does not account for the time value of money and it does not cover a 3-year time frame. The two processes are similar in their acknowledgement that some benefits are qualitative and therefore not quantifiable in terms of monetary savings.

**Ideas Incorporated into Benefit Estimation Process.** The effort to review current practices identified several ideas that merit incorporation into the process to quantify benefits. The effort also identified values for user benefits and safety that will be part of the computational process. Specifically, these items include:

- The 10 benefit categories for research.
- The notion of focusing efforts to quantify benefits on only a few, select projects that were identified as likely having benefits.
- Identifying adopted MnDOT values for computing user and safety benefits.

# CHAPTER 3: DEVELOPMENT OF RESEARCH BENEFIT QUANTIFICATION PROCESS

The intent of this task was to develop an easily applied methodology for comparing the potential monetary benefit to be gained by the implementation of the research recommendations to the cost of the research effort. The resultant methodology is represented by a seven-step process for quantifying research benefits based on potential cost savings and estimating a benefit-cost ratio. The process is adaptable to a variety of research topics and benefit categories. As the process flowchart in Figure 1 shows, most of the steps should be completed in order since the information gained in these steps informs a subsequent step, but a few steps can be performed simultaneously (Steps 3/4/5). The remainder of this chapter documents the development and application of each step in the seven-step quantification process:

1. Determine Benefit Category
2. Build Benefit Estimation Tool
3. Collect Input Data
4. Document Implementation of Recommendations
5. Populate Benefit Estimation Tool
6. Determine Benefit
7. Compare Benefit to Cost

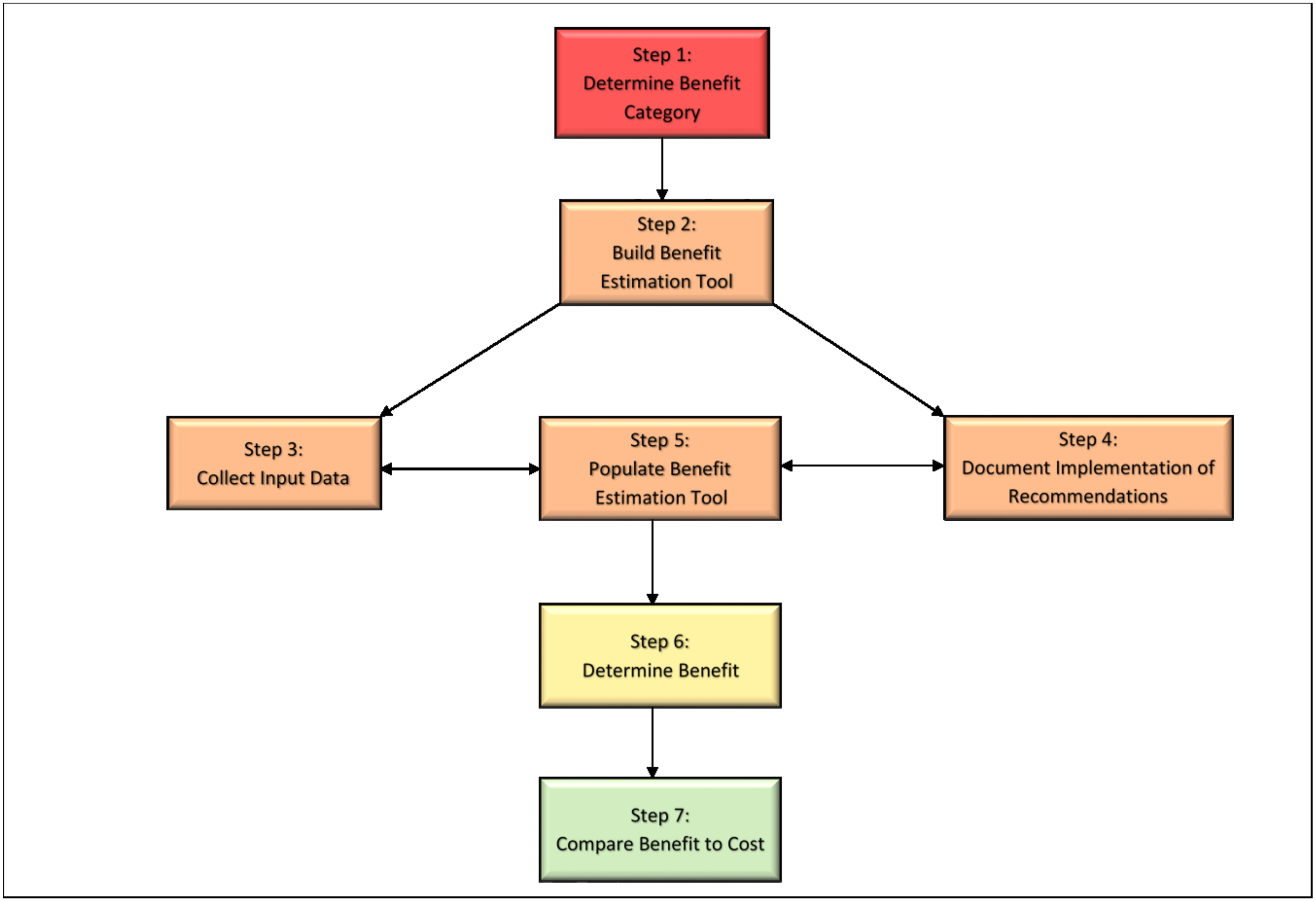



**Figure 1. Benefit Quantification Process Flowchart**

## 3.1 DETERMINE BENEFIT CATEGORY

***Developing the step.*** Development of the quantification process began with identification of the potential benefits to be gained through the implementation of research recommendations. The research projects conducted by the MnDOT generally present recommendations for solving existing problems; achieving cost savings through reductions in time, materials, crashes, or tort claims/fines; or reducing environmental impacts. MnDOT Research Services maintains a database that provides information on all of its sponsored research projects. The Automated Research Tracking System (ARTS) database stratifies benefits into 6 topic areas and 10 benefit categories (shown in Table 1). The need for a Risk Management benefit category was identified during this project and is included in the Benefit Type Matrix. These benefit categories generally capture the nature of the recommendations resulting from the research. Therefore, these categories were the starting point for determining the benefits to include in the quantification process. The benefits are expressed in terms of dollars saved over a defined time period.

Table 1 shows the results of a qualitative assessment of the potential benefits to be realized from research in each topic area. Discussions among the project team led to the decision to exclude two benefit categories from the quantification process (Impact on Policy and Technology) due to limited ability to quantify these benefits. Research projects from all six topic areas were selected for use in developing the quantification process and tool.

***Performing the step.*** The first step in the quantification process is to select the applicable benefit category to include in the evaluation. Multiple benefit categories may be applicable to a research project, so the user should select all appropriate benefit categories from the following list:

- Construction Saving
- Decrease Engineering/Administrative Costs
- Decrease Lifecycle Costs
- Environmental Aspects
- Increase Lifecycle
- Operation and Maintenance Saving
- Safety
- User Benefits
- Risk Management

**Table 1 - Benefit Type Matrix**

| ARTS Benefit Categories | Bridge & Structures | Environmental | Maintenance | Materials | Traffic Operations | Safety |
|---|---|---|---|---|---|---|
| Construction Saving (Materials, labor/time, equipment) | ● | ○ | -- | ● | ○ | -- |
| Decrease Engineering/ Administrative Costs (Planning/design costs, paperwork) | ○ | ○ | ○ | ○ | -- | -- |
| Decrease Lifecycle Costs | ○ | -- | ○ | ○ | -- | -- |
| Environmental Aspect (Pollution, hazardous waste reductions, recycling) | -- | ● | -- | -- | -- | -- |
| Impact on MnDOT Policy (qualitative only) | ○ | ○ | ○ | ○ | ○ | ○ |
| Increase Lifecycle | ○ | -- | ○ | ○ | -- | -- |
| Operation and Maintenance Saving (Materials, labor/time, equipment) | ○ | -- | ● | ○ | -- | -- |
| Safety (Reduction of crash frequency and/or severity) | -- | -- | -- | -- | ○ | ● |
| Technology (Technology transfer, new materials, new methods) | ○ | ○ | ○ | ○ | ○ | ○ |
| User Benefits (Time, dollars) | -- | -- | -- | -- | ● | -- |
| Risk Management (Tort Liability, Environmental Fines) | -- | ○ | -- | -- | -- | ○ |

● High expectation that research will provide benefits

○ Research may provide benefits

-- Low expectation that research will provide benefits

## 3.2 STEP 2: BUILD BENEFIT ESTIMATION TOOL

***Developing the step.*** The benefit estimation tool uses an Excel spreadsheet platform, which was selected because it is widely available and generally understood by most computer users. Spreadsheets to calculate the potential benefits of eleven research projects were developed first. The commonalities among these 10 spreadsheets (note: the two traffic sign projects are included in the same spreadsheet) were then synthesized into 6 template spreadsheets to create the benefit estimation tool.

### 3.2.1 Subject Research Project Spreadsheets

Completed research projects were used as test subjects to gain insight into the benefit estimation process and tool development. The intent was to select projects that were of benefit to a variety of offices within the MnDOT and could be quantified. The following projects were initially identified based on the appearance that they have high benefit value and would be easily quantifiable:

- Assessment and Recommendation for Operation of Standard Sumps as Best Management Practices for Stormwater Treatment
- Economic and Environmental Costs and Benefits of Living Snow Fences: Safety, Mobility, and Transportation Authority Benefits, Farmer Costs, and Carbon Benefits
- Effects of Signing and Lane Markings on the Safety of a Two-Lane Roundabout
- Full-Depth Precast Concrete Bridge Deck System (Phase II)
- Investigation of Low Temperature Cracking in Asphalt Pavements (Phase II)
- Load and Resistance Factor Design Pile Driving Project (Phase II)
- Putting Research into Practice: Snowplow Calibration Guides for MnDOT and Local Governments
- Recycled Unbound Materials
- Systematic Monitoring of Arterial Road Traffic Signals (SMART) Signal
- Traffic Sign Life Expectancy
- Traffic Sign Maintenance/Management Handbook

The project team reviewed these research reports to determine the quantifiable benefits promoted in the report. The review included the identification of measurable factors or features that would be useful in estimating quantities and calculating benefits in terms of dollars. The team then met with staff from MnDOT offices that could implement the research and benefit from the recommendations to confirm the proposed approach to computing the benefits and discuss the ability to measure or quantify the factors involved in the computations. These discussions resulted in the elimination of the *Load and Resistance Factor Design Pile Driving Project* research project due to the inability to quantify any factors appropriate for benefit calculations (however, the research was very valuable to the overall practice of foundation design). This project was replaced with the *Improving Weigh-In-Motion Sensor Accuracy between Calibrations* project.

Once the quantifiable factors for each project were identified, one spreadsheet was developed for each project for use in calculating the potential benefits in terms of cost savings. Although the inputs, calculation formulas, and output varied by project, the same general format was maintained for each of the ten spreadsheets.

Using this formatting, each of the ten spreadsheets was constructed using the quantifiable factors identified from the research reports and discussions with MnDOT staff. The following provides an overview of the components of the ten spreadsheets and associated quantification calculations. The case studies in Appendix A contain an expanded discussion of the projects and include the assumptions applicable to each project and the resultant benefit quantification spreadsheet with the input/output values displayed. The interest rate used in the Net Present Value calculation is 2.0 percent, which is the currently-published MnDOT value. With the exception of the SMART Signal project, the benefits were estimated for two time frames: three years, which is based on similar practices by other state DOTs for estimating the benefits of research programs, and ten years, which is based on similar practices by the MnDOT Office of Materials and Road Research (MnROAD) for estimating the benefits of research project recommendations.

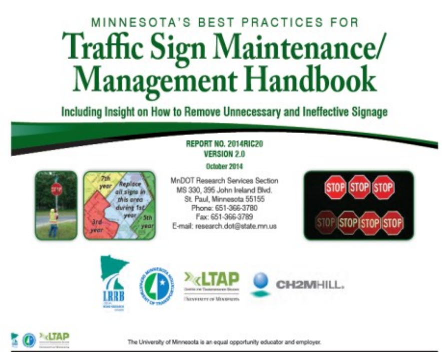
- **Assessment and Recommendation for Operation of Standard Sumps as Best Management Practices for Stormwater Treatment (SAFL Baffle)** – The research proved that sumps with baffles are effective for removing and retaining sediments from stormwater runoff. The research effort developed the Saint Anthony Falls Laboratory (SAFL) baffle, a device that increases the effectiveness of sumps at retaining captured sediments during high flow rates. For purposes of developing the quantification tool, the benefit of this research effort is expressed in terms of reduced cost for the purchase and installation of the SAFL baffle as compared to traditional methods of purchasing and installing baffles in stormwater manholes. The benefit calculation involves estimating the difference between the average cost of other baffles and the SAFL baffle, and then applying the cost difference to the estimated annual number of baffle purchases.
- **Economic and Environmental Costs and Benefits of Living Snow Fences** – Safety, Mobility, and Transportation Authority Benefits, Farmer Costs, and Carbon Benefits – This research effort developed a calculator for estimating optimal payments that would encourage landowners to participate in the establishment and maintenance of living snow fences. There are benefits to living snow fences relative to traffic safety and reduced maintenance requirements. For purposes of developing the quantification tool, the safety benefit of this research effort is expressed as the societal cost savings achieved by a reduction in the frequency of severe (fatal and incapacitating injury) crashes attributed to the implementation of living snow fences. The benefit calculation involves determining the annual crash reduction (the change in crashes attributed to the improvements) by severity level and then multiplying these crash numbers by the respective currently-published MnDOT values for crash cost by severity for fatalities and incapacitating injuries.

## SUBJECT RESEARCH PROJECTS

- Assessment and Recommendation for Operation of Standard Sumps as Best Management Practices for Stormwater Treatment
- Economic and Environmental Costs and Benefits of Living Snow Fences: Safety, Mobility, and Transportation Authority Benefits, Farmer Costs, and Carbon Benefits
- Effects of Signing and Lane Markings on the Safety of a Two-Lane Roundabout
- Full-Depth Precast Concrete Bridge Deck System (Phase II)
- Improving Weigh-In-Motion Sensor Accuracy Between Calibrations
- Investigation of Low Temperature Cracking in Asphalt Pavements (Phase II)
- Putting Research into Practice: Snowplow Calibration Guides for MnDOT and Local Governments
- Recycled Unbound Materials
- SMART Signal
- Traffic Sign Life Expectancy
- Traffic Sign Maintenance/ Management Handbook

- **Effects of Signing and Lane Markings on the Safety of a Two-Lane Roundabout** – This research effort evaluated improvements to signage and lane markings to improve driver understanding of how to navigate two-lane roundabouts. While the report includes before-and-after crash statistics, the research findings express the benefits in terms of reduced driver violations. For purposes of developing the quantification tool, the safety benefit of this research effort is expressed as the societal cost savings achieved by a reduction in the frequency and severity of crashes attributed to the implementation of the signing, pavement marking, and enforcement improvements recommended in the report. The benefit calculation involves determining the annual crash reduction (the change in crashes attributed to the improvements) by severity level and then multiplying these crash numbers by the respective currently-published MnDOT values for crash cost by severity. To calculate the potential annual benefit across the state, the sum of the savings for all severity levels is then multiplied by an estimated number of two-lane roundabouts in Minnesota.
- **Full-Depth Precast Concrete Bridge Deck System (Phase II)** – This research effort identified an improved design/construction technique for use with the Precast Composite Slab Span System (PCSSS) developed by MnDOT in 2005. Over time, MnDOT discovered cracking of the bridge deck surface for some bridges constructed using PCSSS. In response, researchers analyzed three design techniques to determine the optimal design for reducing deck cracking and increasing cost-effectiveness and constructability. For purposes of developing the quantification tool, the benefit of this research effort is expressed in terms of reduced labor cost to design this type of bridge. The benefit calculation involves estimating the labor costs for this type of design with and without use of the improved design technique.
- **Improving Weigh-In-Motion Sensor Accuracy Between Calibrations** – This research effort developed a software program that implements a quality control methodology to identify when a Weigh-In-Motion sensor has lost accuracy. The remote monitoring capability enables the reduction of two rounds of field calibration to one per year. For purposes of developing the quantification tool, the benefit of this research effort is expressed in terms of reduced cost for completing one round of field calibration. The benefit calculation involves estimating the labor, direct expense, and equipment costs for one round of field calibration.
- **Investigation of Low Temperature Cracking in Asphalt Pavements (Phase II)** – This research effort developed an optimal system for selecting low temperature crack-resistant asphalt mixtures for which cracking can be better predicted. The improved predictive capabilities were gained through an increase in knowledge of all the interactions amongst asphalt materials, with fracture toughness (energy) being the key material property for the focus of this research. The application of the testing system ideally results in the selection of better materials for asphalt mixtures, leading to fewer pavement cracks. For purposes of developing the quantification tool, the benefit of this research effort is expressed in terms of reduced maintenance, overlay, and new construction costs. The benefit calculation involves estimating the reduction in cracks sealed, the reduction in overlays performed as a result of a longer service life, and the reduction in new construction realized due to longer pavement service life.
- **Putting Research into Practice: Snowplow Calibration Guides for MnDOT and Local Governments** – This research effort developed guidelines for agencies to follow when calibrating snow plows. For purposes of developing the quantification tool, the benefit of this research effort is expressed in terms of reduced labor cost achieved by following the guidance. The benefit calculation involves estimating the difference between the labor hours required to follow the guidelines and the traditional calibration methods.

- **Recycled Unbound Materials** – The research showed that recycled pavement materials incorporated into granular base layers demonstrated good field performance during the process to monitor the material properties during construction and throughout the pavement life. Performance was defined as very little cracking or rutting and a good pavement ride. For purposes of developing the quantification tool, the benefit of this research effort is expressed in terms of reduced cost for use of the recycled material as compared to traditional granular base material. The benefit calculation involves estimating the difference between the average cost of traditional material and recycled material for an estimated annual lane-miles of road construction.
- **SMART Signal** – This research effort developed a software program that automates the process of collecting traffic data and determining optimal timing plans at signalized intersections. For purposes of developing the quantification tool, the benefit of this research effort is expressed in terms of reduced cost for purchase and installation of the SMART Signal system as compared to traditional methods of collecting traffic data and refining signal timing plans. The benefit calculation involves estimating the difference between the one-time installation cost of the SMART Signal system and the repetitive traditional costs of collecting data and determining optimal timing plans. Unlike the other subject projects, the benefit time frame was chosen to be twelve years because it is the first common time frame between the 4-year and 6-year retiming goals for major and minor arterial intersections, respectively.
- **Traffic Sign Life Expectancy & Traffic Sign Maintenance/Management Handbook** – These research efforts analyzed traffic sign retroreflectivity degradation for the purposes of determining the actual service life of signs and then incorporating these findings into a handbook for managing sign inventories to meet retroreflectivity requirements. The handbook also included guidance for removing unnecessary and ineffective signage. For purposes of developing the quantification tool, the benefit of this research effort is expressed in terms of a reduced cost achieved by decreasing sign inventory and increasing sign service life. The benefit calculation involves two parts. The first is estimating the number of signs that can be decreased in agency inventories and the corresponding procurement cost savings. The second is estimating the reduction in the number of signs to purchase and the associated cost savings that is achieved by leaving the signs in the field for a longer time period.




### 3.2.2 Template Spreadsheets

Once the ten spreadsheets for the subject research projects were completed, they were compared to determine commonalities among them in terms of user input values and formulas for calculating benefit. This comparison effort resulted in 6 template spreadsheets that capture the 9 benefit categories (listed in Step 1) thought to be quantifiable. The template spreadsheets have similar formatting to the subject project spreadsheets:

- Blue cells – indicate user input for project information (title, number, principal investigator, and cost) and given values (standard values that are not unique to the project, such as benefit time frame, interest rate, labor rates, and societal crash costs)

- Orange cells – indicate user input for values that are unique to the project recommendations (such as, material quantities, labor hours required to conduct an activity, and frequency of strategy deployment)
- White cells – output values of the benefit calculations (such as, Annual Benefit, Net Present Value of the strategy over the benefit time frame); the formulas are locked down such that the user cannot alter the formulas that calculate the output values
- Columns - the columns are ordered from left to right such that the inputs are toward the left and the resultant output is toward the right of each row
- Output – the benefits are in the far right column, expressed as the Net Present Value of the annual benefit of implementing the recommendations over the stated time frame
- Blank cells – if there is a calculation error or a cell does not contain an entry, white cells will not populate output values of the benefit calculations, indicating a missing input value

Each template spreadsheet consists of two tabs: one that explains each of the components of the calculation spreadsheet, and one for the inputs and calculations. The following details the components of each of the six template spreadsheets and quantification calculations. These template spreadsheets collectively represent the benefit estimation tool. Appendix B contains the template spreadsheets.

