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Transportation Asset Management Plan

Technical Guide

July 2014

DRAFT

MinnesotaGO
A Collaborative Vision for Transportation

Purpose and Structure of the TAMP Technical Guide

PURPOSE AND STRUCTURE OF THE TAMP TECHNICAL GUIDE

Purpose and Scope

The TAMP Technical Guide provides further detail on the process, methodology, and analyses conducted during the development of the TAMP. While all the information contained in the Technical Guide is relevant and may be of interest to those tasked with developing a TAMP, much of the information was considered too detailed for inclusion in the main document (in that it could potentially disrupt the flow for the reader). Therefore, this Technical Guide was developed to document such details and to serve as a reference for updates to the TAMP.

Structure

The TAMP Technical Guide has been designed to roughly parallel the main TAMP, with eight chapters (in addition to this Introductory chapter), each corresponding to a chapter in the TAMP and following a general format with two key sections:

- A Process section, with a narrative describing the processes MnDOT went through to develop each chapter of the TAMP, including the analyses and the methods of gathering the required information (with visual aids, as necessary)
- A Supporting Documentation/Data section, which highlights and explains the data, analyses, and results (including displays of spreadsheets and worksheets, as applicable)

Depending on the nature of the corresponding TAMP chapter, some Technical Guide chapters are weighted more toward process, while others contain more supporting documentation/data. Several (Chapters 3 and 7) are quite short due to the comprehensiveness of their parallel TAMP chapters.

- Chapter 1(Introduction) and 2 (Asset Management Planning and Programming Framework) – Supplemental Information
    - This chapter provides a narrative on the process of developing MnDOT's first TAMP, including details regarding the workshops and other necessary meetings. A table is provided that maps each MAP-21 requirement to the chapter in which it appears in MnDOT's TAMP.
- Chapter 3 (Asset Management Performance Measures and Targets) – Supplemental Information
    - Chapter 3 of the TAMP contains information pertaining to asset management performance measures and targets. Key terms associated with targets discussed in the TAMP are the focus of this chapter of the Technical Guide.
- Chapter 4 (Asset Inventory and Conditions) – Supplemental Information
    - This chapter describes the steps involved in assembling the asset register/folios. Also discussed are key issues in finalizing the folios for the TAMP and general procedures to update and maintain the asset register/folios.
- Chapter 5 (Risk Management Analysis) – Supplemental Information
    - This chapter provides a detailed description of the various processes involved in identifying and prioritizing the risks and mitigation strategies described in the TAMP. MnDOT's approach to Enterprise Risk Management is presented in this chapter, along with the steps involved in determining the undermanaged risks presented in the TAMP.
- Chapter 6 (Life-Cycle Cost Considerations) – Supplemental Information
    - This chapter provides a detailed description of the various processes involved in analyzing the life-cycle costs associated with the asset categories discussed in the TAMP. Two separate aspects of life-cycle costing are documented: 1) the data used to conduct the analysis and the process for gathering the information; and 2) the metrics and assumptions used in the analysis.
- Chapter 7 (Performance Gaps) – Supplemental Information
    - Chapter 7 contains information pertaining to current and targeted performance levels. This Technical Guide chapter provides a brief overview of how performance gaps are discussed in the TAMP.

- Chapter 8 (Financial Plan and Investment Strategies) – Supplemental Information
    - This chapter provides a description of the asset management investment strategies developed as a part of the Minnesota State Highway Investment Plan (MnSHIP) and how they were incorporated into the TAMP. The investment strategies developed for highway culverts, stormwater tunnels, overhead sign structures and high-mast light tower structures are discussed in greater detail than in the main TAMP document. A summary is also included that details the envisioned process changes regarding how future TAMPs will inform MnSHIP updates.
- Chapter 9 (Implementation and Future Developments) – Supplemental Information
    - This chapter describes a process to help MnDOT decide which assets to consider adding in its next TAMP. A few asset management tools and techniques that MnDOT could potentially implement in the future are also discussed.

Chapter 1

INTRODUCTION:
SUPPLEMENTAL INFORMATION

AND

Chapter 2

ASSET MANAGEMENT PLANNING AND PROGRAMMING FRAMEWORK: SUPPLEMENTAL INFORMATION

INTRODUCTION AND ASSET MANAGEMENT PLANNING AND PROGRAMMING FRAMEWORK: SUPPLEMENTAL INFORMATION

Overview

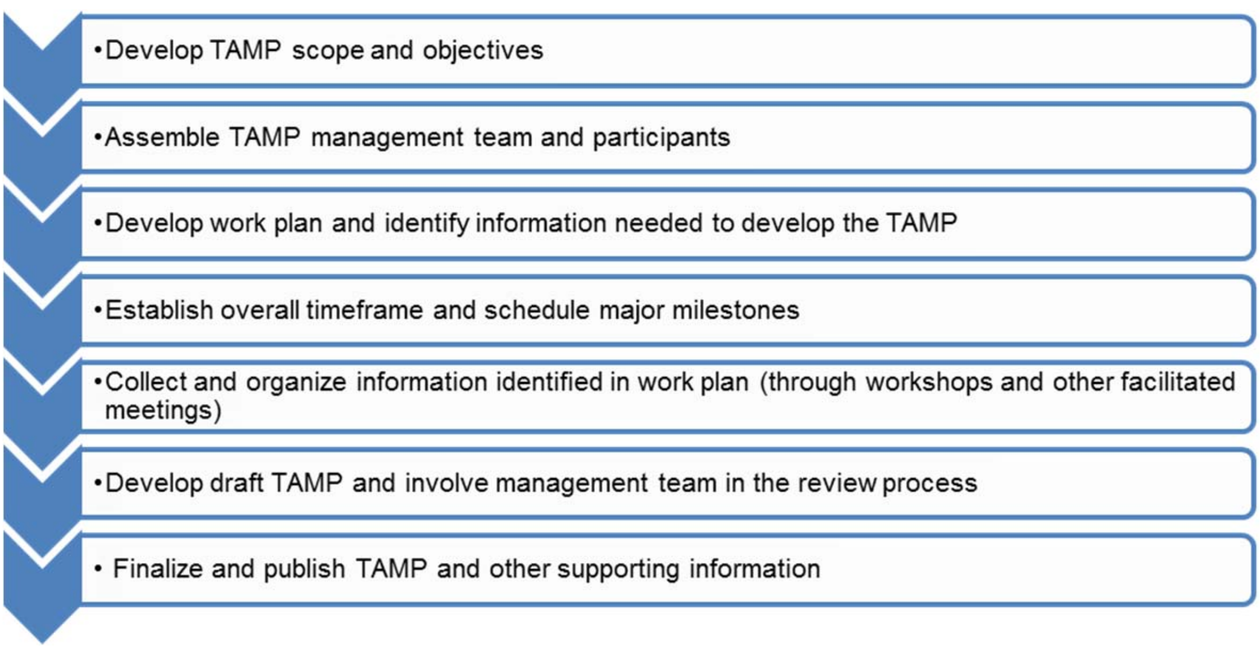
This chapter provides a narrative of the process for the development of MnDOT's first TAMP. Details are provided regarding the basic processes used to develop each section of the TAMP and the face-to-face meetings held to discuss results and findings at each stage of the TAMP development process. A simple table (Figure 1-4) is also provided that discusses MAP-21 requirements and the section of the TAMP that addresses those requirements.

Note:
Chapter 2 of the TAMP provides the necessary documentation regarding MnDOT's planning and programming framework. Therefore, the primary focus of this chapter of the Technical Guide is supplementary information pertaining to the TAMP development process.

Process

This section describes the basic processes involved in developing the TAMP, including the roles and responsibilities of various personnel and groups involved. The critical pieces of information required to develop the TAMP are also highlighted, in addition to the various meetings and facilitated workshops conducted during the TAMP development process. The overall TAMP development process flow is illustrated in Figure 1-1.

Figure 1-1: TAMP Development Process



TAMP SCOPE

The MnDOT TAMP formalized and documented key information on the following six asset categories:

- Pavements
- Bridges
- Highway Culverts
- Deep Stormwater Tunnels
- Overhead Sign Structures
- High-Mast Light Tower Structures

For each asset class, the following information was incorporated into the TAMP:

- Asset inventory and conditions
- Asset management objectives and measures
- Performance gap assessment
- Life-cycle cost (LCC) considerations
- Risk management analysis
- Financial plan and investment strategies
- Asset management process enhancements

TAMP DEVELOPMENT MANAGEMENT AND TIMEFRAME

The development of MnDOT's TAMP was led by Mr. Mark Nelson, Mr. Kirby Becker, and Mr. Matthew Malecha from MnDOT's Office of Transportation System Management. Mr. Nelson served as the contact for the FHWA pilot study and Mr. Becker and Mr. Malecha served as Project Managers for the consulting contract with Applied Pavement Technology, Inc. (APTech). The TAMP development effort commenced in June 2013 and a final version of the TAMP was completed in July 2014.

PARTICIPANTS IN DEVELOPING THE TAMP

The TAMP was developed through the cooperative efforts of several committees, Work Groups, and outside contractors, as described below.

STEERING COMMITTEE

The Steering Committee provided general direction to the TAMP effort and assisted in communicating the purpose and progress to other stakeholders. The Steering Committee met every other month (six times) during development of the TAMP to provide direction on risk, life-cycle cost, performance measures and targets, financial plan and strategies, and next steps.

PROJECT MANAGEMENT TEAM

A multi-disciplinary Project Management Team (PMT) managed the overall TAMP effort and was very involved in project management tasks, such as work plan development. The PMT also collaborated with the outside contractors on a regular basis and served as members of the technical Work Groups. Similar to the Steering Committee, the PMT met every other month (six times) during development of the TAMP. Members on the PMTalso served on the Steering Committee.

WORK GROUPS

Work Groups were developed for each specific asset category and a separate Work Group to help facilitate the risk assessment and management process. These groups assisted in documenting current practices in terms of risk management, life-cycle costing, gap identification, and financial planning. The groups also helped develop and review defined levels of service, performance measures and targets, and maintenance and capital cost estimates for identified asset categories. During development of the TAMP, there were more than twenty Work Group meetings to discuss the above information.

FHWA PILOT STUDY SUPPORT

The FHWA Office of Asset Management supported three state DOTs in a pilot project to develop their first TAMPs, which will serve as models to be studied and as examples for other state or local transportation agencies. Along with MnDOT, agencies participating in the TAMP pilot were the Louisiana Department of Transportation and Development (LADOTD) and the New York State Department of Transportation (NYSDOT).

The contractor for the FHWA pilot project was AMEC, with technical assistance from Cambridge Systematics. The FHWA contractor was responsible for providing technical assistance to and helping to develop TAMPs for the three pilot states. Key contacts for the AMEC/Cambridge Systematics team include Mr. Jonathan Groeger, AMEC, and Mr. Joe Guerre, Cambridge Systematics.

MNDOT CONTRACTOR SUPPORT

MnDOT contracted with Applied Pavement Technology, Inc. (APTech) to assist with the development of MnDOT's comprehensive TAMP. As part of the contract, APTech, in coordination with MnDOT facilitated meetings of the PMT, Steering Committee, and Work Groups and assisted with the development of a comprehensive TAMP and a corresponding Technical Guide. Ms. Katie Zimmerman was the Principal Investigator for APTech. She was assisted by Mr. Prashant Ram, APTech, and Mr. Paul Thompson, an individual consultant to the team.

INFORMATION NEEDED TO DEVELOP THE TAMP

Figure 1-2 summarizes the key information and work activities required to develop the TAMP. Much of the information was obtained through facilitated teleconferences, Work Group assignments, and face-to-face meetings/workshops with the participants involved in the TAMP development process.

Figure 1-2: Information Needed to Develop the TAMP

SECTION	INFORMATION/WORK ACTIVITIES REQUIRED
Asset Management Planning and Programming Framework	• Describe the objectives of the asset management program. • Describe existing asset management policy and various plans and programs currently in place to support asset management. • Discuss MnDOT's overall capital and operations/maintenance investment priorities. • Document the process used to develop the above items.
Asset Management Performance Measures and Targets	• Summarize the performance measures and targets documented to be used in the TAMP. • Assess the adequacy of the performance measures to make investment decisions and make any recommendations for changes. • Determine whether any additional performance measures are needed to report progress towards national goal areas. • Document the process for developing performance measures and establishing performance targets. • Recommend to the Steering Committee any changes to performance measures that might be required. • Document the process for using performance data to support asset management investment decisions at MnDOT.

Asset Inventory and Condition	• Develop an asset register showing the inventory count of each asset, current replacement value, current age and condition, office responsible for the data, and confidence in the data. • Compile documentation on the procedures used to assess asset condition.
Risk Management Analysis	• Describe MnDOT's process for assessing and managing risks. • Document agency and program risks that could impact MnDOT's ability to achieve the goals documented in the TAMP. • Summarize agency and program risks in a risk register that includes the likelihood and consequences of occurrence and recommendations for mitigation. • Document the process used to evaluate risks.
Life-Cycle Cost Considerations	• Describe "life-cycle costs" and explain why they are important. • Provide an example of a typical deterioration model. • Describe strategies for managing assets over their whole lives, from inception to disposal, illustrating the use of a sequence of activities including maintenance and preservation treatments. • Document the typical life-cycle cost of the assets included in the TAMP. • Document the typical life-cycle cost of adding a new lane-mile of roadway and document a process for considering future maintenance costs when evaluating potential roadway expansion projects. • Document the tools used by the agency to manage assets effectively over their life-cycles.
Performance Gaps	• Describe short- and long-term asset management planning horizons. At a minimum, the TAMP will reflect a 10-year planning horizon. • Link the performance to national goal areas, as appropriate. • Present an analysis of future funding versus condition scenarios. • Illustrate the performance gap between existing conditions and future condition targets. • Estimate the cost of addressing the gap in performance. • Document the process used to conduct the performance gap analysis.
Financial Plan and Investment Strategies	• Summarize historic funding levels for the five assets included in the TAMP. • Describe the amount of funding expected to be available for these assets over the next 10 years and describe where these funds will come from. • Describe how these funds will be allocated over the 10-year horizon. • Document the sources of information used to develop the financial plan. • Document any assumptions made in preparing the financial plan. • Present recommended investment strategies that will enable MnDOT to achieve its performance targets (using information from the previous sections). • Document the process used to evaluate and select investment strategies.
Implementation and Future Developments	• Document a governance plan for the TAMP, including how it will be used and when it will be updated. • Describe priorities for asset management process enhancements and implementation. • Provide plans for expanding the TAMP to include other assets.

MEETINGS AND WORKSHOPS

During the TAMP development process, several face-to-face meetings and facilitated workshops (in addition to numerous teleconference calls) were conducted to review progress, discuss action items and gain feedback from the management team on a wide range of topics. A schedule of these meetings and the key agenda topics are summarized in Figure 1-3.

Figure 1-3: Meetings and Workshops Conducted During the TAMP

DATES	MEETING/WORKSHOP AGENDA TOPICS/DISCUSSION ITEMS
May 29, 2013	Project Kick-Off Meeting: • Establish parameters for developing the TAMP • Develop TAMP Work Plan
June 13, 2013	Steering Committee (SC) Meeting: • TAMP objective and scope • Review work plan and schedule • Role of Steering Committee in TAMP development
July 29-30, 2013	PMT Meeting: • Review content of Asset Register • Discuss objective and plan for the LCC section of the TAMP LCC Workshop: • Review information provided by asset Work Groups on LCC • Discuss LCC modeling strategies for the TAMP
September 20, 2013	Risk Assessment Workshop: • Provide overview on risk management • Discuss and validate undermanaged risks identified • Prioritize undermanaged risks and identify strategies for mitigation
September 26, 2013	PMT Meeting: • Review preliminary life-cycle cost analysis results • Identify next steps in risk assessment • Discuss key information required to develop investment strategies and performance targets
November 14-15, 2013	PMT Meeting: • Discuss preliminary recommendations on investment strategies and performance measures • Discuss recommendations for asset management process improvements SC Meeting: • Discuss strategies to overcome undermanaged risks • Prioritize asset management process improvements • Review and refine recommendations for investment strategies and performance targets
Jan 21-22, 2014	PMT Meeting: • Review and recap completed work activities • Discuss draft TAMP development approach SC Meeting: • Finalize investment strategy recommendations • Recommend business process changes Present recommended investment strategies
Mar 20-21, 2014	PMT Meeting: • Review draft TAMP and gain critical feedback • Discuss plans for development of TAMP Technical Guide • Discuss TAMP governance and application recommendations SC Meeting: • Discuss TAMP governance plan and structure and list of process enhancements that MnDOT will implement • Discuss future activities of the Steering Committee

Supporting Data and Documentation

Figure 1-4 summarizes the MAP-21 requirements and the section of the TAMP that addresses those requirements.

Figure 1-4: Summary of MAP-21 Requirements

MAP-21 REQUIREMENT(S)	SECTION OF TAMP/NOTES
Develop a risk-based asset management plan to improve or preserve asset condition and the performance of the system	Entire document
Include strategies that result in achievement of state targets for asset condition and performance of NHS, and supporting progress towards achievement of national goals	Chapters 2, 3, and 8
States are encouraged to include all infrastructure assets with the right-of-way corridor in the TAMP	Chapter 1 MnDOT expanded beyond MAP-21 requirements to include pavements and bridges on the entire state highway system, as well as highway culverts, deep stormwater tunnels, overhead sign structures, and high-mast light tower structures
Include a summary listing of pavement and bridge assets on the NHS in the state, including a description of their condition	Chapter 4
Document asset management objectives and measures	Chapters 2, 3
Identify performance gaps	Chapter 7
Include a life-cycle cost analysis for the assets in the TAMP	Chapter 6
Include a risk management analysis	Chapter 5
Include a financial plan and investment strategies	Chapter 8
Document the process used to develop the TAMP	Chapters 1, 2, and 9
Develop a risk-based asset management plan for the NHS to improve or preserve condition of the assets and the performance of the system	Entire document

Chapter 3

ASSET MANAGEMENT PERFORMANCE MEASURES AND TARGETS: SUPPLEMENTAL INFORMATION

ASSET MANAGEMENT PERFORMANCE MEASURES AND TARGETS: SUPPLEMENTAL INFORMATION

Overview

Chapter 3 of the TAMP describes MnDOT's business practices, performance measures, and targets used to monitor and report asset conditions, as well as the new target terminology used in the TAMP. Figure 3-1 summarizes these new key terms associated with targets, which now override the language used to describe performance outcomes in MnSHIP. Moving forward, MnDOT will use the term "target" to denote desired outcomes. The term "plan outcome" will be used to identify outcomes to which MnDOT is managing, while the term "expected outcome" will be used to demonstrate the results of predictive modeling performed using various analytical tools.

Figure 3-1: Summary of New Key Terms Associated with Targets

TERM	MEANING	USE	BASIS FOR ESTABLISHMENT	TERM
Target	Outcome consistent with agency goals and traveler expectations	• Communicate desired outcome • Evaluate performance • Identify investment needs	Approved by senior leadership; guided by agency policies and public planning process	Less than once per planning cycle
Plan Outcome	Outcome consistent with fiscal constraint/spending priorities	• Communicate spending priorities • Develop/manage programs • Select investments	Establish concurrently with the adoption of investment plans	Once per planning cycle
Expected Outcome	Forecasted outcome based on predictive modeling	• Monitor plan implementation • Promote accountability and/or initiate corrective action	Generated by expert offices based on updated performance information and planned improvements	Annually

Chapters 7 and 8 of the TAMP provide a detailed description of the targets, plan outcomes, and expected outcomes for each of the asset classes discussed in the TAMP.

Note:

Chapter 3 of the TAMP contains the majority of needed information pertaining to asset management performance measures and targets. Therefore, no additional information is provided in this chapter of the Technical Guide.

Chapter 4

ASSET INVENTORY AND CONDITIONS: SUPPLEMENTAL INFORMATION

ASSET INVENTORY AND CONDITIONS: SUPPLEMENTAL INFORMATION

Overview

This chapter describes the steps involved in assembling the asset register, which was then converted into a 'folio' for each asset category. The process of finalizing the folios for the TAMP is also described, along with a general procedure to update and maintain the asset register/folios in the future.

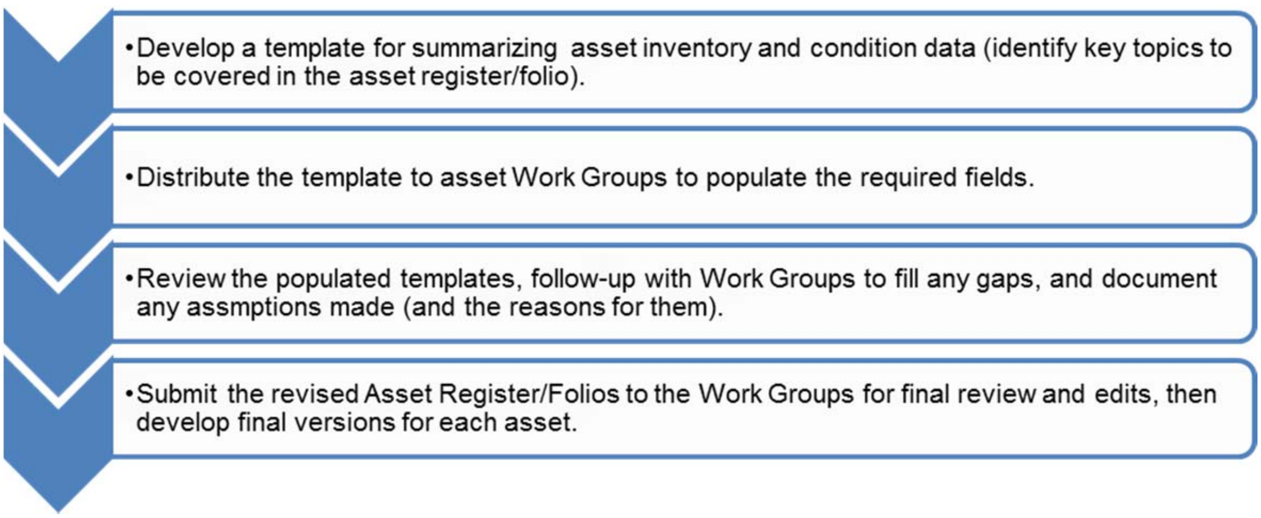
Process

The process of assembling the asset register/folios and the sources of information are presented in this section, and issues related to finalizing the asset register/folios for the TAMP are discussed, along with a simple procedure for maintaining and routinely updating them.

STEPS INVOLVED IN DEVELOPING THE ASSET REGISTER/FOLIOS

The steps involved in developing the asset register/folios are summarized in Figure 4-1.

Figure 4-1: Asset Register/Folios Development Process



KEY INFORMATION SUMMARIZED IN THE ASSET REGISTER/FOLIOS

A typical asset register is divided into six sections. The key information summarized in each section is discussed below. All the information was provided by the asset Work Groups.

ASSET OVERVIEW

This section of the asset register/folio provides a high-level summary of the purpose and importance of the asset and its scope, as covered in the TAMP.

INVENTORY AND REPLACEMENT VALUE

Current asset inventory and replacement value statistics, separated by system or functional classification (if applicable), are summarized in this section.

- **Pavements**: The inventory of flexible (asphalt-surfaced) and rigid (concrete-surfaced) pavements is provided in roadway miles and the total inventory is summarized in both roadway-miles and lane-miles. Replacement value for pavement assets is based on an average replacement cost of $1 million per lane-mile.
- **Bridges**: The bridge inventory is summarized both by count (number of bridges) and by bridge deck area (sq. ft.). Replacement value is computed using a unit cost that ranges from $145 per sq. ft. to $225 per sq. ft., depending on the type of bridge.
- **Hydraulic Infrastructure**: The statewide inventory of highway culverts (count) and deep stormwater tunnels (total length, number of tunnels, and tunnel segments) are summarized. The replacement value for highway culverts was estimated using an average unit cost of $798 per linear ft. (and assuming an average culvert length of 45 ft.), while the replacement value for deep stormwater tunnels was based on the consensus expert opinion of the Work Group.
- **Other Traffic Structures**: The statewide inventory of overhead sign structures and high-mast light tower structures are summarized (a simple count of the structures is used). Replacement values for overhead sign structures and high-mast light tower structures are based on unit costs of $85,000 and $40,000 per structure, respectively.

ASSET AGE PROFILE

This section of the asset register/folio summarizes the age profile (percent of inventory in a given age category) for each asset category included in the TAMP.

DATA COLLECTION, MANAGEMENT, AND REPORTING PRACTICES

The asset data collection protocols and the data management and reporting practices are summarized in this section.

CONDITION RATING SCALE

A graphical representation of the asset condition rating scale used in the TAMP is provided, in order to help compare and contrast the various condition categories used for the different assets.

CONDITION TARGETS AND 10-YEAR INVESTMENT LEVELS

Asset condition (based on the most recent available data), recommended performance targets (discussed in Chapter 3 of the TAMP), and required investment levels to meet those targets (discussed in Chapter 8 of the TAMP) are summarized in this section.

ISSUES IN FINALIZING THE ASSET REGISTER/FOLIOS FOR THE TAMP

Figure 4-2 summarizes the key issues that the project team faced during the development of the asset register/folios – and the strategies adopted to handle them.

Figure 4-2: Information Needed to Develop the TAMP

SECTION	INFORMATION/WORK ACTIVITIES REQUIRED
Too much information covered in asset register, thereby making the format difficult to present in a user-friendly format in the TAMP	In the first version of the asset register, all the assets were included in a single template. To make it more readable, separate folios were created for each asset, rather than forcing a single 'mega-table' for all the TAMP asset categories.
Inconsistencies in data/information from version to version	As the asset register evolved, several inconsistencies were noted in the various versions, primarily because multiple individuals were responsible for updating the data. It was decided that a single person would be responsible for updating the asset register, which resulted in the production of a consistent product (from both content and formatting standpoints).
Uncertainty in data sources and/or assumptions made in arriving at some of the statistics summarized in the asset register	Key assumptions and data sources were summarized as footnotes in the asset register.

PROCESS TO UPDATE AND MAINTAIN THE ASSET REGISTER/FOLIOS

The asset register should be updated on an annual basis; responsibility for delivery of this update should be given to a specific individual at the agency to ensure consistency. The typical process for updating the asset register/folio is summarized below:

- **Step 1**: Provide the most recent version of the asset register/folio to each specific division/department that houses or manages the relevant data. Ask them to review sections 2 through 5 of the asset register/folio (inventory and replacement value; asset age profile; data collection management, and reporting practices; condition rating scale) and provide updates.
- **Step 2**: Update the register/folios based on any new information received and provide a revised copy for final review by the division/department providing the data.
- **Step 3**: Save a final version to the network and make a backup copy.

Chapter 5

RISK MANAGEMENT ANALYSIS: SUPPLEMENTAL INFORMATION

RISK MANAGEMENT ANALYSIS: SUPPLEMENTAL INFORMATION

Overview

This chapter provides a detailed description of the various processes involved in identifying and prioritizing the risks and mitigation strategies described in the TAMP. MnDOT's approach to Enterprise Risk Management is presented in this chapter, along with the steps involved in determining the undermanaged risks presented in the TAMP. The risk management analysis efforts resulted in the production of risk registers specific to each asset category considered in this TAMP. The summarized core content of these risk registers is provided as an attachment at the end of the chapter, along with additional information compiled by each asset Work Group.

Process

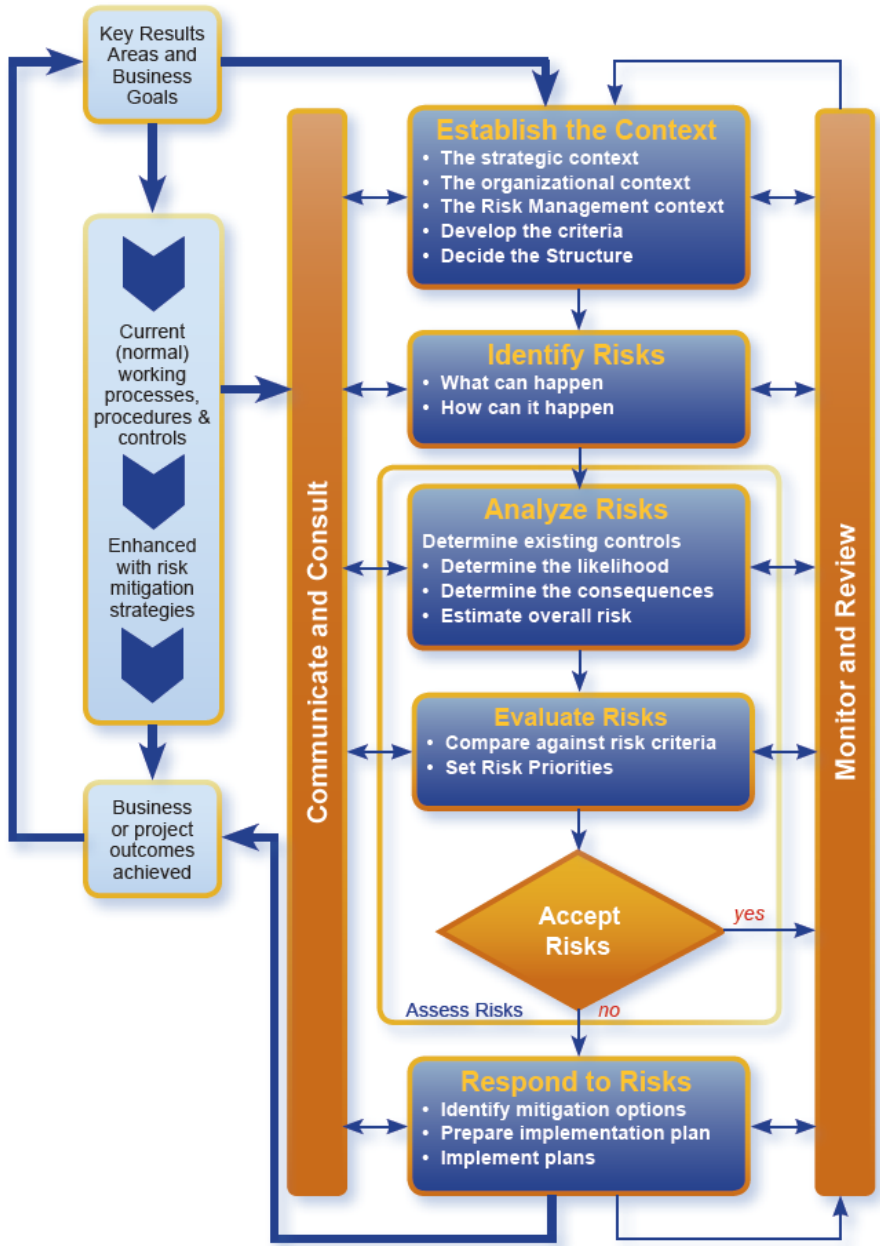
MnDOT's Enterprise Risk Management (ERM) framework – which is used to assess, prioritize, and manage strategic/global risks across the department – is discussed in this section, followed by a discussion of the step-by-step process used in identifying, prioritizing and costing the undermanaged risk opportunities.

ENTERPRISE RISK MANAGEMENT FRAMEWORK

MnDOT has implemented an ERM framework as an integral part of its business processes (illustrated in Figure 5-1[1]). The framework begins with identification of Key Results Areas, which are the MnDOT's priority business and investment objectives. Business planning for these Key Results Areas includes an assessment of strategic risks by senior executives. Business line management groups then assess strategic and business line risks affecting the achievement of their objectives and the delivery of their products and services. At an even more detailed level, project managers identify the risks that threaten project objectives such as scope, schedule, and cost.

Supporting these risk assessment processes, MnDOT maintains a risk register[2], reflecting at any given point in time the current status of strategic and business line risks, including relevant performance measures. The integrated risk register discusses the likelihood and consequences of strategic risks, along with potential

Figure 5-1: MnDOT's Enterprise Risk Management Framework



[1] Source: *MnDOT Enterprise Risk Management Framework and Guidance* (2013).
[2] http://www.dot.state.mn.us/riskmanagement/pdf/july_2013-strategic_risk_register_report.pdf

impacts in the following areas:

- Agency reputation
- Business performance and capability
- Finance
- Security of assets
- Management effort
- Environment
- Legal and compliance
- Health and safety
- Quality
- Stakeholder engagement

The risk register also provides a risk mitigation plan and a governance structure that indicates the division responsible to manage a particular risk. Since the global/strategic risks (e.g. natural hazards, accidents and crashes, traffic congestion) are already handled effectively through the ERM process, the TAMP focuses on undermanaged risks and opportunities to management/mitigate those risks though process changes and/or capital investments. This procedure is discussed in further detail in the following sections.

RISK MANAGEMENT ANALYSIS PROCEDURE USED IN THE TAMP

The step-by-step approach used in identifying the undermanaged risks is illustrated in Figure 5-2.