- **Direct Labor Savings** – The direct labor benefit is expressed as the cost savings achieved by a reduction in labor hours achieved by the implementation of research findings. The spreadsheet provides two options to calculate the benefit – one is to input the number of hours for the current and proposed methods and the other is to input the current number of hours and the estimated percentage of time saved through use of the proposed method. The benefit calculation involves multiplying the hours saved by the applicable hourly labor rate.
- **Safety** – The safety benefit is expressed as the societal cost savings achieved by a reduction in the frequency and severity of crashes attributed to the improvements recommended by the research findings. The spreadsheet provides two options to calculate the benefit– one is to input a known change in annual crashes to represent crash reduction and the other is to input before crash data along with published crash reduction factors which the spreadsheet uses to calculate crash reduction. The benefit calculation involves multiplying the annual crash reduction (the change in crashes attributed to the improvements) by severity level by the respective MnDOT values for crash cost by severity. To calculate the potential annual benefit across the state, the sum of the savings for all severity levels is then multiplied by the estimated deployment across the state. The spreadsheet includes an input value for Level of Confidence, which can be used as a sensitivity analysis based on the likelihood that the entered deployment value will be achieved.
- **Traffic Operations/User Benefits** – The traffic operations/user benefit is calculated for both roadway users and the Department of Transportation. Occupancy is included in the calculations to compute the savings per person. The calculations are separate for passenger vehicles and commercial trucks to reflect the different values of delay for these two user groups. The user benefit is expressed as the monetary savings achieved by a reduction in travel time delay. The Department of Transportation benefit is expressed as the savings achieved from reduced maintenance requirements due to fewer stops and/or the savings in labor hours due to the elimination of tasks no longer required because of the recommendations. The spreadsheet includes an input value for Level of Confidence, which can be used as a sensitivity analysis based on the likelihood that the entered deployment value will be achieved.

- **Materials and Activities** – The materials and activities benefit is expressed as the cost savings realized from a reduction in materials or time. The spreadsheet provides three options to calculate the benefit–a reduction in material quantity due to a different installation practice, a cost savings achieved by use of a lower cost material, or a revised method of completing an activity which requires fewer labor hours. The material quantity savings calculations can be based on the change in quantity or percent reduction in quantity. The material cost savings are based on the change in price for the proposed material. The activity cost savings are based on the percent reduction in cost with use of the proposed method.
- **Lifecycle** – The lifecycle benefit is expressed the cost savings realized from using a product with a longer lifecycle, thus requiring fewer purchase and installation expenditures over time. The spreadsheet can assess the benefit of a one-time investment or annual investments to realize a cost savings due to changing the lifecycle of an item. The spreadsheet also provides the ability to analyze the savings that could be achieved by reducing inventory and increasing lifecycle.
- **Risk Management** – The risk management benefit is expressed as the cost savings realized from a reduction in fines due to implementation or research recommendations for changing actions or practices that result in fines.

***Performing the step***. The second step in the quantification process is to assemble the applicable templates into one spreadsheet file for use in calculating all of the potential benefits. The user selects the templates based on the benefit categories identified in Step 1. Table 2 shows the applicable template for each benefit category.

***Modifications.*** As necessary, the user can save a separate version of a template spreadsheet and modify it to more accurately calculate a potential benefit. The modified formulas should maintain an industry-standard methodology for calculating cost savings. Any modifications should be approved through the Research Services prior to completing the benefit quantification estimate and cost comparison. A separate version of the template is required because the formulas in the standard templates are locked and not subject to modification.

**Table 2 - Applicable Templates for Benefit Categories**

| Benefit Category | Template Spreadsheets |
|---|---|
| Construction Saving | Direct Labor Savings, Materials and Activities |
| Decrease Engineering/Administrative Cost | Direct Labor Savings |
| Decrease Lifecycle Costs | Lifecycle Costs |
| Environmental Aspect | Direct Labor Savings, Materials and Activities, Risk Management |
| Increase Lifecycle | Lifecycle Costs |
| Operation and Maintenance Saving | Direct Labor Savings, Materials and Activities |
| Safety | Safety |
| User Benefits | Traffic Operations User Benefits |
| Risk Management | Risk Management |

### 3.2.3 Step 3: Collect Input Data

***Developing the step.*** The benefit estimation tool requires several input values to perform the benefit calculations. The required input values for each template were determined based on industry standard procedures for estimating the dollar values associated with the various benefit categories. In general, data from before and after implementation is required along with the anticipated level of deployment or frequency of activity to estimate the cost savings proposed by the research recommendations. Examples of input data are labor rates, amount of time required to complete an activity, material quantity required to perform an activity, material costs, and societal crash costs.

***Performing the step*.** The second step in the quantification process to select the applicable templates should be completed prior to initiating the third step, so the user knows what input data are required. The colored cells in the template spreadsheet indicate which values are required to be input by the user. For the given values to be input into the blue cells, the most currently available values should be obtained from MnDOT or from published resources at either the state or national level. The values input into the orange cells will typically be specific to the research project recommendations and could be obtained from the research report or from MnDOT personnel; however, the crash reduction factors are orange-cell inputs that should be identified through published state or national resources. Steps 3 and 5 can be performed simultaneously so the user is entering the input data as it is collected.

### 3.2.4 Step 4: Document Implementation of Recommendations

***Developing the step.*** The potential cost savings associated with implementing the recommendations is dependent upon the magnitude of the implementation effort. Thus, the benefit calculations require a number of locations or a frequency for performing the activity. This input value is built into the spreadsheet formulas. For a safety benefit calculation at one specific location, an implementation date is also required so before and after crash data is appropriately gathered to estimate the crash reduction. It is likely that the magnitude of the implementation effort will have to be estimated to represent the statewide potential for adoption of the research recommendations.

***Performing the step*.** Documentation should include the number of potential locations for implementation, but not necessarily specific locations (with the exception of a safety benefit calculation for a designated location). Data from the existing condition before implementation should be representative of the cost/quantity/activity prior to the start of construction or be representative of the current practices. Crash data should be gathered for a three-year period prior to construction to implement the recommendations. Steps 4 and 5 can be performed simultaneously so the user is entering the input data as it is collected. This information is entered in the *Data Documentation* section of the spreadsheet.

### 3.2.5 Step 5: Populate Benefit Estimation Tool

***Developing the step.*** The tool formatting uses colored cells to indicate to the user where input data is to be entered. The formulas built into the calculation cells reference the colored cells to incorporate the input data into the benefit calculations.

***Performing the step*.** This fifth step involves entering all the required input data into the blue and orange cells. Steps 3, 4, and 5 can be performed simultaneously so the user is entering the input data as it is collected and stored in the spreadsheet.

### 3.2.6 Step 6 Determine Benefit

***Developing the step.*** The templates are organized such that each type of benefit (such as, reduced labor time or reduced material cost) is calculated separately. If a set of recommendations has more than one type of benefit, the individual benefits can be summed to determine the total benefit. The white cells in the Performance Measurements spreadsheet columns show the calculated benefit.

***Performing the step***. The user determines the benefit by referring to the value presented in the Net Present Value column of the template spreadsheet. If more than one type of benefit is likely from a set of recommendations, the user can document the applicable benefit category and corresponding Net Present Value along with the total benefit on one of the benefit calculation tabs in the quantification spreadsheet.

### 3.2.7 Step 7: Compare Benefit to Cost

***Developing the step.*** The benefit estimation tool was developed to provide a consistent methodology for quantifying the potential benefits of research recommendations. A comparison of the benefit to cost provides one piece of input to the assessment of the effectiveness of the research program. The formula built into the template spreadsheet divides the estimated cost savings to be gained through implementation of the recommendations by the cost of conducting the research effort to develop the recommendations. A ratio of less than 1.0 indicates the research costs are greater than the potential monetary benefits whereas a ratio greater than 1.0 indicates the potential benefits outweigh the research costs.

***Performing the step***. The template spreadsheet automatically performs this calculation after the user enters all necessary data and information in the Benefit-Cost Ratio Estimation section of the spreadsheet.

# CHAPTER 4: QUANTITATIVE BENEFITS OF SELECTED RESEARCH PROJECTS

The quantitative benefits, defined as the ratio of the cost savings realized by implementation of the research recommendations to the cost of the research project, were estimated using the spreadsheets developed for each subject research project. Table 3 summarizes the research cost and the estimated benefit to be gained by implementation of the subject research projects for three-year and ten-year time periods (the exception is the SMART Signal benefit calculation, which uses 12 years to achieve a common time frame between the major and minor arterial retiming goals of 4 and 6 years, respectively). The three-year time period was selected based on similar practices by other State Departments of Transportation. The ten-year time period was selected to demonstrate the increased value of continuing to implement the recommendations. It is important to note that these estimated benefits represent the minimum savings that were able to be quantified during this effort and additional monetary benefits are likely to be gained by the implementation of the research recommendations. A savings-to-cost research ratio of less than 1.0 indicates the research cost is greater than the potential benefits whereas a ratio greater than 1.0 indicates the potential benefits outweigh the costs. A ratio of 0.0 indicates no monetary benefit to be gained by implementation of the research recommendations, although non-monetary benefits may be achieved. The case studies in Appendix A include discussions of the quantitative and qualitative benefits of the subject research projects. They also highlight the issues encountered during the benefit estimation efforts.

> The recommendations from the 10 sample projects have the potential to save $69 million over a 3-year period. This equates to a collective benefit-cost ratio of 34.0.

As Table 3 shows, these eleven sample projects have the potential to save approximately $69 million over a three-year period. When compared to a research cost of approximately $2 million, the collective benefit-cost ratio is 34.0. Comparison to the three-year benefit shows an approximately six-fold increase in the monetary benefit of the recommendations for the longer ten-year time period. Note that the savings-to-cost research ratio for the SMART Signal is still less than 1.0, which indicates that it will take more than 12 years to generate enough cost savings to exceed the cost to implement the equipment systemwide.

Over the first three-year period, most of the subject research projects demonstrate a cost savings that is greater than the cost of the effort to develop the recommendations. For example, the traffic sign recommendations suggest a high benefit and significant cost savings through implementation of the recommendations to modify sign service life and reduce sign inventory. The labor savings generated through implementation of the weigh-in-motion sensor and precast concrete bridge deck system recommendations will be greater than the cost of these research efforts over the three-year benefit time period; however, continued use of these recommendations will eventually save costs to a level that exceeds the research effort. The roundabout recommendations led to reduced driver violations, but not fewer crashes, at this particular location. Although these calculations conclude that no benefit is realized from a reduction in societal crash costs, implementation of these recommendations may lead to reduced crashes at other two-lane roundabout locations.

Initially it was determined that none of these projects had reported benefits consistent with the adopted performance measures – the present value of three years' worth of identified annual benefits – and that the effort to obtain the necessary input data would involve reviewing the reports to obtain the data to be entered into the tool. In fact this turned out to be the case for only two of the projects. The process for obtaining the input data for the other projects involved multiple meetings with MnDOT staff, university researchers and a variety of outside sources such as local agency engineers and industry representatives to discuss potential benefits categories, sources of potential data, the extent of potential implementation, and installation and maintenance costs.

This level of effort was unexpected and greatly added to the timeline for completion. Ultimately, enough data was obtained for all but one project. However, in several cases, this involved generating substitutes for actual data using estimation and speculation based on information from sources with varying degrees of reliability. This led to assigning a level of confidence rating to the output. A rating of 1 (high level of confidence) was assigned if the necessary data existed and was from either MnDOT or local agency sources that were considered reliable. A rating of 2 (medium level of confidence) was assigned if there was a lack of data in the report, the dataset was small, and/or a few assumptions were required to be made. A rating of 3 (low level of confidence) was assigned if the data did not exist and substitutes for real data had to be estimated from unreliable sources.

**Table 3 - Summary of Quantitative Benefits for Selected Research Projects for Three- and Ten-Year Time Periods**

| Research Project | Project Number | Research Area | Report Number | Project Cost | Net Present Value of Benefits | | | | Savings-Cost of Research Ratio | | Confidence Level |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Actual | Estimated | Calculated Value | | | | |
| | | | | | | | 3-Year | 10-Year | 3-Year | 10-Year | |
| Assessment and Recommendation for Operation of Standard Sumps as Best Management Practices for Stormwater Treatment | 2008-005 | Environmental Stewardship | 2012-13 | $257,000 | | ✓ | $8.5M | $26.4M | 33.1 | 102.7 | 3 |
| Economic and Environmental Costs and Benefits of Living Snow Fences: Safety, Mobility, and Transportation Authority Benefits, Farmer Costs, and Carbon Benefits | 2009-035 | Maintenance | 2012-03 | $99,000 | | ✓ | $141K | $440K | 1.4 | 4.4 | 3 |
| Effects of Signing and Lane Markings on the Safety of a Two-Lane Roundabout | 2013-053 | Traffic Safety | 2014-04 | $124,920 | ✓ | | $0 | $0 | 0.0 | 0.0 | 2 |
| Full-Depth Precast Concrete Bridge Deck System (Phase II) | 2009-017 | Bridge and Structures | 2012-30 | $165,000 | | ✓ | $29K | $91K | 0.2 | 0.6 | 2 |
| Improving Weigh-In-Motion Sensor Accuracy Between Calibrations | 2015-18 | Materials and Road Research | 2015-18TS | $95,000 | | ✓ | $80K | $249K | 0.8 | 2.6 | 1 |
| Investigation of Low Temperature Cracking in Asphalt Pavements (Phase II) | TPF-5(132) | Materials and Road Research | 2012-23 | $475,000 | ✓ | | $6.6M | $20.8M | 13.9 | 43.8 | 1 |
| Load and Resistance Factor Design (LRFD) Pile Driving Project (Phase II) | 2007-030 | Bridge and Structures | 2014-16 | $160,000 | | | Could not compute | | Could not compute | | 4 |
| Putting Research into Practice: Snowplow Calibration Guides for MnDOT and Local Governments | 2008-104 | Maintenance | 2009RIC08 | $88,705 | ✓ | | $400K | $1.2M | 4.5 | 13.5 | 1 |
| Recycled Unbound Materials | TPF-5(129) | Materials and Road Research | 2012-35 | $349,910 | ✓ | | $2.3M | $7.3M | 6.6 | 20.9 | 1 |
| SMART Signal | Unknown | Traffic Operations | Unknown | $239,000 | | ✓ | $155K | $155K | 0.6 | 0.6 | 3 |
| Traffic Sign Life Expectancy | 2012-063 | Traffic Safety | 2014-20 | $37,722 | | ✓ | $19.7M | $62.5M | 522.2 | 1656.9 | 1 |
| Traffic Sign Maintenance/ Management Handbook | 2013-052 | Traffic Safety | 2014RIC20 | $49,891 | | ✓ | $30.7M | $95.6M | 615.3 | 1916.2 | 1 |

Confidence Level Rating:
1: High level of confidence in the benefit estimation. This level of confidence was assigned if the data used in the estimation effort was either contained in the research report or obtained from a credible source.
2: Medium level of confidence in the benefit estimation. This level of confidence was assigned for one or more of the following reasons: a lack of data in the report, a small dataset, and/or the requirement to make a few assumptions.
3: Low level of confidence in the benefit estimation. This level of confidence was assigned for one or more of the following reasons: a lack of data in the report, inability to find relevant data from a credible source, a small dataset, or the requirement to make several assumptions.
4: Benefits could not be computed.

Comparison to MnROAD Benefits. Two of the subject research projects (Recycled Materials and Low-Temperature Cracking in Asphalt) were also included in the MnROAD Phase-II benefit estimation effort. The report states an estimated annual benefit of $827,000 (MnROAD report Table 2.1a) through use of recycled materials in paving projects. This value is similar to the annual value of $812,000 estimated during the conduct of this effort to develop a benefit quantification process. Furthermore, the MnROAD Phase-II report states an estimated annual benefit of $2.3 million (MnROAD report Table 2.1a) with use of the recommended system for selecting low temperature crack-resistant asphalt mixtures. This value is similar to the annual value of $2.2 million estimated during the conduct of this effort to develop a benefit quantification process. MnDOT staff developed modest performance increase scenarios based on the findings from these two research efforts in order to calculate cost benefits to MnDOT and the CSAH systems. Both benefit quantification procedures used these same MnDOT-generated input values and, thus, the results are similar.

Figure 2 graphically depicts the three-year benefit-cost ratios shown in Table 3. The columns represent the cost to conduct the research project and the line represents the potential cost savings benefit to be achieved through implementation of the recommendations. The benefit-cost ratio is greater than 1.0 where the line plots above the column, indicating the research project provides a monetary savings over a three-year time period that exceeds the cost of the research. The research cost exceeds the three-year monetary savings potential where the line plots within the column. For purposes of making the graph more legible, the maximum benefit shown is a $1 million cost savings, which understates the potential savings (shown in text boxes above the line) for five of the projects (the traffic signs data represents the combination of the two.

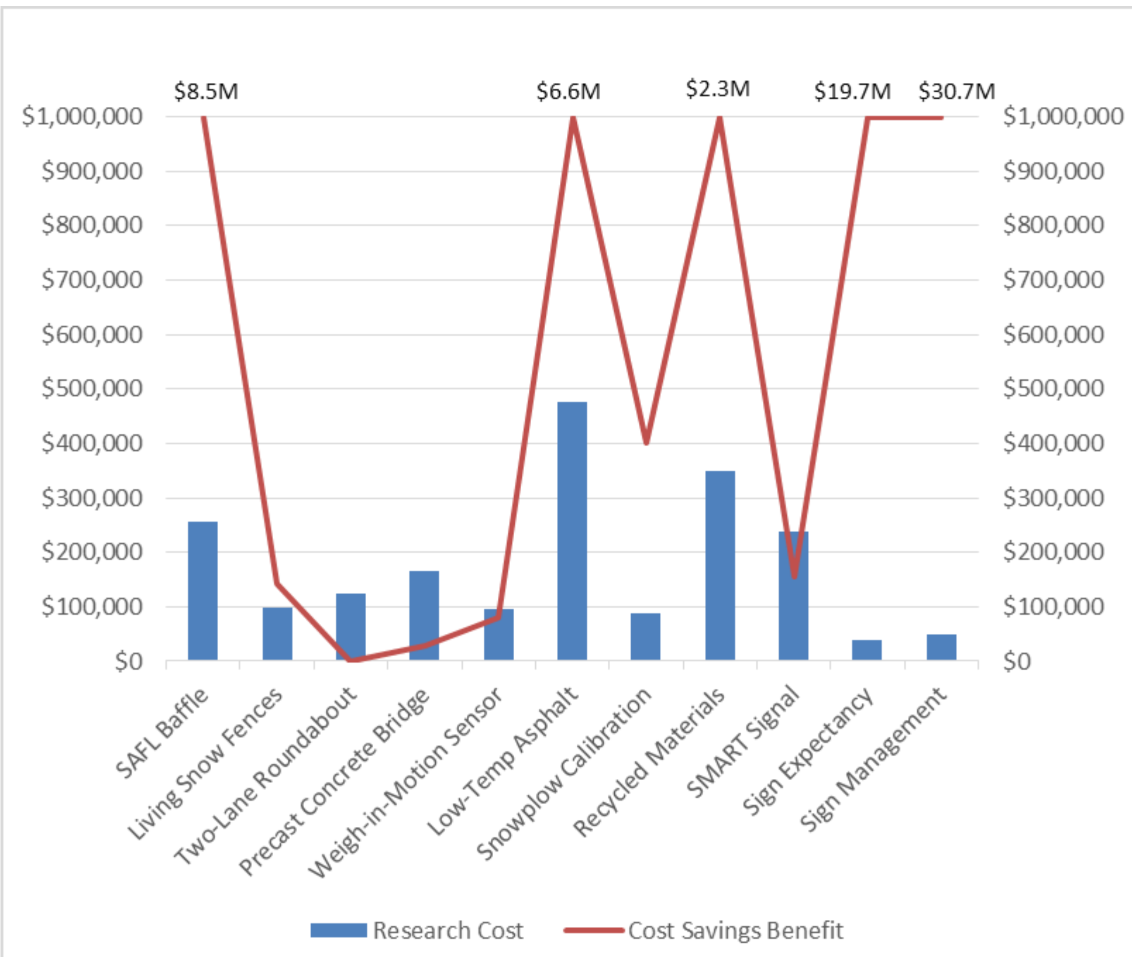



**Figure 2. Benefit-Cost Comparison**

## 4.1 STATEWIDE BENEFITS OF RESEARCH PROGRAM

The genesis of this project was to develop a process to quantify the benefits to be gained through the implementation of recommendations generated through research, and then apply the process to a sample of selected research projects in order to demonstrate that the concept works. The original intent was to then to determine a rough approximation of the broader benefits of MnDOT's entire research program based on an extrapolation of the subject research project results. The ultimate aim was to demonstrate the validity of the research program and its effectiveness to the citizens of Minnesota whose tax dollars fund the research efforts. Through the effort to apply the process to the selected sample of completed research projects, it became apparent that no single, reasonably objective means to estimate the benefits of the entire program exists. A singular approach is not applicable because of the variability of the types of benefits provided by the research recommendations, and, in some cases, the lack of substantive information provided in research reports. In addition, for those projects where benefits were identified and calculated, the results ranged from several thousands of dollars to tens of millions.

This effort did result in a step-by-step, easily applied process for quantifying benefits in terms of cost savings realized by the implementation of recommendations. The process resulted from the experience gained and lessons learned while quantifying the benefits of ten projects sponsored by Research Services. ***The initial assumption that all the necessary information to calculate potential cost savings would be available from the research reports published at the conclusion of these projects proved incorrect.*** In some reports, cost savings are stated, but not supported with references or calculations. These omissions necessitated utilizing other means to gather the information, which included interviewing MnDOT technical staff, interviewing the principal investigator and others involved with the research effort, and consulting applicable national publications. In some cases, local agency staff and other industry experts were consulted to discuss reasonable assumptions for the missing data. Some of the interviews revealed that benefits could not be documented because data for the condition or practices prior to the implementation of recommendations was never recorded, leaving no comparison from which to estimate a change that resulted in a cost savings. This proved to be a time-consuming effort that would not be a reasonable element of an easily-applied process for evaluating every research project.

### RECOMMENDATIONS

- Select a representative sampling of projects to justify research program
- Instill identification and quantification of benefits into all phases of research
- Recognize that quantitative benefits should not be the sole deciding factor in the research proposal selection process
- Assign the responsibility to quantify benefits to Research Services staff
- Recognize that quantitative benefits should not be the sole deciding factor in research proposal selection process
- Follow consistent process to estimate research benefits

These challenges suggest it would be difficult, and in some cases, virtually impossible to determine the cost savings achieved by all past research projects. Furthermore, the lack of sufficient information to quantify benefits would result in minimal confidence in the results. However, an effort of this magnitude is not necessary to justify the continued existence of the overall research program. As the summaries in Tables 2 and 3 suggest, ***the overall value of MnDOT's research program can be demonstrated by focusing on a select few projects for which the data is available to conclusively prove that a high benefit/large cost savings can be achieved by implementing research recommendations. For example, the potential savings associated with the storm water baffle, low-temperature asphalt mixture, and***

***traffic sign research projects collectively exceed three years' of Research Service's annual budget for all research (approximately $10 million), justifying the continuing existence of the research program. Furthermore, the potential three-year cost savings for all eleven of these sample projects (approximately $69 million) would fund the entire research program for approximately seven years.*** Thus, a representative sampling of projects is sufficient to demonstrate a benefit to the state's citizens in the form of dollars saved compared to dollars expended for the research program.

A more viable approach for understanding and justifying the continued investment in the research program would be to instill in all research project participants the need to focus on the identification and quantification of benefits throughout the entire research process, beginning with the selection of the principal investigator and continuing through the preparation of the final research report. Best practices from other DOTs suggest that the effort to identify potential benefits of research should be a shared responsibility between MnDOT staff and the principal investigator. The most effective means to accomplish this would be to start early with researchers and MnDOT staff engaged from the beginning to collaborate on assumptions, data collection, identification of the types and quantities of potential benefits, the application of the quantification process, possible barriers to documenting benefits and the results.

The benefit quantification process should be incorporated in each phase of the research process from proposal generation and selection through evaluation.

This holistic approach would start with the requirement for research proposals to incorporate scope to develop a plan for quantifying the benefits. The plan could be based on the input requirements for the seven-step process discussed in this report and include the anticipated type of benefit, applicable data and sources of the data, the time period for gathering the data, and a realistic level of deployment. The approach ends with the inclusion of a thorough plan in the research report that describes these elements of the plan and provides the data for the existing or before condition to serve as a basis for comparison once the recommendations are implemented. Including these efforts into the research contract is a means to guarantee they are fulfilled by researchers. The ultimate aim of this approach would be that a Research Services employee (or other MnDOT staff) could quantify the benefit of a research project a number of years after recommendations are implemented using only the benefit quantification tool presented in this report and the published research report.

This approach could be successfully implemented if Research Services staff make additional efforts to reach out and communicate with university researchers, both as part of the pre and post proposal process. The pre-proposal effort could take the form of a webinar hosted by MnDOT for all potential responders that provides insights about the required organization of the proposals, how MnDOT staff will evaluate them and the importance in the selection process that will be placed on discussing potential benefits. It should be noted that the use of pre-proposal meetings is fairly common in the industry and has previously been used by MnDOT on a variety of projects. The agenda for the first Technical Advisory Panel (TAP) meeting could include a benefits discussion along with an overview of the quantification process to further emphasize the need to quantify benefits.

The post-proposal effort could take the form of a workshop with the selected university researchers shortly after their notification to proceed. The objective would be to reinforce the importance of including information about potential benefits, identifying approaches for quantifying benefits in their reports and inviting their thoughts about how to go about generating the information and incorporating it into their reports. One way to encourage the researcher's participation in this kind of workshop would be to make it a separate task in their contracts, which would mean they would be paid to attend. It also appears that since much of MnDOT's research is conducted by faculty/staff at the University of Minnesota, the Center for Transportation Studies would be a logical choice to help facilitate and host this workshop. It should be noted that in several other states, the DOTs regularly include a Task Zero in their work scopes – a meeting with the DOT project staff to discuss their desired outcomes for the projects and how the contractor can develop a work scope that reflects these desires.

> The potential to quantify benefits should not be the sole deciding factor when selecting research proposals.

***A discussion of the potential for a project to be able to quantify benefits should be part of the decision process for selecting research proposals, but not the sole deciding factor.*** Many qualitative benefits can be achieved from the results of research efforts, and should be included in the decision process. For example, the effort to develop this benefit quantification process revealed that while the Load and Resistance Factor Design Pile Driving project to refine the pile equation did not necessarily result in a reduction in materials or testing requirements, the project did confirm that the research was very valuable to the overall practice of foundation design and documented the consistency between MnDOT's approach and national guidelines.

Consistently following an established methodology to estimate benefits with reasonable data and assumptions will yield a compelling justification for the overall research program. This pilot effort which required the establishment of several assumptions and surrogates for missing data showed that just over half of the projects provide a net a benefit in a three-year time period. Proof of the value of the research program will only increase with a comprehensive process in place to quantify benefits.

The following list summarizes the recommendations that result from the conduct of this pilot study:

- Select a representative sampling of projects to justify the research program. There is no reasonably objective means to estimate the benefits of the entire research program.
- Instill identification and quantification of benefits into all phases of research:
  - Emphasize the importance of addressing benefits from the beginning – make discussing potential benefits of research a key part of the project selection process. Include a benefits discussion along with an overview of the quantification process in the agenda for the first Technical Advisory Panel (TAP) meeting.
  - Conduct a pre-proposal webinar during the selection process and use that opportunity to make all participants aware that the selection process will include an evaluation of the potential benefits discussion included in the proposal.
  - Require research proposals to include scope to develop a plan for identifying data for quantifying potential benefits.
  - Conduct a post-proposal workshop with the selected university researchers shortly after notification to proceed. The objective would be to reinforce the requirement to include information about potential benefits, identifying approaches for quantifying benefits in their reports, and inviting their thoughts about how to generate the information and incorporate it into their reports. One way to encourage researchers' participation in this workshop would be to make it a separate task in their contract, which means they would be paid to attend.
  - Require that research reports include a discussion of potential benefits and to provide either actual or estimated data for the existing or before condition to serve as a basis for comparison

    once the recommendations are implemented. This discussion should include a realistic timeframe and level of deployment.

    - Require that research reports include evaluation and benefit quantification plans that have collectable data elements into research reports.
    - Encourage investigators and MnDOT staff to collaborate in benefit identification.

- Recognize that quantitative benefits should not be the sole deciding factor in the research proposal selection process. Research recommendations could provide value for modifying practices or policies.
- Assign the responsibility to quantify benefits to the Research Services staff assigned to each project and hold them accountable for computing the value of the benefits using the tool provided as part of this pilot effort and reporting the results to MnDOT management.
- Follow a consistent process to estimate research benefits

# CHAPTER 5: USER'S GUIDE AND TRAINING MATERIALS

A user's guide and related training materials were developed to assist researchers with the application of the benefit quantification process and use of the spreadsheet tool to estimate the potential benefit of a specific research project. The user's guide, spreadsheet tool and training presentation are available for download from Research Services' website:

**User's Guide**

mndot.gov/ research/reports/2017/201713A.pdf

**Quantification Tool**

mndot.gov/ research/reports/2017/201713B.xlsx

**Training Slide Presentation**

mndot.gov/ research/reports/2017/201713C.pptx

## **APPENDIX A:**

## CASE STUDIES FOR SUBJECT RESEARCH PROJECTS

## Appendix A1

# Assessment and Recommendation for Operation of Standard Sumps as Best Management Practices for Stormwater Treatment

MnDOT Report Number: 2012-13

Publication Date: May, 2012

Authors: Kurtis McIntire, Adam Howard, Omid Mohseni and John Gulliver

Project Cost: $257,000

### Project Summary

This research effort concluded that standard sumps and baffles are effective at removing sediment from stormwater during low flow rates, but are not able to retain these sediments during high flow rates. To address this issue, the Saint Anthony Falls Laboratory (SAFL) baffle was developed to work within a sump to reduce the energy of the water entering the sump and improve sediment retainage. The research project recommends use of the SAFL baffle as a lower-cost method to improve sediment retainage.

### Challenges of Data Collection

The research report did not contain sufficient data to do any computation of benefits. The cost of the SAFL baffle was not provided, the cost of competing devices was not provided and an estimate of the number of storm water sumps that would potentially be candidates for installation was not provided.

Efforts were made to document the number of sumps that would be candidates for the baffle in both state and local storm water systems. However, MnDOT staff members Beth Neuendorf and Barb Loida could not provide an estimate and a sample of city engineers in the Minneapolis/St. Paul metropolitan area indicated that there were no candidates in their systems (they already owned vacuum trucks and had staff assigned to clean out their sumps).

An additional effort was made to document the number of baffles MnDOT had already purchased using bid price summaries, however it was determined that the baffle did not have a unique bid number and was included in a catchall – “storm water special design”. Ultimately, an estimate of the potential size of the market for SAFL baffles was produced using material provided by the marketing director for the manufacturer.

### Assumptions for Benefits Estimation

The data collection challenges necessitated development of the following assumptions to proceed with the benefit estimation process:

- Benefit is based on cost difference between SAFL baffle and competitor baffle.

- The other benefits of the SAFL baffle related to reduced maintenance and associated costs, and less sediment in the waterways will not be included in the benefits calculation due to inability to accurately capture these benefits.

- Competitor baffle price of $25,000 is based on estimate of $30,000 from Andy Erikson (SAFL) and $20,000 to $30,000 from AJ Schwibber (president of Upstream Technologies).

- SAFL baffle price of $4000 was provided by AJ Schwibber of Upstream Technologies (produces the SAFL baffle) and confirmed by Omid Mohseni (Principal Investigator).

- Omid Mohseni estimated that 200 SAFL baffles were sold in 2014, 70 to 80 percent of which were to agencies in Minnesota. Assume 70 percent, the lower percentage in this range, as a conservative estimate of potential benefit. 70 percent of 200 equates to 140 SAFL baffles annually purchased and installed in Minnesota.

## Benefits of the Recommendations

The SAFL baffle can be lowered into existing manholes in pieces for installation in existing structures. This ability to assemble on site lowers the cost compared to other baffles which require retrofitting or reconstructing existing structures. The quantitative benefit captured in this estimation effort is based on the reduced cost of the SAFL baffle compared to other baffle and sump installation practices. The SAFL baffle provides another quantitative benefit through reduced maintenance requirements. A potential qualitative benefit is the reduction in sediment deposited in waterways.

## Benefit Quantification Process

The benefit of implementing the recommendation to use the SAFL baffle was quantified as a material savings based on the cost difference between purchase and installation of the SAFL baffle and traditional methods of purchasing and installing baffles in stormwater manholes. The quantification process used a cost of $4000 for the SAFL baffle and an average cost of $25,000 for other baffles, provided by the company that produces the SAFL baffle and the Principal Investigator. Based on recent sales data, the demand for SAFL baffles in Minnesota is estimated to be 140 annually. This data can be seen on the screen captures of the benefit calculation spreadsheets on the following pages.

## Quantitative Benefit of the Recommendations

The potential benefit of implementing the recommendation to use SAFL baffles is approximately $8.5 million over a three-year time period. Comparing this benefit to the cost of the research project results in a benefit-cost ratio of 33. This high ratio indicates the research effort was beneficial and its recommendation will likely result in cost savings for Minnesota agencies that choose to implement the SAFL baffle. The ratio increases to 102.7 for the 10-year benefit estimation time frame, based on a potential savings of $26.4 million.

3-Year Benefit Calculation Spreadsheet

| Project Information | | Given Values | |
|---|---|---|---|
| **Project Title:** | Assessment and Recommendations for the Operation of Standard Sumps as Best Management Practices for Stormwater Treatment | Benefit Time Frame = | 3 |
| **Project Number:** | 2012-13 | Interest Rate = | 2.0% |
| **Principal Investigator:** | Omid Mohseni | SAFL Baffle Cost = | $4,000 |
| **Technical Liaison:** | | Average Other Baffle Cost = | $25,000 |
| **Administrative Liaison:** | | | |

**Determination of Savings in Materials**

| Change in cost due to use of SAFL instead of other baffles | Entered Values: SAFL --- Baffle Cost | | OTHER --- Baffle Cost | | Annual Frequency of SAFL Baffle Purchases | | Benefit Time Frame | Performance Measurements: Annual Cost Savings | Total Cost Savings | Annual Benefit of Baffle Savings | Net Present Value of Baffle Savings |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $ | Unit | $ | Unit | No. | Unit | Yrs. | $ | $ | $ | $ |
| *Use of SAFL baffle instead of other baffles* | 4,000 | baffle | 25,000 | baffle | 140 | baffle | 3 | 2,940,000 | 8,820,000 | 2,940,000 | 8,478,617 |

10-Year Benefit Calculation Spreadsheet

| Project Information | | Given Values | |
|---|---|---|---|
| **Project Title:** | Assessment and Recommendations for the Operation of Standard Sumps as Best Management Practices for Stormwater Treatment | Benefit Time Frame = | 10 |
| **Project Number:** | 2012-13 | Interest Rate = | 2.0% |
| **Principal Investigator:** | Omid Mohseni | SAFL Baffle Cost = | $4,000 |
| **Technical Liaison:** | | Average Other Baffle Cost = | $25,000 |
| **Administrative Liaison:** | | | |

**Determination of Efficiency Savings in Materials**

| Change in cost due to use of SAFL instead of other baffle | Entered Values: SAFL --- Baffle Cost | | OTHER --- Baffle Cost | | Annual Frequency of SAFL Baffle Purchases | | Benefit Time Frame | Performance Measurements: Annual Cost Savings | Total Cost Savings | Annual Benefit of Baffle Savings | Net Present Value of Baffle Savings |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $ | Unit | $ | Unit | No. | Unit | Yrs. | $ | $ | $ | $ |
| *Use of SAFL baffle instead of other baffle* | 4,000 | baffle | 25,000 | baffle | 140 | baffle | 10 | 2,940,000 | 29,400,000 | 2,940,000 | 26,408,800 |

## Appendix A2

### Economic and Environmental Costs and Benefits of Living Snow Fences: Safety, Mobility, and Transportation Authority Benefits, Farmer Costs, and Carbon Benefits

MnDOT Report Number: 2012-03

Publication Date: February, 2012

Authors: Gary Wyatt, Diomy Zamora, David Smith, Sierra Schroeder, Dinesh Paudel, Joe Knight, Don Kilberg, Dean Current, Dan Gullickson, Steve Taff

Project Cost: $99,000

#### Project Summary

This research effort developed a calculator for estimating optimal payments that would encourage landowners to participate in the establishment and maintenance of living snow fences. The optimal payments are based on a cost-benefit analysis of the reduction to be gained in maintenance, crash costs, and carbon emissions. The project recommends use of the calculator to identify sites that would be beneficial for installation of living snow fences.

#### Challenges of Data Collection

The research effort developed an economic calculator useful for determining appropriate payments to landowners to establish and maintain living snow fences. The report stated a potential monetary benefit but did not present supporting assumptions or calculations. The benefit was estimated for the use of living snow fences and not specifically for the savings to be gained as a result of the use of the payment calculator to attract more interest from landowners. The report did contain data regarding the various components of a living snow fence related to the establishment and maintenance of the fences, maintenance costs for clearing snow drifts off of roadways, and general statewide crash data relative to snow/ice conditions. However, this data was not specific to one representative location such that a before/after comparison could be made about the effect of the recommendation.

#### Assumptions for Benefits Estimation

- Benefits in terms of a reduction in maintenance costs for labor/equipment to eliminate snow drifts and an increased number of living snow fences installed/maintained by landowners were not included in this calculation due to a lack of information in the report and the ability to obtain this information from staff.
- Benefit is calculated in terms of societal cost savings due to crash reduction. Societal crash costs were obtained from the MnDOT Office of Planning and Program website at this link: http://www.dot.state.mn.us/planning/program/appendix_a.html.
- A rural interstate, Interstate 94 in MnDOT District 4, was used as a representative facility type along which living snow fences would likely be installed.

- The number of fatal and incapacitating injuries were obtained from a MnDOT report of district wide crashes on Interstate 94 for the years 2009 to 2013.
- A length of 10 miles was used as the deployment level because it results in the lowest savings that exceeds the project cost. Longer lengths would result in higher societal cost savings and a larger benefit-cost ratio.
- Crash Reduction Factor of 8 percent is from the research report and also from source in FHWA Crash Modification Factors Clearinghouse: Elvik, R. and Vaa, T., "Handbook of Road Safety Measures." Oxford, United Kingdom, Elsevier, (2004).

## Benefits of the Recommendations

An increase in the number of living snow fences per the project recommendations would provide quantitative benefits in terms of reduced maintenance costs for plowing roadways and clearing snow drifts as well as reduced societal costs associated with traffic crashes. A potential qualitative benefit is a reduction in carbon emissions which could be achieved through reduced use of maintenance equipment to clear snow drifts. A second potential qualitative benefit is an increased level of satisfaction with the living snow fence program and higher participation from landowners.

## Benefit Quantification Process

The benefit of implementing the recommendation to increase the number of living snow fences was captured in safety terms relative to the potential crash reduction that could be achieved through improved roadway surface conditions in areas prone to drifting and blowing snow. A rural interstate was used as a representative facility type along which living snow fences would likely be installed. Statistics for fatal and incapacitating injury crashes that occurred along this facility when the roadway surface was snowy or icy were obtained from the Minnesota Department of Transportation. A crash reduction factor of 8 percent for living snow fences was obtained from the Federal Highway Administration’s Crash Modification Factors Clearinghouse website. This data can be seen on the screen captures of the benefit calculation spreadsheets on the following pages.

## Quantitative Benefit of the Recommendations

The potential benefit of implementing the recommendation to install living snow fences is approximately $141,000 over a three-year time period. Comparing this benefit to the cost of the research project results in a benefit-cost ratio of 1.4. This ratio increases to 4.4 for the 10-year benefit estimation time period, based on a potential savings of $440,000. Since it is greater than 1.0, this ratio indicates the research effort was beneficial and its recommendation will likely result in cost savings if the calculator results in a greater number of landowners participating in the living snow fence program. This benefit represents installation along 10 miles of rural interstate; this length was selected because it results in the lowest savings that exceeds the research project cost. Longer lengths would result in higher societal cost savings and a larger benefit-cost ratio. It should be noted that the development of the calculator is a one-time expenditure whereas the opportunity to reduce maintenance and safety costs through the use of the calculator is ongoing and has the potential to result in a significant cost savings compared to the cost of the research project. Per industry standards for estimating societal cost savings achieved through crash reduction, the benefit time frame could also be set to equal the service life of a recommendation.