Figure 5-2: TAMP Risk Management Analysis Process

- Develop a plan for addressing risks through a series of discussions with MnDOT's ERM office.
- Conduct facilitated discussions with each asset workgroup to identify: risks; impacts to MnDOT, public, and asset; consequence and likelhood ratings using the framework established in the ERM risk register; risk mitigation strategies. [Workgroup Assignment #1]
- Review, refine and revise the risk registers developed for each asset class included in the TAMP through a series of facilitated discussions.
- Conduct facilitated discussions to identify undermanaged risk opportunities, document current management strategies, develop preferred and alternate mitigation strategies and associated costs. [Workgroup Assignment #2]
- Conduct a series of facilitated workshops with the steering committee to review and prioritize risk management strategies for inclusion in the TAMP.
- Develop a governance plan: establish Office responsible managing each risk indentified and a timeframe for implementing the strategies outlined.

WORK GROUP ASSIGNMENT #1: IDENTIFY BROAD RISKS AND IMPACTS (AUGUST/SEPTEMBER 2013)

The first assignment completed by each asset Work Group included the determination of the broad list of risks relevant to each asset class included in the TAMP and the impact of the risk on the asset, the public, and MnDOT. The Work Groups also documented existing control/mitigation strategies being used, gaps in existing business protocols that are preventing MnDOT from managing the risks effectively and the ideal mitigation strategy for the risk identified.

Figure 5-3 summarizes the comprehensive list of risks identified by the asset Work Groups. These lists were discussed among the Work Group participants and those risks that were considered to be undermanaged are shown in italics. The remaining risks (not identified as being undermanaged) are either being addressed through the current management practices and protocols in place for each asset or they are already addressed through the ERM framework (discussed earlier). The undermanaged risks were reviewed in further detail during the development of the strategies for mitigating/managing these risks, identified during the second Work Group assignment. The complete set of documentation developed by the asset Work Groups as a part of the Work Group Assignment #1 is provided as an attachment at the end of this chapter.

Figure 5-3: Risks Identified by Asset Work Groups

<table>
<tr><th>PAVEMENTS</th><th>BRIDGES</th></tr>
<tr><td>

Not meeting public expectations for pavement quality/condition at the state/district/local levels
Inappropriately managing or not managing pavements such as frontage roads, ramps, and auxiliary lanes
Inability to meet federal requirements (such as MAP-21, GASB, etc.)
Inability to appropriately manage to lowest life-cycle cost
Premature deterioration of pavements
Significant reduction in funding
Occurrence of an unanticipated event such as a natural disaster

</td><td>

Lack of or deferred funding
Inability to manage to lowest life-cycle cost
Occurrence of an unanticipated natural event
Catastrophic failure of the asset
Significant damage to the asset through manmade events
Premature deterioration of the asset
Shortage of workforce

</td></tr>
<tr><th>HIGHWAY CULVERTS AND DEEP STORMWATER TUNNELS</th><th>OVERHEAD SIGN STRUCTURES AND HIGH-MAST LIGHT TOWER STRUCTURES</th></tr>
<tr><td>

Failure/collapse of tunnel/culvert
Flooding and deterioration due lack of tunnel capacity
Lack of culvert capacity
Inability to appropriately manage culverts
Inability to appropriately manage tunnels
Inappropriately distributing funds or inconsistency in culvert investments
Significant damage to culverts through manmade events

</td><td>

Lack of having a mandated process for inspection
Poor contract execution
Inability to manage to lowest life-cycle cost
Significant damage to asset through manmade events
Premature deterioration of the asset
Unforeseen changes in regulatory requirements, travel demands, or technology
Shortage of workforce

</td></tr>
</table>

RISK WORKSHOP #1: VALIDATION OF UNDERMANAGED RISKS AND STRATEGY IDENTIFICATION FOR TOP UNDERMANAGED RISKS (SEPTEMBER 2013)

During this workshop, representatives from MnDOT's ERM office provided a brief overview of MnDOT's approach to risk management and how the agency's standardized risk assessment process aligns with the preliminary risks identified by each asset Work Group (shown in Table 5-1). The presentation, which involved members of the Steering Committee as well as Work Group participants, further discussed the proposed plan to focus the TAMP on undermanaged risks. The participants agreed to the approach and participated in a facilitated discussion to identify general mitigation/management strategies for the top undermanaged risks.

Following this workshop, a meeting was held with TAMP Project Management team (on September 26, 2013) to discuss the results of the risk assessment workshop and the next steps. At the conclusion of this meeting, the asset Work Groups, in conjunction with the representatives of MnDOT's ERM office, were tasked with developing comprehensive risk statements that could be used to develop strategies that would help control/mitigate the highest risks. In order to finalize the risk management analysis section of the TAMP, another assignment, which focused on reviewing the undermanaged risks identified in closer detail and developing specific mitigation strategies, was undertaken by the Work Groups (discussed in the next section).

WORK GROUP ASSIGNMENT #2: REVIEW UNDERMANAGED RISKS AND DEVELOP PREFERRED AND ALTERNATE MITIGATION STRATEGIES (OCTOBER/NOVEMBER 2013)

The second assignment completed by the asset Work Groups built on the previous information but specifically focused on the undermanaged risks. The step-by-step procedure followed by the Work Groups to complete this assignment is summarized below:

- **Step 1**: Define preferred mitigation strategy for addressing the risk identified.
- **Step 2**: Identify data, resources, tools, and/or training required to enact the strategy.
- **Step 3**: Describe whether the strategy will reduce the likelihood of another identified risk.
- **Step 4**: Estimate the approximate cost of implementing the preferred mitigation strategy.
- **Step 5**: Identify whether an alternate strategy might be available that doesn't fully mitigate the risk but lowers the overall likelihood or consequence associated with the risk.
- **Step 6**: Estimate the cost associated with the alternate strategy.
- **Step 7**: For both strategies developed, identify the impact on likelihood and consequence of the original risk should either of the strategies be adopted.

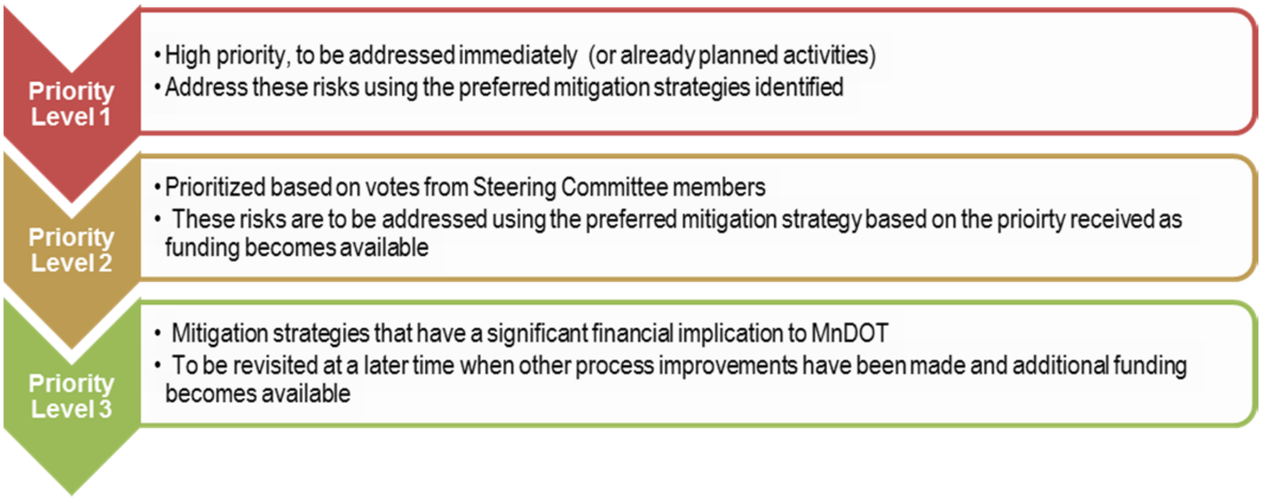
A detailed version of the guidance provided to the Work Groups on Assignment #2 and the results are provided as attachments at the end of this chapter.

RISK WORKSHOP #2: PRIORITIZATION OF RISK MITIGATION STRATEGIES (NOVEMBER 2013)

The undermanaged risks developed by the Work Groups were organized into one of two broad categories: "Capital Investments" or "Process Improvements". Those risks that were considered to be process improvements were ranked by the workshop participants. Strategies that involved capital investments were not included in the prioritization process because those risks would likely be addressed elsewhere within MnDOT. Also, process improvement initiatives that were considered to be very low-cost activities that provided a high return on investment were excluded from the prioritization process because they were clearly high priorities and most of them were already underway. Based on votes from the Steering Committee members, the risk mitigation strategies associated with bridge process improvements received the highest priority, followed by process improvements for highway culverts, deep stormwater tunnels, pavements, and overhead sign structures / high-mast light tower structures.

The results of the Risk Workshop #2 were then used to develop final priorities for the TAMP using the general process summarized in Figure 5-4. (Results of this process are summarized in Figure 5-7 of the main TAMP document).

Figure 5-4: Prioritization Strategy for Risks to be Managed by MnDOT



Supporting Data and Documentation

As discussed in the previous sections, a number of documents were prepared as part of the risk management analysis efforts undertaken by the asset Work Groups. These include:

- Results of Work Group Assignment #1: Identify Broad Risks and Impacts
- Results of Work Group Assignment #2: Review Undermanaged Risks and Develop Preferred and Alternate Mitigation Strategies and Costs

The key findings related to the undermanaged risks (from Work Group Assignments #1 and #2) are summarized in this section, and detailed worksheets prepared by the Work Groups as supporting documentation and detailed instructions are provided at the end of the chapter.

SUMMARY OF FINDINGS FROM THE RISK MANAGEMENT ANALYSIS WORK GROUP EFFORTS

The Work Group process was iterative and extended over two formal workshops, with opportunities between workshops to modify certain aspects of the product. Participants took advantage of the process to learn about the risks, assess the ability of existing information systems to quantify risks and costs, and reach consensus on priorities and approaches for future improvements. Undermanaged risks identified in the TAMP are summarized in the following sections.

PAVEMENTS

The Pavements Work Group developed two risk statements and a set of mitigation strategies and risk ratings for each of them. Figure 5-5 summarizes the risk management analysis performed by the Work Group.

Figure 5-5: Pavement Risk Management Analysis Summary

Risk Statement (#1) Mitigation Strategies, Impacts on Other Risks, and Costs			
Risk Statement #1: Non-Attainment of Objectives: If public expectations for pavement quality or condition are not met, especially at the local/corridor level, then the agency's reputation may suffer, service delays and unsafe conditions may increase and the cost of maintenance may grow. • Current control/mitigation strategies: Using money to manage to lowest life-cycle cost including routine maintenance; money distributed statewide based on need; implementation of performance measures and targets; balanced funding across entire system; MAP-21 direction to allocate funding to the National Highway System; staging of more timely and appropriate treatments; and multiple fixes at each location or on each corridor. • Previously identified mitigation strategies: More timely and appropriate staging of treatments; multiple fixes at location or on corridor (only if LCC treatment intervals modified); more systematic and standardized statewide approach to fixes.			
Preferred Mitigation Strategy, Resources, and Costs: Annually track, monitor and identify roadway segments that have been in Poor condition greater than five years, and consistently consider this information when programming at the district level. The cost would be eight hours of staff time to run a report and coordinate with districts during annual programming activities. (*Process Improvement Strategy*)			
Effect on Other Risks: May reduce the risk of failing to comply with GASB Statement 34 requirements.			
Alternate Mitigation Strategy and Costs: Jurisdictional realignments, to divest maintenance responsibility onto other agencies. Divestiture could cost $200,000 per mile to bring roads up to a standard necessary for acceptance by another agency. An outreach plan and communication strategy – at a possible cost of $25,000 – may reduce the potential loss of reputation if the MnDOT fails to meet objectives.			
Likelihood and Consequence of Adverse Impacts			
	Consequence	Likelihood	Risk Rating
Original Risk Rating	Major	Likely	High
Preferred Strategy	Major	Possible	Medium
Alternate Strategy	Moderate	Likely	Medium

Risk Statement (#2), Mitigation Strategies, Impacts on Other Risks, and Costs			
Risk Statement #2: Exclusion of Auxiliary Roads: If MnDOT does not include ramps, access roads, auxiliary lanes and frontage roads in its pavement inventory and use their condition in its pavement model, then these assets will not be included in pavement management decisions and cannot be managed to achieve the lowest life-cycle cost for all highway pavements. • Current control/mitigation strategies: None. • Previously identified mitigation strategies: Increased indefinite-quantity or blanket-type projects to address localized distresses, with better tracking of deterioration and condition.			
Preferred Mitigation Strategy, Resources, and Costs: 1. Collect additional data in the Metro District with the use of the old Material Office pavement van, at an estimated cost of $100 per mile. (*Process Improvement Strategy*) 2. Build a stand-alone database that will house pavement data and allow for better tracking, with a cost range of $2,000 to $20,000. (*Process Improvement Strategy*)			
Alternate Mitigation Strategy and Costs: Collect data in Greater Minnesota districts by hand, using maintenance staff. Visually collect images through video capture or windshield survey. These would cost around $100/mile to collect data and additional cost/time to enter information into the database.			
Likelihood and Consequence of Adverse Impacts			
	Consequence	Likelihood	Risk Rating
Original Risk Rating	Minor	Possible	Low
Preferred Strategy	Minor	Unlikely	Low
Alternate Strategy	Minor	Unlikely	Low

BRIDGES

Figure 5-6 summarizes the bridge risk management analysis performed by the Bridge Work Group. The Work Group developed two risk statements, an integrated set of mitigation strategies, and associated risk ratings.

Figure 5-6: Bridge Risk Management Analysis Summary

Risk Statements (#1 & #2) Mitigation Strategies, Impacts on Other Risks, and Costs
Risk Statement #1: **Life-Cycle Cost**: If bridge inspection data, bridge model sophistication, and bridge deterioration models are not accurate or complete, then it may be difficult to determine the lowest life-cycle cost strategy for bridges. • Current control/mitigation strategies: BRIM (Bridge Replacement and Improvement Management) system; SIMS (Structure Information Management System); performance measures. • Previously identified mitigation strategies: Link BRIM, SIMS, Swift (MnDOT financial management system), contract preservation costs and AASHTOWare Bridge Management 5.2 (bridge management system) in order to make appropriate management decisions; develop a preventive maintenance performance measure; improve knowledge of deterioration curves.
Risk Statement #2: **Premature Deterioration**: If one or more bridges deteriorate prematurely, then maintenance costs may be higher than expected and there may be unanticipated risks to structural integrity. • Current control/mitigation strategies: Inspection and maintenance tracking to try to anticipate needs; ability to track and prioritize work. • Previously identified mitigation strategies: Better inspection and maintenance tracking; better knowledge of deterioration curves; implementation of the AASHTOWare Bridge Management 5.2 system.

Preferred Mitigation Strategy, Resources, and Costs (Process Improvement Strategy:
1. Finish development of SIMS Maintenance Module.
  • This system is currently in development. MnDOT has in-depth maintenance data back to 2009 which needs to be migrated into the SIMS Maintenance Module.
  • Requires 50 Trainees and 2 instructors for eight 4-hour training sessions located around the state, plus curriculum development and data migration. The total effort is about 400 hours.
2. Develop the Preventive Maintenance (PM) Program, including a performance measure to verify that PM is performed at the right time. This will require collaboration with MnDOT districts, including annual meetings.
3. Develop a Business Intelligence reporting tool to link SIMS and Swift.
  • This is currently in the data discovery phase, and no cost estimate has yet been prepared.
  • Training for three power users with one instructor for two full-day sessions would total 64 hours. Training for 29 regular users with one instructor for one full-day session would total 240 hours.
4. Migrate inspection and maintenance data to AASHTOWare Bridge Management 5.2 (when completed), create and utilize the deterioration curves. As part of this step, existing bridge element condition data will need to be converted according to upcoming Federal requirements and AASHTO specifications.
  • Multi-state collaboration for AASHTOWare development costs $50,000 per year for five years (29 states are participating).
  • MnDOT will need resources and equipment to test and implement the BrM 5.2 system. MnDOT will need to develop deterioration curves and cost models from Minnesota data.
5. Link Construction Costs with Maintenance costs in the new Business Intelligence reporting tool.
6. Link BRIM and AASHTOWare BrM 5.2, which will allow future bridge data and models to participate in the BRIM risk analysis.
7. Compare cost, age, and performance trends of the bridge system to determine effectiveness of management strategy, and adjust accordingly.
8. Research to further identify lowest life-cycle cost (e.g. deterioration models, effectiveness of maintenance activities, products, etc.)
  • Deck deterioration and National Bridge Element research is currently in progress.
  • Other research may be needed.

Approximate Cost of Preferred Mitigation Strategy: **$2 million.** This represents a one-time implementation cost. Following implementation, this will be a low-cost strategy to maintain annually.
Effect on Other Risks: The preferred strategy will mitigate both of the risks identified in this exercise (manage to lowest life-cycle cost and premature deterioration) as well as help to mitigate the lack or deferral of funding.
Alternate Mitigation Strategy and Costs: 1. Finish development of SIMS Maintenance Module (already in progress). 2. Develop the Preventive Maintenance (PM) program and performance measure (in progress) to verify that PM is performed at the right time. 3. Cost accounting tracking through existing systems (WOM, Financial Reports). These systems are not tied with maintenance data in SIMS. 4. Migrate inspection and maintenance data to AASHTOWare BrM 5.2 (when completed) and create/utilize the deterioration curves. As part of this step, existing bridge element condition data will need to be converted according to upcoming Federal requirements and AASHTO specifications. Under this alternate strategy, the Business Intelligence reporting tool would not be used and BRIM would not be linked to future bridge inspection data. Approximate Cost of Alternate Mitigation Strategy: **$1.4 million.** This represents a one-time implementation cost. Following implementation, this will be a low-cost strategy to maintain annually.

Likelihood and Consequence of Adverse Impacts			
	Consequence	Likelihood	Risk Rating
Original Risk Rating	Moderate	Likely	Medium
Preferred Strategy	Minor	Likely	Medium
Alternate Strategy	Moderate	Likely	Medium

HIGHWAY CULVERTS

Figure 5-7 summarizes the highway culvert risk management analysis performed by the Hydraulics Work Group.

Figure 5-7: Highway Culvert Risk Management Analysis Summary

Risk Statement, Mitigation Strategies, Impacts on Other Risks, and Costs
Risk Statement: **Inability to manage culverts**: If highway culverts are not managed effectively, then the risk of failure and the life-cycle cost of ownership may increase. • Current control/mitigation strategies: MnDOT (partially) inventories and inspects highway culverts and the information is used to plan maintenance work and project scoping activities. Highway culvert failures are repaired when they occur. • Previously identified mitigation strategies: Additional funding to be able to implement a systematic management approach based on targeted work, complete life-cycle cost understanding, data provided, shared and used by design, construction, maintenance.

Preferred Mitigation Strategy, Resources, and Costs:
1. Adopt a system condition performance measure, and set performance targets. This will need about 200 hours of staff time. (*Process Improvement Strategy*)
2. Implement the proposed Asset Management System and gather data that will support life-cycle cost analysis (*Process Improvement Strategy*). This will require:
  • Funds to purchase and implement Transportation Asset Management System – at least $1 million and 1000 hours of staff time.
  • Staff and consultant resources to develop business rules – roughly $50,000 in costs and 500 hours of staff time.
  • Staff and consultant resources to collect data for the asset management system. This is estimated to require 16,000 hours per year.
3. Repair or replace highway culverts in accordance with Asset Management System recommendations through capital

projects and maintenance work. This is estimated to require $40 million per year. (*Capital Investment Strategy*)
Effect on Other Risks: The preferred strategy will reduce the likelihood of road failure, interruption of service, lack of adequate capacity, and land owner drainage complaints. The strategy will also reduce the risk of not being able to support the HydInfra information system currently used for culvert data.
Alternate Mitigation Strategy and Costs: Stand-alone construction projects to repair or replace Poor and Very Poor highway culverts. This would entail $1.25 million to implement the Transportation Asset Management System (does not include life-cycle cost functionality) and 800 staff hours. The cost to repair or replace culverts would need to be significantly more than the current $30 million per year and likely more than the $40 million in the preferred strategy, to clear the existing backlog and stabilize future performance.
Likelihood and Consequence of Adverse Impacts

	Consequence	Likelihood	Risk Rating
Original Risk Rating	Moderate	Almost Certain	High
Preferred Strategy	Moderate	Possible	Medium
Alternate Strategy	Moderate	Likely	Medium

DEEP STORMWATER TUNNELS

The Hydraulics Work Group developed two deep stormwater tunnel risk statements and a set of mitigation strategies and risk ratings for each. Figure 5-8 summarizes the risk management analysis performed by the Work Group.

Figure 5-8: Deep Stormwater Tunnel Risk Management Analysis Summary

Risk Statement (#1) Mitigation Strategies, Impacts on Other Risks, and Costs
Risk Statement #1: Capacity: If stormwater tunnel capacity is not adequate for a major rain event and resulting pressurization is too great, then the tunnel will be damaged or collapse, local flooding may occur, property may be damaged, and people may be killed or injured. • Current control/mitigation strategies: None. • Previously identified mitigation strategies: Provide a new tunnel system and back charge City of Minneapolis; City to separate its water (as much as possible); downsize new/modified system as much as possible to save costs
Preferred Mitigation Strategy, Resources, and Costs: 1. Complete research on underground storage options, including the exploration of shallow cavern storage options for South (I-35W) tunnel. The estimated cost is $30,000. Then build the I-35W South underground storage cavern, at a cost of $50 million. (*Process Improvement Strategy*) 2. Develop and implement emergency response plan for business, residential, and freeway areas along the flood-prone I-35W South tunnel. The estimated cost is $15,000. (*Process Improvement Strategy*)
Effect on Other Risks: May reduce the risk of failing to comply with GASB Statement 34 requirements.
Alternate Mitigation Strategy and Costs: Build the I-35W South underground storage cavern, at a cost of $50 million.
Likelihood and Consequence of Adverse Impacts

	Consequence	Likelihood	Risk Rating
Original Risk Rating	Catastrophic	Likely	Extreme
Preferred Strategy	Catastrophic	Rare	High
Alternate Strategy	Catastrophic	Rare	High

Risk Statement (#2), Mitigation Strategies, Impacts on Other Risks, and Costs
Risk Statement #2: Disrepair: If the needed maintenance repairs are not made in a timely manner, then tunnels may collapse in a major rain event, and significant property damage, loss of life, or extensive service disruption may occur and significant reconstruction costs may be necessary. • Current control/mitigation strategies: Tunnels, with the exception of one, have been thoroughly inspected once to gauge baseline condition. Repairs have been prioritized. • Previously identified mitigation strategies: MnDOT and communities prioritize construction funding. Establish detour routes

in advance; map extent of possible flooding; increase funding for rehabilitation, perform data collection and inspection to determine life-cycle costs and deterioration rates; work with Cities to redefine management of tunnels to more of a coordinated effort.
Preferred Mitigation Strategy, Resources, and Costs: 1. Inspect the one remaining uninspected tunnel at a cost of $50,000. (*Process Improvement Strategy*) 2. Install pressure transducers in tunnels to measure pressurization. Cost undetermined. (*Process Improvement Strategy*) 3. Design and implement a mandated inspection frequency (1-5 years) based on tunnel/segment condition rating, at an average cost of $250,000 per inspection. (*Process Improvement Strategy*) 4. Include tunnels in the bridge inventory. This will require cooperative work with district offices and the Central Office bridge group, and may require consultant assistance. (*Process Improvement Strategy*) 5. Prepare plans and implement all repairs needed on the South I-35W tunnel system at MnDOT cost, with City of Minneapolis funding used for all other known repairs on all other tunnels. This may require transportation bond financing of $12 million, which has already been allocated by MnDOT. (*Capital Investment Strategy*)
Effect on Other Risks: This work will improve MnDOT credibility in the event of a failure. It will strategically fix the worst tunnel repair needs. It may reduce the likelihood of failure by having increased information on tunnel condition – as long as funding is available for repairs when conditions warrant it.
Alternate Mitigation Strategy and Costs: 1. Staff from MnDOT (likely Metro Bridge Maintenance), trained on inspections, complete them on select tunnel segments after major rain events. 2. MnDOT hires a consultant to complete inspections on each tunnel, as identified by mandated inspection guidelines. 3. Begin repairs incrementally and withhold funding to cities on other projects if proposed repair schedules are not met. This is estimated to cost an average of $3.5 million per segment.

Likelihood and Consequence of Adverse Impacts			
	Consequence	Likelihood	Risk Rating
Original Risk Rating	Catastrophic	Possible	High
Preferred Strategy	Catastrophic	Possible	High
Alternate Strategy	Catastrophic	Rare	Medium

OVERHEAD SIGN STRUCTURES AND HIGH-MAST LIGHT TOWER STRUCTURES

The Overhead Sign Structures / High-Mast Light Tower Structures Work Group developed three risk statements and a set of correlating mitigation strategies. Figure 5-9 summarizes the risk management analysis performed by the Work Group.

Figure 5-9: Overhead Sign Structures and High-Mast Light Tower Structures Risk Management Analysis Summary

Risk Statement (#1) Mitigation Strategies, Impacts on Other Risks, and Costs
Risk Statement #1: Construction Defects: If overhead sign structures and high-mast light tower structures are not properly installed as part of a construction project, then they may deteriorate more rapidly, requiring more subsequent maintenance. • Current control/mitigation strategies: None. • Previously identified mitigation strategies: Better quality controls (e.g. MnDOT inspections) of construction work outside of edge-of-pavement-to-edge-of-pavement; better checklist to include roadside infrastructure; routine/mandatory workshops at end of each construction project.
Preferred Mitigation Strategy, Resources, and Costs: 1. Change construction specifications to require torque threshold dye washers. This would entail a one-time investment of 40 hours of staff time, and an increased annual cost of $20,000 per year. (*Process Improvement Strategy*) 2. Communicate punch list and specifications with companies that install structures and with construction inspectors. This might increase staff time requirements by 200 hours per year. (*Process Improvement Strategy*)
Effect on Other Risks: Reducing the risk of poor contract execution should extend the life of the structure and reduce maintenance costs, thus reducing life-cycle costs.
Alternate Mitigation Strategy and Costs: MnDOT Maintenance will tighten the nuts on all new structures. A one-time cost of $40,000 would be needed to purchase additional machinery necessary to secure the structures, plus an increased annual cost of $2,000 for additional staff and equipment.

Likelihood and Consequence of Adverse Impacts

Likelihood and Consequence of Adverse Impacts			
	Consequence	Likelihood	Risk Rating
Original Risk Rating	Minor	Likely	Medium
Preferred Strategy	Minor	Rare	Low
Alternate Strategy	Minor	Rare	Low

Risk Statement (#2) Mitigation Strategies, Impacts on Other Risks, and Costs

Risk Statement #2:

Life-Cycle Cost: If overhead sign structure and high-mast light tower structure inspection data and deterioration models are not accurate or complete, then it may be difficult to determine the lowest life-cycle cost for these assets.

- Current control/mitigation strategies: Bridge Office Structural Metals and Bridge Inspection Engineer notify Electrical Services after pole is inspected as to what repairs are required for each pole.
- Previously identified mitigation strategies: Develop an enterprise asset management system for better tracking of asset status and better assignment of responsibility for condition and work accomplishment information.

Preferred Mitigation Strategy, Resources, and Costs:

1. Adopt a MnDOT policy/technical memo requiring a five-year inspection frequency for all overhead structures (approx. 40 staff hours). (*Process Improvement Strategy*)
2. Report annually on inspection frequency results (approx. 40 hours per year). (*Process Improvement Strategy*)
3. Create a training program for inspecting and maintaining structures, develop inspection forms, develop clear condition rating criteria. This would require a one-time cost of 320 hours, plus about 80 hours per year. (*Process Improvement Strategy*)
4. Gain efficiencies by using mobile technology in the field, at a cost of about $10,000 per year. (*Process Improvement Strategy*)

Alternate Mitigation Strategy and Costs:

Use consultants to perform the work, and/or increase inspection intervals. An average of $800 per structure was previously paid for external inspection. Internal inspections cost roughly $100 per structure.

Likelihood and Consequence of Adverse Impacts

	Consequence	Likelihood	Risk Rating
Original Risk Rating	Minor	Likely	Medium
Preferred Strategy	Minor	Rare	Low
Alternate Strategy	Minor	Likely	Medium

Risk Statement (#3), Mitigation Strategies, Impacts on Other Risks, and Costs

Risk Statement #3:

Labor Shortage: If MnDOT is unable to provide a sufficient number of workers to maintain high-mast light tower structures or overhead sign structures, then inspections, maintenance, repairs and replacement may fall short of service standards.

- Current control/mitigation strategies: None.
- Determine risk to public if MnDOT staff is decreased; cross training of staff (redundancy in knowledge).

Preferred Mitigation Strategy, Resources, and Costs:

1. Implement the proposed Transportation Asset Management System to include a work order, resource, and materials cost tracking module. This would entail a one-time cost of $250,000 and annual costs of $100,000 for software maintenance and usage costs. (*Process Improvement Strategy*)
2. Report annually on life-cycle cost and identify and implement refined/additional strategies to reduce costs, at a cost of 80 staff hours per year. (*Process Improvement Strategy*)

Alternate Mitigation Strategy and Costs:

1. Maintain status quo with replacement cycle of 40-50 years.
2. When an overhead sign structure or high-mast light tower structure are due for replacement, remove and replace with 6-8 standard lights or ground mount overhead.
3. Conduct research that will better define/determine deterioration rates and collect additional information.

Likelihood and Consequence of Adverse Impacts

	Consequence	Likelihood	Risk Rating
Original Risk Rating	Minor	Possible	Low
Preferred Strategy	Minor	Rare	Low
Alternate Strategy	Minor	Rare	Low

Work Group Assignment #1: Identification of Pavement Risks (including undermanaged)

Column 1 Risks:	Column 2 Impact of not managing the risk effectively to: (you do not have to have impacts in all three areas for each risk) Asset	Column 3 Public	Column 4 MnDOT	Column 5 Has MnDOT been managing this risk effectively? If Yes, List control/mitigation strategies used	Column 6 If No: List gaps in current business protocols preventing MnDOT from managing the risk effectively	Column 7 Ideal Mitigation Strategy(ies)	Column 8 What is the risk rating? Consequence of Risk Occurring	Column 9 Likelihood of Risk Occurring	Column 10 Overall Risk Rating	Most Undermanaged Risk
Not Meeting Public Expectations for Pavement Quality/Condition	Strain on Rest of System; Economy; Lower Quality of Life; Traveler Safety; Higher Maintenance Costs	Economy (commodities); Lower Quality of Life; Traveler Safety; Service Delays for Traveling Public;	Reputation Higher Maintenance Cost, and other asset maintenance is deferred.	Using money to manage to lowest lifecycle cost including routine maintenance; money distributed statewide based on need, measures & targets; balanced across entire system; MAP-21 direction (allocates $ on NHS); staging of treatments (more timely & appropriate treatments); multiple fixes at location or on corridor		Staging of treatments (more timely & appropriate treatments); multiple fixes at location or on corridor (IF LCC TREATMENT INTERVALS MODIFIED)	Moderate	Possible	Low	x
Statewide							Moderate	Possible	Low	
District Level						Small portion of DRMP is condition based	Moderate	Likely	Medium	
Local Level - Corridor (predicted or premature)						Manage expectations	Major	Likely	High	
Inappropriately Managing or Not Managing Pavements Such as Frontage Roads, Ramps, Auxiliary Lanes, etc.						Increased IDIQ or BARC type projects to address localized distresses	Minor	Possible	Low	x
Federal MAP-21 and GASB Requirements	Shorter/Wrong Fixes (e.g. Medium Mill & Overlay vs. Major Rehab./Construction)	Traveler Safety	Federal Funds withheld, bond rating impacted.	Same as above	Funding assigned to pavement has been too low, leading to low RQI, now it's difficult to catch up.	Provide funding to actually exceed targets, so that we could endure occasional budget shortfalls.	Major	Rare	Low	
Inability to Appropriately Manage Lowest LCC for Pavements	Project Deferrals/Delays or Shorter Term Fixes; Increased Operations Costs. Construction costs go up as conditions worsen. Missing Data and/or Hidden Costs (scope creep)	More Poor Roads; Traveler Safety. More auto repairs, more money spent on gas, risk of tax increases.	Additional Strain on MnDOT Maint./Operations Staff; Additional Funding Needed for Fixes	Same as above		Consistency on types of fixes statewide; managed system-wide (balance between project, district or statewide LCC - all three different); better coordination across offices and jurisdictions (e.g. pavement, safety, bridge, hydraulics, etc.) - think all inclusive corridor investments. Inventory and include all pavement in Pavement Management System.	Moderate	Possible	Medium	
Premature Deterioration of Pavements	Project Deferrals/Delays or Shorter Term Fixes; Increased Operations Costs	More Poor Roads; Traveler Safety	Additional Strain on MnDOT Maint./Operations Staff	Same as above		District Risk Management Program (DRMP) changes to align with shifts in pavement condition; Begin to document	Moderate	Possible	Medium	
Funding Being A Lot Less than Expected	More Poor Roads	More Poor Roads; Traveler Safety	Reputation	Same as above		Invest only in roads with ADT above a certain number (e.g. 2000 ADT)	Minor	Possible	Low	
Occurrence of an unanticipated event, natural disaster	Assets unusable	Service Delays, Traveler safety	Additional funding needed for fixes			Invest network-wide when unforeseen costs occur, stretch funding	Major	Rare	low	

Work Group Assignment #1: Identification of Bridge Risks (including undermanaged)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10			
				Has MnDOT been managing this risk effectively?			What is the risk rating?				Most Undermanaged Risks	
					If No:							
Risk of:	**Impact of not managing the risk effectively to: (you do not have to have impacts in all three areas for each risk)**			**If Yes, List control/mitigation strategies used**	**List gaps in current business protocols preventing MnDOT from managing the risk effectively**	**Ideal Mitigation Strategy**	**Consequence of Risk Occurring**	**Likelihood of Risk Occurring**	**Overall Risk Rating**	**Discussion Comments**		**Validation**
	Asset	**Public**	**MnDOT**									
Lack of or deferred funding (e.g., unexpected budget cuts)	Highest needs first; more reactive maintenance; low cost preservation to limp assets along; more frequent inspections	Potential for unsafe driving conditions; increased service interruptions; decreased public confidence; bridge or route restrictions	Do not meet performance targets; defer non-critical repairs; unmanageable growth of bridge needs; increased operations resource needs	BRIM (Bridge Replacement and Improvement Management); SIMS (Structure Information Management System)	SIMS Maintenance Module (in progress); linking costs to maintenance tasks (Swift, SIMS and BI); SIMS, BRIM and construction cost data not linked; implementation and use of a multi-objective optimization tool in BrM 5.2 (in development)	Link BRIM, SIMS, Swift, contract preservation costs and BrM 5.2 in order to make appropriate management decisions	Moderate	Possible	Medium	Does the likelihood of this risk concur with OCPPM?	x	The management programs (and links between the management programs) are not in place to be able to manage from an "entire system" asset management and life cycle cost approach.
Inability to manage to lowest life-cycle cost (e.g., preventive activities not performed on a timely basis)	Deteriorates faster (reduced bridge service life); more reactive maintenance; higher life cycle cost; manage highest needs first	Increased duration and frequency of service interruptions; decreased public confidence; bridge or route restrictions	More bridges falling into lower service conditions faster; do not meet performance targets; increased operations resource needs	BRIM; SIMS; Performance Measures	SIMS Maintenance Module (in progress); linking costs to maintenance tasks (Swift, SIMS and BI); SIMS, BRIM and construction cost data not linked; Preventive Maintenance Performance Measure still in development; Deterioration Curves; implementation and use of the multi-objective optimization tool in BrM 5.2 (in development)	Link BRIM, SIMS, Swift, contract preservation costs and BrM 5.2 in order to make appropriate management decisions; Preventive Maintenance Performance Measure; Deterioration Curves	Minor to Moderate	Likely	Medium	We could have a >$5M risk potential.	x	The management programs (and links between the management programs) are not in place to be able to manage from an "entire system" asset management and life cycle cost approach.
Occurrence of an unanticipated natural event (e.g. flood, earthquake, adverse weather)	Unexpected need - more resources assigned to that asset; scheduled bridge investments are deferred	Safety; increased service interruptions; detours; congestion	Changed maintenance program: top needs are redefined; unanticipated resources assigned to a single asset and other priorities are deferred	Design preventive measures; regular scour monitoring for scour critical bridges; debris removal; having resources available to react; ability to track and prioritize work	Maintenance resource and scheduling still in development (SIMS Maintenance Module); Up to date emergency response plan or critical infrastructure plan	Preventive Measures; Emergency Response Plan; Resource and Scheduling to reallocate resources	Major Moderate Minor	Rare to Unlikely Possible Likely	Low to Medium Medium Medium	Is this a major event? Are we looking at this from a statewide perspective or a local perspective? This could have three different answers for consequence and likelihood depending on the severity of the event and the perspective.		
Catastrophic failure of the asset (e.g., unexpected bridge collapse)	Unexpected need - more resources assigned to that asset; scheduled bridge investments are deferred	Safety; increased service interruptions; detours; congestion; decreased public confidence	Changed maintenance program: top needs are redefined; unanticipated resources assigned to a single asset and other priorities are deferred; management strategy and policies are investigated and redefined	Inspection frequency and best practices; performing required maintenance; having resources available to react; designing resilient bridges	Comprehensive Inspection Manual (in progress); Up to date emergency response plan or critical infrastructure plan	Inspection and Maintenance; Emergency Response Plan	Catastrophic	Rare	Medium			
Significant damage to the asset through man made events (e.g., crashes, damage from construction activities etc.)	Unexpected need - more resources assigned to that asset; scheduled bridge investments are deferred	Safety; increased service interruptions; detours; congestion	Changed maintenance program: top needs are redefined; unanticipated resources assigned to a single asset and other priorities are deferred	Having resources available to react; ability to track and prioritize work; inspection, permitting and restitution processes; preventive measures; designing resilient bridges	Up to date emergency response plan for at risk bridges; Maintenance resource and scheduling still in development (SIMS Maintenance Module); Restitution tracking; Linking Costs to Maintenance Tasks	Preventive Measures; Emergency Response Plan; Resource and Scheduling to reallocate resources; Inspection; Permitting process; Restitution	Major	Unlikely	Medium	Are we only looking at significant damage? Bridge hits and accidents happen more often than "unlikely" represents, but they do not all result in "significant" damage. What percentage of the bridge system is actually affected? This may be more of a localized risk.		
Premature deterioration of the asset (e.g., service lives 10 to 20 percent shorter than expected)	Unanticipated reactive maintenance or major investments required sooner; reduced service life	Increased duration and frequency of service interruptions; bridge or route restrictions; safety; decreased public confidence	Do not meet performance targets; changed maintenance program; increased operations resource needs	Inspection and maintenance tracking to try to anticipate needs; ability to track and prioritize work	SIMS Maintenance Module (in progress); Deterioration curves; implementation and use of the multi-objective optimization tool in BrM 5.2 (in development)	Inspection and Maintenance tracking; Deterioration curves; BrM 5.2	Moderate to Major	Unlikely	Medium	Is this from a "whole system" perspective or from an individual bridge perspective? This will affect the consequence and likelihood values.	x	The management programs (and links between the management programs) are not in place to be able to manage from an "entire system" asset management and life cycle cost approach. Need improved deterioration models for our bridges.
Shortage of workforce (e.g., early retirements and hiring freezes)	Maintenance not performed when needed; impacts to design, scoping, estimates, load rating, data management, etc.	Decreased public confidence; increased service interruptions	Not enough resources to perform the work and lack of knowledgeable and experienced workers to perform the work efficiently and effectively.	Bridge training program; Bridge Maintenance Academy training; technology; Consultant Contracts	Performance and Efficiency Measures for performing all tasks (design, load rating, scoping, estimates, inspection and actual maintenance on the structure) as well as the link between the measures	Training; Measures; Consultant Contracts	Minor to Moderate	Possible	Low to Medium	What is the magnitude of this event? Depending on the magnitude, a shortage of workforce could be considered a moderate consequence as far as financial impact, service interruptions, and significantly impacted programs (design, construction, load ratings, maintenance, inspection etc).		

Work Group Assignment #1: Identification of Hydraulic Structures Risks (including undermanaged)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	
				Has MnDOT been managing this risk effectively?			What is the risk rating?			
					If No:					
Risks:	**Impact of not managing the risk effectively to: (you do not have to have impacts in all three areas for each risk)**			**If Yes, List control/mitigation strategies used**	**List gaps in current business protocols preventing MnDOT from managing the risk effectively**	**Ideal Mitigation Strategy(ies)**	**Consequence of Risk Occurring**	**Likelihood of Risk Occurring**	**Overall Risk Rating**	**Most Undermanaged Risk**
	Asset	**Public**	**MnDOT**							
Tunnel Failure/Collapse	Strain on Rest of Tunnel System	Trauma or Death to Traveling Public and or Residents; Increased Congestion on Other Arterials and Local System; Service Delays for Traveling Public; Increased Flooding on Roadway & Adjacent Business/Residential	Highways Closures; Loss of Public Trust/Reputation; Large, Short-Term, Immediate Financial Impacts	No	Funding for Repairs and Maintenance. Not a high priority for agency; Inspection/maint. of tunnels done by Cities (need more of a joint process, merge of priorities)	MnDOT and Communities prioritize construction funding. Detour routes established in advance; map extent of possible flooding; increase funding for rehab., data collection & inspection (determine LCC & deterioration); work with Cities to redefine management of tunnels to more of a coordinated effort	Catastrophic	Likely	Extreme	2nd Highest Tunnel Risk
Flooding and Deterioration due to lack of tunnel capacity	Increased Rate of Deterioration; Deterioration of Sandstone Layer Adjacent Tunnel Lining From Pressurized Water	Increased Flooding on Roadway & Adjacent Business/Residential; Loss of Commerce; Tunnel Failure/Collapse	Increased Flooding on Roadway; Deterioration of Tunnels & Other Assets; Loss of Public Trust; Loss of Commerce; Increased Cost to Replace at a Later Time	No	Shared water with City of Minneapolis; Based on maintenance agreement, City of Minneapolis would have cost share and have said they do not have the money	Provide new system & back charge City; City to separate its' water (as much as possible); Downsize new/modified system as much as possible to save costs	Catastrophic	Possible	High	Highest Tunnel Risk
Inability to Appropriately Manage Tunnels (i.e. lack of data, no LCC or deterioration rates; adequate inspection, etc.)	Increased Risk of Failure	Increased Travel Delays	Increased Risk of Failure; Financial Impact to Repair Over Life of Asset	Inspections	Shared maintenance agreements with City of Minneapolis; Shared water with City of Minneapolis; Minneapolis tunnels in worse condition; Frequency of inspections	MnDOT pays and charges Minneapolis interest and/or reduces funding on other projects that City wants; Put information in bridge inventory, not just HydInfra; pressure transducer; installation and monitoring	Moderate	Likely	Medium	
Culvert Failure/Collapse	Requires roadway reconstruction or repair with culvert replacement	Safety of Traveling Public (e.g. car damage, injury or death/fatalities); Service Delay; Emergency Service Disruptions; Flooding to Adjacent Properties	Considerable impact to MnDOT's reputation if fatalities would occur. Higher cost of emergency repairs compared to maintenance.	Partially, have implemented inventory and inspection program to identify bad culverts and begun repairing some pipes. Should minimize surprise failures.	Insufficient funding for adequate maintenance and repairs. Not all culverts needing repaired are fixed during construction projects. MnDOT Maintenance staffing inadequate to address drainage needs.	Culverts identified as in poor or very poor condition are fixed by MnDOT maintenance or in construction projects. Culverts identified as very poor are fixed before failures cause major repair impacts.	Major	Likely	High	Highest Culvert Risk
Lack of Culvert Capacity	Culvert and road failure (e.g. caused by high head, road overtopping, scour or piping)	Detours, delays or property damage (e.g. Flooding to Adjacent Properties)	Staff and funding needed to address problems (e.g. law suits, flood damage, road and culvert repairs and detours)	No	Insufficient resources to upsize culverts and concerns of passing additional water downstream. (e.g. permitting requirements, environmental, ROW impacts, liability)	Parties causing upsize need participate financially. Evaluations done on case by case basis but more resources will be needed. May require designing more storage and investing in flood easements. Watershed coordination.	Minor	almost certain	Medium	3rd Highest Culvert Risk
Inability to Appropriately Manage Culverts (i.e. lack of data, no LCC or deterioration rates; age, adequate inspection, etc.)	Greater likelihood of culvert failure. Higher life cycle cost.	Pays more for drainage infrastructure maintenance; potential traffic impacts, exposure to culvert failure risk. Lack of Ability/Time to Work with Partners to Actually Improve Hydraulics serving constituents.	MnDOT pays more over life cycle, more for emergency repairs, may suffer impacts to trust and confidence. May be investing inefficiently (e.g. Under or Over Investing; Inability to Leverage Appropriate Funding to Meet Targets)	Partially; MnDOT has invested heavily in inventory and condition data collection, a rigorous drainage performance measure remains to be selected. A department wide measure would result in more systematic management of the system.	Selection of a repair measure and target, and corresponding funding. Missing data in HydInfra (i.e. date built, construction as-built, repair records). Robust LCC methodology.	Funding to be able to implement a systematic maintenance approach based on targeted work , complete LCC understanding, data provided and shared by design, construction, maintenance.	Moderate	Possible	Medium	2nd Highest Culvert Risk
Inappropriately Distributing Funds or Inconsistency on Investing in Culverts	Higher likelihood of localized failures	Potential inconsistent levels of service geographically; Potentially differing risks in Safety of Traveling Public (e.g. car damage, injury or death); Service Delay; Emergency Service Disruptions; Flooding to Adjacent Properties	Districts need to make hard decisions about where to spent limited funds, backlogs of needed maintenance or repair could develop.	Unknown	Lack of funds and ability to manage culverts in a cost effective manner	More funds, better information to manage culverts with less money.	Minor	Possible	Low	
Significant Damage to Culvert Through Man-Made Event(s)	Culverts are damaged (e.g. utility installation, vehicle hits apron, damage from fire)	Bears costs ($'s, Inconvenience etc).	Costs to repair culverts.	Unknown	Difficult to predict or prevent.	Respond when event happens.	Insignificant	Likely	Low	

Work Group Assignment #1: Identification of Overhead Sign Structures & High-Mast Light Tower Structures Risks (including undermanaged)

Column 1	*Column 2*	*Column 3*	*Column 4*	*Column 5*	*Column 6*	*Column 7*	*Column 8*	*Column 9*	*Column 10*	
				Has MnDOT been managing this risk effectively?			**What is the risk rating?**			
					If No:					
Risk of:	**Impact of not managing the risk effectively to: (you do not have to have impacts in all three areas for each risk)**			**If Yes, List control/mitigation strategies used**	**List gaps in current business protocols preventing MnDOT from managing the risk effectively**	**Ideal Mitigation Strategy**	**Consequence of Risk Occurring**	**Likelihood of Risk Occurring**	**Overall Risk Rating**	**Most Undermanaged Risk**
	Asset	**Public**	**MnDOT**							
Lack of having a mandated process for inspection	Lower Asset Quality (Not a priority for agency so work (i.e. inspection/fixes) doesn't get completed in a timely manner	increased risk of safety and/or damage to public property (vehicles), increase in cost to public if external resources are used	Staffing; lack of public trust to know the condition of the asset	Bridge Office Structural Metals and Bridge Inspection Engineer performs inspections per technical memorandum on all TL.	Management deciding inspection is a priority. Determining which offices/functional areas will perform and be accountable for the inspections	tech memo. (similar to tower lighting); mandatory 5-year inspection cycle (this is probably a measure and/or target)	Minor	Possible	Low	
Poor contract execution (e.g., inappropriate construction installation)	Poor quality product; deteriorate at a higher rate; increased reactive maintenance.	Safety; decreased public confidence; increased service interruptions.	Staffing; Reputation; More Costs and/or Less Funding; Ability to Scope with Project	No.	Project Engineer relies on contractor to perform installation correctly. There is no understanding of the cost to repair because of poor asset installation	better quality controls (e.g. MnDOT checks) of construction work outside of edge-of-pavement-to-edge-of-pavement; better checklist to include roadside infrastructure; workshops at end of construction project	Minor	Likely	Medium	Highest OSS/TL Risk
Inability to manage to lowest life-cycle cost (e.g., preventive activities not performed on a timely basis)	Deteriorates faster (reduced service life); more reactive maintenance; higher life cycle cost.	Increased duration and frequency of service interruptions; decreased public confidence.	Lower service conditions; does not meet AASHTO light levels; increased operations resource needs	Bridge Office Structural Metals and Bridge Inspection Engineer notifies Electrical Services after pole is inspected as to what repairs are required for each pole.	Funding is rotated to where needs are to try and maintain balance; lack of data on what is optimal lowest LCC	Having an enterprise asset management system in place will help track status of asset (e.g. inspection of asset is completed by maintenance which is part of Engineering Services and fixes are performed by electrical services which is part of Operations Division. There is not a direct and clear connection to notify maint. when fixes are performed.	Minor	Likely	Medium	2nd Highest OSS/TL Risk
Significant damage to the asset through man made events (e.g., crashes, damage from construction activities etc.)	Faster deterioration due to damage to elements; decrease in life of structure	increased risk of safety and/or damage to public property (vehicles)	Increase in tort claims, increase in public complaints	MnDOT monitors roadway cameras and responds to asset damage due to crashes in timely manner; MnDOT pursues restitution with insurance companies to recoup costs		Not sure what factor of safety is being used for structural design?	Minor	Likely	Medium	
Premature deterioration of the asset	Unexpected need- more resources assigned to that asset; other preservation projects are deferred.	Safety; Potential for unsafe driving conditions.	Changed maintenance program: top needs are redefined; unanticipated resources assigned to a single asset and other priorities are deferred.	Inspections of TL keep the premature for failure of the asset to a minimum.	lack of data on what deterioration rates for OSS/TL are		Minor	Likely	Medium	
Unforeseen changes in regulatory requirements, travel demands, or technology (e.g., significant industrial growth in one region of the state, availability of new technology for conducting inspections more efficiently)	Increase in the number of structures, larger structures being built because of additional weight (larger or more elements); more complex structures due to complex traffic control devices	Increase in cost to maintain and build structures	Inquired costs because of new requirements/specs, increase in personnel time to inspect more structures, increase in technical knowledge to perform inspections		communicating hard costs when regulatory requirements are implemented; being able to determine if an additional structure is a "need" or just a "want"	Adding maintenance and inspection costs to capital costs (life cycle costs) when making planning/design decisions	Moderate	Rare	Low	
Shortage of workforce (e.g., early retirements/hiring freezes or need for additional staff to complete work tasks in a timely manner)	decrease in life of structure due to lack of inspections and maintenance	increased risk of safety and/or damage to public property (vehicles)	Inspection intervals increased or not accomplished; maintenance response time slower or not able to accomplish			Determine risk to public if MnDOT staff is decreased.	Minor	Possible	Low	3rd Highest OSS/TL Risk

Work Group Assignment #1 Results: Identified Most Undermanaged Risks

Risks:	Impact of not managing the risk effectively to: (you do not have to have impacts in all three areas for each risk)			Has MnDOT been managing this risk effectively?		
				If Yes, List control/mitigation strategies used	If No:	
					List gaps in current business protocols preventing MnDOT from managing the risk effectively	Ideal Mitigation Strategy(ies)
	Asset	Public	MnDOT			
Pavement						
Not meeting public expectations for pavement quality/condition, specifically at the local/corridor level	Strain on rest of system; economic impacts; traveler safety; higher maintenance costs	Economic (commodities) impacts; lower quality of life; traveler safety; service delays for traveling public	Reputation; higher maintenance costs; other asset maintenance is deferred.	Using money to manage to lowest lifecycle cost including routine maintenance; money distributed statewide based on need; measures & targets; balanced across entire system; MAP-21 direction (allocates $ on NHS); staging of treatments (more timely & appropriate treatments); multiple fixes at location or on corridor		More timely and appropriate staging of treatments; multiple fixes at location or on corridor (only if LCC treatment intervals modified); more systemmatic and standardized statewide approach to fixes
Local Level - Corridor (predicted or premature) NOT STATE OR DISTRICT						Better manage expectations
Inappropriately managing or not managing pavements such as frontage roads, ramps, and auxilary lanes						Increased IDIQ or BARC type projects to address localized distresses; better tracking of deterioration and condition
Bridge						
Inability to manage to lowest life-cycle cost for bridges (corollary risk: lack of or deferred funding)	Deteriorates faster (reduced bridge service life); more reactive maintenance; higher life cycle cost; manage highest needs first	Increased duration and frequency of service interruptions; decreased public confidence; bridge or route restrictions	More bridges falling into lower service conditions faster; do not meet performance targets; increased operations resource needs	BRIM; SIMS; performance measures	SIMS Maintenance Module (in progress); linking costs to maintenance tasks (Swift, SIMS and BI); SIMS, BRIM and construction cost data not linked; Preventive Maintenance Performance Measure still in development; deterioration curves; implementation and use of the multi-objective optimization tool in BrM 5.2 (in development)	Link BRIM, SIMS, Swift, contract preservation costs and BrM 5.2 in order to make appropriate management decisions; preventive maintenance performance measure; better knowledge of deterioration curves
Premature deterioration of a bridge	Unanticipated reactive maintenance or major investments required sooner; reduced service life	Increased duration and frequency of service interruptions; bridge or route restrictions; safety; decreased public confidence	Do not meet performance targets; changed maintenance program; increased operations resource needs	Inspection and maintenance tracking to try to anticipate needs; ability to track and prioritize work	SIMS Maintenance Module (in progress); deterioration curves; implementation and use of the multi-objective optimization tool in BrM 5.2 (in development)	Better inspection and maintenance tracking; better knowledge of deterioration curves; BrM 5.2
Highway Culverts						
Culvert failure/collapse	Requires roadway reconstruction or repair with culvert replacement	Safety of traveling public (e.g. car damage, injury or death/fatalities); service delay; emergency service disruptions; flooding to adjacent properties	Considerable impact to MnDOT's reputation if fatalities occur; higher cost of emergency repairs compared to maintenance.	Partially, have implemented inventory and inspection program to identify bad culverts and begun repairing some pipes. Should minimize surprise failures.	Insufficient funding for adequate maintenance and repairs. Not all culverts needing repaired are fixed during construction projects.	Culverts identified as in poor or very poor condition are fixed by MnDOT maintenance or during construction projects. Culverts identified as very poor are fixed before failures cause major repair impacts. Need a better coordinated process for fixes.
Inability to appropriately manage culverts	Greater likelihood of culvert failure; higher life cycle cost	Pays more for drainage infrastructure maintenance; potential traffic impacts, exposure to culvert failure risk; lack of ability/time to work with partners to improve hydraulics for constituents	Pay more over life cycle; higher costs for emergency repairs: impacts to trust and confidence; investing inefficiently (e.g. under or over investing; inability to leverage appropriate funding to meet targets)	Partially; MnDOT has invested heavily in inventory and condition data collection, a rigorous drainage performance measure remains to be selected. A department-wide measure would result in more systematic management of the system.	Selection of a repair measure and target, and corresponding funding. Missing data in HydInfra (i.e. date built, construction as-built, repair records). Robust LCC methodology.	Additional funding to be able to implement a systematic maintenance approach based on targeted work, complete LCC understanding, data provided and shared by design, construction, maintenance.
Lack of culvert capacity	Culvert and road failure (e.g. caused by high head, road overtopping, scour or piping)	Detours, delays or property damage (e.g. flooding to adjacent properties)	Staff and funding needed to address problems (e.g. law suits, flood damage, road and culvert repairs and detours)	No	Insufficient resources to upsize culverts and concerns of passing additional water downstream. (e.g. permitting requirements, environmental, ROW impacts, liability)	Parties causing upsize need to participate financially; evaluations could be done on case by case basis which would require more resources; may require designing more storage and investing in flood easements; watershed coordination.
Deep Stormwater Tunnels						
Flooding and deterioration due to lack of tunnel capacity	Increased rate of deterioration; deterioration of sandstone layer adjacent tunnel lining from pressurized water	Increased flooding on roadway & adjacent business/residential; loss of commerce; tunnel failure/collapse; service delays	Increased flooding on roadway; deterioration of tunnels & other assets; loss of public trust/reputation; loss of commerce; increased cost to replace at a later time	No	Shared water with City of Minneapolis; based on maintenance agreement, City of Minneapolis would have cost share and have said they do not have the money	Provide new system & back charge City; City to separate its' water (as much as possible); downsize new/modified system as much as possible to save costs
Tunnel failure/collapse because of not managing and mismanagement	Strain on rest of tunnel system	Trauma or death to traveling public and or residents; increased congestion on other arterials and local system; Service delays for traveling public; increased flooding on roadway & adjacent business/residential	Highways closures; loss of public trust/reputation; Large, short-term, immediate financial impacts	No	No funding for repairs and maintenance. Not a high priority for agency; inspection/maint. of tunnels done by Cities (need more of a joint process, merge of priorities)	MnDOT and communities prioritize construction funding. detour routes established in advance; map extent of possible flooding; increase funding for rehab., data collection & inspection (determine LCC & deterioration); work with Cities to redefine management of tunnels to more of a coordinated effort
Overhead Sign Structure & Tower Lighting						
Poor contract execution for installation of overhead sign structures and tower lighting	Poor quality product; deteriorate at a higher rate; increased reactive maintenance	Safety; decreased public confidence; increased service interruptions	Staffing; reputation; more costs and/or less funding; ability to scope with project	No.	Project Engineer relies on contractor to perform installation correctly - lack of oversight on project-by-project case; lack of understanding of costs to repair because of poor asset installation	Better quality controls (e.g. MnDOT checks) of construction work outside of edge-of-pavement-to-edge-of-pavement; better checklist to include roadside infrastructure; routine/mandatory workshops at end of construction project
Inability to manage to lowest life-cycle cost for overhead sign structures and tower lighting	Deteriorates faster (reduced service life); more reactive maintenance; higher life cycle cost	Increased duration and frequency of service interruptions; decreased public confidence	Lower service conditions; does not meet AASHTO light levels; increased operations resource needs	Bridge Office Structural Metals and Bridge Inspection Engineer notifies Electrical Services after pole is inspected as to what repairs are required for each pole.	Funding is rotated to where needs are to try and maintain balance; lack of data on what is optimal lowest LCC	Enterprise asset management system for better tracking asset status (e.g. inspection of asset is completed by maintenance which is part of Engineering Services and fixes are performed by Electrical Services which is part of Operations Division. There is not a direct and clear connection to notify maint. when fixes are performed.
Shortage of workforce for overhead sign structures and tower lighting	Decrease in life of structure due to lack of inspections and maintenance	Increased risk of safety and/or damage to public property (vehicles)	Inspection intervals increased or not accomplished; maintenance response time slower or not able to accomplish			Determine risk to public if MnDOT staff is decreased; cross training of staff (redundancy in knowledge)

Work Group Assignment #2 Detailed Instructions

During your work on identifying and prioritizing undermanaged risks, your group identified mitigation strategies that would enable MnDOT to better manage these risks. The objective of this exercise is to explore those risk mitigation strategies in more detail to help us estimate the overall return on the investment. You will do that by reviewing your risk statements and identifying costs associated with one or two mitigation strategies for each of your asset group's most undermanaged risks (as previously identified – see Excel spreadsheet). The results of this activity will be used in a workshop on November 15, 2013.

Step 1: Define your preferred mitigation strategy for addressing the risk. Be specific as to what needs to be done to better manage risk. For example, instead of saying "better manage customer expectations," it would be more specific to suggest activities such as "develop a press package to help customers set more realistic pavement performance expectations based on the fiscally-constrained environment." Your mitigation strategy should clearly convey to an outsider what will be done to reduce or eliminate the risk.

Step 2: Identify the data, resources, tools, and/or training required to enact your strategy. Without getting too hung up in the details of what will be required, prepare an estimate of the types and quantities of resources that might be needed to implement your strategy, including work force impacts, equipment purchases, software tools, and so on. For example, will you need a 2-person survey crew for 2 months of the year? Do you need an analysis tool to be able to predict asset performance? For the example given in Step 1, the response might look like this:

[Example Response: Requires a Public Information Office employee to develop a campaign using data provided from the pavement management system. Once the campaign materials are developed, the materials must be distributed via appropriate channels and future customer expectations must be monitored every other year.]

Step 3: Describe whether your strategy will reduce the likelihood of another risk identified by your group. For example, a more formal process for managing culverts should reduce the likelihood that unexpected failures will occur.

Step 4: Estimate the approximate cost of implementing the preferred mitigation strategy. Again, do not worry too much about getting your cost estimate exact. If you can adequately estimate the relative magnitude of the strategy cost, that should be close enough. In other words, we would like to know if this is a $20,000 strategy or a $200,000 strategy. Use readily available information to prepare your estimate and document how you arrived at the total cost. For calculating work force salary costs, please use an hourly unit cost of $25/hour. If it is too difficult to estimate the costs associated with your strategy, at least indicate whether your preferred strategy is a low-cost strategy (i.e. less than $250,000 annually to implement), moderate-cost strategy (i.e. between $250,000 and $800,000 annually), or a high-cost strategy (i.e. more than $800,000 annually)

Step 5: Identify whether an alternate strategy might be available that doesn't fully mitigate the risk, but lowers the overall likelihood or consequence associated with the risk. Think about alternate approaches that might not be as effective at reducing the risk, but might cost the agency less than the preferred strategy. For example, the preferred strategy for managing culverts might be to repair all culverts in poor or very poor condition. An alternate strategy might include monitoring all culverts in poor or very poor condition on a quarterly basis to track changes in conditions and to prioritize repairs. This approach won't eliminate unexpected culvert failures, but will provide a way of prioritizing the culverts that are at greatest risk.

Step 6: Estimate the cost associated with the alternate strategy. As in step 4, we are not looking for a detailed estimate, but want you to think about the resources, equipment, or tools that might be needed to implement the alternate strategy.

Step 7: For both of the strategies you've identified, identify the impact on the likelihood and consequence of the original risk should either of the strategies be adopted. This information will allow us to estimate the return on investment associated with each of the two strategies. You can use the chart below to record the changes in likelihood and consequence.