## 3-Year Benefit Calculation Spreadsheet

| Project Information | |
|---|---|
| **Project Title:** | Economic and Environmental Costs and Benefits of Living Snow Fences: Safety, Mobility, and Transportation Authority Benefits, Farmer Costs, and Carbon Benefits |
| **Project Number:** | 2012-03 |
| **Principal Investigator:** | Gary Wyatt |

| Given Values | |
|---|---|
| Benefit Time Frame = | 3 |
| Interest Rate = | 2.0% |
| Fatal Crash = | $10,300,000 |
| Type A Injury Crash = | $550,000 |
| Type B Injury Crash = | $160,000 |
| Type C Injury Crash = | $81,000 |
| Property Damage Only Crash = | $7,400 |
| Operator Labor (per person-hour) = | $32.73 |

### A. User Input

| | | Related Crashes | | | | | | Road System Data | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fatal | Injury | | | Property Damage | Years of Crash Data | | | |
| | | Crashes | Type A Crashes | Type B Crashes | Type C Crashes | Crashes | | Feature Count | | Traffic Growth Rate |
| Recommendation | Location | No. | No. | No. | No. | No. | No. | No. | Unit | % |
| *Living Snow Fences* | *snow/ice roadway surfaces* | 3 | 10 | | | | 5 | 119 | mile | |
| *Living Snow Fences* | *snow/ice roadway surfaces* | 3 | 10 | | | | 5 | 119 | mile | |

| | | Crash Reduction Factors | | | | | | Treatment Costs | | | | Treatment Deployment | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fatal | A Injury | B Injury | C Injury | Property Damage | Unit | Implementation Unit Costs | | Other Annual Cost | Service Life | Amount Deployed | | Level of Confidence |
| Recommendation | Location | % | % | % | % | % | | $ | Unit | $ | Years | No. | Unit | ≤1.0 |
| *Living Snow Fences* | *snow/ice roadway surfaces* | 8% | 8% | | | | | | | | 3 | 10 | mile | 1.0 |
| *Living Snow Fences* | *snow/ice roadway surfaces* | 8% | 8% | | | | | | | | 3 | 50 | mile | 1.0 |

### B. Projected Effectiveness - Crash Reduction Benefits

| | | Annual Projected Crash and Injury Reductions | | | | | | | | | | | | Crash Reduction Benefits | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fatal Crashes | | Type A Injury | | Type B Injury | | Type C Injury | | Property Damage | | Annual Reduction | Annual Reduction | Annual Benefit of Implementation | Present Value of Annual Benefit of Implementation |
| | | Density | Number | Density | Number | Density | Number | Density | Number | Density | Number | Fatal and Type A Injury | Fatal, Injury, & Property Damage | | |
| Recommendation | Location | Crashes/year/unit | Total Reduced | Crashes/year/unit | Total Reduced | Crashes/year/unit | Total Reduced | Crashes/year/unit | Total Reduced | Crashes/year/unit | Total Reduced | Total Reduced | Total Reduced | $ | $ |
| *Living Snow Fences* | *snow/ice roadway surfaces* | 0.005 | 0.004 | 0.017 | 0.013 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.017 | 0.017 | $48,941.18 | $141,141 |
| *Living Snow Fences* | *snow/ice roadway surfaces* | 0.005 | 0.020 | 0.017 | 0.067 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.087 | 0.087 | $244,705.88 | $705,703 |

Notes:
Rural Interstate I-94: 119 miles over 5 years: 8 K / 23 A crashes total; 42% on snow/ice
3 K / 10 A crashes on snow/icy road surfaces
This benefit calculation captures crash reduction cost savings only. There would also be cost savings from reduced maintenance requirements, which are unspecified at this time.
8% CRF from research report and also from source in FHWA CMF Clearinghouse: Elvik, R. and Vaa, T., "Handbook of Road Safety Measures." Oxford, United Kingdom, Elsevier, (2004).

## 10-Year Benefit Calculation Spreadsheet

| Project Information | |
|---|---|
| **Project Title:** | Economic and Environmental Costs and Benefits of Living Snow Fences: Safety, Mobility, and Transportation Authority Benefits, Farmer Costs, and Carbon Benefits |
| **Project Number:** | 2012-03 |
| **Principal Investigator:** | Gary Wyatt |

| Given Values | |
|---|---|
| Benefit Time Frame = | 10 |
| Interest Rate = | 2.0% |
| Fatal Crash = | $10,300,000 |
| Type A Injury Crash = | $550,000 |
| Type B Injury Crash = | $160,000 |
| Type C Injury Crash = | $81,000 |
| Property Damage Only Crash = | $7,400 |
| Operator Labor (per person-hour) = | $32.73 |

### A. User Input

| | | Related Crashes | | | | | | Road System Data | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fatal | Injury | | | Property Damage | Years of Crash Data | | | |
| | | Crashes | Type A Crashes | Type B Crashes | Type C Crashes | Crashes | | Feature Count | | Traffic Growth Rate |
| Recommendation | Location | No. | No. | No. | No. | No. | No. | No. | Unit | % |
| *Living Snow Fences* | *snow/ice roadway surfaces* | 3 | 10 | | | | 5 | 119 | mile | |
| *Living Snow Fences* | *snow/ice roadway surfaces* | 3 | 10 | | | | 5 | 119 | mile | |

| | | Crash Reduction Factors | | | | | | Treatment Costs | | | | Treatment Deployment | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fatal | A Injury | B Injury | C Injury | Property Damage | Unit | Implementation Unit Costs | | Other Annual Cost | Service Life | Amount Deployed | | Level of Confidence |
| Recommendation | Location | % | % | % | % | % | | $ | Unit | $ | Years | No. | Unit | ≤1.0 |
| *Living Snow Fences* | *snow/ice roadway surfaces* | 8% | 8% | | | | | | | | 10 | 10 | mile | 1.0 |
| *Living Snow Fences* | *snow/ice roadway surfaces* | 8% | 8% | | | | | | | | 10 | 50 | mile | 1.0 |

### B. Projected Effectiveness - Crash Reduction Benefits

| | | Annual Projected Crash and Injury Reductions | | | | | | | | | | | | Crash Reduction Benefits | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fatal Crashes | | Type A Injury | | Type B Injury | | Type C Injury | | Property Damage | | Annual Reduction | Annual Reduction | Annual Benefit of Implementation | Present Value of Annual Benefit of Implementation |
| | | Density | Number | Density | Number | Density | Number | Density | Number | Density | Number | Fatal and Type A Injury | Fatal, Injury, & Property Damage | | |
| Recommendation | Location | Crashes/year/unit | Total Reduced | Crashes/year/unit | Total Reduced | Crashes/year/unit | Total Reduced | Crashes/year/unit | Total Reduced | Crashes/year/unit | Total Reduced | Total Reduced | Total Reduced | $ | $ |
| *Living Snow Fences* | *snow/ice roadway surfaces* | 0.005 | 0.004 | 0.017 | 0.013 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.017 | 0.017 | $48,941.18 | $439,618 |
| *Living Snow Fences* | *snow/ice roadway surfaces* | 0.005 | 0.020 | 0.017 | 0.067 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.087 | 0.087 | $244,705.88 | $2,198,091 |

Notes:
Rural Interstate I-94: 119 miles over 5 years: 8 K / 23 A crashes total; 42% on snow/ice
3 K / 10 A crashes on snow/icy road surfaces
This benefit calculation captures crash reduction cost savings only. There would also be cost savings from reduced maintenance requirements, which are unspecified at this time.
8% CRF from research report and also from source in FHWA CMF Clearinghouse: Elvik, R. and Vaa, T., "Handbook of Road Safety Measures." Oxford, United Kingdom, Elsevier, (2004).

# Appendix A3

## Effects of Signing and Lane Markings on the Safety of a Two-Lane Roundabout

MnDOT Report Number: 2014-04

Publication Date: January, 2014

Authors: John Hourdos and Veronica Richfield

Project Cost: $124,920

### Project Summary

The research project identified potential sources of driver confusion about which lane to select upon entering a two-lane roundabout at a location chosen due to its above-average collision rate. Changes to signage and lane markings intended to clarify lane assignments prior to entering this roundabout were implemented and then videos of the traffic flow through the roundabout were analyzed to observe driver behavior. The research project identified a reduction in driver turning violations as a result of these changes, which were implemented along with enforcement to encourage compliance with the signs and markings. The project recommends analysis of individual roundabouts to identify and implement appropriate changes to signage and pavement markings.

### Challenges of Data Collection

The research report included driver violation and crash data for the time periods before and after implementation of the recommendations, which was useful for the estimation of benefits. However, the crash data was presented in terms of total crashes and not by severity. Estimation of societal crash savings necessitates crash distribution by severity. Therefore, additional effort was required to obtain crash data by severity for roundabouts within the state of Minnesota and calculate the percentage severity distribution to apply to the total crash data provided in the report.

### Assumptions for Benefits Estimation

- The before and after crash data presented in the report is in terms of total crashes. To determine a distribution by severity, the statewide crash database was queried for crashes coded as circle/roundabout for the years 2009–2013. The resultant severity distribution was applied to the total before and after crashes identified in the report:
  - 118 total roundabout crashes from 2009 to 2013: 71 Rural / 47 Non rural
  - Non Rural: 7 C injury (15%) and 40 property damage only (85%)
  - Entire State:
    - 29 injury/0 fatal/89 pdo
    - 25% injury/75% pdo
    - 3% A injury/21% B injury/76% C injury

- The report presents a total number of crashes along with a time period for the before and after crash data. The total crashes were divided by the time period to determine an annual average of crashes before and after the recommendations were installed.
  - Per report: 89 before crashes in 35 months (use 2.9 years for average calculation)
    - 89 crashes/2.9 years = 30.7 crashes per year
    - 15% (30.7) = 4.6 C injury crash per year
    - 85% (30.7) = 26.1 pdo crash per year
  - Per report: 40 after crashes in 16 months (use 1.33 years for average calculation)
    - 40 crashes/1.33 years = 30.7 crashes per year
    - 15% (30.7) = 4.6 C injury crash per year
    - 85% (30.7) = 26.1 pdo crash per year
- Per MN Spreadsheet: 2-lane roundabouts in state as of July 2014: 24 constructed, 6 in construction, 1 in design, and 1 traffic circle constructed.
- Societal crash costs were obtained from the MnDOT Office of Planning and Program website at this link: http://www.dot.state.mn.us/planning/program/appendix_a.html.

## Benefits of the Recommendations

Modifying the signage and pavement markings at the study location resulted in a reduction by nearly half in the rate of turning violations, indicating that the modified signage and markings improve driver guidance and increased driver understanding of how to navigate the roundabout. This is a qualitative benefit and could be a quantitative benefit in terms of reduced fines for citations. This project focused on driver violations and not crashes, although it could be assumed that improved driver guidance has the potential to reduce crashes and provide qualitative benefits.

## Benefit Quantification Process

The benefit of implementing the recommendation to improve the signage and pavement markings for two-lane roundabouts was quantified in safety terms relative to the societal cost savings achieved by a reduction in the frequency and severity of crashes attributed to the implementation of the signing, pavement marking, and enforcement improvements recommended in the report. The severity distribution of two-lane roundabout crashes was obtained from the Minnesota statewide database for the years 2009 through 2013, to coincide with the timing of the research project. This distribution was applied to the total number of before and after crashes presented in the report. Societal costs per crash severity, obtained from the Minnesota Department of Transportation, were applied to the number of crashes per severity level. This data is contained in the assumptions section of this case study.

## Quantitative Benefit of the Recommendations

The annual average number of crashes did not change after the implementation of the research recommendations. Thus, there is no quantitative safety benefit in terms of crash reductions. When expressed in terms of the benefit to be gained by reduced crashes, the benefit-cost ratio for this research project is 0. However, implementation of the recommendations at other existing two-lane roundabout locations or during the design phase for new two-lane roundabouts could reduce the potential for and occurrence of crashes. Per industry standards for estimating societal cost savings achieved through crash reduction, the benefit time frame could also be set to equal the service life of a recommendation.

## 3-Year Benefit Calculation Spreadsheet

| Project Information | | Given Values | |
|---|---|---|---|
| **Project Title:** | Effects of Signage and Markings on the Safety of a Two-Lane Roundabout | Benefit Time Frame = | 3 |
| **Project Number:** | 2014-04 | Interest Rate = | 2.0% |
| **Principal Investigator:** | John Hourdos | Fatal Crash = | $10,300,000 |
| | | Type A Injury Crash = | $550,000 |
| | | Type B Injury Crash = | $160,000 |
| | | Type C Injury Crash = | $81,000 |
| | | Property Damage Only Crash = | $7,400 |

**Projected Recommendation Effectiveness and Benefits**

| | | Change in Annual Related Crashes | | | | | Road System Data | | | Treatment Deployment | | Benefits | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fatal | Injury | | | Property Damage | | | | | | | |
| | | Crashes | Type A Crashes | Type B Crashes | Type C Crashes | Crashes | Feature Count | | Traffic Growth Rate | Amount Deployed | | Annual Benefit of Implementation | Present Value of Annual Benefit of Implementation |
| Recommendation | Related Crash Types | No. | No. | No. | No. | No. | No. | Unit | % | No. | Unit | $ | $ |
| *Pavement & Lane Markings/ Signing/ Education/ Enforcement* | turn violations/yield violations/lane change crashes except environment-related or drug-alcohol involved | 0 | 0 | 0 | 0 | 0 | | | | 32 | roundabouts | $0 | $0 |

Notes:
The annual average number of crashes did not change after the implementation of the research recommendations. Thus, there is no safety benefit in terms of crash reductions.
However, the research recommendations did result in qualitative benefits in terms of a reduction in traffic violations and an improved understanding of how to navigate the roundabout.

## 10-Year Benefit Calculation Spreadsheet

| Project Information | | Given Values | |
|---|---|---|---|
| **Project Title:** | Effects of Signing and Marking on the Safety of a Two-Lane Roundabout | Benefit Time Frame = | 10 |
| **Project Number:** | 2014-04 | Interest Rate = | 2.0% |
| **Principal Investigator:** | John Hourdos | Fatal Crash = | $10,300,000 |
| | | Type A Injury Crash = | $550,000 |
| | | Type B Injury Crash = | $160,000 |
| | | Type C Injury Crash = | $81,000 |
| | | Property Damage Only Crash = | $7,400 |

**Projected Recommendation Effectiveness and Benefits**

| | | Change in Annual Related Crashes | | | | | Road System Data | | | Treatment Deployment | | Benefits | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fatal | Injury | | | Property Damage | | | | | | | |
| | | Crashes | Type A Crashes | Type B Crashes | Type C Crashes | Crashes | Feature Count | | Traffic Growth Rate | Amount Deployed | | Annual Benefit of Implementation | Present Value of Annual Benefit of Implementation |
| Recommendation | Related Crash Types | No. | No. | No. | No. | No. | No. | Unit | % | No. | Unit | $ | $ |
| *Pavement & Lane Markings/ Signing/ Education/ Enforcement* | turn violations/yield violations/lane change crashes except environment-related or drug-alcohol involved | 0 | 0 | 0 | 0 | 0 | | | | 32 | roundabouts | $0 | $0 |

Notes:
The annual average number of crashes did not change after the implementation of the research recommendations. Thus, there is no safety benefit in terms of crash reductions.
However, the research recommendations did result in qualitative benefits in terms of a reduction in traffic violations and an improved understanding of how to navigate the roundabout.

# Appendix A4

## Full-Depth Precast Concrete Bridge Deck System (Phase II)

MnDOT Report Number: 2012-30

Publication Date: October, 2012

Authors: Max Halverson, Catherine French, and Carol Shield

Project Cost: $165,000

### Project Summary

This research effort evaluated three options to improve design/construction techniques for the decks of bridges being designed and constructed with the Precast Composite Slab Span System (PCSSS) developed by MnDOT in 2005. The research project recommends use of the design technique that proved to be most efficient for reducing deck cracking and increasing cost-effectiveness and constructability.

### Challenges of Data Collection

The research report did not contain enough information to either identify or support computation of benefits. At a follow-up meeting with MnDOT staff member Paul Rowekamp, it was concluded that the project would not result in any material savings benefits and no effort had been made during the research to understand or document potential user benefits. It was concluded that the only possible benefits that could be documented were reductions in the labor costs associated with the future designs using this particular technique. As a follow-up, MnDOT staff provided information about the design costs and the likely number of bridges that would be candidates using this design process.

### Assumptions for Benefits Estimation

- Initially there was consideration of the cost benefit of using precast deck systems resulting in accelerated construction and potential reduced user impacts. However, this study was focused on a particular performance issue of the already developed precast deck system, so this was not considered a direct benefit of this study.
- After meeting with MnDOT, it was identified that the study resulted in revised design/construction techniques intended to reduce the deck cracking issue in future use of this type of structure. The cost benefit resulting from an improved design technique is a reduction in labor hours to design a bridge of this type.
- Benefit will be based on the estimated labor savings through reduced design hours per bridge.
- Assumed time savings on a first time design: 130 hours.
- Assumed time savings on each future bridge designed by the same designer: 24 hours.
- Assume 3 to 4 bridges built per year.
- Assume one first time designer per year.
- Assume labor rate of $50.22 per hour, provided by MnDOT.

- This bridge type is expected to be used by counties and cities in the future, and they will experience the savings.

### Benefits of the Recommendations

The improved design technique requires fewer labor hours for design, which results in a cost savings. The technique incorporates factors such as shrinkage restraint, reflective crack control, composite action, and tolerance definitions which will likely lead to reduced maintenance costs once the bridge is in service.

### Benefit Quantification Process

The benefit of implementing the recommendation to use the design technique was quantified in terms of the labor savings between the design labor time previously required and the time required with the new technique. To acknowledge the efficiency gained through multiple iterations of a design process, this time savings was quantified as the sum of the time savings for the first-time use of the recommended technique and the savings by designers familiar with the technique. The Minnesota Department of Transportation provided the hourly labor costs for bridge designers and the number of hours saved for a first-time use (130 hours) and subsequent uses of the design technique (24 hours) per bridge. This data can be seen on the screen captures of the benefit calculation spreadsheets on the following pages.

### Quantitative Benefit of the Recommendations

The potential benefit of implementing the recommendation to use the improved design technique is approximately $29,000 over a three-year time period. Comparing this benefit to the cost of the research project results in a benefit-cost ratio of 0.2. This low ratio is reflective of the fact that the development of the technique was more costly than the application of the technique for the limited number of bridges constructed in the initial years of implementation. It should be noted that continued use of the PCSSS over time will result in additional cost savings over time. The ratio increases to 0.6 for the 10-year benefit estimation time frame, based on a potential savings of $91,000.