Risk 1:	**Original Risk Rating**	**Risk Ratings for Preferred Strategy** (From Step 1)	**Risk Ratings for Alternate Strategy** (From Step 6)
Likelihood of Event (Select from: Rare, Unlikely, Possible, Likely, or Almost Certain)			
Consequence of Event (Select from: Insignificant, Minor, Moderate, Major, or Catastrophic)			

Risk 2:	**Original Risk Rating**	**Risk Ratings for Preferred Strategy** (From Step 1)	**Risk Ratings for Alternate Strategy** (From Step 6)
Likelihood of Event			
Consequence of Event			

Risk 3:	**Original Risk Rating**	**Risk Ratings for Preferred Strategy** (From Step 1)	**Risk Ratings for Alternate Strategy** (From Step 6)
Likelihood of Event			
Consequence of Event			

Work Group Assignment #2: Identification of Pavement Undermanaged Risk Mitigation Strategies and Costs

			Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7		
									Estimate Likelihood & Consequence of Strategy		
Undermanaged Opportunity	Current Control/Mitigation Strategy(ies)	Previously Identified Mitigation Strategy(ies)	Preferred Mitigation Strategy(ies)	Data, Tools Resources and/or Training Required to Make Strategy Reality	Describe if Strategy Will Reduce Likelihood of Another Risk	Estimate Approximate Cost of Preferred Mitigation Strategy(ies)	Alternate Mitigation Strategy	Estimate Approximate Cost of Alternate Strategy	Original Risk Rating	Preferred Strategy Rating	Alternate Strategy Rating
Pavement											
If public expectations for pavement quality or condition are not met, especially at the local/corridor level, then the agency's reputation may suffer, service delays and unsafe conditions may increase and the cost of maintenance may grow.	Using money to manage to lowest lifecycle cost including routine maintenance; money distributed statewide based on need; measures & targets; balanced across entire system; MAP-21 direction (allocates $ on NHS); staging of treatments (more timely & appropriate treatments); multiple fixes at location or on corridor	More timely and appropriate staging of treatments; multiple fixes at location or on corridor (only if LCC treatment intervals modified); more systemmatic and standardized statewide approach to fixes	1. Annually track, monitor and identify roadway segments that have been in poor condition greater than 5 years, and consistently consider when programming at the District level	Query out miles by poor with no treatments within last 5-years or some extended period of time.	Strategy will not reduce likelihood of the 2nd risk but may reduce the previous risk (likelihood) of meeting GASB 34 (previously identified risk - not under-managed)	1. 8 hours of staff time to run report and coordinate with districts during annual programming activities.	3. Turnbacks (jurisditional realignment) 4. Outreach plan or communication tool	3. $200k per mile to bring roads up to standard for realignment 4. $25k	C: Major L: Likely	C: Major L: Possible	C: Moderate L: Likely
If MnDOT does not include ramps, access roads, auxiliary lanes and frontage roads in its pavement inventory and use their condition in its pavement model, then these assets will not be included in pavement management decisions and cannot be managed to achieve the lowest lifecycle cost for all highway pavements.	No	Increased IDIQ or BARC type projects to address localized distresses; better tracking of deterioration and condition	1. Collect additional information/data in the Metro District with the use of old Material Office pavement van. 2. Build a stand alone database that will house information/data and allow for better tracking.	Use old Material Office pavement van, MS Excel or Access software for database	Strategy will not reduce likelihood of the 1st risk.	1. $100/mile 2. $2000-4000. Rough cost to put database together and communicate to districts. Cost might be more toward $10-20k if a consultant was hired.	3a. Collect data in Greater MN districts by hand, using maintenance staff. 3b. Visually collect images through video capture or windshield survey.	3a/3b. $100/mile to collect data and additional cost/time to enter information into database. This time and cost would be determined by the data (# of facilities, collection detail, etc.)	C: Minor L: Possible	C: Minor L: Unlikely	C: Minor L: Unlikely

Work Group Assignment #2: Identification of Bridge Undermanaged Risk Mitigation Strategies and Costs

Undermanaged Opportunity	Current Control/Mitigation Strategy(ies)	Previously Identified Mitigation Strategy(ies)	Step 1 Preferred Mitigation Strategy	Step 2 Data, Tools Resources and/or Training Required to Make Strategy Reality	Step 3 Describe if Strategy Will Reduce Likelihood of Another Risk	Step 4 Estimate Approximate Cost of Preferred Mitigation Strategy	Step 5 Alternate Mitigation Strategy	Step 6 Estimate Approximate Cost of Alternate Strategy	Step 7 Estimate Likelihood & Consequence of Strategy Original Risk Rating	Step 7 Preferred Strategy Rating	Step 7 Alternate Strategy Rating
Bridge											
If bridge inspection data, bridge model sophistication and bridge deterioration models are not accurate or complete, then it may be difficult to determine the lowest lifecycle cost strategy for bridges. AND If one or more bridges deteriorate prematurely, then maintenance costs may be higher than expected and there may be unanticipated risks to structural integrity.	BRIM; SIMS; performance measures Inspection and maintenance tracking to try to anticipate needs; ability to track and prioritize work	Link BRIM, SIMS, Swift, contract preservation costs and BrM 5.2 in order to make appropriate management decisions; preventive maintenance performance measure; better knowledge of deterioration curves Better inspection and maintenance tracking; better knowledge of deterioration curves; BrM 5.2	1. Finish development of SIMS Maintenance Module 2. Develop the Preventive Maintenance (PM) Program/Performance Measure (in progress) to verify that PM is performed at the right time. 3. Develop BI reporting tool to link SIMS and Swift (in discovery phase now). 4. Migrate inspection (and maintenance?) data to BrM 5.2 (BrM 5.2 is still in development) and create/utilize the deterioration curves. As part of this step, the CORE AASHTO elements need to be translated to the new AASHTO National Bridge Elements (NBE). 5. Link Construction Costs with Maintenance costs in BI 6. Link BRIM and BrM 5.2 7. Compare cost, age and performance trends of the bridge system to determine effectiveness of management strategy and adjust accordingly 8. Research to further identify lowest lifecycle cost (i.e. deterioration models, effectiveness of maintenance activities, products etc.)	1a. SIMS Maintenance Module is currently in development with Bentley. We have in depth maintenance data back to 2009 which needs to be migrated into the SIMS Maintenance Module. 1b. Training Required (50 Trainees + 2 instructors for 8 4-hour training sessions located around the state + curriculum development and data migration = 400 hours total) 2. Need to develop the measure. Also need collaboration from the Districts (Annual Meetings between Bridge Office Staff and District Staff) 3a. BI Bridge Maintenance tool is currently in the data discovery phase. We do not have a project assigned yet and therefore do not have any associated costs. All costs included in this strategy are estimates and may actually be higher or lower given many factors. 3b. Training (Power Users: 3 Trainees + 1 instructor for 2 full day sessions = 64 hours total; Regular Users: 29 Trainees + 1 instructor for 1 full day session = 240 hours total) 4a. Multi-state collaboration for development. $50,000 per year for 5 years for BrM 5.2 development (29 states participate) 4b. Need resources and equipment to test and implement the BrM 5.2 system. Need to develop deterioration curves from Minnesota data. 5. Need to develop a plan on how to link Construction Costs to the BI reporting tool. 6a. BRIM Development 6b. Need to develop a plan on how to integrate BRIM risk analysis into BrM 5.2. 7. Development 8a. Deck Deterioration and NBE Research is currently in progress. 8b. Other Research may be needed.	This strategy will mitigate both of the risks identified in this exercise (manage to lowest lifecycle cost and premature deterioration) as well as help to mitigate the lack of or deferred funding.	$2 Million (This represents a one time implementation cost. Following implementation, this will be a low cost strategy to maintain annually)	1. Finish development of SIMS Maintenance Module (already in progress). 2. Develop the Preventive Maintenance (PM) Program/Performance Measure (in progress) to verify that PM is performed at the right time. 3. Cost accounting tracking through existing systems (WOM, Financial Reports). These systems are not tied with maintenance data in SIMS. 4. Migrate inspection (and maintenance?) data to BrM 5.2 (BrM 5.2 is still in development) and create/utilize the deterioration curves. As part of this step, the CORE AASHTO elements need to be translated to the new AASHTO National Bridge Elements (NBE). 5. Not included in alternate mitigation strategy. 6. Use BRIM as currently developed. 7. Not included in alternate mitigation strategy. 8. Current Research	$1.4 Million (This represents a one time implementation cost. Following implementation, this will be a low cost strategy to maintain annually)	C: Moderate L: Likely	C: Minor L: Likely	C: Moderate L: Likely

Work Group Assignment #2: Identification of Hydraulic Undermanaged Risk Mitigation Strategies and Costs

			Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7		
Undermanaged Opportunity	Current Control/Mitigation Strategy(ies)	Previously Identified Mitigation Strategy(ies)	Preferred Mitigation Strategy(ies)	Data, Tools Resources and/or Training Required to Make Strategy Reality	Describe if Strategy Will Reduce Likelihood of Another Risk	Estimate Approximate Cost of Preferred Mitigation Strategy(ies)	Alternate Mitigation Strategy	Estimate Approximate Cost of Alternate Strategy	Estimate Likelihood & Consequence of Strategy		
									Original Risk Rating	Preferred Strategy Rating	Alternate Strategy Rating
Highway Culverts											
Inability to manage highway culverts increases risk of failure and the life cycle cost (LCC).	Partially, MnDOT inventories and inspects highway culverts and the information is used to plan maintenance work and project scoping activities. Culvert failues are repaired when they occur.	Additional funding to be able to implement a systematic management approach based on targeted work, complete LCC understanding, data provided, shared and used by design, construction, maintenance.	1. Adopt System Condition Performance Measure (including defining target, etc.) 2. Implement Asset Management System and Data that will support LCC 3. Repair or replace Highway Culverts in accordance with Asset Management System Recommendations through Captial Projects and Maintenance work.	1. Staff time to develop and implement performance measures 2a. Funds to purchase and implement Transportation Asset Management System 2b. Staff & consultant resources to develop LCC business rules 2c. Staff & consultant resources to collect data for asset management system 3. Funding for capital and maintenance work needs to repair and replace culverts	Strategy will reduce the likelihood of road failure, interruption of service, lack of adequate capacity, and land owner drainage complaints. Strategy will also reduce the risk of not being able to support HydInfra system.	1. 200 hours staff time 2a. >$1M for software, consultant, and equipment purchase. 1000 hours staff time. 2b. $50,000 Research or consultant project. 500 hours staff time for internal rule development and training. 2c. 16,000 hours per year for highway culverts (assume around 12,000 hours currently, estimate extra 3000 hours/per year for unknown condition culverts, plus 1000 hours per year to meet inspection targets) 3. $40M per year (approximate $30M current investment, and additional $10M per year to repair or replace poor and very poor highway culverts).	Stand-alone construction projects to repair or replace poor and very poor highway culverts.	1. NA 2a. $1.25 M to implement Transportation Asset Management system (does not include LCC functionality) and 800 staff hours. 2b. NA 2c. 16,000 hours/year (no change) 3. $30M current investment + funding for additional stand-alone construction projects	C: Moderate L: Almost Certain HIGH	C: Moderate L: Possible MEDIUM	C: Moderate L: Likely MEDIUM
Deep Stormwater Tunnels											
If stormwater tunnel capacity is not adequate for a major rain event and resulting pressurization is too great, then the tunnel will be damaged or collapse, local flooding may occur, property may be damaged, and people may be killed or injured.	No	Provide new system & back charge City; City to separate its' water (as much as possible); downsize new/modified system as much as possible to save costs	1. Complete research on underground storage options, including the exploration of shallow cavern storage options for south (I-35W) tunnel. 2. Develop & implement emergency response plan for business, residential, and freeway area along floodprone I-35W south tunnel.	Consultants and funding needed	If #1 is installed, then risk will be mitigated; #2 only deals with event when it occurs.	1. $30,000 2. $15,000	1. Build I-35W south underground storage cavern.	1. $50 M	C: Catastrophic L: Likely	C. Catastrophic L. Possible Improved Credability and may lead to lower cost solution than a parallel tunnel	C. Catastrophic L. Rare
If the suggested maintenance repairs are not made in a timely manner, then the tunnels may collapse in a major rain event, and significant property damage, loss of life, or extensive service disruption may occur and significant reconstruction costs may be necessary.	Tunnels, with exception of one, have been throughly inspected once to gauge baseline condition. Repairs have been prioritized.	MnDOT and communities prioritize construction funding. detour routes established in advance; map extent of possible flooding; increase funding for rehab., data collection & inspection (determine LCC & deterioration); work with Cities to redefine management of tunnels to more of a coordinated effort	1. Inspect one remaining tunnel. 2. Put pressure tranducers in tunnels to measure pressurization. 3. Put together and implement a mandated inspection frequency (1-5 yrs.) based on tunnel/segment condition rating. 4. Include tunnels in bridge inventory. 5. Prepare plans and implement all repairs needed on south I-35W tunnel system at MnDOT cost and city to fully fund all other known repairs on all other tunnels.	Staff, priorities, funding for consultants, TH bond funding for repairs	This work will improve our credability in the event of a failure. It will strategically fix the worst tunnels repair needs. It may reduce the event of a failure by having increased information on tunnel condition - as long as funding is available for repairs when conditions warrant it.	1. $50,000 2. Estimate is being obtained. 3. $250,000 per inspection (basic walk through). 4. Process for approval would come from Metro Maintenance and CO Bridge Office Directors. Metro WRE MS4 staff would work with Metro Bridge Maintenance and CO Bridge to transfer info to forms. May need consultant assistance. 5. TH Bond funds $12 M.	1. Staff from MnDOT (likely Metro Bridge Maintenance) trained on inspections to complete them on select tunnel segments after major rain events. 2. MnDOT hires a consultant to complete inspections on each tunnel, as identified by mandated inspection guidelines. 3. Begin repairs incrementally and withhold funding to cities on other projects if proposed repair schedules are not met.	1. Training cost and inspection time required. 2. Political acceptance? Roughly $3.5 M per segment.	C: Catastrophic L: Possible	C: Catastrophic L: Possible Improved Credability	C. Catastrophic L. Rare

Work Group Assignment #2: Identification of Other Traffic Structures Undermanaged Risk Mitigation Strategies and Costs

Undermanaged Opportunity	Current Control/Mitigation Strategy(ies)	Previously Identified Mitigation Strategy(ies)	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7		
			Preferred Mitigation Strategy(ies)	Data, Tools Resources and/or Training Required to Make Strategy Reality	Describe if Strategy Will Reduce Likelihood of Another Risk	Estimate Approximate Cost of Preferred Mitigation Strategy(ies)	Alternate Mitigation Strategy	Estimate Approximate Cost of Alternate Strategy	Estimate Likelihood & Consequence of Strategy		
									Original Risk Rating	Preferred Strategy Rating	Alternate Strategy Rating
Overhead Sign Structure & High-Mast Light Tower Structures											
If tower lights and overhead sign structures are not properly installed as part of a construction project, then they may deteriorate more rapidly, and will require more subsequent maintenance.	No	Better quality controls (e.g. MnDOT checks) of construction work outside of edge-of-pavement-to-edge-of-pavement; better checklist to include roadside infrastructure; routine/mandatory workshops at end of construction project	1. Change construction specifications to require torque threshold dye washers 2. Communicate punchlist and specifications with companies that install structures and with construction inspectors.	1. Additional staff time to write the specification and update detail plan sheets; change in element used during construction. 2. Additional staff time.	Reducing the risk of poor contract execution should extend the life of the structure and reduce maintenance costs (Risk 2), thus reducing life-cycle costs.	1. One-time fee of $1000 (40 hours of staff time). Increased annual cost of $20,000/year (if additional $1000/structure @ 20 structures/year to add dye washers). 2. Increased annual cost of $5000/year (4 hours inspection per structure and 20 structures/year is 80 hours of inspection; and 120 hours of additional communication)	MnDOT Maintenance will tighten the nuts on all new structures.	One-time fee of $40,000 to purchase an additional wrench. Increased annual cost of $2000 additional staff and equipment ($100/structure at 20 structures).	C: Minor L: Likely	C: Minor L: Rare	C: Minor L: Rare
If light tower and sign structure inspection data and deterioration models are not accurate or complete, then it may be difficult to determine the lowest life-cycle cost for these assets.	Bridge Office Structural Metals and Bridge Inspection Engineer notifies Electrical Services after pole is inspected as to what repairs are required for each pole.	Enterprise asset management system for better tracking asset status (e.g. inspection of asset is completed by maintenance which is part of Engineering Services and fixes are performed by Electrical Services which is part of Operations Division. There is not a direct and clear connection to notify maint. when fixes are performed.	1. Implement TAMS that includes a work order, resource, and materials cost tracking module. 2. Report annually on life-cycle cost and identify and implement refined/additional strategies to reduce costs.	1. Additional staff and/or consultant time to implement new software system. 2. Additional staff time to report annual performance.	Managing OSS/TL structures to lowest LCC cannot occur if Risk 1 is not mitigated.	1. One-time fee of $250,000 to add structures data into TAMS software (staff time). Increased annual maintenance and user costs of $100,000/year for software. 2. Increased annual cost of $2000/year (80 staff hours).	1. Maintain status quo with replacement cycle for OSS/TL, which is 40-50 years. 2. When OSS/TL due for replacement, remove and replace with 6-8 standard lights or ground mount overhead. 3. Conduct research that will better define/determine deterioration rates and collect other addtional info.	Overhead structure life cycles could be doubled; thereby reducing costs. Amount unknown.	C: Minor L: Likely	C: Minor L: Rare	C: Minor L: Likely
If MnDOT is unable to provide a sufficient number of workers to maintain high-mast light tower structures or overhead sign structures, then inspections, maintenance, repairs and replacement may fall short of service standards.		Determine risk to public if MnDOT staff is decreased; cross training of staff (redundancy in knowledge)	1. Adopt a MnDOT policy/technical memo requiring a 5-year inspection frequency for all overhead structures. 2. Report annually on inspection frequency results. 3. Create a training program for inspecting and maintaining structures, develop inspection forms, develop clear condition rating criteria. 4. Gain efficiencies by using mobile technology in the field	1-3. Additional staff time. 4. Additional equipment expense.	Adopting a policy/technical memo of inspecting and reporting will help mitigate Risk 1.	1. One-time cost of $1000 (40 hours staff time) to write policy. 2. Increased annual cost of $1000 (40 hours/year staff time) to report on performance. 3. One-time cost of $8000 (320 staff hours). Increased annual cost of $2000/year (80 hours/year staff time) to train. 4. Increased annual cost of $10,000/year to use mobile handheld devices.	1. Use consultants to perform work. 2. Increase inspection intervals (Strategies can be either/or/both)	An average of $800/structure was previously paid for external inspection. Internal inspections cost roughly $100/structure.	C: Minor L: Possible	C: Minor L: Rare	C:Minor L: Rare

Chapter 6

LIFE-CYCLE COST CONSIDERATIONS: SUPPLEMENTAL INFORMATION

LIFE-CYCLE COST CONSIDERATIONS: SUPPLEMENTAL INFORMATION

Overview

This chapter provides a detailed description of the various processes involved in analyzing the life-cycle costs associated with the asset classes discussed in the TAMP. Two aspects of life-cycling costing are documented: 1) the data used to conduct the analysis and the process for gathering the information, and 2) the metrics and assumptions used in the analysis. In addition to the documentation of the tools used to model life-cycle strategies, examples (attachments) are provided at the end of the chapter.

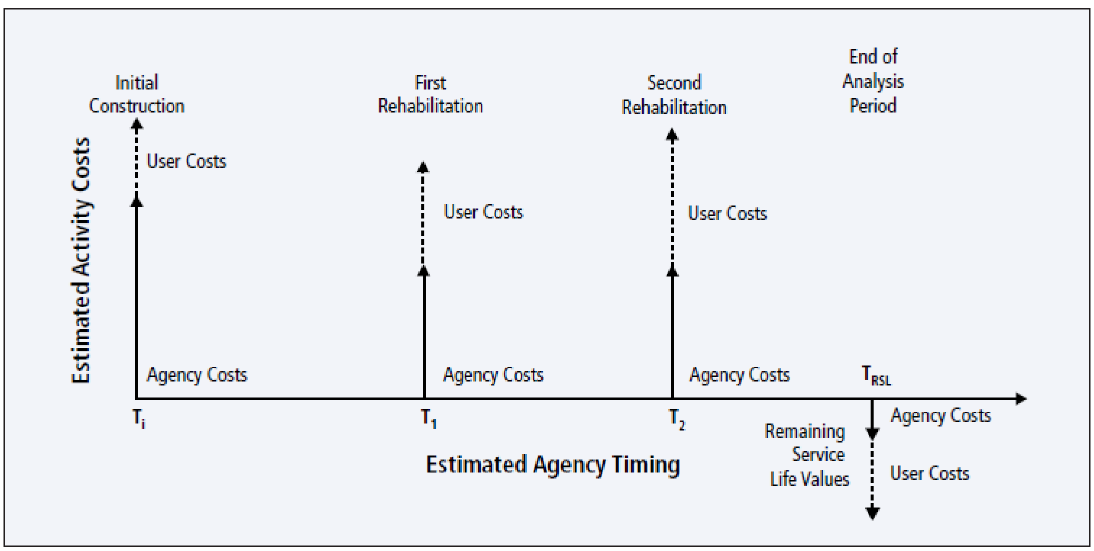
Process

The inputs for conducting a Life-Cycle Cost Analysis (LCCA) are presented first, followed by the key metrics/terms associated with an LCCA. The LCCA procedures used in developing the TAMP are then documented.

LCCA FUNDAMENTALS AND ANALYSIS COMPONENTS

The basic LCCA process requires the analyst to first define the schedule for initial and future activities associated with a specific strategy for managing an asset. Next, the costs associated with each of these activities are defined. The typical activity schedule and associated costs are used to develop a life-cycle cost stream (an example is shown in figure 6-1). Life-cycle cost stream diagrams are typically used in project-level LCCA, however, the same fundamental principles also apply to a network-level LCCA. Instead of programming treatment cycles and costs associated with a specific project, expert opinion provided by the asset Work Groups was used to estimate the same metrics at the network level (which were then scaled down to a unit level – e.g. costs per bridge or per lane-mile of pavement – to allow for comparison of life-cycle costs between various asset categories included in the TAMP).

Figure 6-1: Projected Life-Cycle Cost Stream Diagram[1]



Project-level LCCA typically includes both agency costs (direct costs to the agency as a result of the construction operations) and user costs (costs not directly borne by the agency but that affect the agency's customers, such as traffic delays during construction or maintenance activities, and can impact customer perceptions of agency performance). However, since a network-level LCCA was conducted as a part of the TAMP, user costs were not considered due to the significant variability and uncertainty that exists from project to project.

Key inputs required for conducting a network-level LCCA include:

- Asset Condition Deterioration Rates: The rate at which the condition of the asset deteriorates over time with and without the application of routine, reactive, and preventive maintenance treatments.
- Treatment Types, Costs, and Cycles: The various types of treatments applied to an asset over its life-cycle, including the type of the treatment (whether it is a routine maintenance, reactive maintenance, preventive maintenance, or major rehabilitation/replacement/reconstruction activity); the condition level (e.g. Good, Fair, or Poor) when the treatment is applied; and the resulting condition level after the application of the treatment; typical treatment costs; and treatment cycles.

This information was gathered through an assignment (discussed later) that was distributed to each of the asset Work Groups.

KEY METRICS/TERMS ASSOCIATED WITH LCCA

The key terms/metrics associated with the LCCA conducted in the TAMP are:

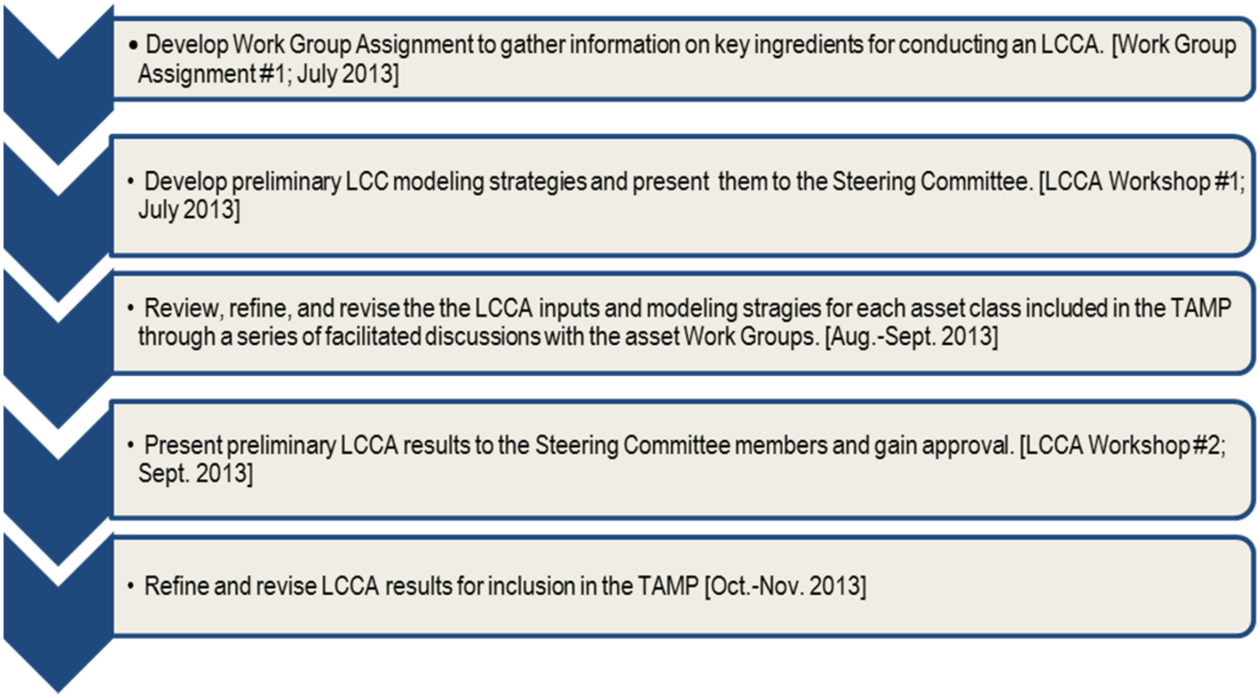
- Analysis Period: The timeframe over which the LCCA is performed. Theoretically, once a section of state highway is built, the agency is responsible for all future costs to keep that road in service, including the costs to reconstruct components of the road when they reach the end of their physical lives. However, because of discounting, costs in the far future have very little effect on any decisions made during the 10-year period covered by the TAMP. Forecasts of future deterioration and future needs become very unreliable if these predictions are extended too far into the future. In best practice, the analysis period of a life-cycle cost analysis should be as short as possible while still satisfying the following criteria:
    - Long enough that further costs make no significant difference in the results.
    - Long enough that at least the first complete asset replacement cycle is included.

  The reason for the second criterion is that replacement costs are typically much larger than any other costs during an asset's life, so these costs can remain significant even if discounted over a relatively long period. A fair comparison of alternatives should therefore include at least the first replacement cycle for each of the alternatives being compared.
- Discount Rate: Future costs converted into present day dollars using an economic technique known as "discounting". MnDOT's policy is to analyze all investments using a *real annual discount rate*, which is currently 2.2 percent. The term "real" means that the effects of inflation are removed from the computation in order to make the cost tradeoffs easier to understand.
- Life-Cycle Cost (in today's dollars): The total cost of asset ownership over the analysis period when the costs incurred in future years are converted to current dollars.
- Future Maintenance Costs as a Percent of Initial Investment: The total future agency costs (including maintenance, rehabilitation, and inspection, but not operations costs) as a fraction of the initial construction cost of the asset. This value represents the future cost commitment that MnDOT makes for every dollar spent on a capital project.
- Equivalent Uniform Annual Cost: The analysis method that shows the annual costs of a life-cycle management strategy if they occurred uniformly throughout the analysis period.

LIFE-CYCLE COST ANALYSIS PROCEDURE USED IN THE TAMP

The step-by-step approach used in analyzing life-cycle costs for the TAMP is illustrated in Figure 6-2.

Figure 6-2: TAMP Life-Cycle Analysis Process



WORK GROUP ASSIGNMENT #1: COMPILE DATA ON KEY INPUTS FOR LCCA (JULY 2013)

As discussed above, an assignment was distributed to each asset Work Group to compile the key inputs required to conduct a network-level LCCA. The inputs included asset condition deterioration rates, treatment types, treatment costs, and treatment cycles. The assignment was completed by each Work Group and a copy of the results is provided at the end of this chapter. The Work Group assignment was followed by a workshop (discussed in the next section) to discuss the modeling strategies and gain input, feedback, and buy-in from the TAMP Steering Committee.

LCCA WORKSHOP #1: FINALIZE LCCA METHODOLOGY FOR TAMP (JULY 2013)

This workshop built upon the data gathered during the Work Group assignment (discussed above) to finalize the deterioration rates, unit costs, and treatment strategies for each asset. Topics covered during this workshop included:

- The level of detail required to complete the assignment.
- The development of asset deterioration rates.
- Actual versus desired maintenance strategies.
- Definitions of various condition categories and performance metrics (where none existed).
- Process changes to better incorporate whole life costing into investment decisions, which involved:
    - Identifying appropriate planned maintenance regimes to ensure assets met design lives in a cost-effective manner.
    - Capturing information in computerized systems to assist in the analysis of current and future planning activities.

The major decision made during this workshop was that representative examples would be used to characterize the life-cycle strategies for each asset included in the TAMP. However, the representative examples would be based on detailed life-cycle cost calculations computed using actual MnDOT data. It was decided that the life-cycle portion of the TAMP would serve to:

- Describe life-cycle costs and explain why they are important.
- Explain typical MnDOT infrastructure life-cycle costs using examples of deterioration rates and preservation cycles.
- Describe strategies for managing assets over their whole lives, from inception to disposal, illustrating the use of a sequence of activities, including maintenance and preservation treatments. Illustrate how these actions are helpful in delaying or slowing deterioration and maximizing the service life of an asset.
- Document the tools that MnDOT has available to help forecast life-cycle costs for some assets.
- Document typical life-cycle cost of the assets included in the TAMP.
- Explain the commitment and steps MnDOT is taking to improve its effectiveness in minimizing life-cycle costs.
- Document the typical life-cycle cost of adding a new lane-mile of roadway and document a process for considering future maintenance costs when evaluating potential roadway expansion projects.

Following this workshop, several facilitated teleconferences were held with the Work Groups to review, refine, and revise the LCCA inputs and modeling strategies used in the TAMP and to develop preliminary asset life-cycle costs.

LCCA WORKSHOP #2: PRESENT PRELIMINARY LCCA RESULTS AND GAIN FEEDBACK FROM STEERING COMMITTEE (SEPTEMBER 2013)

The preliminary life-cycle costs developed for each asset were presented at this meeting to gain critical feedback from the TAMP Steering Committee and identify additional required information or analysis. The Steering Committee provided valuable suggestions for how the life-cycle costing strategies could be presented in the TAMP. The input and feedback from this meeting was used to finalize the LCCA results for the TAMP.

Supporting Data and Documentation

This section presents the LCCA assumptions and tools used to conduct the network-level LCCA.

LCCA INPUTS AND ASSUMPTIONS

As discussed in the TAMP, three LCCA modeling strategies were used to represent "Typical", "Worst-First", and "Desired" treatment strategies. The "Typical" strategy reflects MnDOT's current practices for managing the assets and the "Worst-First" strategy assumes that no treatments are applied until the complete replacement of the asset when it deteriorates to a Poor condition. The "Desired" strategy (established only for pavements due to a lack of sufficient data for bridges, hydraulic infrastructure, overhead sign structures, and high-mast light tower structures) corresponds to the strategy that MnDOT aspires to adopt in order to further reduce total life-cycle costs.

PAVEMENTS

The key inputs and assumptions specific to pavements are summarized below:

- Analysis Period: 70 years; Discount Rate: 2.2 percent
- All costs presented in dollars per lane-mile
- Only direct agency costs considered in the LCCA model; inspection costs and other operational costs like debris removal, snow and ice removal, etc. not included.

- Flexible pavements and rigid pavement LCCA modeled separately and overall life-cycle costs combined into a single composite value based on weighted averages of percent of rigid and flexible pavements in MnDOT's roadway network (11 percent rigid pavements, 89 percent flexible pavements)
- Routine and reactive maintenance costs included in the LCCA model based on the following:
  - MnDOT spent approximately $1.4 Million in 2012 (in the Minneapolis-St. Paul Metro Region). This value was used to extrapolate costs for the pavement network considered in the LCCA.
  - Investments made by pavement condition category could not be determined; therefore, weighting factors were applied to maintenance costs (for each of the three pavement condition categories: Good, Fair, Poor) based on expert input from the Work Groups. The final weighting factors (Good: 0.8; Fair: 1.2; Poor: 1.8) resulted in the following maintenance costs per condition category: Good: $2,340 per lane-mile; Fair: $3,480 per lane-mile; Poor: $5,229 per lane-mile.

The assumptions specific to the "Worst-First" strategy for pavements are summarized below:

- Flexible Pavements: the end-of-life activity is expected to occur between 15 and 25 years, with a "most likely" age of 25 years when no preventive maintenance is performed. The end-of-life activity is expected to cost anywhere between $210,000 per lane-mile for a full-depth reclamation (FDR) activity to $2 million per lane-mile for complete reconstruction, with the typical cost being $210,000 per lane-mile.
- Rigid Pavements: the end-of-life activity is expected to occur between 25 and 35 years, with a "most likely" age of 30 years when no preventive maintenance is performed. The end-of-life activity is expected to cost anywhere between $450,000 per lane-mile for an unbonded overlay to $2 million per lane-mile for complete reconstruction, with the typical cost being $450,000 per lane-mile.

Figure 6-3 summarizes the "Typical" strategy used to manage flexible pavements and Figure 6-4 summarizes the "Desired" strategy for managing flexible pavements. Figure 6-5 summarizes the life-cycle management strategy for rigid pavements (the "Typical" and "Desired" strategies are the sam for rigid pavements).

Figure 6-3: "Typical" Life-Cycle Management Strategy for Flexible Pavements (Mill and Overlay Strategy)

Typical Pavement Age* (yrs)	Pavement Age Range** (yrs)	Treatment	Typical Condition When Applied	Typical Cost ($/ln-mi)***	Cost Range ($/ln-mi)***
0	0	Initial Construction	-	$657,500#	$210,000 - $2,000,000
8	6-10	Crack Treatment	Good	$6,000	$3,000 - $10,000
12	10-14	Surface Treatment	Good	$15,000	$10,000 - $30,000
20	18-22	Mill & Overlay (1st Overlay)	Fair	$155,000*	$145,000 - $175,000
24	21-25	Crack Treatment	Good	$6,000	$3,000 - $10,000
26	25-29	Surface Treatment	Fair	$15,000	$10,000 - $30,000
35	33-35	Mill & Overlay (2nd Overlay)	Fair	$155,000	$145,000 - $175,000
39	36-40	Crack Treatment	Good	$6,000	$3,000 - $10,000
41	39-43	Surface Treatment	Fair	$15,000	$10,000 - $30,000
47	45-49	Mill & Overlay (3rd Overlay)	Poor	$155,000	$145,000 - $175,000
51	49-53	Crack Treatment	Good	$6,000	$3,000 - $10,000
53	51-55	Surface Treatment	Fair	$15,000	$10,000 - $30,000
57	55-59	Mill & Overlay (4th Overlay)	Poor	$155,000	$145,000 - $175,000
61	59-63	Crack Treatment	Good	$6,000	$3,000 - $10,000
63	61-65	Surface Treatment	Fair	$15,000	$10,000 - $30,000
65	63-67	Mill & Overlay (5th Overlay)	Poor	$155,000	$145,000 - $175,000
68	66-70	Crack Treatment	Good	$6,000	$3,000 - $10,000
70	68-72	Reconstruction	Fair	$657,500#	$210,000 - $2,000,000

Notes:
* Based on Values from MnDOT Pavement Design Manual Chapter 7 and input provided by MnDOT TAMP Pavement Work Group
** Range assumed based on general input from MnDOT TAMP Pavement Work Group
***Cost data provided by MnDOT TAMP Pavement Work Group, some assumptions to develop cost ranges based on data provided
#Value based on assumption that typically, 75% of the projects involve FDR and 25% involve complete reconstruction

Figure 6-4: "Desired" Life-Cycle Management Strategy for Flexible Pavements (FDR strategy)

Typical Pavement Age* (yrs)	Pavement Age Range** (yrs)	Treatment	Typical Condition When Applied	Typical Cost ($/ln-mi)***	Cost Range ($/ln-mi)***
0	0	Initial Construction	-	$657,500[#]	$210,000 - $2,000,000
8	6-10	Crack Treatment	Good	$6,000	$3,000 - $10,000
12	10-14	Surface Treatment	Good	$15,000	$10,000 - $30,000
20	18-22	Mill & Overlay (1st Overlay)	Fair	$155,000	$145,000 - $175,000
23	21-25	Crack Treatment	Good	$6,000	$3,000 - $10,000
27	25-29	Surface Treatment	Fair	$15,000	$10,000 - $30,000
35	33-35	Mill & Overlay (2nd Overlay)	Fair	$155,000	$145,000 - $175,000
38	36-40	Crack Treatment	Good	$6,000	$3,000 - $10,000
43	41-45	Surface Treatment	Fair	$15,000	$10,000 - $30,000
50	47-53	FDR/Reconstruction	-	$657,500[#]	$210,000 - $2,000,000
58	56-60	Crack Treatment	Good	$6,000	$3,000 - $10,000
62	60-64	Surface Treatment	Good	$15,000	$10,000 - $30,000
70	68-72	Mill & Overlay (1st Overlay after FDR/Reconstruction)	Fair	$155,000	$145,000 - $175,000

Notes:
* Based on Values from MnDOT Pavement Design Manual Chapter 7 and input provided by MnDOT TAMP Pavement Work Group
** Range assumed based on general input from MnDOT TAMP Pavement Work Group
***Cost data provided by MnDOT TAMP Pavement Work Group, some assumptions to develop cost ranges based on data provided
[#]Value based on assumption that typically, 75% of the projects involve FDR and 25% involve complete reconstruction

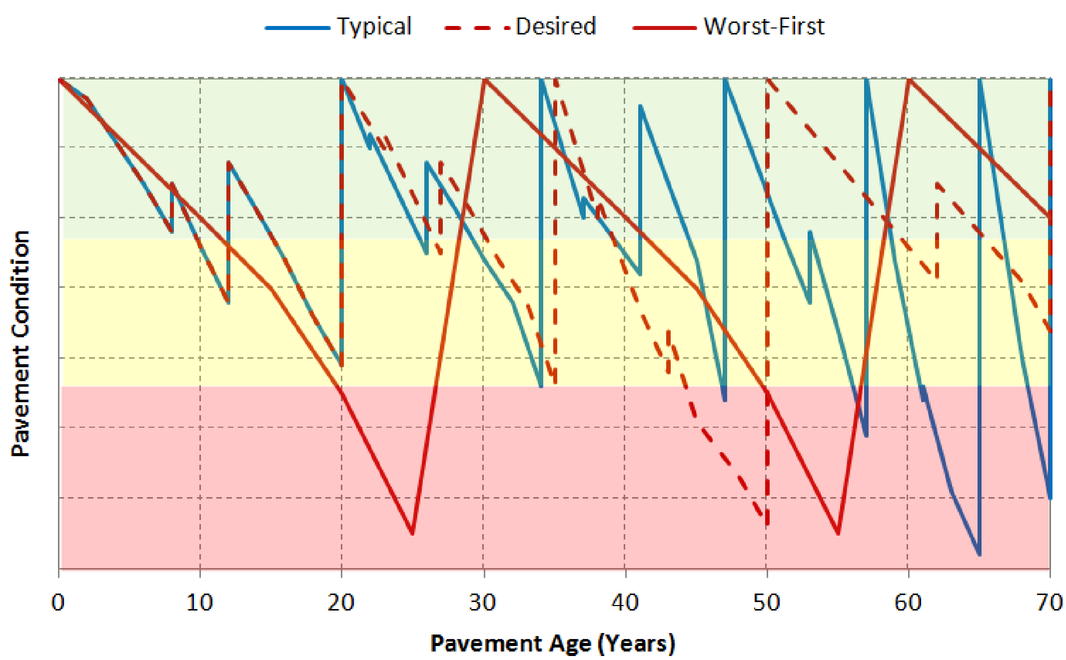
Figure 6-5: Life-Cycle Management Strategy for Rigid Pavements

Typical Pavement Age* (yrs)	Pavement Age Range** (yrs)	Treatment	Typical Condition When Applied	Typical Cost ($/ln-mi)***	Cost Range ($/ln-mi)***
0	0	Initial Construction	-	$450,000	$450,000 - $2,000,000
10	6 - 20	Reseal joints and partial depth repairs	Good	$10,000	$5000 - $15,000
16	13 - 31	Minor CPR (some full depth repairs)	Fair	$80,000	$55,000 - $80,000
26	8 - 26	Major CPR (and grinding)	Fair	$230,000	$135,000 - $230,000
50	46-54	Unbonded Overlay/Reconstruction	Poor	$450,000	$450,000 - $2,000,000
60	56 - 70	Reseal joints and partial depth repairs	Good	$10,000	$5000 - $15,000
66	63-81	Minor CPR (some full depth repairs)	Fair	$80,000	$55,000 - $80,000

Notes:
The Pavement Work Group indicated that the desired and typical life-cycle strategies are fairly close for rigid pavements and recommended using the same values for both
* Based on Values from MnDOT Pavement Design Manual Chapter 7 and input provided by MnDOT TAMP Pavement Work Group
** Range assumed based on general input from MnDOT TAMP Pavement Work Group
***Cost data provided by MnDOT TAMP Pavement Work Group, some assumptions to develop cost ranges based on data provided

An illustration of the deterioration models representing pavement performance over the 70-year analysis period for the three strategies considered is provided in Figure 6-6.

Figure 6-6: Deterioration Models for Various LCCA Scenarios (Pavements)



BRIDGE STRUCTURES (BRIDGES AND LARGE CULVERTS)

The key inputs and assumptions specific to bridge structures are summarized below:

- Analysis Period: 200 years; Discount Rate: 2.2 percent
- Markov models used to model condition deterioration based on expert input from the Bridge Work Group
- All costs presented in dollars per bridge and dollars per square foot (deck area)
- Routine maintenance activities applied to all bridges in appropriate condition, on a scheduled basis to slow the rate of deterioration
- Corrective action is used to repair defects and prevent further deterioration. Activities that fall under this category are considered to be infeasible when the structure is in Poor condition.
- Rehabilitation and replacement activities are performed when the service life of all or part of the structure cannot be extended. This activity is generally performed when the structure is in Poor condition.

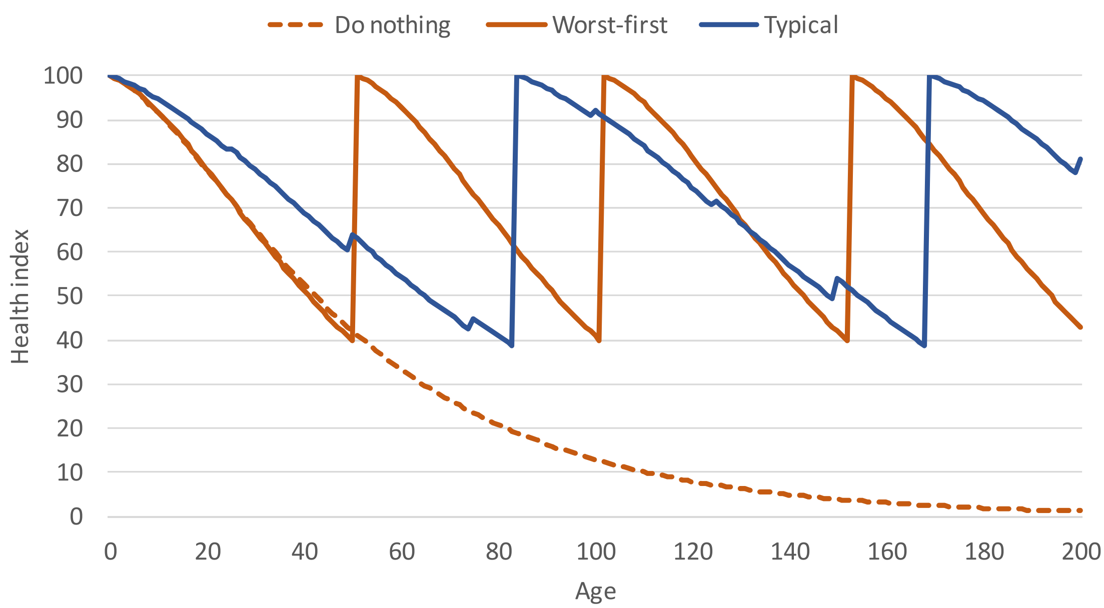
The costs and treatment strategies used in the LCCA model for bridge structures are summarized in Figure 6-7.

Figure 6-7: Costs and Treatment Strategies Used in the LCCA Model for Bridge Structures

Treatment	$/Bridge	% Bridges Acted Upon Annually			
		Good	Satisfactory	Fair	Poor
Routine Maintenance: Bridge Decks					
Joint sealing	$1,529	13%	13%	13%	
Deck sealing	$37,406	14%	14%	14%	
Crack Sealing	$1,500	20%	20%	20%	
Routine Maintenance: Bridge Superstructures					
Inspection	$1,111	60%	60%	60%	60%
Flushing	$500	75%	75%	75%	75%
Lube Bearings	$26,600	0.1%	0.2%		
Routine Maintenance: Bridge Culverts					
Inspection	$1,111	60%	60%	60%	60%
Corrective Action: Bridge Decks					
Joint repair (patch)	$38,215		1%	2%	
Deck repair	$16,833		2%	35%	15%
Overlay	$130,921			5%	2%
Rail repair/replace	$127,705		1%	5%	
Corrective Action: Bridge Substructures					
Patching	$56,070			10%	15%
Slope paving repair	$26,166		1%	1%	
Erosion/Scour Repair	$25,000			5%	5%
Corrective Action: Bridge Superstructures					
Spot Painting	$19,500		2%	5%	
Full Painting	$377,480		3%	5%	
Patching	$30,000		1%	3%	5%
Repair/Replace bearings	$46,549				5%
Repair Steel	$50,000			2%	5%
Corrective Action: Bridge Culverts					
Patching	$12,104			5%	10%
Rehab and Replacement: Bridge Decks					
Redeck	$1,122,184				5%
Rehab and Replacement: Bridge Substructures					
Replace Elements	$100,000				1%
Rehab and Replacement: Bridge Superstructures					
Replace Elements	$100,000				1%
Replace Structure	$2,702,941				20%
Rehab and Replacement: Bridge Culverts					
Replacement	$250,000				25%

An illustration of the deterioration models describing the performance of bridge structures over the 200-year analysis period is provided in Figure 6-8.

Figure 6-8: Deterioration Models for Various LCCA Scenarios (Bridge Structures)



CENTERLINE CULVERTS AND STORMWATER TUNNELS

The key inputs and assumptions specific to centerline culverts and stormwater tunnels are summarized below:

- Analysis Period: 200 years; Discount Rate: 2.2 percent
- Markov models used to model condition deterioration based on expert input from the Hydraulics Work Group
- All costs presented in dollars per structure
- Routine maintenance activities applied to all structures in appropriate condition, on a scheduled basis to slow the rate of deterioration
- Corrective action is used to repair defects and prevent further deterioration. Activities that fall under this category are infeasible when the structure is in Poor condition.
- Rehabilitation and replacement activities are performed when the service life of all or part of the structure cannot be extended. This activity is generally performed when the structure is in Poor condition.

The costs used in the LCCA model for centerline culverts and stormwater tunnels are summarized in Figure 6-9.

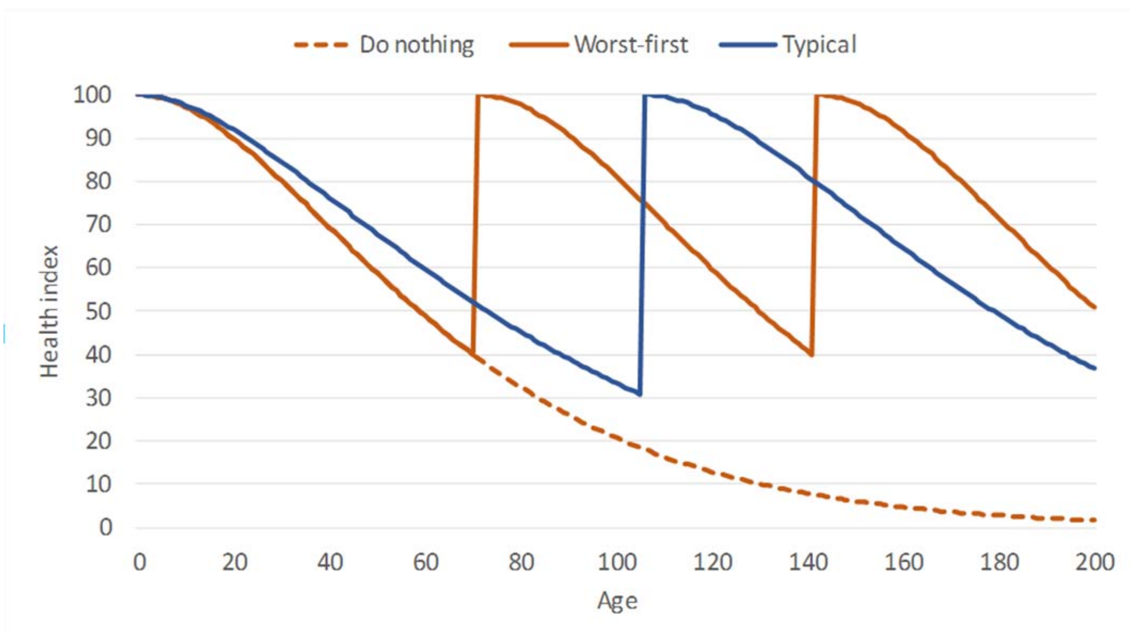
Figure 6-9: Life-Cycle Management Strategy for Centerline Culverts and Stormwater Tunnels

Treatment	$/Bridge	% Bridges Acted Upon Annually			
		Good	Satisfactory	Fair	Poor
Routine Maintenance: Centerline Culverts					
Inspection	$62	25%	25%	25%	25%
Cleaning	$100	10%	10%	10%	10%
Routine Maintenance: Stormwater Tunnels					
Inspection	$200,000	25%	25%	25%	25%
Corrective Action: Centerline Culverts					
Reset ends	$2,695		1%	2%	1%
Joint repair	$1,429		1%	1%	1%
Pave invert	$804			2%	1%
Corrective Action: Stormwater Tunnels					
Fill Voids and Cracks	$3.5 M				
Rehab and Replacement: Centerline Culverts					
Slipliner	$8,664				1%
CIPP	$6,418				2%
Replace - Trench	$32,235			1%	5%
Replace - Jack	$35,888			1%	2%
Rehab and Replacement: Stormwater Tunnels					
Replacement	$5,099,500				1%

Illustrations of the deterioration models describing the performance of centerline culverts and stormwater tunnels over the 200-year analysis period are provided in Figures 6-10 and 6-11, respectively.

Figure 6-10: Deterioration Models for Various LCCA Scenarios (Centerline Culverts)

Figure 6-11: Deterioration Models for Various LCCA Scenarios (Stormwater Tunnels)



OVERHEAD SIGN STRUCTURES (OSS) AND HIGH-MAST LIGHT TOWER STRUCTURES (HMLTS)

The key inputs and assumptions specific to overhead sign structures and high-mast light tower structures are summarized below:

- Analysis Period: 100 years; Discount Rate: 2.2 percent
- All costs presented in dollars per structure

- Inspection costs are included in the LCCA model because they are considered an important maintenance activity. Other costs, such as traffic control and mobilization, were not explicitly considered.
    - Average inspection costs for OSS: $950/structure (applied on a 4 year cycle)
    - Average inspection costs for HMLTS: $1000/structure (applied on a 5 year cycle)

The "Worst-First" strategy for OSS and HMLTS involved the replacement of the structure on a 40-year cycle with routine inspections and minimal maintenance activities. The typical life-cycle management strategies used in the LCCA model for OSS and HMLTS are summarized in Figures 6-12 and 6-13, respectively.

Figure 6-12: "Typical" Life-Cycle Management Strategy for OSS

Typical Age (yrs)	Age Range (yrs)	Treatment	Treatment Cycle (yrs)	Typical Condition When Applied	Typical Cost ($/structure)	Cost Range ($/structure)
0	0	Initial Cost of Structure	100	Poor	$85,000	$60,000 - $110,000
4	3 - 5	Tighten Nuts	8	Poor	$200	$200 - $400
8	6 - 8	Remove Grout	8	Poor	$1,000	$800 - $1,200
20	15 - 25	Re-grade footing, replace weld, remove catwalks/lighting, new mounting posts	20	Poor	$3,000	$1700 - $6000
40	35 - 45	Replace foundation or replace truss or other elements	40	Poor	$25,000	$8,000 - $30,000
100	N/A	End of Analysis Period	N/A	N/A	N/A	N/A

Figure 6-13: "Typical" Life-Cycle Management Strategy for HMLTS

Typical Age (yrs)	Age Range (yrs)	Treatment	Treatment Cycle (yrs)	Typical Condition When Applied	Typical Cost ($/structure)	Cost Range ($/structure)
0	0	Initial Cost of Structure	100	-	$40,000	$30,000 - $60,000
5	3 - 7	Routine Maintenance	5	Fair	$500	$200 - $1000
100	N/A	End of Analysis Period	N/A	N/A	N/A	N/A

LCCA TOOLS USED

The Federal Highway Administration's RealCost tool[1] was used to conduct the network-level life-cycle cost analyses for pavements, OSS, and HMLTS. The bridge structures and hydraulic infrastructure models were developed specifically for this study. Examples of several of these models are included at the end of the chapter.

[1] FHWA RealCost Tool. (Web Link)

LIFE-CYCLE COST CONSIDERATION WORKSHOP
WORK GROUP ASSIGNMENT #1 (RESULTS)

LIFE-CYCLE COST CONSIDERATION WORKSHEET - PAVEMENTS

Pavement Subset (ex: NHS): All State Trunk Highways (NHS and Non-NHS, IS, US, MN)

Deterioration Rates

On average, what is the shortest length of time (in years) before these pavements are at a condition when they should be reconstructed (assuming no other capital improvements are conducted)? 15 years

On average, what is the longest length of time (in years) before these pavements are at a condition when they should be reconstructed (assuming no other capital improvements are conducted)? 40 years

On average, what would you estimate to be the most typical length of time for the asset to reach a condition when it should be reconstructed (assuming no other capital improvements are conducted)? 25 years

Does the point at which pavements needed to be reconstructed equate to your Poor condition category? (Yes or No) If No, please comment Yes

Inspection Costs

What is the estimated average annual cost to collect and process pavement condition data so it can be used for reporting performance?

Average annual collection/processing costs: $37 per roadway mile

Treatment Costs

Five categories of repair are listed in tables P-1 and P-2, for flexible and rigid pavements respectively. Composite pavements should be considered to be rigid pavements that have received a treatment. For each of the repair categories, identify representative treatments that fit within that category, the typical condition range when these treatments are applied (e.g., Good, Fair, or Poor), and the condition after the treatment has been constructed. Also provide the typical price range for the treatments in that category and a cost that your Work Group considers to be the most representative cost within the price range. Be sure to indicate the units used for your costs.

Table P-1. Typical treatments and costs for flexible pavements.

Treatment Category	Representative Treatments	Typical Condition Level When Applied (e.g., G/F/P)	Most Likely Condition After Treatment	Typical Cost Range ($/lane-mile)	Most Representative Cost ($/lane-mile)
Preventive Maintenance	Chip Seal Crack Seal Micro-surface	Good	Good	$3K-$30K	$15K (Chip Seal)
Minor Rehabilitation	Thin Mill/OL Rut Fill	Fair	Good	$55K-$75K	$75K (Thin M/O)
Major Rehabilitation	Medium Mill/OL Thick Mill/OL CIR	Fair/Poor	Good	$145-$175K	$155K (Med M/O)
Reconstruction	Reconstruction Reclaim	Poor	Good	$210K-$2M	$210K (Reclaim)

Table P-2. Typical treatments and costs for rigid pavements.

Treatment Category	Representative Treatments	Typical Condition Level When Applied (e.g., G/F/P)	Most Likely Condition After Treatment	Typical Cost Range ($/lane-mile)	Most Representative Cost ($/lane-mile)
Preventive Maintenance	Joint Seal Diamond Grind	Good/Fair	Good	$20K-$30K	$30K (Grind)
Minor Rehabilitation	Minor CPR Minor CPR/Grind	Fair	Good	$55K-$80K	$80K (Minor CPR/Grind)
Major Rehabilitation	Major CPR/Grind Thick OL	Fair/Poor	Good	$125K-$230K	$230K (Major CPR/Grind)
Reconstruction	Reconstruction Unbonded OL	Poor	Good	$450K-$2M	$450K (Unbonded)

Treatment Cycles

Tables P-3 and P-4 are provided for you to enter the treatment cycles for both flexible and rigid pavements within this category of pavements. For each type of pavement, enter the following information:

- Column A: The type of activity that is applied. You can enter a category of treatments or a specific treatment.
- Columns B and C: The range of years in which the treatment is first applied. In column B identify the range of years in which the first application of this treatment is typically applied in your agency. In column C enter the range of years in which you think the treatment should be applied if funding were not an issue.

- Columns D and E: The year in which the treatment is most commonly applied. Instead of entering a range, identify the single age at which the treatment is typically applied for the first time in column D (this may be the mean or median in a set of values). In column E enter the age at which you think the treatment should be applied for the first time.
- Columns F and G: The typical application cycle for that treatment. In column F enter the typical frequency with which the treatment is applied by your agency. In column G enter the preferred treatment cycle. Once you have entered a treatment cycle, you do NOT need to enter the treatment in the table again. For instance, in the example, crack sealing is typically applied first applied in year 8 and then in year 13, since it is applied on a 5-year cycle.

Table P-3. Flexible pavement treatment cycle.

Column A Activity	Range of Years During Which the Treatment is First Applied		Year in Which the Treatment is Most Commonly Applied		Application Cycle (in years)	
	Column B Typical	*Column C* Desired	*Column D* Typical	*Column E* Desired	*Column F* Typical	*Column G* Desired
Initial Construction			0	0		
Crack Seal	3 - 5		8	8		
Chip Seal	4 - 8		12	12		
Medium Mill/OL	10 - 20		20	20		
Crack Seal			23	23		
Chip Seal			27	27		
Medium Mill/OL			35	35		
Add more rows if necessary						
End of Life Reconstruction			50	∞		

Table P-4. Rigid pavement treatment cycle.

Activity	Typical Range of Years During Which the Treatment is Applied		Most Typical Year in Which the Treatment is Applied		Application Cycle (in years)	
	Typical	Desired	Typical	Desired	Typical	Desired
Initial Construction			0	0		
Reseal joints & partial depth repairs	6 - 20		17	17		
Minor CPR and some full depth repairs	13 - 31		27	27		
Major CPR/grind	8 - 26		40	40		
Add more rows if necessary						
End of Life Reconstruction			50	∞		

LIFE-CYCLE COST CONSIDERATION WORKSHEET - BRIDGES

Bridge Subset (ex: State, NHS, Non-NHS): All Decked Bridges for Deterioration; NHS for Maintenance Info

To simplify the lifecycle cost analysis, assume the following condition categories from the NBI ratings:

- Good condition: NBI rating 7 to 9.
- Satisfactory condition: NBI rating 6.
- Fair condition: NBI rating 5.
- Poor condition: NBI rating 4 or less.

Deterioration Rates

Bridge Decks

- Suppose 100 bridge decks on this subset are currently in Good (7 or greater) condition. After how many years will 50 of them have deteriorated to Satisfactory (6) or worse condition, if no preservation action has been taken? 20-25 years
- Suppose 100 bridge decks on this subset are currently in Satisfactory (6) condition. After how many years will 50 of them have deteriorated to Fair (5) or worse condition, if no preservation action has been taken? 5-10 years (25-35 years total)
- Suppose 100 bridge decks on this subset are currently in Fair (5) condition. After how many years will 50 of them have deteriorated to Poor (4 or less) or worse condition, if no preservation action has been taken? 5-10 years (35-45 years total)
- Suppose 100 bridge decks on this subset are currently in Poor condition. After how many years will 50 of them have deteriorated to Failed condition, if no preservation action has been taken? _____N/A__________________
  - Ranges due to ADT (>10K, 4-10K, <4K) and different bridge types
  - Includes bridges with decks; does not include culverts

Bridge Superstructures

- Suppose 100 bridge superstructures on this subset are currently in Good (7 or greater) condition. After how many years will 50 of them have deteriorated to Satisfactory (6) or worse condition, if no preservation action has been taken? 40-50 years
- Suppose 100 bridge superstructures on this subset are currently in Satisfactory (6) condition. After how many years will 50 of them have deteriorated to Fair (5) or worse condition, if no preservation action has been taken? 10-20 years (50-70 years)
- Suppose 100 bridge superstructures on this subset are currently in Fair (5) condition. After how many years will 50 of them have deteriorated to Poor (4 or less) or worse condition, if no preservation action has been taken? 10-30 years (60-100 years)
- Suppose 100 bridge superstructures on this subset are currently in Poor condition. After how many years will 50 of them have deteriorated to Failed condition, if no preservation action has been taken? ____N/A_________________
  - Assumptions: Ranges due to sampling from 1960's built to present day and different superstructure types

Bridge Substructures

- Suppose 100 bridge substructures on this subset are currently in Good (7 or greater) condition. After how many years will 50 of them have deteriorated to Satisfactory or worse condition, if no preservation action has been taken? 40-50 years
- Suppose 100 bridge substructures on this subset are currently in Satisfactory (6) condition. After how many years will 50 of them have deteriorated to Fair (5) or worse condition, if no preservation action has been taken? 10-20 years (50-70 years)
- Suppose 100 bridge substructures on this subset are currently in Fair (5) condition. After how many years will 50 of them have deteriorated to Poor (4 or less) or worse condition, if no preservation action has been taken? 10-30 years(60-100 years)
- Suppose 100 bridge substructures on this subset are currently in Poor condition. After how many years will 50 of them have deteriorated to Failed condition, if no preservation action has been taken? ________N/A_________________

Inspection Costs

What is the estimated average annual cost to collect and process bridge condition data so it can be used for reporting performance?

Average annual collection costs: $4.5 Million (includes culverts)

Average annual processing costs: $0.5 Million (includes culverts)

Treatment Costs

Five categories of repair are listed in tables B-1 through B-3, for bridge decks, superstructures, and substructures respectively. For each of the categories, identify representative treatments that fit within that category, the typical condition range when these treatments are applied (e.g., Good, Fair, or Poor), and the condition after the treatment has been constructed. Also provide the typical price range for the treatments in that category and a cost that your Work Group considers to be the most representative cost within the price range. Be sure to indicate the units used for your costs.

Table B-1. Typical treatments and costs for bridge decks.

Treatment Category	Representative Treatments	Typical Condition Level When Applied (e.g., Excellent, Good, Fair, or Poor)	Most Likely Condition After Treatment	Typical Cost Range	Most Representative Cost
Routine Maintenance (Subset of Preventive Maintenance)	Flushing Deck, Joints, Drains	All Bridges with Decks	Same but slows deterioration rate	$100 - $1500/ Bridge	$500/ Bridge (Flushing entire bridge)
	Crack Sealing	Fair (5) or greater; dependent on programming and element condition state	Fair (5) or greater but improved element condition state	$2.5 -$4/LF of Crack	$3/ LF of Crack
	Deck Sealing			$0.2 - $4/ SF of deck	Highly dependent on material used
	Joint Sealing			$3 - $5/ LF of joint	$4/ LF of joint
	Rail Sealing			$3-$4/ LF of rail	$3.50/ LF of rail
Preventive Maintenance	Poured Joint Repair	Fair (5) or greater; dependent on programming and element condition state	Fair (5) or greater but improved element condition state	$50 – $200/ LF of joint	$100/ LF of Joint
	Expansion Joint Repair (Gland)			$100 – $400/ LF of joint	$250/ LF of joint
	Replace Joint			$375-$750/ LF of joint	Depends on joint type
	Relief Joint Repair			$5 - $50/ LF of joint	Depends on Repair
Minor Rehabilitation (Reactive Maintenance)	Deck Repair	Fair to Poor	Satisfactory	$20 - $55/ SF of repair area	$30/ SF of repair area
	Underdeck-Remove loose concrete/ repair	Fair to Poor	Same	Infrequent Reactive Maint	Infrequent Reactive Maint
	Polymer Overlay	Good to Satisfactory	Same	$7/ SF of deck	$7/ SF of deck
	LS Overlay	Poor	Satisfactory to Fair	$6-$8/ SF of deck	$7/ SF of deck

	Rail Repair	Good to Fair; dependent on element condition state	Same; improves element condition state	$100 - $165/ LF of rail repair area	$150/ LF of rail repair area
	Approach Panels	Dependent on element condition state	Improves element condition state	$10 - $20/ SF of repair area	$15/ SF of repair area
	Underpin (Infrequent Reactive Maint)	Poor	Poor; preserve public safety	Infrequent Reactive Maint	Infrequent Reactive Maint
Major Rehabilitation	Replace Railing	Good to Fair; dependent on element condition state	Same; improves element condition state	$150 - $300/ LF of rail	$200/ LF of rail
	Redeck	Poor	Good	$50 -$70/ SF of deck	$60/SF of deck
Reconstruction (Entire Bridge)	Reconstruction	Poor	Good	Variable	$145/ SF

For each condition level, what percent of the time do you end up taking no action at all in a year and just allowing the bridge to deteriorate some more? *This analysis does not include routine maintenance, although routine maintenance, such as flushing, is performed annually to slow deterioration rates. Crack sealing is also performed to preserve the bridge deck and slow further deterioration.

- Good _100_%*
- Fair _70_%
- Poor _65_%

Table B-2. Typical treatments and costs for bridge superstructures.

Treatment Category	Representative Treatments	Typical Condition Level When Applied (e.g., Excellent, Good, Fair, or Poor)	Most Likely Condition After Treatment	Typical Cost Range	Most Representative Cost
Routine Maintenance (Subset of Preventive Maintenance)	Flushing Bearings, Beam Ends, Truss Members	All Bridges with Decks	Same but slows deterioration rate	$100 - $1500/ Bridge	$500/ Bridge (Flushing entire bridge)
	Clean and Lubricate Bearings	Good to Fair; dependent on element condition state	Good to Fair; improves element condition state	$800-$1100/ EACH Bearing	$1000/ EACH
Preventive Maintenance	Sealing/ Epoxy Injection	Good to Poor	Good to Fair	Infrequent Reactive Maint	Infrequent Reactive Maint
	Painting Beams	Good to Fair; dependent on element condition state	Good to Fair; improves element condition state	$12-$15/ SF of painted area	$13/ SF of painted area
Minor Rehabilitation (Reactive Maintenance)	Reset Bearings	Good to Fair; dependent on element condition state	Good to Fair; improves element condition state	$200-$500/ EACH Bearing	$300/ EACH Bearing
	Remove Loose Concrete	Fair to Poor; dependent on element condition state	Fair to Poor; improves element condition state	Infrequent Reactive Maint	Infrequent Reactive Maint
	Patching/ Gunite/Shot Crete	Fair to Poor; dependent on element condition state	Satisfactory to Fair; improves element condition state	$55 - $150/ SF of patch area	$100/ SF of patch area
	Arresting Fatigue Cracks	Poor	Fair	Infrequent Reactive Maint	Infrequent Reactive Maint
Major Rehabilitation	Repair/ Replace Bearings	Poor	Good to Fair	$1600 - $2000/ EACH Bearing	$1750/ EACH Bearing
	Heat Straightening (*Infrequent reactive maint; typically in response to	Fair to Poor	Satisfactory	$6,500 - $9,000 per day + mob*	$6,500 per day + mob*

	bridge hits)				
	Repair Steel Elements (splice plates, stiffeners, etc)	Fair to Poor	Satisfactory to Fair	In response to bridge hits or older trusses (smaller subset of bridges)	In response to bridge hits or older trusses (smaller subset of bridges)
	Widening (Performed in response to increased traffic needs)	Poor	Good to Satisfactory	$300/ SF of deck (includes super, sub and deck)	$300/ SF of deck (includes super, sub and deck)
	Replace Concrete and Steel Elements	Poor	Good to Satisfactory	Infrequent Reactive Maint	Infrequent Reactive Maint
	Repair/ Replace Connections	Poor	Good to Fair	In response to critical findings or advanced section	In response to critical findings or advanced section
Reconstruction (Entire Bridge)	Reconstruction	Poor	Good	Variable	$145/ SF

For each condition level, what percent of the time do you end up taking no action at all in a year and just allowing the bridge to deteriorate some more? *This analysis does not include routine maintenance, although routine maintenance, such as flushing, is performed annually to slow deterioration rates. Other routine maintenance, such as sealing, is performed as needed and can help slow deterioration.

- Good _100_%
- Fair _90_%
- Poor _75_%

Table B-3. Typical treatments and costs for bridge substructures.