3-Year Benefit Calculation Spreadsheet

| Project Information | | Given Values | |
|---|---|---|---|
| **Project Title:** | Full-Depth Precast Concrete Bridge Deck System (Phase II) | Benefit Time Frame = | 3 |
| **Publication Number:** | 2009-017 | Interest Rate = | 2.0% |
| **Principal Investigator:** | Cathy French (Univ. of Minnesota) | Average Labor Rate = | $50.22 |
| **Technical Liaison:** | Paul Rowekamp | | |
| **Administrative Liaison:** | | | |

**Determination of Direct Labor Savings**

| | Entered Values | | | | | | Performance Measurements | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Change in number of labor hours to complete activity** | **Average Labor Rate** | **BEFORE --- Number of Hours** | **AFTER --- Number of Hours** | **Annual Frequency of Activity** | | **Benefit Time Frame** | **Annual Labor Savings** | **Total Labor Savings** | **Annual Benefit of Labor Reduction** | **Net Present Value of Labor Reduction** |
| | $ | No. | No. | No. | Unit | Yrs. | No. | No. | $ | $ |
| *Projected design labor savings, first time designers* | $ 50.22 | 130 | 0 | 1 | bridges | 3 | 130 | 390 | $ 6,528.60 | $ 18,827.72 |
| *Projected design labor savings, by same designers* | $ 50.22 | 24 | 0 | 3 | bridges | 3 | 72 | 216 | $ 3,615.84 | $ 10,427.66 |

10-Year Benefit Calculation Spreadsheet

| Project Information | | Given Values | |
|---|---|---|---|
| **Project Title:** | Full-Depth Precast Concrete Bridge Deck System (Phase II) | Benefit Time Frame = | 10 |
| **Publication Number:** | 2009-017 | Interest Rate = | 2.0% |
| **Principal Investigator:** | Cathy French (Univ. of Minnesota) | Average Labor Rate = | $50.22 |
| **Technical Liaison:** | Paul Rowekamp | | |
| **Administrative Liaison:** | | | |

**Determination of Direct Labor Savings**

| | Entered Values | | | | | | Performance Measurements | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Change in number of labor hours to complete activity** | **Average Labor Rate** | **BEFORE --- Number of Hours** | **AFTER --- Number of Hours** | **Annual Frequency of Activity** | | **Benefit Time Frame** | **Annual Labor Savings** | **Total Labor Savings** | **Annual Benefit of Labor Reduction** | **Net Present Value of Labor Reduction** |
| | $ | No. | No. | No. | Unit | Yrs. | No. | No. | $ | $ |
| *Projected design labor savings, first time designers* | $ 50.22 | 130 | 0 | 1 | bridges | 10 | 130 | 1,300 | $ 6,528.60 | $ 58,643.70 |
| *Projected design labor savings, by same designers* | $ 50.22 | 24 | 0 | 3 | bridges | 10 | 72 | 720 | $ 3,615.84 | $ 32,479.59 |

# Appendix A5

## Improving Weigh-In Motion Sensor Accuracy between Calibrations

MnDOT Report Number: 2015-18TS

Publication Date: June, 2015

Author: Chen-Fu Liao

Project Cost: $95,000

### Project Summary

This research effort developed a methodology for remotely monitoring Weigh-In-Motion sensors. This methodology can immediately identify when a sensor has lost accuracy, enabling recalibration efforts to occur as necessary rather than on a semiannual schedule. The research project recommends use of the software system to monitor Weigh-In-Motion sensors and reduction of the semiannual field calibration effort to an annual effort.

### Challenges of Data Collection

The research report did not contain information that would support the computation of benefits. Possible benefits were discussed by MnDOT staff during a follow-up meeting after which they made the effort to track down all of the information – labor costs, vehicle costs and the number of candidate locations – necessary to compute statewide benefits. This information was provided by Ben Timerson in the Transportation Data Section.

### Assumptions for Benefits Estimation

- Labor and equipment costs derived from “Calibration_Costs” spreadsheet provided by MnDOT.
- Average labor rate determined by dividing total labor cost by sum of hours for the three labor wages provided in spreadsheet.
- Equipment costs represent two rounds of calibration, so the costs were divided in half to represent a reduction of one round of calibration.
- Expenses are included only for the trips requiring multiple days and overnight stays.

### Benefits of the Recommendations

Elimination of one round of field calibration is a quantitative benefit because it reduces labor, direct expense, and equipment costs. Recalibrating sensors as necessary reduces the amount of faulty data that is collected by the sensors and thereby improves data quality. Better data provides the ability to design pavements more precisely so they can reach their desired lifespan. This is a qualitative and a quantitative benefit. Another qualitative benefit the system provides is the ability to identify vehicles that might exceed weight restrictions and cause damage to pavements and bridges.

## Benefit Quantification Process

The benefit of implementing the recommendation to use the software system was quantified in terms of the labor and equipment savings between one and two rounds of field calibration. MnDOT provided the total costs incurred in 2014 for the labor to drive the specialized vehicle to the sensor sites and perform the calibration tests, the direct expenses when overnight trips were required due to the remoteness of the sensor location, and the equipment costs associated with operating and maintaining the specialized vehicle. These costs were divided in half to represent the costs incurred for one round of field calibration, realizing a savings of 158 hours and 2 days of travel. This data can be seen on the screen captures of the benefit calculation spreadsheets on the following pages.

## Quantitative Benefit of the Recommendations

The potential benefit of implementing the recommendation to use the software system is approximately $80,000 over a three-year time period. Comparing this benefit to the cost of the research project results in a benefit-cost ratio of 0.8. This low ratio is reflective of the fact that the effort to develop the system was more costly than one round of field calibration. It should be noted that the development of the system is a one-time expenditure whereas the opportunity to reduce labor and equipment costs through the use of the system is ongoing and has the potential to result in a significant cost savings compared to the cost of the research project. This is evidenced by the benefit-cost ratio of 2.6 achieved when the benefit estimation time frame is 10 years, based on a potential savings of $249,000.

3-Year Benefit Calculation Spreadsheet

## Project Information

| | |
|---|---|
| **Project Title:** | Improving Weigh-In-Motion Sensor Accuracy Between Calibrations |
| **Project Number:** | 2015-18TS |
| **Principal Investigator:** | Chen-Fu Liao |
| **Technical Liaison:** | |
| **Administrative Liaison:** | |

## Given Values

| | |
|---|---|
| Benefit Time Frame = | 3 |
| Interest Rate = | 2.0% |
| Average Labor Rate = | $42.40 |
| Per Diem = | $186.00 |
| Annual Average Equipment Operating Cost Per Round of Calibration = | $20,637.00 |

**Entered Values** | **Performance Measurements**

## A Determination of Direct Labor Savings

| A.1 Change in number of labor hours to complete activity | Average Labor Rate | | BEFORE --- Number of Hours | AFTER --- Number of Hours | Benefit Time Frame | Annual Labor Hour Savings | Total Labor Hour Savings | Annual Benefit of Labor Reduction | Net Present Value of Labor Reduction |
|---|---|---|---|---|---|---|---|---|---|
| | $ | Unit | No. | No. | Yrs. | No. | No. | $ | $ |
| *Driving truck to WIM sensor locations* | $ 42.40 | hour | 316 | 158 | 3 | 158 | 474 | $ 6,699.20 | $ 19,319.71 |

| A.2 Percent reduction in number of labor hours to complete activity | Average Labor Rate | | BEFORE --- Number of Hours | AFTER --- Percent Reduction in Labor Hours | Benefit Time Frame | Annual Labor Hour Savings | Total Labor Hour Savings | Annual Benefit of Labor Reduction | Net Present Value of Labor Reduction |
|---|---|---|---|---|---|---|---|---|---|
| | $ | Unit | No. | % | Yrs. | No. | No. | $ | $ |
| *Driving truck to WIM sensor locations* | $ 42.40 | hour | 316 | 50% | 3 | 158 | 474 | $ 6,699.20 | $ 19,319.71 |

## B Determination of Employee Direct Cost Savings

| B.1 Change in number of overnight stays to complete activity | Per Diem | | BEFORE --- Number of Overnight Stays | AFTER --- Number of Overnight Stays | Benefit Time Frame | Annual Per Diem Day Savings | Total Per Diem Day Savings | Annual Benefit of Per Diem Reduction | Net Present Value of Per Diem Reduction |
|---|---|---|---|---|---|---|---|---|---|
| | $ | Unit | No. | No. | Yrs. | No. | No. | $ | $ |
| *Driving truck to WIM sensor locations* | $ 186.00 | day | 4 | 2 | 3 | 2 | 6 | $ 372.00 | $ 1,072.80 |

| B.2 Percent reduction in number of overnight stays to complete activity | Per Diem | | BEFORE --- Number of Overnight Stays | AFTER --- Percent Reduction in Overnight Stays | Benefit Time Frame | Annual Per Diem Day Savings | Total Per Diem Day Savings | Annual Benefit of Per Diem Reduction | Net Present Value of Per Diem Reduction |
|---|---|---|---|---|---|---|---|---|---|
| | $ | Unit | No. | % | Yrs. | No. | No. | $ | $ |
| *Driving truck to WIM sensor locations* | $ 186.00 | day | 4 | 50% | 3 | 2 | 6 | $ 372.00 | $ 1,072.80 |

## C Determination of Equipment Savings

| C.1 Change in cost due to reduction in truck trips | Average Operating Cost | | BEFORE --- Number of Calibration Rounds | AFTER --- Number of Calibration Rounds | Benefit Time Frame | Annual Equipment Savings | Total Equipment Savings | Annual Benefit of Equipment Savings | Net Present Value of Equipment Savings |
|---|---|---|---|---|---|---|---|---|---|
| | $ | Unit | No. | No. | Yrs. | No. | No. | $ | $ |
| *Driving truck to WIM sensor locations* | $20,637.00 | round of calibration | 2 | 1 | 3 | 1 | 3 | $ 20,637.00 | $ 59,514.70 |

| C.2 Percent reduction in truck trips | Average Operating Cost | | BEFORE --- Number of Calibration Rounds | AFTER --- Percent Reduction in Calibration Rounds | Benefit Time Frame | Annual Equipment Savings | Total Equipment Savings | Annual Benefit of Equipment Savings | Net Present Value of Equipment Savings |
|---|---|---|---|---|---|---|---|---|---|
| | $ | Unit | No. | % | Yrs. | No. | No. | $ | $ |
| *Driving truck to WIM sensor locations* | $20,637.00 | round of calibration | 2 | 50% | 3 | 1 | 3 | $ 20,637.00 | $ 59,514.70 |

10-Year Benefit Calculation Spreadsheet

| Project Information | | Given Values | |
|---|---|---|---|
| Project Title: | Improving Weigh-In-Motion Sensor Accuracy Between Calibrations | Benefit Time Frame = | 10 |
| Project Number: | 2015-18TS | Interest Rate = | 2.0% |
| Principal Investigator: | Chen-Fu Liao | Average Labor Rate = | $42.40 |
| Technical Liaison: | | Per Diem = | $186.00 |
| Administrative Liaison: | | Annual Average Equipment Operating Cost Per Round of Calibration = | $20,637.00 |

Entered Values / Performance Measurements

## A Determination of Direct Labor Savings

| A.1 | Change in number of labor hours to complete activity | Average Labor Rate | | BEFORE --- Number of Hours | AFTER --- Number of Hours | Benefit Time Frame | Annual Labor Hour Savings | Total Labor Hour Savings | Annual Benefit of Labor Reduction | Net Present Value of Labor Reduction |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $ | Unit | No. | No. | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $ 42.40 | hour | 316 | 158 | 10 | 158 | 1,580 | $ 6,699.20 | $ 60,176.13 |

| A.2 | Percent reduction in number of labor hours to complete activity | Average Labor Rate | | BEFORE --- Number of Hours | AFTER --- Percent Reduction in Labor Hours | Benefit Time Frame | Annual Labor Hour Savings | Total Labor Hour Savings | Annual Benefit of Labor Reduction | Net Present Value of Labor Reduction |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $ | Unit | No. | % | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $ 42.40 | hour | 316 | 50% | 10 | 158 | 1,580 | $ 6,699.20 | $ 60,176.13 |

## B Determination of Employee Direct Cost Savings

| B.1 | Change in number of days to complete activity | Per Diem | | BEFORE --- Number of Days | AFTER --- Number of Days | Benefit Time Frame | Annual Per Diem Day Savings | Total Per Diem Day Savings | Annual Benefit of Per Diem Reduction | Net Present Value of Per Diem Reduction |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $ | Unit | No. | No. | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $ 186.00 | day | 4 | 2 | 10 | 2 | 20 | $ 372.00 | $ 3,341.52 |

| B.2 | Percent reduction in number of days to complete activity | Per Diem | | BEFORE --- Number of Days | AFTER --- Percent Reduction in Days | Benefit Time Frame | Annual Per Diem Day Savings | Total Per Diem Day Savings | Annual Benefit of Per Diem Reduction | Net Present Value of Per Diem Reduction |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $ | Unit | No. | % | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $ 186.00 | day | 4 | 50% | 10 | 2 | 20 | $ 372.00 | $ 3,341.52 |

## B Determination of Equipment Savings

| B.1 | Change in cost due to reduction in truck trips | Average Operating Cost | | BEFORE --- Number of Calibration Rounds | AFTER --- Number of Calibration Rounds | Benefit Time Frame | Annual Equipment Savings | Total Equipment Savings | Annual Benefit of Equipment Savings | Net Present Value of Equipment Savings |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $ | Unit | No. | No. | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $20,637.00 | round of calibration | 2 | 1 | 10 | 1 | 10 | $ 20,637.00 | $ 185,373.61 |

| B.2 | Percent reduction in truck trips | Average Operating Cost | | BEFORE --- Number of Calibration Rounds | AFTER --- Percent Reduction in Calibration Rounds | Benefit Time Frame | Annual Equipment Savings | Total Equipment Savings | Annual Benefit of Equipment Savings | Net Present Value of Equipment Savings |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $ | Unit | No. | % | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $20,637.00 | round of calibration | 2 | 50% | 10 | 1 | 10 | $ 20,637.00 | $ 185,373.61 |

# Appendix A6

## Investigation of Low Temperature Cracking in Asphalt Pavements (Phase II)

MnDOT Report Number: 2012-23

Publication Date: August, 2012

Author: Mihai Marasteanu, William Buttlar, Hussain Bahia, and Christopher Williams, et al.

Project Cost: $475,000

### Project Summary

The research developed an optimal system for selecting low-temperature crack resistant asphalt mixtures for which cracking can be better predicted. The research project recommends use of the system to select more appropriate materials for asphalt pavement mixtures.

### Challenges of Data Collection

The research report did not contain any data or information necessary to estimate quantitative benefits. MnDOT staff developed a modest performance increase scenario based on the findings from these two research efforts in order to calculate cost benefits to MnDOT and the CSAH systems. MnDOT staff member Ben Worel provided the data from this scenario that was necessary to estimate the potential effect of implementing the recommendations.

### Assumptions for Benefits Estimation

- MnDOT bituminous pavement management system data for new and reconstructed roadways were analyzed to determine performance relative to crack formation and the impact of binder performance-grading (PG) implemented in 1999. Performance data for a period of seven years after initial construction were gathered. The following general observations are reasonable to make: for pavements constructed prior to PG implementation, typical cracking performance 7 years after construction (1991 to 1994) was about 15 cracks per 1,000 feet. For pavements constructed after 1999 observed cracking rate is about 2 cracks per 1,000 feet.
- Based on the above performance data the following modest performance increase scenarios were assumed in order to calculate cost benefits to MnDOT and the County State Aid Highway (CSAH) systems:
  - New roadways will experience a 20 percent increase in initial pavement life from 17.5 years to 21 years.
  - Existing roadways with cracks and defects that are resurfaced will experience a 10 percent reduction in maintenance costs due to a reduction in cracking, from 2,000 to 1,800 linear feet per mile.
  - Increased resurfacing life due to reduced rates of deterioration suggests the average life of an overlay will increase 10 percent from 13.5 years in 2000 to 14.9 years in the future.

- Based on MnDOT construction program between 2009–2013, approximately 180 lane-miles of new/reconstruction and 400 lane-miles of resurfacing occur each year, and presumably used the specified PG binder.
- The average annual CSAH lane-miles of bituminous surfacing construction over the same period is about 1,100 lane-miles. It is assumed that the ratio between new/reconstruction and resurfacing is about 20 percent based on MnDOT data.
- Average cost of new bituminous pavement construction and mill / overlays are approximately $273,000 and $122,000 per lane-mile, respectively; crack sealing averages $3,500 per lane-mile. These figures represent bituminous costs only, not total construction.
- Crack sealant lasts for 4 years.
- Total savings = sum of fewer cracks to maintain + overlay life extension + new/reconstruction life extension.

### Benefits of the Recommendations

More appropriate asphalt pavement mixtures for low-temperature conditions will ideally lead to fewer pavement cracks and reduced maintenance costs for crack sealing and overlay projects. Less wear and tear from cracking will provide a longer pavement lifespan. Roadway system users will receive qualitative benefits from improved ride quality.

### Benefit Quantification Process

The benefit of using the system for selecting low temperature crack resistant asphalt mixtures was quantified in terms of the material / activity and lifecycle savings associated with the reduction in cracks sealed, overlays performed as a result of a longer service life, and new construction realized due to longer pavement service life. The mixture selection is assumed to reduce the number of cracks sealed by 10 percent, extend the life of an overlay by 1.5 years, and extend pavement service life by 3.5 years. The Minnesota Department of Transportation provided the costs and annual lane-miles associated with these activities. This data can be seen on the screen captures of the benefit calculation spreadsheets on the following pages.

### Quantitative Benefit of the Recommendations

The potential benefit of implementing the recommendation to use the low-temperature asphalt mixture selection system is approximately $6.6 million over a three-year time period. Comparing this benefit to the cost of the research project results in a benefit-cost ratio of 13.9. This high ratio indicates the research effort was beneficial and its recommendation will likely result in cost savings for Minnesota agencies that choose to incorporate recycled pavement materials into pavement base layers. The ratio increases to 43.8 for the 10-year benefit estimation time frame, based on a potential savings of $20.8 million.

### Comparison to MnROAD Benefits Estimate

The MnROAD Phase-II report states an estimated annual benefit of $2.3 million (Table 2.1a) with use of the recommended system for selecting low temperature crack-resistant asphalt mixtures. This value is similar to the annual value of $2.2 million estimated during the conduct of this effort to develop a benefit quantification process. The data and assumptions necessary to quantify this benefit in terms of dollars saved were provided by MnDOT staff. Both benefit quantification procedures used the same input values and, thus, the results are similar.

3-Year Benefit Calculation Spreadsheet

**Project Information**

| | |
|---|---|
| **Project Title:** | Improving Weigh-In-Motion Sensor Accuracy Between Calibrations |
| **Project Number:** | 2015-18TS |
| **Principal Investigator:** | Chen-Fu Liao |
| **Technical Liaison:** | |
| **Administrative Liaison:** | |

**Given Values**

| | |
|---|---|
| Benefit Time Frame = | 3 |
| Interest Rate = | 2.0% |
| Average Labor Rate = | $42.40 |
| Per Diem = | $186.00 |
| Annual Average Equipment Operating Cost Per Round of Calibration = | $20,637.00 |

**Entered Values** / **Performance Measurements**

## A Determination of Direct Labor Savings

| | | | | Entered Values | | | Performance Measurements | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **A.1** | **Change in number of labor hours to complete activity** | **Average Labor Rate** | | **BEFORE --- Number of Hours** | **AFTER --- Number of Hours** | **Benefit Time Frame** | **Annual Labor Hour Savings** | **Total Labor Hour Savings** | **Annual Benefit of Labor Reduction** | **Net Present Value of Labor Reduction** |
| | | $ | Unit | No. | No. | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $ 42.40 | hour | 316 | 158 | 3 | 158 | 474 | $ 6,699.20 | $ 19,319.71 |
| **A.2** | **Percent reduction in number of labor hours to complete activity** | **Average Labor Rate** | | **BEFORE --- Number of Hours** | **AFTER --- Percent Reduction in Labor Hours** | **Benefit Time Frame** | **Annual Labor Hour Savings** | **Total Labor Hour Savings** | **Annual Benefit of Labor Reduction** | **Net Present Value of Labor Reduction** |
| | | $ | Unit | No. | % | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $ 42.40 | hour | 316 | 50% | 3 | 158 | 474 | $ 6,699.20 | $ 19,319.71 |

## B Determination of Employee Direct Cost Savings

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **B.1** | **Change in number of overnight stays to complete activity** | **Per Diem** | | **BEFORE --- Number of Overnight Stays** | **AFTER --- Number of Overnight Stays** | **Benefit Time Frame** | **Annual Per Diem Day Savings** | **Total Per Diem Day Savings** | **Annual Benefit of Per Diem Reduction** | **Net Present Value of Per Diem Reduction** |
| | | $ | Unit | No. | No. | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $ 186.00 | day | 4 | 2 | 3 | 2 | 6 | $ 372.00 | $ 1,072.80 |
| **B.2** | **Percent reduction in number of overnight stays to complete activity** | **Per Diem** | | **BEFORE --- Number of Overnight Stays** | **AFTER --- Percent Reduction in Overnight Stays** | **Benefit Time Frame** | **Annual Per Diem Day Savings** | **Total Per Diem Day Savings** | **Annual Benefit of Per Diem Reduction** | **Net Present Value of Per Diem Reduction** |
| | | $ | Unit | No. | % | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $ 186.00 | day | 4 | 50% | 3 | 2 | 6 | $ 372.00 | $ 1,072.80 |