Treatment Category	Representative Treatments	Typical Condition Level When Applied (e.g., Excellent, Good, Fair, or Poor)	Most Likely Condition After Treatment	Typical Cost Range	Most Representative Cost
Routine Maintenance (Subset of Preventive Maintenance)	Flushing bridge seats, pier caps	All Bridges with Decks	Same but slows deterioration rate	$100 - $1500/ Bridge	$500/ Bridge (Flushing entire bridge)
Preventive Maintenance	Sealing	Good to Poor	Good to Fair	Infrequent Reactive Maint	Infrequent Reactive Maint
	Painting	Good to Fair; dependent on element condition state	Good to Fair; improves element condition state	Infrequent Reactive Maint	Infrequent Reactive Maint
Reactive Maintenance	Debris Removal	All	Same, but prevents debris from causing more problems	Not applied directly to the substructure	Not applied directly to the substructure
Minor Rehabilitation (Reactive Maintenance)	Patching	Fair to Poor	Satisfactory to Fair	$55 - $150/ SF of patch area	$100/ SF of patch area
	Slope Paving Repair	Dependent on element condition state	Improves element condition state	$10 - $25/ SF of repair area	$20/ SF of repair area
	Riprap (Infrequent Reactive Maint)	Fair to Poor	Good to Satisfactory	$10,000 - $500,000	Depends on extent of project
Major Rehabilitation	Scour Repair	Fair to Poor	Good to Satisfactory	$50,000 - $500,000	Depends on extent of project
	Repair Steel Elements	Fair to Poor	Satisfactory to Fair	Infrequent Reactive Maint	Infrequent Reactive Maint
	Replace Steel Elements	Poor	Good to Satisfactory	Infrequent Reactive Maint	Infrequent Reactive Maint
	Replace Concrete Elements	Poor	Good to Satisfactory	Infrequent Reactive Maint	Infrequent Reactive Maint
Reconstruction (Entire Bridge)	Reconstruction	Poor	Good	Variable	$145/ SF

For each condition level, what percent of the time do you end up taking no action at all in a year and just allowing the bridge to deteriorate some more? *This analysis does not include routine maintenance, although routine maintenance, such as flushing, is performed annually to slow deterioration rates. Other routine maintenance, such as sealing, is performed as needed and can help slow deterioration.

- Good _100_%
- Fair _90_%
- Poor _75_%

Overall Health Index

Please answer the following question to tell us the relative value you would place on each condition level, considering the effect on routine maintenance needs and on the quality of service given to the public, including risk. If Excellent condition is worth 100 points and Failed condition is worth zero points, how much should the other levels be worth?

- Good condition 100 points.
- Satisfactory condition 80 points.
- Fair condition 50 points.
- Poor condition 0 points.

LIFE-CYCLE COST CONSIDERATION WORKSHEET – BRIDGE CULVERTS

Bridge Subset (ex: State, NHS, Non-NHS): Concrete Box Culverts > 10 FT

To simplify the lifecycle cost analysis, assume the following condition categories from the NBI ratings:

- Good condition: NBI rating 7 to 9.
- Satisfactory condition: NBI rating 6.
- Fair condition: NBI rating 5.
- Poor condition: NBI rating 4 or less.

Deterioration Rates

Culverts

- Suppose 100 culverts on this subset are currently in Good (7 or greater) condition. After how many years will 50 of them have deteriorated to Satisfactory (6) or worse condition, if no preservation action has been taken? 50 years
- Suppose 100 culverts on this subset are currently in Satisfactory (6) condition. After how many years will 50 of them have deteriorated to Fair (5) or worse condition, if no preservation action has been taken? 20 years (70 years total)
- Suppose 100 culverts on this subset are currently in Fair (5) condition. After how many years will 50 of them have deteriorated to Poor (4 or less) or worse condition, if no preservation action has been taken? 30 years (100 years total)
- Suppose 100 bridge decks on this subset are currently in Poor condition. After how many years will 50 of them have deteriorated to Failed condition, if no preservation action has been taken? _____N/A____________

Inspection Costs

What is the estimated average annual cost to collect and process bridge condition data so it can be used for reporting performance?

Average annual collection costs: $4.5 Million_(includes culverts)

Average annual processing costs: $0.5 Million_(includes culverts)

Treatment Costs

Five categories of repair are listed in tables B-4, for culverts. For each of the categories, identify representative treatments that fit within that category, the typical condition range when these treatments are applied (e.g., Good, Fair, or Poor), and the condition after the treatment has been constructed. Also provide the typical price range for the treatments in that category and a cost that your Work Group considers to be the most representative cost within the price range. Be sure to indicate the units used for your costs.

Table B-4. Typical treatments and costs for culverts.

Treatment Category	Representative Treatments	Typical Condition Level When Applied (e.g., Excellent, Good, Fair, or Poor)	Most Likely Condition After Treatment	Typical Cost Range	Most Representativ e Cost
Routine Maintenance	None				
Preventive Maintenance	None				
Minor Rehabilitation (Reactive Maintenance)	Patching/ Minor Repairs	Fair to Poor	Satisfactory to Fair	$20 - $55/ SF of repair area	$30/ SF of repair area
	Debris Removal	All	Same, but prevents debris from causing more problems	Not applied directly to the culvert	Not applied directly to the culvert
	Scour Repair	Fair to Poor	Good to Satisfactory	$1000 - $10,000	Depends on extent of project
Major Rehabilitation	Wingwall/Headwall Rehab	Poor	Satisfactory to Fair	Infrequent Reactive Maint	Infrequent Reactive Maint
	Extend	Good to Fair	Good to Fair	Variable	$200,000
Reconstruction	Reconstruction	Poor	Good	Variable	$250,000

For each condition level, what percent of the time do you end up taking no action at all in a year and just allowing the culvert to deteriorate some more?

- Good _100__%
- Fair _90__%
- Poor _55__%

LIFE-CYCLE COST CONSIDERATION WORKSHEET - HYDRAULICS

To simplify the lifecycle cost analysis, assume the following condition categories from the HydInfra ratings:

- Excellent (like new) condition: 1
- Fair condition: 2
- Poor condition: 3
- Very poor condition: 4

Deterioration Rates

Culverts

- Suppose 100 culverts are currently in Excellent condition. After how many years will 50 of them have deteriorated to Fair or worse condition, if no preservation action has been taken?
  - For Concrete Pipe: _____23________
  - For Metal Pipe: _______13_________
- Suppose 100 culverts are currently in Fair condition. After how many years will 50 of them have deteriorated to Poor or worse condition, if no preservation action has been taken?
  - For Concrete Pipe: _____33________
  - For Metal Pipe: ________16________
- Suppose 100 culverts are currently in Poor condition. After how many years will 50 of them have deteriorated to Very Poor condition, if no preservation action has been taken?
  - For Concrete Pipe: _____15________
  - For Metal Pipe: ________8________

Stormwater Tunnels

(Metro District has 7 stormwater tunnel systems that have been divided up into 50 segments. These tunnels were built between the early 1960's and late 1970's. The degradation of each tunnel is specific to the tunnel system. For example, the I-35W south tunnel is under a significant amount of pressure and it can go from good to fair to poor at a much higher rate than the other tunnels.)

Currently 32% of the 50 tunnel segments are rated fair, 42% are rated poor, and 26% are rated very poor.

Inspection Costs

What is the estimated average annual cost to collect and process culvert and tunnel condition data so it can be used for reporting performance?

Average annual collection costs for culverts: 7900 hours x $75/hr. (includes hourly rate $30 + 1.5 overhead rate) = $592,500 + $66,667 (consultant contract annualized over 3 years): Total $659,167 ($660K)

Average annual processing costs for culverts: 880 hours (same as above) = $66,000

Tunnel inspection costs (inspection and reports) are done via consultants. Typically $200,000 each year. The shared tunnels in the City of Minneapolis are on a 3-5 year inspection schedule.

Treatment Costs

Five categories of repair are listed in table H-1 and H-2 for culverts and tunnels, respectively. For each of the categories, identify representative treatments that fit within that category, the typical condition range when these treatments are applied (e.g., Good, Fair, or Poor) and the condition after the treatment has been constructed. Also provide the typical price range for the treatments in that category and a cost that your Work Group considers to be the most representative cost within the price range. Be sure to indicate the units used for your costs.

Culverts

Table H-1. Typical treatments and costs for culverts.

Treatment Category	Representative Treatments	Typical Condition Level When Applied (e.g., Excellent, Good, Fair, or Poor)	Most Likely Condition After Treatment	Typical Cost Range	Most Representative Cost
Routine Maintenance					
Preventive Maintenance					
Minor Rehabilitation		Poor or very poor	Fair		
	Reset ends				$2694.78 Each
	joint repair/Grout				$35.73/LF
	pave invert				$17.86/LF
Major Rehabilitation	Slipliner	Very poor	Excellent or Fair		$192.54
	CIPP				$142.62/LF
Replacement	Trench	Poor or very poor	Excellent		$71.91/LF + $28999.12/Ea
	Jack				$797.50/LF

Estimated repair costs based on 2010 Spreadsheet developed by Dave Solsrud/Dave Johnston of D8. Trench replacement cost includes the cost of the pavement replacement – will be much less expensive if done as part of a pavement project. Unit repair costs include the 10% contingency that was added in the spreadsheet estimation.

For each condition level, what percent of the time do you end up taking no action at all in a year and just allowing the culvert to deteriorate some more?

- Excellent __100___%
- Fair ___98_____%
- Poor ___95_____%
- Very poor __88_____%

Stormwater Tunnels

Table H-2. Typical treatments and costs for stormwater tunnels.

Treatment Category	Representative Treatments	Typical Age or Condition Level When Applied (e.g., Excellent, Good, Fair, or Poor)	Most Likely Condition After Treatment	Typical Cost Range	Most Representative Cost
Routine Maintenance	Remove sediment and debris	Not routinely done, only done when would cause plugging	Fair		
Preventive Maintenance	Seal cracks and infiltration points	Urgent	Fair		
Maintenance	Flush and grout voids, fill cracks	Urgent/poor	Good	Contractors can do $3.5 M per season	About $25M in needs that are known now
Major Maintenance	Repair broken crown/broken liner	Urgent/poor	Good		About $500,000 in needs that are known now
Replacement or Added Capacity	Replacement or Added Capacity	Never done this yet	Excellent		About $200M in needs that are known now

For each condition level, what percent of the time do you end up taking no action at all in a year and just allowing the tunnel to deteriorate some more?

- Excellent __100____%
- Fair ___100_____%
- Poor _99___%
- Very Poor ______%

Overall Health Index

Please answer the following question to tell us the relative value you would place on each condition level, considering the effect on routine maintenance needs and on the quality of service given to the public, including risk. If Excellent condition is worth 100 points and Failed condition is worth zero points, how much should the other levels be worth?

- Fair condition _____99______ points.
- Poor condition _____40______ points.
- Very Poor condition _____20______ points.

LIFE-CYCLE COST CONSIDERATION WORKSHEET – OTHER TRAFFIC STRUCTURES

Deterioration Rates

Tracked condition summaries and available research used to make assumptions on structure deterioration. See table below.

Summary of Current Condition

Overall Condition Rating	Description	SRF - Number of structures per rating	Structures that have Maintenance work done and/or planned construction work will move from 2,3,4,5 to 6	**7-2-13** Structures per condition rating	% of total	Structures with loose anchorages/nuts from condition ratings 2, 3, 4*	total after fixing nuts & moving to satisfactory	% of total after fixing nuts	Combined %	Proposed Performance Measure
2	Critical	143	**26**	117	6%	85	32	2.3%		
3	Serious	257	**53**	204	11%	92	112	7.9%	10.2%	10% or less
4	Poor	423	**81**	342	18%	237	105	7.4%	17.6%	20% or less
5	Fair	357	**70**	287	15%	0	287	20.3%		
6	Satisfactory	200	*49*	**430**	23%	0	**844**	59.6%		
7	Good	32	*2*	32	2%	0	32	2.3%		
8	Very Good	3	0	3	0%	0	3	0.2%		
			281	1415		414	1415			
			230 moved to 6							

CO Active Structures	1857	663	414
Retired per Metro	4		0.624434389
Not inspected	**438**		
Condition Total	1415		

For structures not inspected, the most reasonable assumption would be to go with the Good/Fair/Poor distribution observed for the structures inspected. This can be revised in the Asset Register

Poor	36%	62% (414) of these have loose anchorages/nuts
Fair	15%	
Good	25%	

Based on inspected structures:

Poor	249	17.6%	77		326	13.8%
Fair	287	20.3%	89		376	15.9%
Good	879	62.1%	272	510	1661	70.3%
Totals	**1415**		**438**		2363	

Modified percentages after structures statewide have been included. All remaining 510 structures are reported to be in 100% good condition.

]

Use the results of any of your inspections to record the types of repairs needed. Use table S-1 to record your results. If you have had more than 7 inspections, please add rows to the table. We will use the results to establish preliminary rates of deterioration.

Table S-1. Repairs required based on overhead sign structure inspections.

Inspection Cycle	Year		No of Structures Requiring:					
		No. of Structures Inspected	No Maintenance	Routine Maintenance	Preventive Maintenance	Minor Rehabilitation	Major Rehabilitation	Replacement
1	2006-07	718	159	504	NA	25	14	16
2	2010-11	856	591	231	NA	15	2	17
3	2012	86	0	0	NA	0	0	0
4								
5								
6								
7								

Inspection Costs

What is the estimated average annual cost to collect and process condition data on overhead sign structures and high mast light towers so it can be used for reporting performance?

- 2006-07 Metro consultant contract to inspect/report on 718 cantilevers $460,197; $640/structure
- 2010-11 Metro… " "… on 856 non-cantilever $1,007,967; $1170/structure
- 2012 District 6 worked 90 hours of inspection time including ultrasonic inspection of anchor rods on their cantilever signs. At an average rate of n$50.00/hour this works out to an approximate cost of $4500.00

Treatment Costs

Five categories of repair are listed in tables S-3 and S-4 for overhead sign structures and high mast light towers, respectively. For each of the categories, identify representative treatments that fit within that category, the typical condition range when these treatments are applied (e.g., Good, Fair, or Poor) and the condition after the treatment has been constructed. Also provide the typical price range for the treatments in that category and a cost that your Work Group considers to be the most representative cost within the price range. Be sure to indicate the units used for your costs.

We recognize that there are few preventive maintenance treatments that are applied to high mast tower light poles. Therefore, you may not have a response for each row in table S-4. As long as you provide us with information that tells us what types of repairs are needed, the typical age at which these repairs are made, and the average cost of the repairs, we will do our best to develop a life cycle treatment cycle for these structures.

Table S-3. Typical treatments and costs for overhead sign structures.

Treatment Category	Representative Treatments	Typical Age or Condition Level When Applied (e.g., Excellent, Good, Fair, or Poor)	Most Likely Condition After Treatment	Typical Cost Range	Most Representative Cost
Routine Maintenance (such as tightening bolts)	-Tighten base nuts -Remove Grout	Poor Poor	Fair Poor		(1) (2)
Preventive Maintenance (such as adding nuts/bolts to strengthen the structure and preserve life)	NA	NA	NA	NA	NA
Minor Rehabilitation (such as replacement of one or more minor structural components)	Re-grade footing, replace weld, remove catwalks/lighting, new mounting post	Poor	Fair - Good	$1700 - $6000	$3000
Major Rehabilitation (such as replacement of significant portions of the structure)	Replace foundation or replace truss or other elements	Poor	Good	$8,000- $30,000	$25,000
Replacement (including complete removal and replacement of the structure)	Replacement	40 years	New	$10,000- $110,000	(3)

(1) Our crews tightened nuts on 300 overhead structures: 1015 hours @ $50/person = $50,750 and $6800 Equipment Cost = $57550/300 = $200/structure* and $40,000 for wrench. * Does not include traffic control costs

(2) Mendota removed 15 signs with grout in their area; 276 hours @ $50/person = $14,000 and $1400 equipment cost = $15,400/15 signs = $1000/sign*. *Does not include traffic control costs.

(3) Metro assumes a scoping replacement cost of $10K for bridge mounts, $60K for scoping of cantilever replacement, and $110K for scoping of sign bridges. Contracts (does not include mobilization or traffic control: usually assumed to be 20% of total project cost):

    (4) 2009 – Minor Rehab = $6,000 (1 structure); Major rehab $8000 (1 structure)
    2010 – Minor Rehab = $1,700 (1); Major rehab $300,000 (13) $30K average
    2011 – Major $340,000 (14) $24K average
    2012 – Major $270,000 (18) $15K average

LIFE-CYCLE COST ANALYSES
MODELING EXAMPLES
(INPUTS AND RESULTS)

PAVEMENT MODEL*

INPUTS

*The Other Traffic Structures (Overhead Sign Structures and High-Mast Tower Lighting Structures) model included the same format spreadsheets.

INPUT WORKSHEET

1. Economic Variables

Value of Time for Passenger Cars ($/hour)	$2.00
Value of Time for Single Unit Trucks ($/hour)	$2.00
Value of Time for Combination Trucks ($/hour)	$2.00

2. Analysis Options

Include User Costs in Analysis	No
Include User Cost Remaining Life Value	Yes
Use Differential User Costs	Yes
User Cost Computation Method	Calculated
Include Agency Cost Remaining Life Value	Yes
Traffic Direction	Both
Analysis Period (Years)	50
Beginning of Analysis Period	2013
Discount Rate (%)	2.2
Number of Alternatives	5

3. Project Details

State Route	
Project Name	MnDOT LCCA: AC Pavements - Desired
Region	
County	
Analyzed By	
Mileposts	
Begin	
End	
Length of Project (miles)	0.00
Comments	

4. Traffic Data

AADT Construction Year (total for both directions)	2,000
Cars as Percentage of AADT (%)	96.0
Single Unit Trucks as Percentage of AADT (%)	2.0
Combination Trucks as Percentage of AADT (%)	2.0
Annual Growth Rate of Traffic (%)	2.0
Speed Limit Under Normal Operating Conditions (mph)	55
No of Lanes in Each Direction During Normal Conditions	1
Free Flow Capacity (vphpl)	2157
Rural or Urban Hourly Traffic Distribution	Rural
Queue Dissipation Capacity (vphpl)	200
Maximum AADT (total for both directions)	2,577
Maximum Queue Length (miles)	1.0

5. Construction

	Alternative 1	Alternative 2	Alternative 3
Alternative	Flexible Pavements - Desired Srategy	Flexible Pavements - Typical Strategy	Flexible Pavement - Worst First
Number of Activities	10	11	3

Activity 1	Initial Construction	Initial Construction	Initial Construction
Agency Construction Cost ($1000)	#NAME?	#NAME?	#NAME?
User Work Zone Costs ($1000)			
Work Zone Duration (days)	5	5	5
No of Lanes Open in Each Direction During Work Zone	1	1	1
Activity Service Life (years)	#NAME?	#NAME?	#NAME?
Activity Structural Life (years)	20.0	15.0	20.0
Maintenance Frequency (years)	3	3	3
Agency Maintenance Cost ($1000)	2.38	2.38	2.38
Work Zone Length (miles)	1.00	1.00	1.00
Work Zone Speed Limit (mph)	55	55	55
Work Zone Capacity (vphpl)	200	200	200
Traffic Hourly Distribution	Week Day 1	Week Day 1	Week Day 1
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)			
Inbound	Start / End	Start / End	Start / End
First period of lane closure			
Second period of lane closure			
Third period of lane closure			
Outbound	Start / End	Start / End	Start / End
First period of lane closure			
Second period of lane closure			
Third period of lane closure			

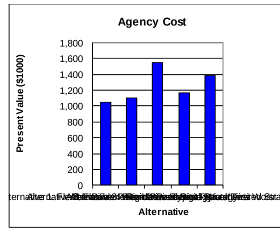
Activity 2	Crack Treatment	Crack Treatment	Reconstruction - 1
Agency Construction Cost ($1000)	#NAME?	#NAME?	#NAME?
User Work Zone Costs ($1000)			
Work Zone Duration (days)	5	5	5
No of Lanes Open in Each Direction During Work Zone	1	1	1
Activity Service Life (years)	#NAME?	#NAME?	#NAME?
Activity Structural Life (years)	0.0	0.0	20.0
Maintenance Frequency (years)	3	3	3
Agency Maintenance Cost ($1000)	2.38	2.38	2.38
Work Zone Length (miles)	1.00	1.00	1.00
Work Zone Speed Limit (mph)	55	55	55
Work Zone Capacity (vphpl)	200	200	200
Traffic Hourly Distribution	Week Day 1	Week Day 1	Week Day 1
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)			
Inbound	Start / End	Start / End	Start / End
First period of lane closure			
Second period of lane closure			
Third period of lane closure			
Outbound	Start / End	Start / End	Start / End
First period of lane closure			
Second period of lane closure			
Third period of lane closure			

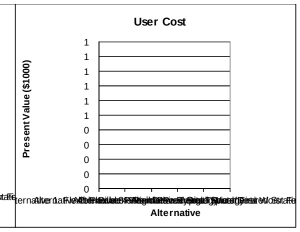
Activity 3	Surface Treatment	Surface Treatment	Reconstruction - 2
Agency Construction Cost ($1000)	#NAME?	#NAME?	#NAME?
User Work Zone Costs ($1000)			
Work Zone Duration (days)	5	5	5
No of Lanes Open in Each Direction During Work Zone	1	1	1
Activity Service Life (years)	#NAME?	#NAME?	#NAME?
Activity Structural Life (years)	8.0	9.0	20.0
Maintenance Frequency (years)	3	3	3
Agency Maintenance Cost ($1000)	2.38	2.38	2.38
Work Zone Length (miles)	1.00	1.00	1.00
Work Zone Speed Limit (mph)	55	55	55
Work Zone Capacity (vphpl)	200	200	200
Traffic Hourly Distribution	Week Day 1	Week Day 1	Week Day 1
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)			
Inbound	Start / End	Start / End	Start / End
First period of lane closure			
Second period of lane closure			
Third period of lane closure			
Outbound	Start / End	Start / End	Start / End
First period of lane closure			
Second period of lane closure			
Third period of lane closure			

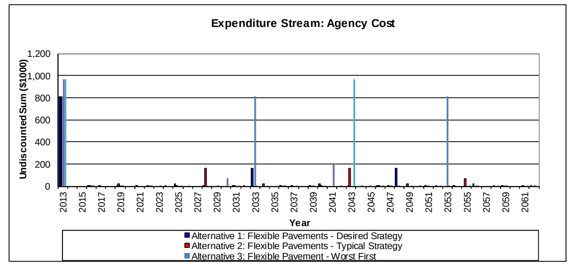
DETERMINISTIC RESULTS

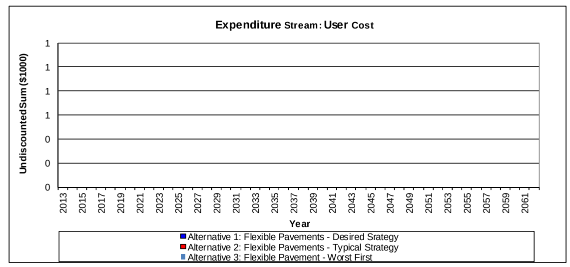
Total Cost										
	Alternative 1: Flexible Pavements - Desired Srategy		Alternative 2: Flexible Pavements - Typical Strategy		Alternative 3: Flexible Pavement - Worst First		Alternative 4: Rigid Pavements Typical/Desired Strategy		Alternative 5: Rigid Pavements Worst First	
Total Cost	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Undiscounted Sum	*$1,233.07*	*$0.00*	*$1,302.42*	*$0.00*	*$2,052.37*	*$0.00*	*$1,305.62*	*$0.00*	*$1,656.11*	*$0.00*
Present Value	**$1,046.58**	**$0.00**	**$1,099.92**	**$0.00**	**$1,552.06**	**$0.00**	**$1,163.60**	**$0.00**	**$1,388.59**	**$0.00**
EUAC	$34.72	$0.00	$36.49	$0.00	$51.49	$0.00	$38.60	$0.00	$46.07	$0.00
Lowest Present Value Agency Cost	Alternative 1: Flexible Pavements - Desired Srategy									
Lowest Present Value User Cost	Alternative 1: Flexible Pavements - Desired Srategy									

Expenditure Stream										
	ve 1: Flexible Pavements - Desire		ve 2: Flexible Pavements - Typica		ative 3: Flexible Pavement - Wors		4: Rigid Pavements Typical/Desir		native 5: Rigid Pavements Worst	
Year	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
2013	$806.67		$806.67		$806.67		$966.67		$966.67	
2014										
2015										
2016	$2.38		$2.38		$2.38		$2.38		$3.00	
2017			$6.33							
2018										
2019	$2.38		$18.33		$2.38		$2.38		$3.00	
2020										
2021	$6.33									
2022			$2.38		$2.38		$2.38		$3.00	
2023							$10.00			
2024	$2.38									
2025	$18.33		$2.38		$2.38				$3.00	
2026							$2.38			
2027										
2028	$2.38		$158.33		$2.38				$3.00	
2029							$2.38			
2030							$71.67			
2031	$2.38		$3.48		$2.38				$3.00	
2032			$6.33							
2033	$158.33				$806.67		$3.48			
2034			$18.33						$3.00	
2035										
2036	$6.33				$2.38		$3.48			
2037			$3.48						$3.00	
2038										
2039	$3.48				$2.38		$3.48			
2040	$18.33		$3.48						$3.00	
2041							$198.33			
2042					$2.38					
2043	$3.48		$158.33						$966.67	
2044							$5.23			
2045					$2.38					
2046	$3.48		$3.48						$3.00	
2047			$6.33				$5.23			
2048	$158.33				$2.38					
2049			$18.33						$3.00	
2050							$5.23			
2051	$6.33				$2.38					
2052			$5.23						$3.00	
2053					$806.67		$5.23			
2054	$5.23									
2055			$68.33						$3.00	
2056	$18.33				$2.38		$5.23			
2057										
2058			$5.23						$3.00	
2059	$5.23				$2.38		$5.23			
2060										
2061			$5.23						$3.00	
2062	$5.23				$2.38		$5.23			
2063	($2.29)				($403.33)				($322.22)	



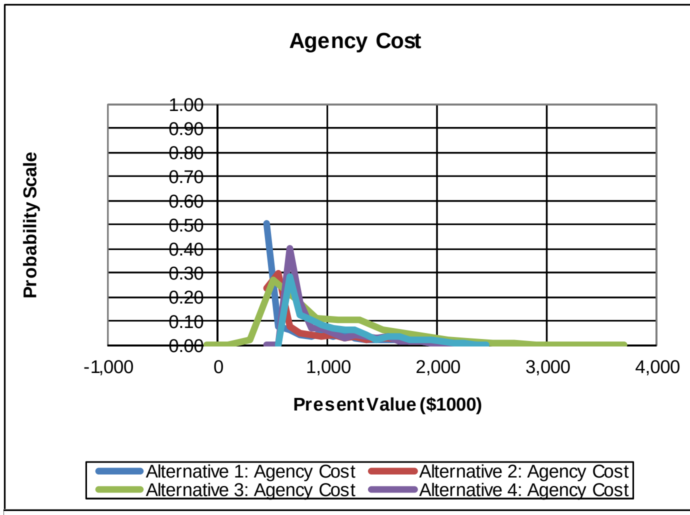


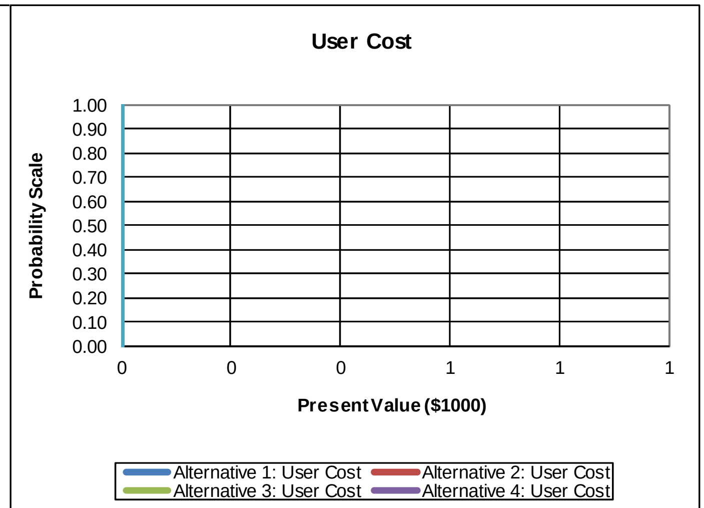


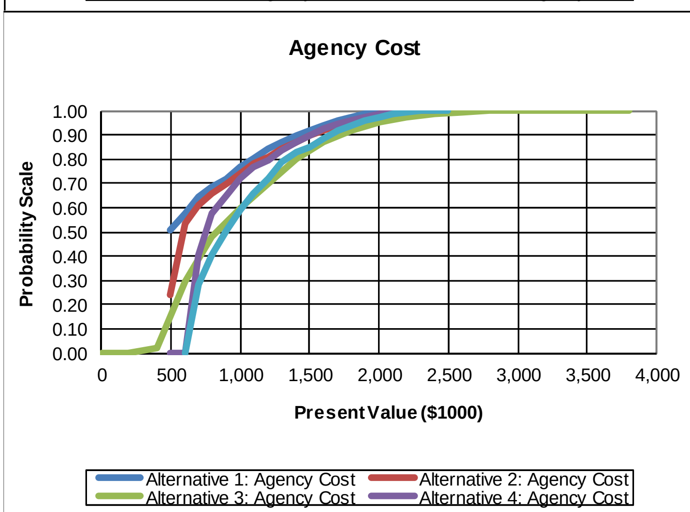


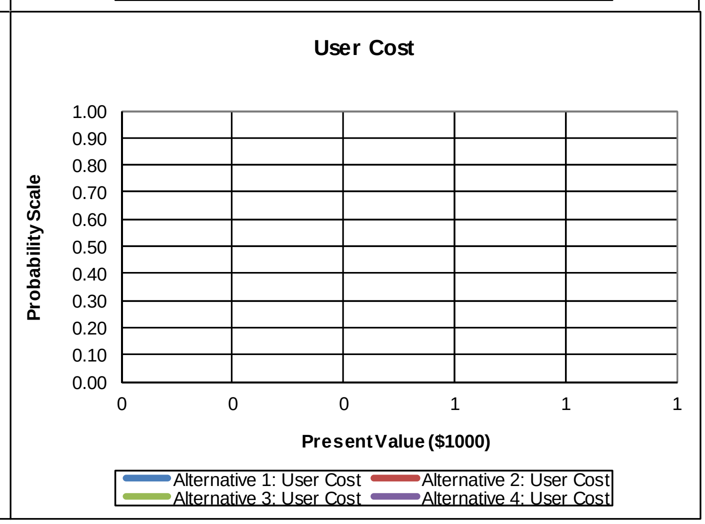
PROBABLISTIC RESULTS

Total Cost										
Total Cost (Present Value)	Alternative 1: Flexible Pavements - Desired		Alternative 2: Flexible Pavements - Typical		Alternative 3: Flexible Pavement - Worst First		Alternative 4: Rigid Pavements		Alternative 5: Rigid Pavements Worst First	
	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Mean	$741.81	$0.00	$806.63	$0.00	$979.54	$0.00	$923.66	$0.00	$1,025.66	$0.00
Standard Deviation	$414.33	$0.00	$427.91	$0.00	$518.40	$0.00	$359.33	$0.00	$395.24	$0.00
Minimum	$408.66	$0.00	$455.56	$0.00	$371.45	$0.00	$611.75	$0.00	$612.54	$0.00
Maximum	$2,164.02	$0.00	$2,215.59	$0.00	$3,067.49	$0.00	$2,187.16	$0.00	$2,394.71	$0.00







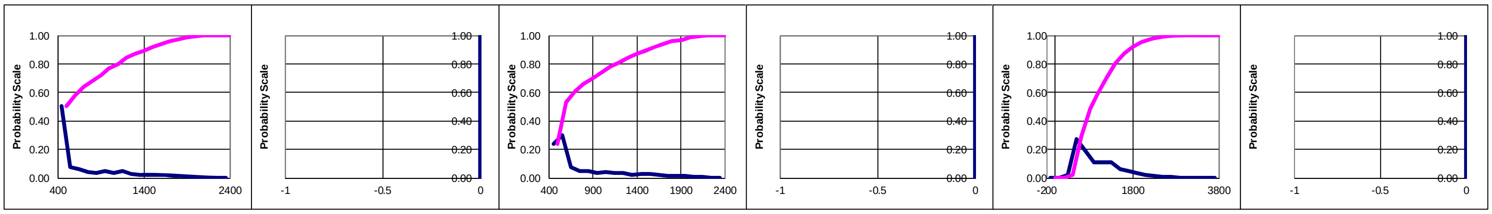


OUTPUT DISTRIBUTIONS

Alternative 1: Agency Cost				Alternative 1: User Cost			
Bin	Mid Point	Rel. Freq.	Cum. Rel. Freq.	Bin	Mid Point	Rel. Freq.	Cum. Rel. Freq.
500	450	0.50	0.50	0	0	1.00	1.00
600	550	0.07	0.58	0	0	0.00	1.00
700	650	0.06	0.64	0	0	0.00	1.00
800	750	0.04	0.68	0	0	0.00	1.00
900	850	0.04	0.72	0	0	0.00	1.00
1000	950	0.05	0.77	0	0	0.00	1.00
1100	1050	0.03	0.80	0	0	0.00	1.00
1200	1150	0.05	0.84	0	0	0.00	1.00
1300	1250	0.03	0.87	0	0	0.00	1.00
1400	1350	0.02	0.89	0	0	0.00	1.00
1500	1450	0.02	0.92	0	0	0.00	1.00
1600	1550	0.02	0.94	0	0	0.00	1.00
1700	1650	0.02	0.96	0	0	0.00	1.00
1800	1750	0.01	0.97	0	0	0.00	1.00
1900	1850	0.01	0.98	0	0	0.00	1.00
2000	1950	0.01	0.99	0	0	0.00	1.00
2100	2050	0.01	1.00	0	0	0.00	1.00
2200	2150	0.00	1.00	0	0	0.00	1.00
2300	2250	0.00	1.00	0	0	0.00	1.00
2400	2350	0.00	1.00	0	0	0.00	1.00

Alternative 2: Agency Cost				Alternative 2: User Cost			
Bin	Mid Point	Rel. Freq.	Cum. Rel. Freq.	Bin	Mid Point	Rel. Freq.	Cum. Rel. Freq.
500	450	0.24	0.24	0	0	1.00	1.00
600	550	0.30	0.53	0	0	0.00	1.00
700	650	0.07	0.61	0	0	0.00	1.00
800	750	0.05	0.66	0	0	0.00	1.00
900	850	0.04	0.70	0	0	0.00	1.00
1000	950	0.04	0.74	0	0	0.00	1.00
1100	1050	0.04	0.78	0	0	0.00	1.00
1200	1150	0.03	0.81	0	0	0.00	1.00
1300	1250	0.03	0.85	0	0	0.00	1.00
1400	1350	0.02	0.87	0	0	0.00	1.00
1500	1450	0.03	0.89	0	0	0.00	1.00
1600	1550	0.03	0.92	0	0	0.00	1.00
1700	1650	0.02	0.94	0	0	0.00	1.00
1800	1750	0.02	0.96	0	0	0.00	1.00
1900	1850	0.01	0.97	0	0	0.00	1.00
2000	1950	0.02	0.98	0	0	0.00	1.00
2100	2050	0.01	0.99	0	0	0.00	1.00
2200	2150	0.01	1.00	0	0	0.00	1.00
2300	2250	0.00	1.00	0	0	0.00	1.00
2400	2350	0.00	1.00	0	0	0.00	1.00

Alternative 3: Agency Cost				Alternative 3: User Cost			
Bin	Mid Point	Rel. Freq.	Cum. Rel. Freq.	Bin	Mid Point	Rel. Freq.	Cum. Rel. Freq.
0	-100	0.00	0.00	0	0	1.00	1.00
200	100	0.00	0.00	0	0	0.00	1.00
400	300	0.02	0.02	0	0	0.00	1.00
600	500	0.27	0.29	0	0	0.00	1.00
800	700	0.19	0.48	0	0	0.00	1.00
1000	900	0.11	0.59	0	0	0.00	1.00
1200	1100	0.11	0.70	0	0	0.00	1.00
1400	1300	0.11	0.80	0	0	0.00	1.00
1600	1500	0.06	0.87	0	0	0.00	1.00
1800	1700	0.05	0.92	0	0	0.00	1.00
2000	1900	0.04	0.95	0	0	0.00	1.00
2200	2100	0.02	0.97	0	0	0.00	1.00
2400	2300	0.01	0.99	0	0	0.00	1.00
2600	2500	0.01	0.99	0	0	0.00	1.00
2800	2700	0.00	1.00	0	0	0.00	1.00
3000	2900	0.00	1.00	0	0	0.00	1.00
3200	3100	0.00	1.00	0	0	0.00	1.00
3400	3300	0.00	1.00	0	0	0.00	1.00
3600	3500	0.00	1.00	0	0	0.00	1.00
3800	3700	0.00	1.00	0	0	0.00	1.00



EXTREME TAIL ANALAYSIS

Input Variable		Alternative 1: Agency Cost				Alternative 1: User Cost			
Name	Probability Function	5%	10%	90%	95%	5%	10%	90%	95%
Alternative 1: Activity 1: Agency (	LCCATRIANG(210,210,2000)	-0.01	-0.01	2.89	3.31	-0.01	-0.01	2.89	3.31
Alternative 2: Activity 1: Agency (	LCCATRIANG(210,210,2000)	0.17	0.07	0.08	0.07	0.17	0.07	0.08	0.07
Alternative 3: Activity 1: Agency (	LCCATRIANG(210,210,2000)	0.09	0.01	0.20	0.37	0.09	0.01	0.20	0.37
Alternative 4: Activity 1: Agency (	LCCATRIANG(450,450,2000)	0.00	0.00	0.01	0.25	0.00	0.00	0.01	0.25
Alternative 5: Activity 1: Agency (	LCCATRIANG(450,450,2000)	-0.01	0.18	0.01	-0.01	-0.01	0.18	0.01	-0.01
Alternative 1: Activity 1: Service L	LCCATRIANG(6,8,10)	1.08	0.82	0.07	0.13	1.08	0.82	0.07	0.13
Alternative 2: Activity 1: Service L	LCCATRIANG(3,4,5)	-0.12	-0.09	-0.16	-0.16	-0.12	-0.09	-0.16	-0.16
Alternative 3: Activity 1: Service L	LCCATRIANG(15,20,25)	-0.05	-0.09	-0.21	-0.13	-0.05	-0.09	-0.21	-0.13
Alternative 4: Activity 1: Service L	LCCATRIANG(8,10,12)	-0.08	-0.06	0.02	0.15	-0.08	-0.06	0.02	0.15
Alternative 5: Activity 1: Service L	LCCATRIANG(25,30,35)	0.04	-0.04	0.09	0.00	0.04	-0.04	0.09	0.00
Alternative 1: Activity 2: Agency (	LCCATRIANG(3,6,10)	-0.04	-0.12	0.00	-0.04	-0.04	-0.12	0.00	-0.04
Alternative 2: Activity 2: Agency (	LCCATRIANG(3,6,10)	-0.20	-0.08	0.11	0.11	-0.20	-0.08	0.11	0.11
Alternative 3: Activity 2: Agency (	LCCATRIANG(210,210,2000)	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.18
Alternative 4: Activity 2: Agency (	LCCATRIANG(5,10,15)	0.05	0.12	0.10	-0.04	0.05	0.12	0.10	-0.04
Alternative 5: Activity 2: Agency (	LCCATRIANG(450,450,2000)	-0.06	-0.06	0.14	0.13	-0.06	-0.06	0.14	0.13
Alternative 1: Activity 2: Service L	LCCATRIANG(3,4,5)	0.44	0.39	-0.01	-0.17	0.44	0.39	-0.01	-0.17
Alternative 2: Activity 2: Service L	LCCATRIANG(1,2,3)	-0.11	0.00	0.07	-0.08	-0.11	0.00	0.07	-0.08
Alternative 3: Activity 2: Service L	LCCATRIANG(15,20,25)	-0.07	0.08	-0.02	-0.02	-0.07	0.08	-0.02	-0.02
Alternative 4: Activity 2: Service L	LCCATRIANG(6,6,8)	0.57	0.14	0.03	0.02	0.57	0.14	0.03	0.02
Alternative 5: Activity 2: Service L	LCCATRIANG(25,30,35)	0.30	0.08	-0.28	-0.46	0.30	0.08	-0.28	-0.46

SIMULATION OUTPUT

Statistics	LCCA Output: Alternative 1: Agency Cost	LCCA Output: Alternative 1: User Cost	LCCA Output :Alternative 2: Agency Cost	LCCA Output :Alternative 2: User Cost	LCCA Output :Alternative 3: Agency Cost	LCCA Outpu t:Alternative 3: User Cost
Probability Function						
Minimum	$408.66	$0.00	$455.56	$0.00	$371.45	$0.00
Maximum	$2,164.02	$0.00	$2,215.59	$0.00	$3,067.49	$0.00
Mean	$741.81	$0.00	$806.63	$0.00	$979.54	$0.00
Median	$495.19	$0.00	$557.84	$0.00	$842.96	$0.00
Standard Deviation	$414.33	$0.00	$427.91	$0.00	$518.40	$0.00
Percentile (5%)	$425.12	$0.00	$482.63	$0.00	$412.15	$0.00
Percentile (10%)	$431.22	$0.00	$488.23	$0.00	$428.70	$0.00
Percentile (90%)	$1,412.54	$0.00	$1,521.90	$0.00	$1,733.18	$0.00
Percentile (95%)	$1,647.93	$0.00	$1,734.60	$0.00	$1,980.51	$0.00
Iteration 1	$608.58	$0.00	$2,215.59	$0.00	$662.11	$0.00
2	$1,327.23	$0.00	$877.60	$0.00	$540.96	$0.00
3	$924.45	$0.00	$590.15	$0.00	$1,012.94	$0.00
4	$413.46	$0.00	$720.77	$0.00	$816.52	$0.00
5	$476.86	$0.00	$1,783.80	$0.00	$703.60	$0.00
6	$1,147.69	$0.00	$487.28	$0.00	$1,662.16	$0.00
7	$451.26	$0.00	$562.08	$0.00	$1,485.15	$0.00
8	$1,789.60	$0.00	$1,542.13	$0.00	$812.27	$0.00
9	$797.38	$0.00	$475.61	$0.00	$595.76	$0.00
10	$1,540.23	$0.00	$560.27	$0.00	$632.49	$0.00

PAVEMENT LCCA RESULTS

Deterministic Analysis			
	FDR/Reconstruct	Mill OL	Worst-First
Undiscounted Sum	$766,261	$984,441	$1,988,023
Net Present Value (NPV)	$386,180	$409,698	$976,317
Equivalent Uniform Annual Cost (EUAC)	$10,864	$11,526	$27,466
% of initial cost	111%	142%	287%
Probabilistic Analysis			
Mean Net Present value (NPV)	$375,668	$392,754	$635,313
Standard Deviation	$34,609	$33,862	$314,516

Note: All costs in $/lane-mi

Initial costs not included in analysis

BRIDGE MODEL*

BRIDGE DECK INPUTS

Life cycle cost inputs - Bridge decks

MnDOT Modified

General	Good	Satis	Fair	Poor	Total			
Number of bridges	1029	283	74	15	1401	Deck area	26.203	million sq.ft
Health index weight	100	80	50	0		Joint quantity	535398	LF
Discount rate	2.2%					Rail quantity	1118213	LF

Comments:
1. Modified Bridge Counts, Deck Area, Joint Qty and Rail Qty based on Thomas' email from 8/14
2. Added Crack Sealing to Routine Maintenance
3. Added Gland Repair/Replace to Corrective Action
4. Added Redeck to Rehab/Replacement
5. Modified percentages based on maintenance data and typical frequencies
6. Modified deck repair unit/bridge based on bridge maintenance supervisor input

Deterioration model - without preservation	Years	Good	Satis	Fair	Poor
Good	18	96.2%	3.8%	0.0%	0.0%
Satis	5		87.1%	12.9%	0.0%
Fair	5			87.1%	12.9%
Poor	--				100%

Deterioration model - with preservation	Years	Good	Satis	Fair	Poor
Good	22.5	97.0%	3.0%	0.0%	0.0%
Satis	7.5		91.2%	8.8%	0.0%
Fair	7.5			91.2%	8.8%
Poor	--				100%

Routine maintenance					% bridges acted upon in a year				Real ✓								
Treatment	Units	$/unit	Unit/br	$k/br	Good	Satis	Fair	Poor	$M/yr	Good	Satis	Fair	Poor	Totals			
Inspection	Bridge	1111	0	0.0	60%	60%	60%	60%	0.0	617.4	169.8	44.4	9	840.6		4500 state bridges over 10 ft (including culverts)	
Flushing	Bridge	500	0	0.0	75%	75%	75%	75%	0.0	771.75	212.25	55.5	11.25	1050.8	350.25	560.4	375.5
Joint sealing	LF	4	382	1.5	13%	13%	13%		0.3	128.63	35.375	9.25	0	173.25	175.13	12.50%	(8 year cycle)
Deck sealing	SF	2	18703	37.4	14%	14%	14%		7.3	144.06	39.62	10.36	0	194.04	200.34	14.30%	(7 year cycle
Crack Sealing	LF	3	500	1.5	20%	20%	20%		0.4	205.8	56.6	14.8	0	277.2	280.2	20%	(5 year cycle)
Annual cost per bridge - no preservation ($k)					0.0	0.0	0.0	0.0	0.0								
Annual cost per bridge - preservation scenario ($k)					5.7	5.7	5.7	0.0	7.9								

Corrective action					% bridges acted upon in a year				Real ✓	Percent improved											
Treatment	Units	$/unit	Unit/br	$k/br	Good	Satis	Fair	Poor	$M/yr	Effect	Good	Satis	Fair	Poor	Satis	Fair	Poor	Totals	From Maint Total		0.3111
Joint repair (patch)	SF	100	382	38.2		1%	2%		0.2	0.3	0.0%	0.3%	0.6%	0.0%	2.83	1.48	0	4.31	11.75	3.525	
Gland Repair/Replace	LF	250	382			1%	5%		0.0	0.5	0.0%	0.5%	2.5%	0.0%	2.83	3.7	0	6.53		0	
Deck repair	SF	30	561	16.8		2%	35%	15%	0.6	0.5	0.0%	1.0%	17.5%	7.5%	5.66	25.9	2.25	33.81	130	39	0.0241
Overlay	Each	7	18703	130.9		0%	5%	2%	0.5	0.8	0.0%	0.0%	4.0%	1.6%	0	3.7	0.3	4	7	2.1	
Rail repair/replace	Bridge	160	798	127.7		1%	5%		0.8	0.2	0.0%	0.2%	1.0%	0.0%	2.83	3.7	0	6.53	22.5	6.75	
Total percent acted upon					0%	5%	52%	17%							14.15	38.48	2.55	55.18			
Annual cost per bridge ($k)					0.0	2.0	19.6	5.1	2.1		0.0%	2.0%	25.6%	9.1%							
Approximate interval (years)									25.4												

Rehab/replacement					% bridges acted upon in a year				Real ✓	Resulting condition			
Treatment	Units	$/unit	Unit/br	$k/br	Good	Satis	Fair	Poor	$M/yr	Good	Satis	Fair	Poor
Redeck	SF	60	18703	1122.2				5%	0.8	100%			
Replace Structure	SF	145	0	0.0				20%	0.0	100%			
Total percent acted upon					0%	0%	0%	25%					
Annual cost per bridge ($k)					0.0	0.0	0.0	56.1	0.8	100.0%	0.0%		
								42%		0.0222			
										0.0107			

*The Hydraulic Infrastructure (highway culverts and deep stormwater tunnels) model included the same format spreadsheets.

BRIDGE SUPERSTRUCTURE INPUTS

Life cycle cost inputs - Bridge superstructures

General	Good	Satis	Fair	Poor	Total			
Number of bridges	1047	272	65	17	1401	Deck area	26.116	million sq.ft
Health index weight	100	80	50	0		Bearing count	37,266	
Discount rate	2.2%							

MnDOT Modified

Comments:
1. Modified Bridge Counts, Deck Area, Joint Qty and Rail Qty based on Thomas' email from 8/14
2. Added Full Painting to list of corrective action
3. Modified percentages based on maintenance data, contract data and typical frequencies
4. Modified Painting and Patching Unit/Br based on bridge maintenance supervisor input

Deterioration model - without preservation	Years	Good	Satis	Fair	Poor
Good	30	97.7%	2.3%	0.0%	0.0%
Satis	10		93.3%	6.7%	0.0%
Fair	10			93.3%	6.7%
Poor	--				100%

Deterioration model - with preservation	Years	Good	Satis	Fair	Poor
Good	45	98.5%	1.5%	0.0%	0.0%
Satis	15		95.5%	4.5%	0.0%
Fair	20			96.6%	3.4%
Poor	--				100%

Routine maintenance					% bridges acted upon in a year				Real ✓								
Treatment	Units	$/unit	Unit/br	$k/br	Good	Satis	Fair	Poor	$M/yr	Good	Satisfactory	Fair	Poor	Totals			
Inspection	Bridge	1111	1	1.1	60%	60%	60%	60%	0.9	628.2	163.2	39	10.2	840.6	602-752		
Flushing	Bridge	500	1	0.5	75%	75%	75%	75%	0.5	785.25	204	48.75	12.75	1050.8			
Lube bearings	Each	1000	27	26.6	0%	0%	0%		0.0	1.047	0.544	0	0	1.591		6	1.8
Annual cost per bridge - no preservation ($k)					0.7	0.7	0.7	0.7	0.9								2%
Annual cost per bridge - preservation scenario ($k)					1.1	1.1	1.0	1.0	1.5								

Corrective action					% bridges acted upon in a year				Real ✓	Percent improved										From Maint Data	
Treatment	Units	$/unit	Unit/br	$k/br	Good	Satis	Fair	Poor	$M/yr	Effect	Good	Satis	Fair	Poor	Good	Satis	Fair	Poor	Totals		
Spot Painting	SF	13	1500	19.5		2%	5%		0.2	0.7	0.0%	1.4%	3.5%	0.0%	0	5.44	3.25	0	8.69	33	9.9
Full Painting	SF	14	27961	377.5		3%	5%		4.3	1	0.0%	3.0%	5.0%	0.0%	0	8.16	3.25	0	11.41	13	
Patching	SF	100	300	30.0		1%	3%	5%	0.2	0.5	0.0%	0.5%	1.5%	2.5%	0	2.72	1.95	0.85	5.52	16	4.8
Repair/repl bearings	Each	1750	27	46.5				5%	0.0	0.6	0.0%	0.0%	0.0%	3.0%	0	0	0	0.85	0.85	3	0.9
Repair steel	Bridge	50000	1	50.0			2%	5%	0.1	0.3	0.0%	0.0%	0.6%	1.5%	0	0	1.3	0.85	2.15	7	2.1
Total percent acted upon					0%	6%	15%	15%							0	16.32	9.75	2.55	28.62		
Annual cost per bridge ($k)					0.0	12.0	21.7	6.3	4.8		0.0%	4.9%	10.6%	7.0%					0.0204		
Approximate interval (years)									49.0												

Rehab/replacement					% bridges acted upon in a year				Real ✓	Resulting condition				
Treatment	Units	$/unit	Unit/br	$k/br	Good	Satis	Fair	Poor	$M/yr	Good	Satis	Fair	Poor	Poor
Replace elements	Bridge	100000	1	100.0				1%	0.0	90%	10%			0.085
Replace structure	SF	145	18641	2702.9				20%	9.2	100%				3.4
Total percent acted upon					0%	0%	0%	21%						
Annual cost per bridge ($k)					0.0	0.0	0.0	541.1	9.2	99.8%	0.2%			
								36%						

BRIDGE SUPERSTRUCTURE INPUTS

Life cycle cost inputs - Bridge substructures

MnDOT Modified

General	Good	Satis	Fair	Poor	Total		
Number of bridges	1061	271	62	9	1403	Deck area	26.222 million sq.ft
Health index weight	100	80	50	0			
Discount rate	2.2%						

Comments:
1. Modified Bridge Counts, Deck Area, Joint Qty and Rail Qty based on Thomas' email from 8/14
2. Modified action title "Scour repair" to "Erosion/scour repair". Modified cost because there may be smaller projects involved.
3. Modified percentages based on maintenance data, contract data and typical frequencies
4. Modified patching and slope paving repair unit/br based on bridge

Deterioration model - without preservation	Years	Good	Satis	Fair	Poor
Good	30	97.7%	2.3%	0.0%	0.0%
Satis	10		93.3%	6.7%	0.0%
Fair	10			93.3%	6.7%
Poor	--				100%

Deterioration model - with preservation	Years	Good	Satis	Fair	Poor
Good	45	98.5%	1.5%	0.0%	0.0%
Satis	15		95.5%	4.5%	0.0%
Fair	20			96.6%	3.4%
Poor	--				100%

Routine maintenance					% bridges acted upon in a year				Real ✓
Treatment	Units	$/unit	Unit/br	$k/br	Good	Satis	Fair	Poor	$M/yr
Inspection	Bridge	1111	0	0.0	60%	60%	60%	60%	0.0
Flushing	Bridge	500	0	0.0	75%	75%	75%	75%	0.0
Not used	Each	0	1	0.0					0.0
Annual cost per bridge - no preservation ($k)					0.0	0.0	0.0	0.0	0.0
Annual cost per bridge - preservation scenario ($k)					0.0	0.0	0.0	0.0	0.0

Corrective action					% bridges acted upon in a year				Real ✓	Percent improved											
Treatment	Units	$/unit	Unit/br	$k/br	Good	Satis	Fair	Poor	$M/yr	Effect	Good	Satis	Fair	Poor	Good	Satis	Fair	Poor	Totals	From Maintenance Data	
Patching	SF	100	561	56.1			10%	15%	0.4	0.5	0.0%	0.0%	5.0%	7.5%	0	0	6.2	1.35	7.55	29	8.7
Slope paving repair	SF	20	1308	26.2		1%	1%		0.1	0.2	0.0%	0.1%	0.2%	0.0%	0	1.355	0.62	0	1.975	5	1.5
Erosion/Scour Repair	Each	25000	1	25.0			5%	5%	0.1	0.1	0.0%	0.0%	0.5%	0.5%	0	0	3.1	0.45	3.55	15	4.5
Not used	Each	0	1	0.0					0.0		0.0%	0.0%	0.0%	0.0%	0	0	0	0	0		
Total percent acted upon					0%	1%	16%	20%							0	1.355	9.92	1.8	13.075		
Annual cost per bridge ($k)					0.0	0.1	7.1	9.7	0.6		0.0%	0.1%	5.7%	8.0%							
Approximate interval (years)									107.3												

Rehab/replacement					% bridges acted upon in a year				Real ✓	Resulting condition				
Treatment	Units	$/unit	Unit/br	$k/br	Good	Satis	Fair	Poor	$M/yr	Good	Satis	Fair	Poor	Poor
Replace elements	Bridge	100000	1	100.0				1%	0.0	90%	10%			0.045
Replace structure	SF	145	0	0.0				20%	0.0	100%				1.8
Total percent acted upon					0%	0%	0%	21%						
Annual cost per bridge ($k)					0.0	0.0	0.0	0.5	0.0	99.8%	0.2%			
								41%						

BRIDGE DECK PROJECTIONS (20 OF 200 YEAR ANALYSIS)

Forecast condition and cost - Bridge decks

	Pure deterioration - no maint					Pure deterioration - routine maint					Worst-first scenario					($M)	Worst-first - typical bridge					Preservation scenario					($M)	Preservation - typical bridge				
Year	Good	Satis	Fair	Poor	Health	Good	Satis	Fair	Poor	Health	Good	Satis	Fair	Poor	Cost	PV$	Good	Satis	Fair	Poor	Health	Good	Satis	Fair	Poor	Cost	PV$	Good	Satis	Fair	Poor	Health
0	1.000	0.000	0.000	0.000	100.0	1.000	0.000	0.000	0.000	100.0	1.000	0.000	0.000	0.000	0.00	0.00	1.000	0.000	0.000	0.000	100.0	1.000	0.000	0.000	0.000	8.02	8.02	1.000	0.000	0.000	0.000	100.0
1	0.962	0.038	0.000	0.000	99.24	0.970	0.030	0.000	0.000	99.39	0.962	0.038	0.000	0.000	0.00	0.00	0.962	0.038	0.000	0.000	99.24	0.970	0.030	0.000	0.000	8.11	7.94	0.970	0.030	0.000	0.000	99.39
2	0.926	0.069	0.005	0.000	98.37	0.940	0.057	0.003	0.000	98.72	0.926	0.069	0.005	0.000	0.00	0.00	0.926	0.069	0.005	0.000	98.37	0.941	0.057	0.003	0.000	8.25	7.90	0.940	0.057	0.003	0.000	98.72
3	0.891	0.095	0.013	0.001	97.37	0.912	0.081	0.007	0.000	97.99	0.891	0.095	0.013	0.001	0.05	0.05	0.891	0.095	0.013	0.001	97.37	0.913	0.080	0.007	0.000	8.44	7.91	0.912	0.081	0.007	0.000	97.99
4	0.857	0.117	0.024	0.002	96.24	0.884	0.101	0.014	0.001	97.19	0.857	0.117	0.024	0.002	0.17	0.16	0.857	0.117	0.024	0.002	96.24	0.887	0.101	0.011	0.001	8.66	7.94	0.884	0.101	0.014	0.001	97.19
5	0.825	0.134	0.036	0.005	94.99	0.857	0.119	0.022	0.002	96.33	0.826	0.134	0.036	0.005	0.37	0.33	0.825	0.134	0.036	0.005	94.99	0.863	0.120	0.017	0.001	8.90	7.98	0.857	0.119	0.022	0.002	96.33
6	0.794	0.148	0.049	0.010	93.61	0.831	0.135	0.030	0.004	95.40	0.796	0.148	0.049	0.008	0.64	0.56	0.794	0.148	0.049	0.010	93.61	0.839	0.137	0.022	0.002	9.15	8.03	0.831	0.135	0.030	0.004	95.40
7	0.764	0.159	0.061	0.016	92.13	0.806	0.148	0.039	0.007	94.40	0.768	0.159	0.061	0.012	0.98	0.84	0.764	0.159	0.061	0.016	92.13	0.817	0.154	0.027	0.003	9.39	8.07	0.806	0.148	0.039	0.007	94.40
8	0.735	0.167	0.074	0.024	90.54	0.782	0.159	0.049	0.010	93.35	0.742	0.167	0.074	0.017	1.36	1.14	0.735	0.167	0.074	0.024	90.54	0.796	0.169	0.032	0.003	9.64	8.10	0.782	0.159	0.049	0.010	93.35
9	0.707	0.173	0.086	0.034	88.85	0.758	0.169	0.059	0.015	92.23	0.718	0.173	0.086	0.023	1.77	1.46	0.707	0.173	0.086	0.034	88.85	0.776	0.183	0.036	0.004	9.88	8.12	0.758	0.169	0.059	0.015	92.23
10	0.680	0.177	0.097	0.045	87.09	0.735	0.177	0.068	0.020	91.07	0.696	0.178	0.097	0.028	2.20	1.77	0.680	0.177	0.097	0.045	87.09	0.757	0.197	0.041	0.005	10.11	8.13	0.735	0.177	0.068	0.020	91.07
11	0.655	0.180	0.108	0.058	85.26	0.713	0.184	0.078	0.026	89.85	0.677	0.181	0.108	0.034	2.64	2.08	0.655	0.180	0.108	0.058	85.26	0.739	0.209	0.045	0.006	10.33	8.13	0.713	0.184	0.078	0.026	89.85
12	0.630	0.182	0.117	0.072	83.37	0.691	0.189	0.087	0.033	88.59	0.660	0.184	0.117	0.039	3.08	2.37	0.630	0.182	0.117	0.072	83.37	0.723	0.221	0.049	0.007	10.54	8.12	0.691	0.189	0.087	0.033	88.59
13	0.606	0.182	0.125	0.087	81.43	0.670	0.193	0.096	0.040	87.28	0.645	0.185	0.126	0.045	3.50	2.64	0.606	0.182	0.125	0.087	81.43	0.707	0.232	0.053	0.008	10.75	8.10	0.670	0.193	0.096	0.040	87.28
14	0.583	0.181	0.133	0.103	79.45	0.650	0.197	0.105	0.049	85.94	0.632	0.185	0.134	0.050	3.91	2.88	0.583	0.181	0.133	0.103	79.45	0.692	0.242	0.057	0.009	10.94	8.07	0.650	0.197	0.105	0.049	85.94
15	0.561	0.180	0.139	0.120	77.45	0.630	0.199	0.113	0.058	84.56	0.620	0.185	0.140	0.055	4.29	3.10	0.561	0.180	0.139	0.120	77.45	0.678	0.252	0.060	0.009	11.12	8.02	0.630	0.199	0.113	0.058	84.56
16	0.540	0.178	0.144	0.138	75.43	0.611	0.200	0.121	0.068	83.15	0.610	0.185	0.146	0.059	4.64	3.28	0.540	0.178	0.144	0.138	75.43	0.665	0.261	0.064	0.010	11.29	7.97	0.611	0.200	0.121	0.068	83.15
17	0.520	0.175	0.149	0.157	73.40	0.592	0.201	0.128	0.079	81.72	0.602	0.184	0.151	0.063	4.97	3.43	0.520	0.175	0.149	0.157	73.40	0.653	0.270	0.067	0.011	11.46	7.91	0.592	0.201	0.128	0.079	81.72
18	0.500	0.172	0.152	0.176	71.36	0.574	0.202	0.134	0.090	80.26	0.595	0.183	0.155	0.067	5.26	3.56	0.500	0.172	0.152	0.176	71.36	0.641	0.278	0.070	0.012	11.61	7.85	0.574	0.202	0.134	0.090	80.26
19	0.481	0.169	0.155	0.196	69.33	0.557	0.201	0.140	0.102	78.79	0.589	0.181	0.159	0.070	5.53	3.66	0.481	0.169	0.155	0.196	69.33	0.630	0.286	0.072	0.012	11.76	7.77	0.557	0.201	0.140	0.102	78.79
20	0.463	0.165	0.156	0.216	67.32	0.540	0.200	0.145	0.114	77.30	0.585	0.180	0.162	0.073	5.76	3.73	0.463	0.165	0.156	0.216	67.32	0.620	0.293	0.075	0.013	11.89	7.70	0.540	0.200	0.145	0.114	77.30

BRIDGE SUPERSTRUCTURE PROJECTIONS (20 OF 200 YEAR ANALYSIS)