## C Determination of Equipment Savings

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **C.1** | **Change in cost due to reduction in truck trips** | **Average Operating Cost** | | **BEFORE --- Number of Calibration Rounds** | **AFTER --- Number of Calibration Rounds** | **Benefit Time Frame** | **Annual Equipment Savings** | **Total Equipment Savings** | **Annual Benefit of Equipment Savings** | **Net Present Value of Equipment Savings** |
| | | $ | Unit | No. | No. | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $20,637.00 | round of calibration | 2 | 1 | 3 | 1 | 3 | $ 20,637.00 | $ 59,514.70 |
| **C.2** | **Percent reduction in truck trips** | **Average Operating Cost** | | **BEFORE --- Number of Calibration Rounds** | **AFTER --- Percent Reduction in Calibration Rounds** | **Benefit Time Frame** | **Annual Equipment Savings** | **Total Equipment Savings** | **Annual Benefit of Equipment Savings** | **Net Present Value of Equipment Savings** |
| | | $ | Unit | No. | % | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $20,637.00 | round of calibration | 2 | 50% | 3 | 1 | 3 | $ 20,637.00 | $ 59,514.70 |

10-Year Benefit Calculation Spreadsheet

| Project Information | |
|---|---|
| **Project Title:** | Improving Weigh-In-Motion Sensor Accuracy Between Calibrations |
| **Project Number:** | 2015-18TS |
| **Principal Investigator:** | Chen-Fu Liao |
| **Technical Liaison:** | |
| **Administrative Liaison:** | |

| Given Values | |
|---|---|
| Benefit Time Frame = | 10 |
| Interest Rate = | 2.0% |
| Average Labor Rate = | $42.40 |
| Per Diem = | $186.00 |
| Annual Average Equipment Operating Cost Per Round of Calibration = | $20,637.00 |

**Entered Values** / **Performance Measurements**

## A Determination of Direct Labor Savings

| A.1 | Change in number of labor hours to complete activity | Average Labor Rate | | BEFORE --- Number of Hours | AFTER --- Number of Hours | Benefit Time Frame | Annual Labor Hour Savings | Total Labor Hour Savings | Annual Benefit of Labor Reduction | Net Present Value of Labor Reduction |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $ | Unit | No. | No. | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $ 42.40 | hour | 316 | 158 | 10 | 158 | 1,580 | $ 6,699.20 | $ 60,176.13 |

| A.2 | Percent reduction in number of labor hours to complete activity | Average Labor Rate | | BEFORE --- Number of Hours | AFTER --- Percent Reduction in Labor Hours | Benefit Time Frame | Annual Labor Hour Savings | Total Labor Hour Savings | Annual Benefit of Labor Reduction | Net Present Value of Labor Reduction |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $ | Unit | No. | % | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $ 42.40 | hour | 316 | 50% | 10 | 158 | 1,580 | $ 6,699.20 | $ 60,176.13 |

## B Determination of Employee Direct Cost Savings

| B.1 | Change in number of days to complete activity | Per Diem | | BEFORE --- Number of Days | AFTER --- Number of Days | Benefit Time Frame | Annual Per Diem Day Savings | Total Per Diem Day Savings | Annual Benefit of Per Diem Reduction | Net Present Value of Per Diem Reduction |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $ | Unit | No. | No. | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $ 186.00 | day | 4 | 2 | 10 | 2 | 20 | $ 372.00 | $ 3,341.52 |

| B.2 | Percent reduction in number of days to complete activity | Per Diem | | BEFORE --- Number of Days | AFTER --- Percent Reduction in Days | Benefit Time Frame | Annual Per Diem Day Savings | Total Per Diem Day Savings | Annual Benefit of Per Diem Reduction | Net Present Value of Per Diem Reduction |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $ | Unit | No. | % | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $ 186.00 | day | 4 | 50% | 10 | 2 | 20 | $ 372.00 | $ 3,341.52 |

## B Determination of Equipment Savings

| B.1 | Change in cost due to reduction in truck trips | Average Operating Cost | | BEFORE --- Number of Calibration Rounds | AFTER --- Number of Calibration Rounds | Benefit Time Frame | Annual Equipment Savings | Total Equipment Savings | Annual Benefit of Equipment Savings | Net Present Value of Equipment Savings |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $ | Unit | No. | No. | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $20,637.00 | round of calibration | 2 | 1 | 10 | 1 | 10 | $ 20,637.00 | $ 185,373.61 |

| B.2 | Percent reduction in truck trips | Average Operating Cost | | BEFORE --- Number of Calibration Rounds | AFTER --- Percent Reduction in Calibration Rounds | Benefit Time Frame | Annual Equipment Savings | Total Equipment Savings | Annual Benefit of Equipment Savings | Net Present Value of Equipment Savings |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $ | Unit | No. | % | Yrs. | No. | No. | $ | $ |
| | *Driving truck to WIM sensor locations* | $20,637.00 | round of calibration | 2 | 50% | 10 | 1 | 10 | $ 20,637.00 | $ 185,373.61 |

## Appendix A7

### Putting Research into Practice: Snowplow Calibration Guides for MnDOT and Local Governments

MnDOT Report Number: 2009RIC08

Publication Date: December, 2009

Authors: Gary Peterson, Paul Keranen, Rod Pletan

Project Cost: $88,705

#### Project Summary

This research effort developed guidelines for agencies to follow when calibrating snow plows. A tray device was invented as part of the research effort. The research project recommends use of the tray and guidelines to improve calibration practices

#### Challenges of Data Collection

The research report did not contain any data or information necessary to estimate quantitative benefits. During follow-up meetings with MnDOT staff members Tom Peters and Kathleen Schaefer, it was determined that no information existed that addressed either potential reductions in materials used or user benefits. Furthermore, no before condition information was collected and could not be derived for individual trucks, eliminating the possibility to calculate the difference in material usage with and without the snow plow being calibrated. A review of the salt usage during plowing operations showed that the amounts varied with the amount of snowfall, and there were no readily identifiable patterns across the state. MnDOT staff did suggest that it would be possible to document a reduction in the labor costs associated with calibrating the plows as a result of a device that was developed during the research and provided the necessary information to support the computations.

#### Assumptions for Benefits Estimation

- Initially tried to identify a reduction in material (salt) as a benefit – could not do the computations because MnDOT could not provide any record of long term usage prior to the initiation of calibrating back in the mid-1990's.
- With help of MnDOT Maintenance staff decided to focus on computing the benefits associated with the reduction in labor cost required to calibrate plows.
- MnDOT said they have 800 snowplows and that prior to the research it took two people one hour to calibrate each truck and that as a result of the research (and a tray device that was invented as part of the research) the time to calibrate each truck was cut in half – to 0.5 hours.
- MnDOT provided the average labor cost for the staff doing the calibration - $23/hour.
- Given that MnDOT's system has 11,900 miles of road and they have 800 plows that results in a ratio of 14.9 miles of road for each plow.
- The number of plows owned/operated by the 87 counties is unknown, so the same ratio was assumed and applied to the 45,000 mile county system = (approximately) 3,000 plows.

- The number of plows owned/operated by cities is unknown, but one data point was generated when the City of Eagan shared that they have 12 plows to cover their 240 miles of city streets. That results in a ratio of 20 miles of street for each plow and that was applied to the 22,000 miles of city streets in Minnesota = (approximately) 1,100 plows.
- The remaining 64,000 miles of roads in Minnesota belong to the townships and it was assumed that around two-thirds of the miles are gravel and one-third of the miles are paved. It was also assumed that snow removal on the gravel roads would be handled by a motor grader that does not dispense salt, so no benefit and that the 20 to 1 ratio found for city streets would be a good guess for the paved townships roads = (approximately) 1,100 plows.

### Benefits of the Recommendations

Following the guidelines and using the tray reduces the time and associated labor cost required to calibrate snow plows on each truck. Another benefit is a cost savings associated with a reduction in salt quantity that can be achieved by following the recommendations. All transportation agencies (state, county, city, and township) can benefit from these recommendations.

### Benefit Quantification Process

The benefit of implementing the recommendation to use the tray and guidelines was quantified in terms of the labor savings between the hours required to follow the guidelines (0.5 hours) and the traditional calibration methods (1.0 hour). The Minnesota Department of Transportation provided the number of labor hours before and after implementation of the recommendations, along with the average labor rate for the personnel who perform the calibrating. This data can be seen on the screen captures of the benefit calculation spreadsheets on the following pages.

### Quantitative Benefit of the Recommendations

The potential benefit of implementing the recommendation to calibrate snow plows is approximately $0.4 million over a three-year time period. Comparing this benefit to the cost of the research project results in a benefit-cost ratio of 4.5. This high ratio indicates the research effort was beneficial and its recommendation will likely result in cost savings for Minnesota agencies that choose to implement the calibration guidelines. The ratio increases to 13.5 for the 10-year benefit estimation time frame, based on a potential savings of $1.2 million.

3-Year Benefit Calculation Spreadsheet

| Project Information | | Given Values | |
|---|---|---|---|
| **Project Title:** | Putting Research into Practice: Snowplow Calibration Guides for MnDOT and Local Governments | Benefit Time Frame = | 3 |
| **Publication Number:** | 2012-03 | Interest Rate = | 2.0% |
| **Principal Investigator:** | | Average Labor Rate = | $23.00 |
| **Technical Liaison:** | | | |
| **Administrative Liaison:** | | | |

**Entered Values** / **Performance Measurements**

## Determination of Direct Labor Savings

| Change in number of labor hours to complete activity | Average Labor Rate | BEFORE --- Number of Hours | AFTER --- Number of Hours | Annual Frequency of Activity | | Benefit Time Frame | Annual Labor Savings | Total Labor Savings | Annual Benefit of Labor Reduction | Net Present Value of Labor Reduction |
|---|---|---|---|---|---|---|---|---|---|---|
| | $ | No. | No. | No. | Unit | Yrs. | No. | No. | $ | $ |
| *Snow Plow Salt & Sander Calibration - MnDOT* | $ 23.00 | 2 | 1 | 800 | snow plows | 3 | 800 | 2,400 | $ 18,400.00 | $ 53,063.45 |
| *Snow Plow Salt & Sander Calibration - County* | $ 23.00 | 2 | 1 | 3000 | snow plows | 3 | 3,000 | 9,000 | $ 69,000.00 | $ 198,987.95 |
| *Snow Plow Salt & Sander Calibration - City* | $ 23.00 | 2 | 1 | 1100 | snow plows | 3 | 1,100 | 3,300 | $ 25,300.00 | $ 72,962.25 |
| *Snow Plow Salt & Sander Calibration - Township* | $ 23.00 | 2 | 1 | 1100 | snow plows | 3 | 1,100 | 3,300 | $ 25,300.00 | $ 72,962.25 |

10-Year Benefit Calculation Spreadsheet

| Project Information | | Given Values | |
|---|---|---|---|
| **Project Title:** | Putting Research into Practice: Snowplow Calibration Guides for MnDOT and Local Governments | Benefit Time Frame = | 10 |
| **Publication Number:** | 2012-03 | Interest Rate = | 2.0% |
| **Principal Investigator:** | | Average Labor Rate = | $23.00 |
| **Technical Liaison:** | | | |
| **Administrative Liaison:** | | | |

**Entered Values** / **Performance Measurements**

## Determination of Direct Labor Savings

| Change in number of labor hours to complete activity | Average Labor Rate | BEFORE --- Number of Hours | AFTER --- Number of Hours | Annual Frequency of Activity | | Benefit Time Frame | Annual Labor Savings | Total Labor Savings | Annual Benefit of Labor Reduction | Net Present Value of Labor Reduction |
|---|---|---|---|---|---|---|---|---|---|---|
| | $ | No. | No. | No. | Unit | Yrs. | No. | No. | $ | $ |
| *Snow Plow Salt & Sander Calibration - MnDOT* | $ 23.00 | 2 | 1 | 800 | snow plows | 10 | 800 | 8,000 | $ 18,400.00 | $ 165,279.56 |
| *Snow Plow Salt & Sander Calibration - County* | $ 23.00 | 2 | 1 | 3000 | snow plows | 10 | 3,000 | 30,000 | $ 69,000.00 | $ 619,798.37 |
| *Snow Plow Salt & Sander Calibration - City* | $ 23.00 | 2 | 1 | 1100 | snow plows | 10 | 1,100 | 11,000 | $ 25,300.00 | $ 227,259.40 |
| *Snow Plow Salt & Sander Calibration - Township* | $ 23.00 | 2 | 1 | 1100 | snow plows | 10 | 1,100 | 11,000 | $ 25,300.00 | $ 227,259.40 |

# Appendix A8

## Recycled Unbound Materials

MnDOT Report Number: 2012-35

Publication Date: November, 2012

Authors: Tuncer B. Edil, James M. Tinjum, and Craig H. Benson

Project Cost: $349,910

### Project Summary

The research showed that recycled pavement materials incorporated into granular base layers demonstrated good field performance as very little cracking or rutting was observed and a good pavement ride was provided during the process to monitor the material properties during construction and throughout the pavement life. The research project recommends use of recycled pavement materials as a lower-cost alternative to traditional aggregate in pavement base layers.

### Challenges of Data Collection

The research report did not contain any data or information necessary to estimate quantitative benefits. MnDOT staff developed a modest performance increase scenario based on the findings from these two research efforts in order to calculate cost benefits to MnDOT and the CSAH systems. MnDOT staff member Ben Worel provided the data from this scenario that was necessary to estimate the potential effect of implementing the recommendations.

### Assumptions for Benefits Estimation

- MnDOT built on average 180 lane-miles per year from 2009-2013 of new/reconstruction for which Class 5 or 6 base placement (traditional granular base) is typically specified. However, contractors almost always substitute with less expensive Class 7 (recycled) base. This results in increased innovation and competitiveness, and reduced agency costs.
- Average aggregate costs/ton
- Class 7 (recycled base) = $16.00/cubic yard (yd$^3$) (estimated)
- Class 5 (virgin base) = $19.84/yd$^3$
- 6 inch typical Class 5 base thickness specified in both hot mix asphalt and Portland cement concrete designs.
- Approximate volume of base per lane-mile = 1,173 yd$^3$.

### Benefits of the Recommendations

Incorporation of recycled pavement materials into paving projects results in a cost savings during construction. The materials work with other elements of the pavement design to contribute to a smooth ride quality with little cracking or rutting.

## Benefit Quantification Process

The benefit of implementing the recommendation to use the recycled materials was quantified in terms of material savings based on the cost difference between Class 7 recycled material and Class 5 aggregate material. The Minnesota Department of Transportation provided the material costs and quantities for use in the benefit quantification. The Class 7 material cost is $3.84 less per cubic yard, with 1173 cubic yards required per lane mile of asphalt. The Department's annual construction is assumed to be 180 lane-miles. This data can be seen on the screen captures of the benefit calculation spreadsheets on the following pages.

## Quantitative Benefit of the Recommendations

The potential benefit of implementing the recommendation to use recycled pavement materials is approximately $2.3 million over a three-year time period. Comparing this benefit to the cost of the research project results in a benefit-cost ratio of 6.6. This high ratio indicates the research effort was beneficial and its recommendation will likely result in cost savings for Minnesota agencies that choose to incorporate recycled pavement materials into pavement base layers. The ratio increases to 20.9 for the 10-year benefit estimation time frame, based on a potential savings of $7.3 million.

## Comparison to MnROAD Benefits Estimate

The MnROAD Phase-II report states an estimated annual benefit of $827,000 (Table 2.1a) through use of recycled materials in paving projects. This value is similar to the annual value of $812,000 estimated during the conduct of this effort to develop a benefit quantification process. The data and assumptions necessary to quantify this benefit in terms of dollars saved were provided by MnDOT staff. Both benefit quantification procedures used the same input values and, thus, the results are similar.

3-Year Benefit Calculation Spreadsheet

| Project Information | | Given Values | |
|---|---|---|---|
| **Project Title:** | Developing a Guide for Recycled Unbound Pavement Materials | Benefit Time Frame = | 3 |
| **Project Number:** | TPF-5(129) | Interest Rate = | 2.0% |
| **Principal Investigator:** | | Average Labor Rate = | $32.73 |
| **Technical Liaison:** | | | |
| **Administrative Liaison:** | | | |

**Entered Values** | **Performance Measurements**

## Determination of Efficiency Savings in Materials

| Supplement with lower cost material | Number of Units of Material | | BEFORE --- Average Material Cost | AFTER --- Percent Reduction in Units of Material | Annual Frequency of Projects where Material savings are realized | | Benefit Time Frame | Annual Benefit of Material Reduction | Net Present Value of Material Reduction |
|---|---|---|---|---|---|---|---|---|---|
| | No. | Unit | $ | No. | No. | Unit | Yrs. | $ | $ |
| *Use Class 7 (recycled base) instead of Class 5 (virgin base)* | 1,173 | cubic yards per l: | $ 19.84 | $ 16.00 | 180 | lane-miles per year | 3 | $ 810,777.60 | $ 2,338,187.96 |

10-Year Benefit Calculation Spreadsheet

| Project Information | | Given Values | |
|---|---|---|---|
| **Project Title:** | Developing a Guide for Recycled Unbound Pavement Materials | Benefit Time Frame = | 10 |
| **Project Number:** | TPF-5(129) | Interest Rate = | 2.0% |
| **Principal Investigator:** | | Average Labor Rate = | $32.73 |
| **Technical Liaison:** | | | |
| **Administrative Liaison:** | | | |

**Entered Values** | **Performance Measurements**

## Determination of Efficiency Savings in Materials

| Supplement with lower cost material | Number of Units of Material | | BEFORE --- Average Material Cost | AFTER --- Percent Reduction in Units of Material | Annual Frequency of Projects where Material savings are realized | | Benefit Time Frame | Annual Benefit of Material Reduction | Net Present Value of Material Reduction |
|---|---|---|---|---|---|---|---|---|---|
| | No. | Unit | $ | No. | No. | Unit | Yrs. | $ | $ |
| *Use Class 7 (recycled base) instead of Class 5 (virgin base)* | 1,173 | cubic yards per l: | $ 19.84 | $ 16.00 | 180 | lane-miles per year | 10 | $ 810,777.60 | $ 7,282,878.71 |

# Appendix A9

## SMART Signal

MnDOT Report Number: NA

Publication Date: NA

Authors: NA

Project Cost: $239,000

### Project Summary

The research effort produced an automated system to collect data and retime signals with minimal human interaction. The system permits the retiming of signal cycles with regard to optimizing performance at arterial intersections rather than on a fixed schedule. The research project recommends use of the SMART Signal System as a lower cost and more responsive option for collecting data and retiming signals than traditional retiming methods.

### Challenges of Data Collection

The research report did not contain any data or information necessary to estimate quantitative benefits. During follow-up meetings with MnDOT staff members Steve Misgen and Henry Liu, it was concluded that potential user benefits could not be computed because there had been no effort to collect this information prior to installation of SMART signal. A separate project unrelated to this research effort looked at operations benefits in particular corridors, but MnDOT staff determined these results could not be extrapolated across the system and therefore would not be appropriate for quantifying benefits. Staff ultimately determined that there would be benefits associated with reducing the costs of re-timing signals using traffic count data provided by the system. However, it was also determined that because of the schedule for re-timing (every 4 years for major corridors and 6 years for minor corridors), a longer payback period would be required than the three year period adopted for this benefit quantification effort.

### Assumptions for Benefits Estimation

- All 730 intersections in metro area have ability to accept SMART signal.
- Number of major arterial intersections and retiming goal: 331 signals every 4 years.
- Number of minor arterial intersections and retiming goal: 399 signals every 6 years.
- Initial cost difference is installation of smart signal versus traditional data collection/evaluation.
- Later cost difference is related to traditional data collection/evaluation.
- Similar cost to retime controllers, so not included in calculations.
- SMART Signal installation cost: $6100
  - Cost for hardware and software per intersection: $6000

- Total installation cost (labor, vehicle) = $84, round up to $100
    - Hourly labor rate for technician to install smart signal: $36.62
    - Average round trip travel distance per intersection: 20 miles
    - Vehicle cost for trip is $0.55 per mile (current government rate) = $11
    - Installation requires 2 labor hours per intersection (1 hour drive time and 1 hour installation)

- No annual cost after SMART Signal hardware and software are installed.
- Cost to retime one signal: $3,500 based on MnDOT meeting notes and Center for Transportation Studies Catalyst news release
  - Cost to collect turning movement counts: $1400 (40% of 3500, which is in between 33-50% shown in email)
  - Cost to retime controllers remotely (2 hours for engineer): $100
  - Cost to evaluate data and determine optimal timing: $2000 (3500-1400 for data collection-100 retiming) or 40 engineer hours
  - Use $3400 in calculations because this excludes the $100 for the retiming
- Benefit time frame equals 12 years rather than 3 because it is common to both the major and minor retiming goals.
- Calculated Equivalent Annual Cost over 12 year period and used the difference as the benefit.

## Benefits of the Recommendations

The system provides quantitative benefits in terms of reduced cost for data collection and retiming efforts currently conducted by Minnesota Department of Transportation personnel. Other quantitative benefits are travel time savings for motorists and lower maintenance costs due to fewer vehicle stops that degrade the pavement quality. Qualitative benefits are also provided through improved signal operations for motorists which will result in less delay and elimination of personnel collecting data in the field. The data quality may also be improved with removal of the potential for human error. This data can be seen on the screen captures of the benefit calculation spreadsheets on the following pages.

## Benefit Quantification Process

The benefit of implementing the recommendation to use the SMART Signal system was quantified in terms of the activity savings between one-time installation of the system and perpetual data collection and retiming efforts. A benefit time frame of 12 years was used because it is the first common time period between the goals to retime major arterial intersections every 4 years and minor arterial intersections every 6 years. The quantification process used a cost of $6100 to install the system and a cost of $3,400 to collect data/develop timing plans, both of which were obtained from the Minnesota Department of Transportation. Because the installation occurs one time only and the data collection/retiming effort is recurring, the equivalent annual cost of each method was calculated to enable a homogeneous comparison. The benefit was estimated by comparing the difference between the two equivalent annual cost values.

## Quantitative Benefit of the Recommendations

The potential benefit of implementing the recommendation to use the SMART Signal system is approximately $155,000 over a twelve-year time period. Comparing this benefit to the cost of the research project results in a benefit-cost ratio of 0.6. This low ratio is reflective of the fact that the system installation is more costly than one round of the traditional method. It should be noted that once the expenditure to install the system at all eligible intersections is finished, the cost savings will be significant compared to continuing the traditional retiming methods.

12-Year Benefit Calculation Spreadsheet

| Project Information | |
|---|---|
| **Project Title:** | SMART Signal |
| **Project Number:** | |
| **Principal Investigator:** | |
| **Technical Liaison:** | |
| **Administrative Liaison:** | |

| Given Values | |
|---|---|
| Benefit Time Frame = | 12 |
| Interest Rate = | 2.0% |
| Traditional Retiming Cost = | $3,400 |
| SMART Signal Installation Cost = | $6,100 |

**Entered Values** | **Performance Measurements**

## Determination of Efficiency Savings in Activity

| Change in cost due to automation of process | Traditional Method --- Retiming Cost | | SMART Signal --- Installation Cost | | Frequency of Retiming Efforts | | Frequency of SMART Signal Installations | | Benefit Time Frame | Equivalent Annual Cost for Retiming | Equivalent Annual Cost for Installation | Cost Savings over 12 Years |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $ | Unit | $ | Unit | No. | Unit | No. | Unit | Yrs. | $ | $ | $ |
| *Retime major arterials (331 intersections) every 4 years and minor arterials (399 intersections) every 6 years for 12 years* | 3400 | intersection | 6,100 | intersection | 1791 | occurrences | 730 | installations | 12 | 575,811 | 421,074 | 154,737 |

Notes:
12-Year benefit time frame assumed rather than 3 years to achieve a common time frame between the major and minor arterial retiming goals of 4 and 6 years, respectively.
Costs do not include the effort to reprogram the controllers with the new timing plan, because this is assumed to be equal in both methods.

10-Year Benefit Calculation Spreadsheet

| Project Information | |
|---|---|
| **Project Title:** | SMART Signal |
| **Project Number:** | |
| **Principal Investigator:** | |
| **Technical Liaison:** | |
| **Administrative Liaison:** | |

| Given Values | |
|---|---|
| Benefit Time Frame = | 12 |
| Interest Rate = | 2.0% |
| Traditional Retiming Cost = | $3,400 |
| SMART Signal Installation Cost = | $6,100 |

**Entered Values** | **Performance Measurements**

## Determination of Efficiency Savings in Activity

| Change in cost due to automation of process | Traditional Method --- Retiming Cost | | SMART Signal --- Installation Cost | | Frequency of Retiming Efforts | | Frequency of SMART Signal Installations | | Benefit Time Frame | Equivalent Annual Cost for Retiming | Equivalent Annual Cost for Installation | Cost Savings over 12 Years |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $ | Unit | $ | Unit | No. | Unit | No. | Unit | Yrs. | $ | $ | $ |
| *Retime major arterials (331 intersections) every 4 years and minor arterials (399 intersections) every 6 years for 12 years* | 3400 | intersection | 6,100 | intersection | 1791 | occurrences | 730 | installations | 12 | 575,811 | 421,074 | 154,737 |

Notes:
12-Year benefit time frame assumed rather than 3 years to achieve a common time frame between the major and minor arterial retiming goals of 4 and 6 years, respectively.
Costs do not include the effort to reprogram the controllers with the new timing plan, because this is assumed to be equal in both methods.

## Appendix A10

### Traffic Sign Life Expectancy & Traffic Sign Maintenance/Management Handbook

MnDOT Report Numbers: 2014-20/2014RIC20

Publication Date: June, 2014/October, 2014

Authors: Howard Preston, Kristin C. Atkins, Matthew Lebens, and Maureen Jensen/Howard Preston, Michael Barry, and Kristin C. Atkins

Project Cost: $37,722/49,891

#### Project Summary

This research effort analyzed traffic sign retroreflectivity degradation for the purposes of determining the actual service life of signs and then incorporating these findings into a handbook for managing sign inventories to meet retroreflectivity requirements. The handbook also included guidance for removing unnecessary and ineffective signage. The project recommended removing signs that are not required by the *Minnesota Manual on Uniform Traffic Control Devices* and have no history of reducing crashes. The project also recommended the adoption of management practices to replace signs according to the service life as determined by the data analysis and not per the retroreflectivity sheeting manufacturer's warranty period.

#### Challenges of Data Collection

The research reports contained sufficient information to support the computation of benefits. Therefore, no challenges were encountered during data collection and additional meetings with MnDOT technical experts were not necessary.

#### Assumptions for Benefits Estimation

- An agency's annual sign maintenance costs can be reduced by removing a fraction of the sign inventory – if a sign isn't out along an agency's road system, it can't be knocked down or vandalized and it doesn't have to be replaced at some future date. The 28 percent reduction assumed in the computations is based on the actual outcome of a sign replacement project that involved the townships in Stevens County (a rural county in the southwestern part of the state). Training was provided to the County (that was administering the project), the township officials and the contractor hired to do the project. Over 90 percent of the signs that were removed were some kind of warning sign, virtually none of which are required to be installed by the Minnesota Manual on Uniform Traffic Control Devices and for which the national literature could find no history of crash reduction.
- An agency's annual maintenance costs can be reduced by using the longer effective life of the sheeting material indicated in the research project. Sign maintenance is now required for all agencies that operate road systems and some were using the warranty period for the sheeting material to determine a replacement cycle. For the most common types of sheeting material in Minnesota the warranty is 12 years. However, the research found that the actual life span of the material is likely much longer, between 20 and 30 years and that agencies could reduce annual costs

- By using the longer life span. It was determined that MnDOT already assumes a sign life of 18 years and that the majority of the counties and cities use 15 years, so those values became the base conditions.
- The estimated benefits were computed for each major category of road ownership in Minnesota (State, county, city and township) based on road miles and a density of signs taken from a sample from each agency and then extrapolated across the entire category of system mileage. This resulted in an assumed inventory of 400,000 signs along State highways, 900,560 signs along county roads, 557,275 regulatory and warning signs and 133,746 guide signs along city streets and 382,620 signs on township roads (for a grand total of more than 2.3 million signs across Minnesota).
- The minimum dollar value for the estimated benefit shown in the summary table is based on increasing the lifecycle one time to a 20-year lifecycle, according to the Traffic Sign Life Expectancy research project. The maximum dollar value estimated benefit is based on the combination of increasing lifecycle to a 30-year lifecycle and decreasing inventory per the Traffic Sign Maintenance/Management Handbook project. Both computations include each major category of road ownership in Minnesota (State, county, city and township).

## Benefits of the Recommendations

Reducing the sign inventory provides a qualitative benefit because maintenance costs would be reduced if there are fewer signs in the field. Qualitative benefits to this inventory reduction are less roadside clutter and improved driver compliance that could be achieved with the remaining signs once the ineffective and inappropriate signs are removed. Increasing the service life of signs results in a quantitative benefit achieved through a reduction in sign purchase and installation costs. All transportation agencies (state, county, city, and township) can benefit from these recommendations. The computed benefits are considered to be potential because the various highway agencies would have to take the initiative to remove signs and to manage their sign maintenance programs in ways consistent with the research in order to achieve the identified benefits. It is also acknowledged that the longer life cycle benefits associated with certain types of sheeting material may not be possible in parts of Minnesota where signs are regularly vandalized by both gun fire and paint balls. This data can be seen on the screen captures of the benefit calculation spreadsheets on the following pages.

## Benefit Quantification Process

The benefit of implementing the recommendation to reduce inventory and increase service life was quantified as material and lifecyle savings in terms of the reduced cost to purchase signs. The percentage of signs that could be removed from an agency's inventory was based on the outcome of a sign replacement project in a rural county in southwestern Minnesota. The number of signs by road ownership category (state, county, city, and township) was estimated based on road miles and a density of signs taken from an agency sample from each ownership category, and then extrapolated across the entire category of system mileage. The sign costs are from agency historical cost data.

## Quantitative Benefit of the Recommendations

The potential benefit of implementing the recommendation to decrease inventory and increase service life is approximately $19.7 million over a three-year time period. Comparing this benefit to the cost of the research project results in a benefit-cost ratio greater than 100. This high ratio indicates the research effort was beneficial and its recommendation will likely result in cost savings for Minnesota agencies that choose to modify their sign management practices. The ratio increases nearly three times for the 10-year benefit estimation time frame, based on a potential savings of $62.5 million.

3-Year Benefit Calculation Spreadsheet

| Project Information | |
|---|---|
| **Project Title:** | Traffic Sign Life Expectancy & Traffic Sign Maintenance/Management Handbook |
| **Publication Number:** | 2014-20 & 2014RIC20 |
| **Principal Investigator:** | Howard Preston |
| **Technical Liaison:** | |
| **Administrative Liaison:** | |

| Given Values | |
|---|---|
| Benefit Time Frame = | 3 |
| Interest Rate = | 2.0% |
| Average Labor Rate = | $32.73 |

**Entered Values** — **Performance Measurements**

## B Determination of Efficiency Savings in Materials

**B.1 Change in cost of due to reduction in materials used**

| | Average Material Cost | | BEFORE --- Number of Units of Material | AFTER --- Number of Units of Material | Annual Frequency of Projects where Material savings are realized | | Benefit Time Frame | Annual Material Savings | Total Material Savings | Annual Benefit of Material Reduction | Net Present Value of Material Reduction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $ | Unit | No. | No. | No. | Unit | Yrs. | No. | No. | $ | $ |
| <<Add Description>> | | | | | | projects | 3 | 0 | 0 | $ - | $ - |

**B.2 Percent reduction in materials used**

| | Average Material Cost | | BEFORE --- Number of Units of Material | AFTER --- Percent Reduction in Units of Material | Annual Frequency of Projects where Material savings are realized | | Benefit Time Frame | Annual Material Savings | Total Material Savings | Annual Benefit of Material Reduction | Net Present Value of Material Reduction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $ | Unit | No. | % | No. | Unit | Yrs. | No. | No. | $ | $ |
| *Reduce Sign Inventory by 28% - MnDOT* | $ 200.00 | sign | 31,822 | 28% | 1 | projects | 3 | 8,910 | 26,731 | $ 1,782,044.44 | $ 5,139,208.16 |
| *Reduce Sign Inventory by 28% - County* | $ 200.00 | sign | 81,651 | 28% | 1 | projects | 3 | 22,862 | 68,587 | $ 4,572,443.31 | $ 13,186,392.77 |
| *Reduce Sign Inventory by 28% - City (Regulatory and Warning)* | $ 200.00 | sign | 50,526 | 28% | 1 | projects | 3 | 14,147 | 42,442 | $ 2,829,470.93 | $ 8,159,863.90 |
| *Reduce Sign Inventory by 28% - Township* | $ 150.00 | sign | 34,691 | 28% | 1 | projects | 3 | 9,713 | 29,140 | $ 1,457,016.96 | $ 4,201,866.84 |
| *<<Add Description>>* | | | | | | projects | 3 | 0 | 0 | $ - | $ - |

## C Change in Life Cycle

**C.1 Increase in Life Cycle - Occurs Annually**

| | Average Activity Cost | | BEFORE --- Life Cycle | AFTER --- Life Cycle | Annual Frequency of Projects where life cycle is increased | | Benefit Time Frame | Net Present Value of Life Cycle Cost Savings (3 years) |
|---|---|---|---|---|---|---|---|---|
| | $ | Unit | Yrs. | Yrs. | No. | Unit | Yrs. | $ |
| *<<Add Description>>* | | | | | | | *3* | *$ -* |

**C.2 Increase in Life Cycle - Occurs Once**

| | Average Activity Cost | | BEFORE --- Life Cycle | AFTER --- Life Cycle | Annual Frequency of Projects where life cycle is increased | | Benefit Time Frame | Net Present Value of Life Cycle Cost Savings (3 years) |
|---|---|---|---|---|---|---|---|---|
| | $ | Unit | Yrs. | Yrs. | No. | Unit | Yrs. | $ |
| *Increase sign life expectancy - MnDOT* | $ 200.00 | sign | 18.0 | 20.0 | 400,000 | signs | 3 | $ 1,279,379.22 |
| *Increase sign life expectancy - County* | $ 200.00 | sign | 15.0 | 20.0 | 900,560 | signs | 3 | $ 8,658,117.34 |
| *Increase sign life expectancy - City (Regulatory and Warning)* | $ 200.00 | sign | 15.0 | 20.0 | 557,275 | signs | 3 | $ 5,357,724.46 |
| *Increase sign life expectancy - City (Guide)* | $ 250.00 | sign | 15.0 | 20.0 | 133,746 | signs | 3 | $ 1,607,317.34 |
| *Increase sign life expectancy - Township* | $ 150.00 | sign | 15.0 | 20.0 | 382,620 | signs | 3 | $ 2,758,924.05 |
| *Increase sign life expectancy - MnDOT* | $ 200.00 | sign | 18.0 | 30.0 | 400,000 | signs | 3 | $ 5,087,673.01 |
| *Increase sign life expectancy - County* | $ 200.00 | sign | 15.0 | 30.0 | 900,560 | signs | 3 | $ 17,232,109.98 |
| *Increase sign life expectancy - City (Regulatory and Warning)* | $ 200.00 | sign | 15.0 | 30.0 | 557,275 | signs | 3 | $ 10,663,391.77 |
| *Increase sign life expectancy - City (Guide)* | $ 250.00 | sign | 15.0 | 30.0 | 133,746 | signs | 3 | $ 3,199,017.53 |
| *Increase sign life expectancy - Township* | $ 150.00 | sign | 15.0 | 30.0 | 382,620 | signs | 3 | $ 5,491,041.62 |

**C.3 Increase in Life Cycle & Decrease in Quantities - Occurs Once**

| | Average Activity Cost | | BEFORE --- Life Cycle | AFTER --- Life Cycle | Annual Frequency of Projects where life cycle is increased | | Benefit Time Frame | AFTER --- Percent Reduction in Units of Material | Net Present Value of Life Cycle Cost Savings (3 years) |
|---|---|---|---|---|---|---|---|---|---|
| | $ | Unit | Yrs. | Yrs. | No. | Unit | Yrs. | % | $ |
| *Increase sign life expectancy - MnDOT* | $ 200.00 | sign | 18.0 | 20.0 | 400,000 | signs | 3 | 28% | $ 5,230,041.15 |
| *Increase sign life expectancy - County* | $ 200.00 | sign | 15.0 | 20.0 | 900,560 | signs | 3 | 28% | $ 17,552,637.62 |
| *Increase sign life expectancy - City (Regulatory and Warning)* | $ 200.00 | sign | 15.0 | 20.0 | 557,275 | signs | 3 | 28% | $ 10,861,737.29 |
| *Increase sign life expectancy - City (Guide)* | $ 250.00 | sign | 15.0 | 20.0 | 133,746 | signs | 3 | 0% | $ 1,607,317.34 |
| *Increase sign life expectancy - Township* | $ 150.00 | sign | 15.0 | 20.0 | 382,620 | signs | 3 | 28% | $ 5,593,178.31 |
| *Increase sign life expectancy - MnDOT* | $ 200.00 | sign | 18.0 | 30.0 | 400,000 | signs | 3 | 28% | $ 7,972,012.68 |
| *Increase sign life expectancy - County* | $ 200.00 | sign | 15.0 | 30.0 | 900,560 | signs | 3 | 28% | $ 23,725,912.32 |
| *Increase sign life expectancy - City (Regulatory and Warning)* | $ 200.00 | sign | 15.0 | 30.0 | 557,275 | signs | 3 | 28% | $ 14,681,817.75 |
| *Increase sign life expectancy - City (Guide)* | $ 250.00 | sign | 15.0 | 30.0 | 133,746 | signs | 3 | 0% | $ 3,199,017.53 |
| *Increase sign life expectancy - Township* | $ 150.00 | sign | 15.0 | 30.0 | 382,620 | signs | 3 | 28% | $ 7,560,302.96 |

10-Year Benefit Calculation Spreadsheet

| Project Information | |
|---|---|
| Project Title: | Traffic Sign Life Expectancy & Traffic Sign Maintenance/Management Handbook |
| Publication Number: | 2014-20 & 2014RIC20 |
| Principal Investigator: | Howard Preston |
| Technical Liaison: | |
| Administrative Liaison: | |

| Given Values | |
|---|---|
| Benefit Time Frame = | 10 |
| Interest Rate = | 2.0% |
| Average Labor Rate = | $32.73 |

Entered Values | Performance Measurements

## B Determination of Efficiency Savings in Materials

| B.1 Change in cost of due to reduction in materials used | Average Material Cost $ | Unit | BEFORE --- Number of Units of Material No. | AFTER --- Number of Units of Material No. | Annual Frequency of Projects where Material savings are realized No. | Unit | Benefit Time Frame Yrs. | Annual Material Savings No. | Total Material Savings No. | Annual Benefit of Material Reduction $ | Net Present Value of Material Reduction $ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| <<Add Description>> | | | | | | projects | 10 | 0 | 0 | $ - | $ - |

| B.2 Percent reduction in materials used | Average Material Cost $ | Unit | BEFORE --- Number of Units of Material No. | AFTER --- Percent Reduction in Units of Material % | Annual Frequency of Projects where Material savings are realized No. | Unit | Benefit Time Frame Yrs. | Annual Material Savings No. | Total Material Savings No. | Annual Benefit of Material Reduction $ | Net Present Value of Material Reduction $ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Reduce Sign Inventory by 28% - MnDOT | $ 200.00 | sign | 31,822 | 28% | 1 | projects | 10 | 8,910 | 89,102 | $ 1,782,044.44 | $ 16,007,365.71 |
| Reduce Sign Inventory by 28% - County | $ 200.00 | sign | 81,651 | 28% | 1 | projects | 10 | 22,862 | 228,622 | $ 4,572,443.31 | $ 41,072,360.69 |
| Reduce Sign Inventory by 28% - City (Regulatory and Warning) | $ 200.00 | sign | 50,526 | 28% | 1 | projects | 10 | 14,147 | 141,474 | $ 2,829,470.93 | $ 25,415,963.18 |
| Reduce Sign Inventory by 28% - Township | $ 150.00 | sign | 34,691 | 28% | 1 | projects | 10 | 9,713 | 97,134 | $ 1,457,016.96 | $ 13,087,778.70 |
| <<Add Description>> | | | | | | projects | 10 | 0 | 0 | $ - | $ - |

## C Change in Life Cycle

| C.1 Increase in Life Cycle - Occurs Annually | Average Activity Cost $ | Unit | BEFORE --- Life Cycle Yrs. | AFTER --- Life Cycle Yrs. | Annual Frequency of Projects where life cycle is increased No. | Unit | Benefit Time Frame Yrs. | Net Present Value of Life Cycle Cost Savings (10 years) $ |
|---|---|---|---|---|---|---|---|---|
| <<Add Description>> | | | | | | | 10 | $ - |

| C.2 Increase in Life Cycle - Occurs Once | Average Activity Cost $ | Unit | BEFORE --- Life Cycle Yrs. | AFTER --- Life Cycle Yrs. | Annual Frequency of Projects where life cycle is increased No. | Unit | Benefit Time Frame Yrs. | Net Present Value of Life Cycle Cost Savings (10 years) $ |
|---|---|---|---|---|---|---|---|---|
| Increase sign life expectancy - MnDOT | $ 200.00 | sign | 18.0 | 20.0 | 400,000 | signs | 10 | $ 4,064,649.69 |
| Increase sign life expectancy - County | $ 200.00 | sign | 15.0 | 20.0 | 900,560 | signs | 10 | $ 27,507,257.74 |
| Increase sign life expectancy - City (Regulatory and Warning) | $ 200.00 | sign | 15.0 | 20.0 | 557,275 | signs | 10 | $ 17,021,749.87 |
| Increase sign life expectancy - City (Guide) | $ 250.00 | sign | 15.0 | 20.0 | 133,746 | signs | 10 | $ 5,106,524.96 |
| Increase sign life expectancy - Township | $ 150.00 | sign | 15.0 | 20.0 | 382,620 | signs | 10 | $ 8,765,235.21 |
| Increase sign life expectancy - MnDOT | $ 200.00 | sign | 18.0 | 30.0 | 400,000 | signs | 10 | $ 16,163,783.34 |
| Increase sign life expectancy - County | $ 200.00 | sign | 15.0 | 30.0 | 900,560 | signs | 10 | $ 54,747,247.25 |
| Increase sign life expectancy - City (Regulatory and Warning) | $ 200.00 | sign | 15.0 | 30.0 | 557,275 | signs | 10 | $ 33,878,111.63 |
| Increase sign life expectancy - City (Guide) | $ 250.00 | sign | 15.0 | 30.0 | 133,746 | signs | 10 | $ 10,163,433.49 |
| Increase sign life expectancy - Township | $ 150.00 | sign | 15.0 | 30.0 | 382,620 | signs | 10 | $ 17,445,304.93 |

| C.3 Increase in Life Cycle & Decrease in Quantities - Occurs Once | Average Activity Cost $ | Unit | BEFORE --- Life Cycle Yrs. | AFTER --- Life Cycle Yrs. | Annual Frequency of Projects where life cycle is increased No. | Unit | Benefit Time Frame Yrs. | AFTER --- Percent Reduction in Units of Material % | Net Present Value of Life Cycle Cost Savings (10 years) $ |
|---|---|---|---|---|---|---|---|---|---|
| Increase sign life expectancy - MnDOT | $ 200.00 | sign | 18.0 | 20.0 | 400,000 | signs | 10 | 28% | $ 16,616,093.82 |
| Increase sign life expectancy - County | $ 200.00 | sign | 15.0 | 20.0 | 900,560 | signs | 10 | 28% | $ 55,765,579.08 |
| Increase sign life expectancy - City (Regulatory and Warning) | $ 200.00 | sign | 15.0 | 20.0 | 557,275 | signs | 10 | 28% | $ 34,508,264.95 |
| Increase sign life expectancy - City (Guide) | $ 250.00 | sign | 15.0 | 20.0 | 133,746 | signs | 10 | 0% | $ 5,106,524.96 |
| Increase sign life expectancy - Township | $ 150.00 | sign | 15.0 | 20.0 | 382,620 | signs | 10 | 28% | $ 17,769,798.13 |
| Increase sign life expectancy - MnDOT | $ 200.00 | sign | 18.0 | 30.0 | 400,000 | signs | 10 | 28% | $ 25,327,470.06 |
| Increase sign life expectancy - County | $ 200.00 | sign | 15.0 | 30.0 | 900,560 | signs | 10 | 28% | $ 75,378,371.53 |
| Increase sign life expectancy - City (Regulatory and Warning) | $ 200.00 | sign | 15.0 | 30.0 | 557,275 | signs | 10 | 28% | $ 46,644,845.42 |
| Increase sign life expectancy - City (Guide) | $ 250.00 | sign | 15.0 | 30.0 | 133,746 | signs | 10 | 0% | $ 10,163,433.49 |
| Increase sign life expectancy - Township | $ 150.00 | sign | 15.0 | 30.0 | 382,620 | signs | 10 | 28% | $ 24,019,448.33 |

# APPENDIX B:
## TEMPLATE SPREADSHEETS

The Excel spreadsheet tool is available at mndot.gov/research/reports/2017/2017B.xlsx

## Appendix B1

Direct Labor Savings

Direct Labor Savings Template Spreadsheet

**Project Information**

| | |
|---|---|
| **Project Title:** | |
| **Project Number:** | |
| **Principal Investigator:** | |
| **Project Cost:** | |
| **Technical Liaison:** | |
| **Administrative Liaison:** | |

**Given Values**

| | |
|---|---|
| Benefit Time Frame = | |
| Interest Rate = | |
| Average Labor Rate = | |

**Entered Values** | **Performance Measurements**

## Determination of Direct Labor Savings

| Change in number of labor hours to complete activity<br>Recommendations | Average Labor Rate<br>$ | BEFORE<br>---<br>Number of Hours<br>No. | AFTER<br>---<br>Number of Hours<br>No. | Annual Frequency of Activity<br>No. | <br>Unit | Benefit Time Frame<br>Yrs. | Annual Labor Savings<br>No. | Total Labor Savings<br>No. | Annual Benefit of Labor Savings<br>$ | Net Present Value of Labor Savings<br>$ |
|---|---|---|---|---|---|---|---|---|---|---|
| *<<Add Description>>* | | | | | | | | | | |
| *<<Add Description>>* | | | | | | | | | | |

| Percent reduction in number of labor hours to complete activity<br>Recommendations | Average Labor Rate<br>$ | BEFORE<br>---<br>Number of Hours<br>No. | AFTER<br>---<br>Percent Reduction in Labor Hours<br>% | Annual Frequency of Activity<br>No. | <br>Unit | Benefit Time Frame<br>Yrs. | Annual Labor Savings<br>No. | Total Labor Savings<br>No. | Annual Benefit of Labor Savings<br>$ | Net Present Value of Labor Savings<br>$ |
|---|---|---|---|---|---|---|---|---|---|---|
| *<<Add Description>>* | | | | | | | | | | |
| *<<Add Description>>* | | | | | | | | | | |

## Data Documentation

## Benefit - Cost Ratio Estimation

| Calculation Components | Benefit Sum<br>$ | Research Cost<br>$ | Ratio |
|---|---|---|---|
| Sum of Benefits from all Categories | | | |
| Cost of Research Project | | | |

## Appendix B2

Safety

Safety Template Spreadsheet

| Project Information | |
|---|---|
| Project Title: | |
| Project Number: | |
| Principal Investigator: | |
| Project Cost: | |
| Technical Liaison: | |
| Administrative Liaison: | |

| Crash | Definitions & Distributions | |
|---|---|---|
| Fatal | | 1% |
| Type A Injury | Serious | 1% |
| Type B Injury | Moderate | 8% |
| Type C Injury | Minor | 20% |
| Property Damage | | 70% |

| Injury Crash | Definitions & Distributions | |
|---|---|---|
| Type A | Serious | 5% |
| Type B | Moderate | 26% |
| Type C | Minor | 69% |

| Given Values | |
|---|---|
| Benefit Time Frame = | |
| Interest Rate = | |
| Fatal Crash = | |
| Type A Injury Crash = | |
| Type B Injury Crash = | |
| Type C Injury Crash = | |
| Property Damage Only Crash = | |

## User Input – Historical Crash Data

| | | Related Crashes | | | | | | Road System Data | | | Crash Reduction Factors | | | | | | Service Life | Treatment Deployment | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fatal | Injury | | | Property Damage | | | | | | | | | | | | | | |
| | | Crashes | Type A Crashes | Type B Crashes | Type C Crashes | Crashes | Years of Crash Data | Feature Count | | Traffic Growth Rate | Fatal | A Injury | B Injury | C Injury | Property Damage | Unit | Service Life | Amount Deployed | | Level of Confidence |
| Recommendations | Related Crash Types | No. | No. | No. | No. | No. | No. | No. | Unit | % | % | % | % | % | % | | Years | No. | Unit | ≤1.0 |
| <<Add Description of Recommendation>> | | | | | | | | | | | | | | | | | 0 | | | |
| <<Add Description of Recommendation>> | | | | | | | | | | | | | | | | | 0 | | | |

## Projected Recommendation Effectiveness and Benefits

| | | Annual Projected Crash and Injury Reductions | | | | | | | | | | | | Benefits | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fatal Crashes | | Type A Injury | | Type B Injury | | Type C Injury | | Property Damage | | Annual Reduction | Annual Reduction | | |
| | | Density | Number | Density | Number | Density | Number | Density | Number | Density | Number | Fatal and Type A Injury | Fatal, Injury, & Property Damage | Annual Benefit of Implementation | Net Present Value of Annual Benefit of Implementation |
| Recommendations | Related Crash Types | Crashes/year/unit | Reduced Crashes | Crashes/year/unit | Reduced Crashes | Crashes/year/unit | Reduced Crashes | Crashes/year/unit | Reduced Crashes | Crashes/year/unit | Reduced Crashes | Reduced Crashes | Reduced Crashes | $ | $ |
| <<Add Description of Recommendation>> | | | | | | | | | | | | | | | |
| <<Add Description of Recommendation>> | | | | | | | | | | | | | | | |

## Projected Recommendation Effectiveness and Benefits – Change in Crashes

| | | Change in Annual Related Crashes | | | | | Road System Data | | | Treatment Deployment | | Benefits | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fatal | Injury | | | Property Damage | | | | | | | |
| | | Crashes | Type A Crashes | Type B Crashes | Type C Crashes | Crashes | Feature Count | | Traffic Growth Rate | Amount Deployed | | Annual Benefit of Implementation | Present Value of Annual Benefit of Implementation |
| Recommendations | Related Crash Types | No. | No. | No. | No. | No. | No. | Unit | % | No. | Unit | $ | $ |
| <<Add Description of Recommendation>> | | | | | | | | | | | | $0 | |
| <<Add Description of Recommendation>> | | | | | | | | | | | | $0 | |

## Data Documentation

## Benefit - Cost Ratio Estimation

| Calculation Components | Benefit Sum | Research Cost | Ratio |
|---|---|---|---|
| | $ | $ | |
| Sum of Benefits from all Categories | | | |
| Cost of Research Project | | | |

## Appendix B3

Traffic Operations/User Benefits

Traffic Operations/User Benefits Template Spreadsheet

| Project Information | |
|---|---|
| Project Title: | |
| Project Number: | |
| Principal Investigator: | |
| Project Cost: | |
| Technical Liaison: | |
| Administrative Liaison: | |

| Given Values | |
|---|---|
| Benefit Time Frame = | |
| Interest Rate = | |
| Auto - Value of Time (per person-hour) = | |
| Truck - Value of Time (per person-hour) = | |
| Value of Vehicle Stop = | |
| Design Labor (per person-hour) = | |

## User Input

| | | Automobile Change in Travel Hours | | | | Truck Change in Travel Hours | | | | Total Change in Number of Stops | | Design Labor | | Treatment Deployment | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | BEFORE — Veh. Hours of Delay (per weekday) | AFTER — Veh. Hours of Delay (per weekday) | Auto Occupancy | | BEFORE — Veh. Hours of Delay (per weekday) | AFTER — Veh. Hours of Delay (per weekday) | Truck Occupancy | | BEFORE — Number of Stops (per weekday) | AFTER — Number of Stops (per weekday) | Total Hours | | Amount Deployed | | Level of Confidence |
| Recommendations | Location | No. | No. | No. | Unit | No. | No. | No. | Unit | No. | No. | No. | Unit | No. | Unit | ≤1.0 |
| <<Add Description>> | <<Add Location>> | | | | persons per veh. | | | | persons per veh. | | | | per location | | | |
| <<Add Description>> | <<Add Location>> | | | | persons per veh. | | | | persons per veh. | | | | per location | | | |

## Projected Recommendation Effectiveness - User Benefits

| | | Automobile Travel Time Savings | | | | Truck Travel Time Savings | | | | Automobile and Truck Total Time Savings | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Percent Reduction in Hours of Delay | Annual Time Savings (person-hour) | Annual Benefit of Implementation | Total Time Savings (person-hour) | Percent Reduction in Hours of Delay | Annual Time Savings (person-hour) | Annual Benefit of Implementation | Total Time Savings (person-hour) | Annual Time Savings (person-hour) | Annual Benefit of Implementation | Total Time Savings (person-hour) |
| Recommendations | Location | % | No. | $ | No. | % | No. | $ | No. | No. | $ | No. |
| <<Add Description>> | <<Add Location>> | | | | | | | | | | | |
| <<Add Description>> | <<Add Location>> | | | | | | | | | | | |

## Projected Recommendation Effectiveness - DOT Benefits

| | | Reduction in Stops | | | Design Labor Savings | |
|---|---|---|---|---|---|---|
| | | Annual Reduction in Stops | Annual Benefit of Reduced Stops | Total Reduction in Stops | Labor Hours Saved | Value of Labor Hours Saved |
| Recommendations | Location | No. | $ | No. | No. | $ |
| <<Add Description>> | <<Add Location>> | | | | | |
| <<Add Description>> | <<Add Location>> | | | | | |

## Annual Benefit of Implementation

| | | Total Annual Benefit of Implementation | Present Value of Total Annual Benefit of Implementation |
|---|---|---|---|
| Recommendations | Location | $ | $ |
| <<Add Description>> | <<Add Location>> | | |
| <<Add Description>> | <<Add Location>> | | |

## Data Documentation

## Benefit - Cost Ratio Estimation

| Calculation Components | Benefit Sum $ | Research Cost $ | Ratio |
|---|---|---|---|
| Sum of Benefits from all Categories | | | |
| Cost of Research Project | | | |

## Appendix B4

Materials and Activities

Materials and Activities Template Spreadsheet

| Project Information | |
|---|---|
| **Project Title:** | |
| **Project Number:** | |
| **Principal Investigator:** | |
| **Project Cost:** | |
| **Technical Liaison:** | |
| **Administrative Liaison:** | |

| Given Values | |
|---|---|
| Benefit Time Frame = | |
| Interest Rate = | |

Entered Values | Performance Measurements

## Determination of Savings in Materials or Activity

| Change in cost due to reduction in material quantity Recommendations | Average Material Cost $ | Unit | BEFORE --- Number of Units of Material No. | AFTER --- Number of Units of Material No. | Annual Frequency of Projects with Material Savings No. | Unit | Benefit Time Frame Yrs. | Annual Material Savings No. | Total Material Savings No. | Annual Benefit of Material Reduction $ | Net Present Value of Material Reduction $ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| <<Add Description>> | | | | | | | | | | | |
| <<Add Description>> | | | | | | | | | | | |

| Percent reduction in material quantity Recommendations | Average Material Cost $ | Unit | BEFORE --- Number of Units of Material No. | AFTER --- Percent Reduction in Units of Material % | Annual Frequency of Projects with Material Savings No. | Unit | Benefit Time Frame Yrs. | Annual Material Savings No. | Total Material Savings No. | Annual Benefit of Material Reduction $ | Net Present Value of Material Reduction $ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| <<Add Description>> | | | | | | | | | | | |
| <<Add Description>> | | | | | | | | | | | |

| Change in cost due to lower cost material Recommendations | Number of Units of Material No. | Unit | BEFORE --- Average Material Cost $ | AFTER --- Average Material Cost $ | Annual Frequency of Projects with Material Savings No. | Unit | Benefit Time Frame Yrs. | Annual Cost Savings No. | Total Cost Savings No. | Annual Benefit of Lower Cost Material $ | Net Present Value of Lower Cost Material $ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| <<Add Description>> | | | | | | | | | | | |
| <<Add Description>> | | | | | | | | | | | |

| Percent reduction in activity cost Recommendations | BEFORE --- Average Activity Cost $ | Unit | AFTER --- Percent Reduction in Activity Cost % | Annual Frequency of Activity No. | Unit | Benefit Time Frame Yrs. | Annual Benefit of Activity Savings $ | Net Present Value of Activity Savings $ |
|---|---|---|---|---|---|---|---|---|
| <<Add Description>> | | | | | | | | |
| <<Add Description>> | | | | | | | | |

## Data Documentation

## Benefit - Cost Ratio Estimation

| Calculation Components | Benefit Sum $ | Research Cost $ | Ratio |
|---|---|---|---|
| Sum of Benefits from all Categories | | | |
| Cost of Research Project | | | |

## Appendix B5

Lifecycle

Lifecycle Template Spreadsheet

**Project Information**

| | |
|---|---|
| **Project Title:** | |
| **Publication Number:** | |
| **Principal Investigator:** | |
| **Project Cost:** | |
| **Technical Liaison:** | |
| **Administrative Liaison:** | |

**Given Values**

| | |
|---|---|
| Benefit Time Frame = | |
| Interest Rate = | |

**Entered Values** | **Performance Measurements**

## Change in Life Cycle

| Increase in Life Cycle - Occurs Annually Recommendations | Average Activity Cost $ | Unit | BEFORE --- Lifecycle Yrs. | AFTER --- Lifecycle Yrs. | Annual Frequency of Projects With Increased Lifecycle No. | Unit | Benefit Time Frame Yrs. | Net Present Value of Lifecycle Cost Savings ( years) $ |
|---|---|---|---|---|---|---|---|---|
| <<Add Description>> | | | | | | | | $ - |
| <<Add Description>> | | | | | | | | $ - |

| Increase in Life Cycle - Occurs Once | Average Activity Cost $ | Unit | BEFORE --- Lifecycle Yrs. | AFTER --- Lifecycle Yrs. | Annual Frequency of Projects With Increased Lifecycle No. | Unit | Benefit Time Frame Yrs. | Net Present Value of Lifecycle Cost Savings ( years) $ |
|---|---|---|---|---|---|---|---|---|
| <<Add Description>> | | | | | | | | $ - |
| <<Add Description>> | | | | | | | | $ - |

| Increase in Life Cycle & Decrease in Quantities - Occurs Once Recommendations | Average Activity Cost $ | Unit | BEFORE --- Lifecycle Yrs. | AFTER --- Lifecycle Yrs. | Annual Frequency of Projects With Increased Lifecycle No. | Unit | AFTER --- Percent Reduction in Items % | Benefit Time Frame Yrs. | Net Present Value of Lifecycle Cost Savings ( years) $ |
|---|---|---|---|---|---|---|---|---|---|
| <<Add Description>> | | | | | | | | | $ - |
| <<Add Description>> | | | | | | | | | $ - |

## Data Documentation

## Benefit - Cost Ratio Estimation

| Calculation Components | Benefit Sum $ | Research Cost $ | Ratio |
|---|---|---|---|
| Sum of Benefits from all Categories | | | |
| Cost of Research Project | | | |

## Appendix B6

Risk Management

Risk Management Template Spreadsheet

| Project Information | |
|---|---|
| **Project Title:** | |
| **Project Number:** | |
| **Principal Investigator:** | |
| **Project Cost:** | |
| **Technical Liaison:** | |
| **Administrative Liaison:** | |

| Given Values | |
|---|---|
| Benefit Time Frame = | |
| Interest Rate = | |

Entered Values

Performance Measurements

## Determination of Savings from Reduced Fines

| Change in cost due to reduction in actions that result in fines | Average Cost of Fines | | BEFORE --- Number of Actions Resulting in Fines | AFTER --- Number of Actions Resulting in Fines | Annual Frequency of Implemented Actions | | Benefit Time Frame | Annual Reduction in Actions Resulting in Fines | Total Reduction in Actions Resulting in Fines | Annual Benefit of Action Reduction | Net Present Value of Action Reduction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Recommendations | $ | Action | No. | No. | No. | Unit | Yrs. | No. | No. | $ | $ |
| *<<Add Description>>* | | | | | | | | | | | |
| *<<Add Description>>* | | | | | | | | | | | |

## Data Documentation

## Benefit - Cost Ratio Estimation

| Calculation Components | Benefit Sum | Research Cost | Ratio |
|---|---|---|---|
| | $ | $ | |
| Sum of Benefits from all Categories | | | |
| Cost of Research Project | | | |