Forecast condition and cost - Bridge superstructures

	Pure deterioration - no maint					Pure deterioration - routine maint					Worst-first scenario					($M)	Worst-first - typical bridge					Preservation scenario					($M)	Preservation - typical bridge				
Year	Good	Satis	Fair	Poor	Health	Good	Satis	Fair	Poor	Health	Good	Satis	Fair	Poor	Cost	PV$	Good	Satis	Fair	Poor	Health	Good	Satis	Fair	Poor	Cost	PV$	Good	Satis	Fair	Poor	Health
0	1.000	0.000	0.000	0.000	100.0	1.000	0.000	0.000	0.000	100.0	1.000	0.000	0.000	0.000	0.93	0.93	1.000	0.000	0.000	0.000	100.0	1.000	0.000	0.000	0.000	1.50	1.50	1.000	0.000	0.000	0.000	100.0
1	0.977	0.023	0.000	0.000	99.54	0.985	0.015	0.000	0.000	99.69	0.977	0.023	0.000	0.000	0.93	0.91	0.977	0.023	0.000	0.000	99.54	0.985	0.015	0.000	0.000	1.75	1.72	0.985	0.015	0.000	0.000	99.69
2	0.955	0.044	0.002	0.000	99.05	0.970	0.030	0.001	0.000	99.37	0.955	0.044	0.002	0.000	0.93	0.89	0.955	0.044	0.002	0.000	99.05	0.970	0.029	0.001	0.000	2.00	1.92	0.970	0.030	0.001	0.000	99.37
3	0.933	0.063	0.004	0.000	98.52	0.955	0.043	0.002	0.000	99.03	0.933	0.063	0.004	0.000	1.01	0.95	0.933	0.063	0.004	0.000	98.52	0.957	0.041	0.002	0.000	2.26	2.12	0.955	0.043	0.002	0.000	99.03
4	0.912	0.080	0.008	0.000	97.96	0.940	0.056	0.004	0.000	98.68	0.912	0.080	0.008	0.000	1.22	1.12	0.912	0.080	0.008	0.000	97.96	0.944	0.052	0.003	0.000	2.53	2.32	0.940	0.056	0.004	0.000	98.68
5	0.891	0.095	0.013	0.001	97.35	0.926	0.068	0.006	0.000	98.31	0.891	0.095	0.013	0.001	1.58	1.41	0.891	0.095	0.013	0.001	97.35	0.933	0.062	0.005	0.000	2.82	2.53	0.926	0.068	0.006	0.000	98.31
6	0.871	0.109	0.019	0.002	96.71	0.912	0.079	0.009	0.000	97.93	0.871	0.109	0.019	0.002	2.11	1.85	0.871	0.109	0.019	0.002	96.71	0.921	0.071	0.007	0.000	3.12	2.74	0.912	0.079	0.009	0.000	97.93
7	0.851	0.122	0.025	0.003	96.03	0.898	0.089	0.012	0.001	97.53	0.851	0.122	0.025	0.002	2.81	2.41	0.851	0.122	0.025	0.003	96.03	0.911	0.080	0.009	0.000	3.43	2.95	0.898	0.089	0.012	0.001	97.53
8	0.831	0.133	0.031	0.005	95.32	0.884	0.099	0.016	0.001	97.11	0.832	0.133	0.031	0.004	3.67	3.08	0.831	0.133	0.031	0.005	95.32	0.901	0.087	0.011	0.001	3.76	3.16	0.884	0.099	0.016	0.001	97.11
9	0.812	0.143	0.038	0.007	94.56	0.871	0.108	0.020	0.002	96.68	0.814	0.143	0.038	0.005	4.69	3.85	0.812	0.143	0.038	0.007	94.56	0.891	0.094	0.014	0.001	4.09	3.36	0.871	0.108	0.020	0.002	96.68
10	0.794	0.152	0.045	0.009	93.78	0.857	0.116	0.024	0.002	96.23	0.796	0.152	0.045	0.006	5.84	4.70	0.794	0.152	0.045	0.009	93.78	0.883	0.101	0.016	0.001	4.42	3.56	0.857	0.116	0.024	0.002	96.23
11	0.776	0.160	0.052	0.012	92.96	0.844	0.124	0.029	0.003	95.77	0.780	0.160	0.052	0.008	7.12	5.60	0.776	0.160	0.052	0.012	92.96	0.874	0.106	0.018	0.001	4.75	3.74	0.844	0.124	0.029	0.003	95.77
12	0.758	0.167	0.059	0.016	92.11	0.831	0.131	0.033	0.004	95.30	0.763	0.167	0.059	0.010	8.50	6.55	0.758	0.167	0.059	0.016	92.11	0.866	0.112	0.020	0.001	5.08	3.92	0.831	0.131	0.033	0.004	95.30
13	0.741	0.173	0.067	0.020	91.23	0.819	0.138	0.038	0.005	94.81	0.748	0.173	0.067	0.012	9.96	7.51	0.741	0.173	0.067	0.020	91.23	0.859	0.117	0.022	0.002	5.41	4.08	0.819	0.138	0.038	0.005	94.81
14	0.724	0.178	0.074	0.024	90.32	0.806	0.144	0.043	0.007	94.31	0.733	0.179	0.074	0.014	11.49	8.47	0.724	0.178	0.074	0.024	90.32	0.852	0.122	0.024	0.002	5.73	4.23	0.806	0.144	0.043	0.007	94.31
15	0.707	0.183	0.081	0.029	89.39	0.794	0.150	0.048	0.008	93.79	0.720	0.184	0.081	0.016	13.07	9.43	0.707	0.183	0.081	0.029	89.39	0.845	0.126	0.027	0.002	6.05	4.36	0.794	0.150	0.048	0.008	93.79
16	0.691	0.187	0.088	0.035	88.42	0.782	0.156	0.053	0.010	93.26	0.706	0.188	0.088	0.018	14.68	10.37	0.691	0.187	0.088	0.035	88.42	0.839	0.130	0.028	0.002	6.35	4.48	0.782	0.156	0.053	0.010	93.26
17	0.675	0.190	0.094	0.040	87.44	0.770	0.161	0.058	0.012	92.72	0.694	0.191	0.094	0.020	16.32	11.27	0.675	0.190	0.094	0.040	87.44	0.833	0.134	0.030	0.003	6.65	4.59	0.770	0.161	0.058	0.012	92.72
18	0.660	0.193	0.101	0.047	86.43	0.758	0.165	0.064	0.013	92.17	0.682	0.194	0.101	0.022	17.95	12.14	0.660	0.193	0.101	0.047	86.43	0.827	0.138	0.032	0.003	6.93	4.68	0.758	0.165	0.064	0.013	92.17
19	0.645	0.195	0.107	0.054	85.41	0.746	0.169	0.069	0.016	91.61	0.671	0.197	0.107	0.025	19.59	12.95	0.645	0.195	0.107	0.054	85.41	0.822	0.141	0.034	0.003	7.20	4.76	0.746	0.169	0.069	0.016	91.61
20	0.630	0.197	0.113	0.061	84.37	0.735	0.173	0.074	0.018	91.03	0.661	0.199	0.113	0.027	21.20	13.72	0.630	0.197	0.113	0.061	84.37	0.817	0.144	0.036	0.003	7.47	4.83	0.735	0.173	0.074	0.018	91.03

BRIDGE SUBSTRUCTURE PROJECTIONS (20 OF 200 YEAR ANALYSIS)

Forecast condition and cost - Bridge substructures

	Pure deterioration - no maint					Pure deterioration - routine maint					Worst-first scenario					($M)	Worst-first - typical bridge					Preservation scenario					($M)	Preservation - typical bridge				
Year	Good	Satis	Fair	Poor	Health	Good	Satis	Fair	Poor	Health	Good	Satis	Fair	Poor	Cost	PV$	Good	Satis	Fair	Poor	Health	Good	Satis	Fair	Poor	Cost	PV$	Good	Satis	Fair	Poor	Health
0	1.000	0.000	0.000	0.000	100.0	1.000	0.000	0.000	0.000	100.0	1.000	0.000	0.000	0.000	0.00	0.00	1.000	0.000	0.000	0.000	100.0	1.000	0.000	0.000	0.000	0.00	0.00	1.000	0.000	0.000	0.000	100.0
1	0.977	0.023	0.000	0.000	99.54	0.985	0.015	0.000	0.000	99.69	0.977	0.023	0.000	0.000	0.00	0.00	0.977	0.023	0.000	0.000	99.54	0.985	0.015	0.000	0.000	0.00	0.00	0.985	0.015	0.000	0.000	99.69
2	0.955	0.044	0.002	0.000	99.05	0.970	0.030	0.001	0.000	99.37	0.955	0.044	0.002	0.000	0.00	0.00	0.955	0.044	0.002	0.000	99.05	0.970	0.030	0.001	0.000	0.01	0.01	0.970	0.030	0.001	0.000	99.37
3	0.933	0.063	0.004	0.000	98.52	0.955	0.043	0.002	0.000	99.03	0.933	0.063	0.004	0.000	0.00	0.00	0.933	0.063	0.004	0.000	98.52	0.955	0.043	0.002	0.000	0.03	0.03	0.955	0.043	0.002	0.000	99.03
4	0.912	0.080	0.008	0.000	97.96	0.940	0.056	0.004	0.000	98.68	0.912	0.080	0.008	0.000	0.00	0.00	0.912	0.080	0.008	0.000	97.96	0.940	0.056	0.004	0.000	0.05	0.04	0.940	0.056	0.004	0.000	98.68
5	0.891	0.095	0.013	0.001	97.35	0.926	0.068	0.006	0.000	98.31	0.891	0.095	0.013	0.001	0.00	0.00	0.891	0.095	0.013	0.001	97.35	0.926	0.068	0.006	0.000	0.07	0.07	0.926	0.068	0.006	0.000	98.31
6	0.871	0.109	0.019	0.002	96.71	0.912	0.079	0.009	0.000	97.93	0.871	0.109	0.019	0.002	0.00	0.00	0.871	0.109	0.019	0.002	96.71	0.912	0.079	0.008	0.000	0.10	0.09	0.912	0.079	0.009	0.000	97.93
7	0.851	0.122	0.025	0.003	96.03	0.898	0.089	0.012	0.001	97.53	0.851	0.122	0.025	0.002	0.00	0.00	0.851	0.122	0.025	0.003	96.03	0.898	0.090	0.011	0.000	0.14	0.12	0.898	0.089	0.012	0.001	97.53
8	0.831	0.133	0.031	0.005	95.32	0.884	0.099	0.016	0.001	97.11	0.832	0.133	0.031	0.004	0.00	0.00	0.831	0.133	0.031	0.005	95.32	0.885	0.100	0.014	0.001	0.17	0.15	0.884	0.099	0.016	0.001	97.11
9	0.812	0.143	0.038	0.007	94.56	0.871	0.108	0.020	0.002	96.68	0.814	0.143	0.038	0.005	0.00	0.00	0.812	0.143	0.038	0.007	94.56	0.871	0.110	0.018	0.001	0.21	0.17	0.871	0.108	0.020	0.002	96.68
10	0.794	0.152	0.045	0.009	93.78	0.857	0.116	0.024	0.002	96.23	0.796	0.152	0.045	0.006	0.00	0.00	0.794	0.152	0.045	0.009	93.78	0.858	0.119	0.021	0.001	0.25	0.20	0.857	0.116	0.024	0.002	96.23
11	0.776	0.160	0.052	0.012	92.96	0.844	0.124	0.029	0.003	95.77	0.780	0.160	0.052	0.008	0.01	0.00	0.776	0.160	0.052	0.012	92.96	0.846	0.128	0.025	0.002	0.29	0.23	0.844	0.124	0.029	0.003	95.77
12	0.758	0.167	0.059	0.016	92.11	0.831	0.131	0.033	0.004	95.30	0.763	0.167	0.059	0.010	0.01	0.01	0.758	0.167	0.059	0.016	92.11	0.833	0.136	0.028	0.002	0.34	0.26	0.831	0.131	0.033	0.004	95.30
13	0.741	0.173	0.067	0.020	91.23	0.819	0.138	0.038	0.005	94.81	0.748	0.173	0.067	0.012	0.01	0.01	0.741	0.173	0.067	0.020	91.23	0.821	0.145	0.032	0.002	0.38	0.29	0.819	0.138	0.038	0.005	94.81
14	0.724	0.178	0.074	0.024	90.32	0.806	0.144	0.043	0.007	94.31	0.733	0.179	0.074	0.014	0.01	0.01	0.724	0.178	0.074	0.024	90.32	0.809	0.152	0.036	0.003	0.43	0.31	0.806	0.144	0.043	0.007	94.31
15	0.707	0.183	0.081	0.029	89.39	0.794	0.150	0.048	0.008	93.79	0.720	0.184	0.081	0.016	0.01	0.01	0.707	0.183	0.081	0.029	89.39	0.797	0.160	0.040	0.003	0.47	0.34	0.794	0.150	0.048	0.008	93.79
16	0.691	0.187	0.088	0.035	88.42	0.782	0.156	0.053	0.010	93.26	0.706	0.188	0.088	0.018	0.01	0.01	0.691	0.187	0.088	0.035	88.42	0.786	0.167	0.044	0.003	0.52	0.37	0.782	0.156	0.053	0.010	93.26
17	0.675	0.190	0.094	0.040	87.44	0.770	0.161	0.058	0.012	92.72	0.694	0.191	0.094	0.020	0.01	0.01	0.675	0.190	0.094	0.040	87.44	0.775	0.174	0.048	0.004	0.56	0.39	0.770	0.161	0.058	0.012	92.72
18	0.660	0.193	0.101	0.047	86.43	0.758	0.165	0.064	0.013	92.17	0.682	0.194	0.101	0.022	0.02	0.01	0.660	0.193	0.101	0.047	86.43	0.764	0.180	0.052	0.004	0.61	0.41	0.758	0.165	0.064	0.013	92.17
19	0.645	0.195	0.107	0.054	85.41	0.746	0.169	0.069	0.016	91.61	0.671	0.197	0.107	0.025	0.02	0.01	0.645	0.195	0.107	0.054	85.41	0.753	0.186	0.055	0.005	0.66	0.43	0.746	0.169	0.069	0.016	91.61
20	0.630	0.197	0.113	0.061	84.37	0.735	0.173	0.074	0.018	91.03	0.661	0.199	0.113	0.027	0.02	0.01	0.630	0.197	0.113	0.061	84.37	0.743	0.193	0.059	0.005	0.70	0.45	0.735	0.173	0.074	0.018	91.03

Bridge Decks		
	Typical	Worst First
Undiscounted Sum	4,307,399	9,890,119
Net Present Value (NPV)	801,887	1,803,674
Equivalent Uniform Annual Cost (EUAC)	17,872	40,198
% of initial cost	159%	365%
Bridge Superstructures		
	Typical	Worst First
Undiscounted Sum	1,599,110	6,088,156
Net Present Value (NPV)	277,749	962,546
Equivalent Uniform Annual Cost (EUAC)	6,190	21,452
% of initial cost	59%	225%
Bridge Substructures		
	Typical	Worst First
Undiscounted Sum	2,555,022	6,103,786
Net Present Value (NPV)	347,826	964,992
Equivalent Uniform Annual Cost (EUAC)	7,752	21,507
% of initial cost	94%	225%

Note: All costs in $/bridge
Initial costs not included in analysis

Chapter 7

PERFORMANCE GAPS: SUPPLEMENTAL INFORMATION

PERFORMANCE GAPS: SUPPLEMENTAL INFORMATION

Overview

Chapter 3 of the TAMP describes MnDOT's business practices, performance measures, and targets used to monitor and report asset conditions, as well as the new target terminology used in the TAMP. Figure 3-1 summarizes these new key terms associated with targets, which now override the language used to describe performance outcomes in MnSHIP. Moving forward, MnDOT will use the term "target" to denote desired outcomes. The term "plan outcome" will be used to identify outcomes to which MnDOT is managing, while the term "expected outcome" will be used to demonstrate the results of predictive modeling performed using various analytical tools.

Note:

Chapter 7 of the TAMP contains all the necessary information pertaining to current and targeted performance levels. Hence, no additional information is provided in this chapter of the Technical Guide.

Chapter 8

FINANCIAL PLAN AND INVESTMENT STRATEGIES: SUPPLEMENTAL INFORMATION

FINANCIAL PLAN AND INVESTMENT STRATEGIES: SUPPLEMENTAL INFORMATION

Overview

This chapter provides a description of the asset management investment strategies developed and how they were incorporated into the TAMP. While specific strategies were laid out for investments in pavement and bridge assets in the Minnesota State Highway Investment Plan (MnSHIP), the investment strategy for other "Roadside Infrastructure" assets (including, but not limited to, highway culverts, deep stormwater tunnels, overhead sign structures and high-mast light tower structures) was generic and focused primarily on maintaining operable conditions at expected funding levels. MnSHIP does not explicitly break out the asset types within the Roadside Infrastructure investment category. Therefore, as a part of the TAMP development process, investment strategies for highway culverts, deep stormwater tunnels, overhead sign structures and high-mast light tower structures were examined more closely and tools were developed to estimate the level of investment needed to maintain these assets over the 10-year period covered in the TAMP.

Process

This chapter includes brief descriptions of the investment strategies developed in MnSHIP and the Highway Systems Operations Plan (HSOP) and how they were incorporated into the TAMP. This is followed by a discussion on the process for developing investment strategies for highway culverts, overhead sign structures, and high-mast light tower structures. Finally, a summary is provided regarding the envisioned process changes for how future TAMPs will inform MnSHIP.

INVESTMENT STRATEGIES

As discussed in Chapter 2 of the TAMP, tradeoffs between investment levels, performance levels, and risks were evaluated as a part of the MnSHIP development process to understand and demonstrate the impact of a holistic investment decision methodology. Three approaches were considered during the MnSHIP scenario planning process:

- Approach A: Focus on maintaining existing infrastructure on the entire system, leaving little-to-no ability to invest in local priorities and mobility.
- Approach B (Adopted): Maintain an approach similar to MnDOT's current priorities – emphasizing pavements, bridges, and safety – with some improvements in local priorities and mobility.
- Approach C: Greater emphasis on mobility for all modes and addressing local concerns at priority locations, which will result in significant declines in infrastructure condition on most state highways.

Considering two primary risks – (a) failure to implement federal policy set in MAP-21 and (b) failure to preserve the state's bond rating by falling below the thresholds set in Government Accounting Standards Board Statement 34 (GASB 34) – the investment strategy adopted for the first 10 years focused on maintaining a diverse mix of improvements to reduce overall life-cycle costs, as well as enhancing mobility and MnDOT's ability to respond to evolving needs. The asset management investment strategy laid out in MnSHIP is summarized in Figure 8-1.

Figure 8-1: MnSHIP Investment Strategies

INVESTMENT CATEGORY		10-YEAR STRATEGY
Asset Management	Pavements	• Maintain conditions on NHS pavements. • Allow non-NHS pavements to deteriorate to a slightly lower condition, while maintaining safe conditions for the traveling public. • Use low-cost maintenance and preservation strategies. • Use performance-based design to select projects that address pavement and safety needs. • Alternate bidding and contracting mechanisms to determine the most cost-effective solutions. • Research/evaluate innovative materials and construction techniques.
	Bridges	• Maintain condition of NHS bridges. • Allow non-NHS bridges to deteriorate to a slightly lower condition, while keeping them safe and operable to the traveling public. • Invest in state highway bridges at optimum points in their life- cycles to ensure safety and structural health. • Conduct bridge inspections to ensure timely application of maintenance and capital improvements. • Apply appropriate measures to ensure bridges achieve or exceed their intended service lives.
	Roadside Infrastructure	• Maintain culverts, signals, sign structures, sign panels, lighting structures, rest areas, barriers, and retaining walls in safe operable conditions with the understanding that their general conditions are expected to deteriorate with current expected funding levels.

In addition to the capital investment strategies outlined in MnSHIP, HSOP provides a framework for managing key operations and maintenance activities throughout Minnesota and complements other strategic planning efforts, such as MnDOT's District Highway Investment Plans, which focus on capital infrastructure needs. Specific maintenance/operations strategies to address a host of critical issues faced by MnDOT – ranging from aging infrastructure to increased responsibilities (as a result of state and federal mandates) to declining staff levels – are discussed in detail in HSOP (and summarized in Chapter 2 of the TAMP).

The strategies laid out in MnSHIP and HSOP are carried forward in MnDOT's TAMP. Moving forward, future TAMPs are expected to inform MnSHIP updates and streamline the investment planning process (discussed later).

ASSET INVESTMENT STRATEGIES PRESENTED IN THE TAMP

The specific investment strategies adopted for the asset categories discussed in the TAMP are summarized below.

PAVEMENTS

After performance targets were established for pavements (see Chapter 3 of the TAMP), investment levels and strategies to achieve those targets were developed using MnDOT's Highway Pavement Management Application (HPMA) by modeling performance-constrained scenarios. Because this effort was already completed as a part of the MnSHIP process, the results were carried forward and adopted in the TAMP.

BRIDGES

After performance targets were established for bridges (see Chapter 3 of the TAMP), investment levels and strategies to achieve those targets were developed using MnDOT's Pontis bridge management system, for bridge inventory and condition data, and MnDOT's Bridge Replacement and

Improvement Management System (BRIM), for prioritizing projects and developing network-level cost estimates. This effort, too, was already completed as a part of the MnSHIP process, and these results were also carried forward and adopted in the TAMP.

HIGHWAY CULVERTS AND DEEP STORMWATER TUNNELS (HYDRAULIC INFRASTRUCTURE)

As discussed in the TAMP, MnSHIP does not explicitly break out the asset categories within the Roadside Infrastructure investment category, but highway culverts and deep stormwater tunnel needs are provided for in the investment plan. Costs specific to culvert and stormwater tunnel needs were obtained from the MnSHIP investment planning team for reporting in the TAMP.

MnDOT recognizes that fixing hydraulic assets in Very Poor condition (HydInfra Condition Level 4) is more expensive than repairing them before they have reached this condition; cheaper treatments are not feasible when assets deteriorate to a Very Poor condition. Therefore, and due to the high cost and risk of catastrophic failure associated with these assets, MnDOT has adopted a preventive maintenance strategy of applying treatments to culverts and tunnels before they reach a condition of Very Poor.

A spreadsheet-based repair projection model was developed by MnDOT to estimate the repair needs for highway culverts over the 10-year TAMP planning horizon. The projections make some general assumptions:

- Culverts degrading to a Very Poor condition were previously one level better (HydInfra Condition Level 3: Poor) and any fixes applied to culverts in Very Poor and Poor conditions restore the conditions to an Excellent (HydInfra Condition Level 1) or a Fair (HydInfra Condition Level 2) level.
- No new culverts are built over the next 10 years and none of the existing culverts are taken out of service.
- The oldest pipes are fixed first.

Using the assumptions listed above and adopting a simple deterioration model, it was estimated that approximately 600 culverts in Very Poor condition would need to be repaired each year over the next 10 years to achieve the recommended performance targets.

OVERHEAD SIGN STRUCTURES AND HIGH-MAST LIGHT TOWER STRUCTURES (OTHER TRAFFIC STRUCTURES)

The investment strategy for overhead sign structures and high-mast light tower structures was developed using an approach that considers the fraction of structures in various condition levels and makes a balanced investment according to expert input from the Other Traffic Structures Work Group.

Investment needs for these assets are based on inspection costs (which account for the bulk of the need) and assumptions about treatment needs over the next 10 years (based on discussions with the Work Group). A spreadsheet tool was developed to assist with determination of the investment needs.

INVESTMENT PLANNING WORKSHOPS

Two formal workshops were held to discuss the recommendations for investment strategies to be adopted as part of the TAMP:

- Investment Planning Workshop #1 (November 2013): Preliminary recommendations for the investment strategies and performance targets were discussed during this workshop. Targets for pavements and bridges were tweaked based on discussions held during this meeting. The group (TAMP Steering Committee plus representatives from MnDOT's senior leadership) also recognized that targets for highway culverts, deep stormwater tunnels, overhead sign structures, and high-mast light tower structures were largely based on expert opinion for this first TAMP, but that future TAMPs will work toward developing objective and outcome-based targets.
- Investment Planning Workshop #2 (January 2013): This workshop focused on finalizing the investment levels and performance targets that were incorporated into the TAMP.

FUTURE PROCESS CHANGES

Because much of the investment planning process was already completed as a part of the MnSHIP process, the efforts were not duplicated for the TAMP. The results were validated, refined, and incorporated into the TAMP after approval by the Steering Committee. In order to establish a more streamlined process moving forward, the investment planning process will be conducted as a part of future TAMPs and the outcomes will serve as the basis for MnSHIP updates (for assets covered in the TAMP).

MnDOT is also in the process of implementing management systems for asset categories beyond pavements and bridges. These systems, collectively referred to as Transportation Asset Management Systems (TAMS), will allow MnDOT to better manage roadside infrastructure through an objective, data-driven approach, which will also improve the development of investment strategies and targets. The first TAMS implementation will focus on traffic signals and lighting.

Supporting Data and Documentation

As discussed earlier, spreadsheet tools were developed to estimate the level of investment required for hydraulic infrastructure and other traffic structures over the 10-year planning horizon covered in the TAMP. Examples of these tools are included as attachments at the end of the chapter.

Attachments

Highway Culvert Target Methodology

Pipes quantity per condition category with NO FIXING

	year 0	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10
condition 1,2	39810	39260	38710	38160	37610	37060	36510	35960	35410	34860	34310
condition 3	4739	4859	4979	5099	5219	5339	5459	5579	5699	5819	5939
condition 4	2844	3274	3704	4134	4564	4994	5424	5854	6284	6714	7144
										Total:	47393

FIXES NEEDED OVER 10 YEARS

condition 3 repairs for 10 years	2148
condition 3 repairs /year needed	215
condition 4 repairs for 10 years	5722
number of condition 4 repair /year needed	572
TOTAL FIXES PER YEAR	787

Prevision to reach 10-year targets/Amount of pipes required in each condition category

	year 0	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10	TARGET
condition 1,2	39810	40047	40284	40521	40758	40995	41232	41469	41706	41943	42180	42180
condition 3	4739	4645	4550	4455	4360	4265	4171	4076	3981	3886	3791	3791
condition 4	2844	2701	2559	2417	2275	2133	1991	1848	1706	1564	1422	1422
											Total:	47393

CURRENT CONDITIONS

	2012
% Condition 4	0.06
% Condition 3	0.1
% Condition 1,2	0.84
Total culverts	47393
Amount of pipes becoming condition 4/year	430
Amount of pipes becoming condition 3/year	550

	Percent
2022 target for condition 4	0.03
2022 target for condition 3	0.08
fixing capability /yr	430

Assumptions used for the previsions:

1 - We assume that the pipes degrading to condition 4 were previously condition 3 pipes. Similarly, pipes degrading to condition 3 were previously in condition 2.

2 - The prevision assumes that no extra pipes will be built and that no pipes will be taken away. We use a total of 47,393 pipes over the ten years.

3 - a fixed pipe returns to a condition 1 or 2 pipe.

Highway Culvert Repair Projection Model

CONDITION 4 CULVERTS

	AGE											
YEARS	?	1	2	3	4	5	6	7	8	9	10	count
0	2843											
1	2271	430										
2	1699	430	430	0	0	0	0	0	0	0	0	
3	1127	430	430	430	0	0	0	0	0	0	0	
4	555	430	430	430	430	0	0	0	0	0	0	
5	0	430	430	430	430	413	0	0	0	0	0	17
6	0	430	430	430	430	271	0	0	0	0	0	159
7	0	430	430	430	430	129	0	0	0	0	0	301
8	0	430	430	430	417	0	0	0	0	0	0	443
9	0	430	430	430	275	0	0	0	0	0	0	155
10	0	430	430	430	133	0	0	0	0	0	0	297

Number of Condition 4 repair/year 572

Fix existing condition 4		5
Fix New condition 4		
Added	year 1	6
	year 2	6
	year 3	6
	year 4	5
	year 5	5
	year 6	5
	year 7	5
	year 8	?
	year 9	?
	year 10	?

ASSUMPTIONS

1 - The oldest pipes are always fixed first
2 - 572 pipes are repaired each year

Summary of Current Overhead Sign Structure Condition

Overall Condition Rating	Description	SRF - Number of structures per rating	Structures that have Maintenance work done and/or planned construction work will move from 2,3,4,5 to 6	7-2-13 Structures per condition rating	% of total		New Totals	New Percentages
2	Critical	143	26	117	6%		42	1.78%
3	Serious	257	53	204	11%		147	6.22%
4	Poor	423	81	342	18%		137	5.80%
5	Fair	357	70	287	15%		376	15.91%
6	Satisfactory	200	*49*	430	23%		1595	67.50%
7	Good	32	*2*	32	2%		60	2.54%
8	Very Good	3	0	3	0%		6	0.25%
			281	1415			2363	100.00%
			230 moved to 6					

CO Active Structures	1857
Retired per Metro	4
Not inspected	438
Condition Total	1415

Modified percentages after structures statewide have been included. All remaining 510 structures are reported to be in 100% good condition.

Poor	36%	62% (414) of these have loose anchorages/nuts
Fair	15%	
Good	25%	

For structures not inspected, the most reasonable assumption would be to go with the Good/Fair/Poor distribution observed for the structures inspected. This can be revised in the Asset Register

Based on inspected structures:

Poor	249	17.6%	77		326	13.8%
Fair	287	20.3%	89		376	15.9%
Good	879	62.1%	272	510	1661	70.3%
Totals	1415		438		2363	

Summary of Overhead Sign Structures Investment History

Metro	328
Total No.	475
Others	147

Total Statewide Figures (Based on Extrapolation of Metro Numbers Statewide)

Inspection Cycle	Year	No. of Structures Inspected	No of Structures Requiring: No Maintenance	Routine Maintenance	Preventive Maintenance	Minor Rehabilitation	Major Rehabilitation	Replacement
1	2012	149	120	22	NA	7	0	0
2	2011	301	203	59	NA	39	0	0
3	2010	49	26	19	NA	4	0	0
4	2009	310	256	54	NA	0	0	0
5	2007	55	30	25	NA	0	0	0
6	2005	142	101	12	NA	0	0	0
7	2003	155	155	0	NA	0	0	0
8	2001	181	181	0	NA	0	0	0
Avg. /yr		168		18.8%		17		
Std. Dev.		97						
Average + SD		265						

Only Metro

Inspection Cycle	Year	No. of Structures Inspected	No of Structures Requiring: No Maintenance	Routine Maintenance	Preventive Maintenance	Minor Rehabilitation	Major Rehabilitation	Replacement
1	2012	103	83	15	NA	5	0	0
2	2011	208	140	41	NA	27	0	0
3	2010	34	18	13	NA	3	0	0
4	2009	214	177	37	NA	0	0	0
5	2007	38	21	17	NA	0	0	0
6	2005	98	70	8	NA	0	0	0
7	2003	107	107	0	NA	0	0	0
8	2001	125	125	0	NA	0	0	0
Avg. /yr		116		18.8%		12		
Std. Dev.		67						
Average + SD		183						

Other Structures Statewide (Extrapolated from Metro numbers)

Inspection Cycle	Year	No. of Structures Inspected	No of Structures Requiring: No Maintenance	Routine Maintenance	Preventive Maintenance	Minor Rehabilitation	Major Rehabilitation	Replacement
1	2012	46	37	7	NA	2	0	0
2	2011	93	63	18	NA	12	0	0
3	2010	15	8	6	NA	1	0	0
4	2009	96	79	17	NA	0	0	0
5	2007	17	9	8	NA	0	0	0
6	2005	44	31	4	NA	0	0	0
7	2003	48	48	0	NA	0	0	0
8	2001	56	56	0	NA	0	0	0
Avg. /yr		52		18.8%		5		
Std. Dev.		30						
Average + SD		82						

Approach 1:

Assumptions:

1. 183 Structures are inspected each year from 2014 - 2023 (10 year period), which gives a total of 1830 inspections.
2. Average inspection cost of $1000/structure.
3. Average Routine maintenance cost of $500/structure, 18.8% of structures inspected receive routine maintenance per year.
4. Average replacement cost of $40,000/structure, assuming 1 structure replaced per year over next 10 years.
5. Minor rehabilitation cost assumed to be $2000 per structure (value not provided by work group), 12 strucures assumed to receive minor rehab per year.

Total Inspections 10-yr inspections	2650

		10-Yr Number	10-Yr Cost
Inspection Cost (per structure)	$1,000	2650	$2,650,006
Routine Maintenance Cost (per structure)	$500	499	$249,749
Minor Rehabilitation Cost (per structure)	$2,000	169	$337,907
Replacement Cost (per strucutre)	$40,000	10	$400,000
		Total	$3,637,662

Approach 2:

Assumptions:

1. Using a 5-year inspection cycle, assumed that 95 structures are inspected each each on an average.
2. Average inspection cost of $1000/structure.
3. Average Routine maintenance cost of $500/structure, 18.8% of structures inspected receive routine maintenance per year.
4. Average replacement cost of $40,000/structure, assuming 1 structure replaced per year over next 10 years.
5. Minor rehabilitation cost assumed to be $2000 per structure (value not provided by work group), 12 strucures assumed to receive minor rehab per year.

Total Inspections 10-yr inspections	950

		10-Yr Number	10-Yr Cost
Inspection Cost (per structure)	$1,000	950	$950,000
Routine Maintenance Cost (per structure)	$500	179	$89,532
Minor Rehabilitation Cost (per structure)	$2,000	169	$337,907
Replacement Cost (per strucutre)	$40,000	10	$400,000
		Total	$1,777,439

Summary of Overhead Sign Structures Investments Needed to Achieve 10-year Targets

Inventory			Inspections			Tighten Nuts			Remove Grout			Regrade footing, Replace weld...			Replace foundation...			Replace Structure			10-Yr Investment
Condition	Total	Percent	No. of Cycles	Number	Cost	Fraction	Number	Cost	Fraction	Number	Cost	Fraction	Number	Cost	Fraction	Number	Cost	Fraction	Number	Cost	
Good	1661	70%	2	2335	$2,682,654	0%	0	$0	0%	0	$0	0%	0	$0	0%	0	$0	0%	0	$0	$2,682,654
Fair	376	16%	2	120	$606,979	0%	0	$0	0%	0	$0	0%	0	$0	0%	0	$0	0%	0	$0	$606,979
Poor	326	14%	2	90	$526,612	40%	111	$55,433	15%	42	$41,575	10%	28	$83,149	17%	47	$1,177,948	10%	28	$2,355,896	$4,240,613
Total	2363	100%			$3,816,245			$55,433			$41,575			$83,149			$1,177,948			$2,355,896	$7,530,246

	Inspections	Tighten Nuts	Remove Grout	Regrade footing, Replace weld...	Replace foundation...	Replace Structure
Avg. Unit Costs/structure	$950	$500	$1,000	$3,000	$25,000	$85,000
Inspection %	85%	85%	85%	85%	85%	85%

User input
Computation
Output

	C/S/P	Poor	Serious	Critical	Ser+Crit
		42%	45%	13%	
2013 % Poor	13.8%	5.8%	6.2%	1.8%	8.0%
%Poor acted on in the next 10 years	12.7%				
Estimation %Overlap b/w treatments	3.0%				
Estimated 2023 % Poor	4.1%	1.7%	1.9%	0.5%	2.4%

Potential 10 yr Targets

Chapter 9

IMPLEMENTATION AND FUTURE DEVELOPMENTS: SUPPLEMENTAL INFORMATION

IMPLEMENTATION AND FUTURE DEVELOPMENTS: SUPPLEMENTAL INFORMATION

Overview

This chapter describes a process to help MnDOT decide which assets to consider adding when it develops future TAMPs. A few asset management tools and techniques that MnDOT could potentially implement in the future are also discussed.

Process

This section describes a generic process that MnDOT can use to help identify future enhancements to the TAMP. For instance, it includes a process for identifying assets that can be added to future versions of the TAMP. It also includes information on the gap analysis technique used for evaluating current and desired practices and for identifying priorities for actions needed to achieve agency goals. Other performance metrics are also included that can be used to track the financial sustainability of MnDOT's investments.

INCORPORATING OTHER ASSETS IN THE TAMP

Figure 9-1 depicts a process for evaluating the availability and maturity of data for a given asset category, to determine whether it can or needs to be included in the TAMP.

Figure 9-1: Process Used to Collect and Summarize Asset Data

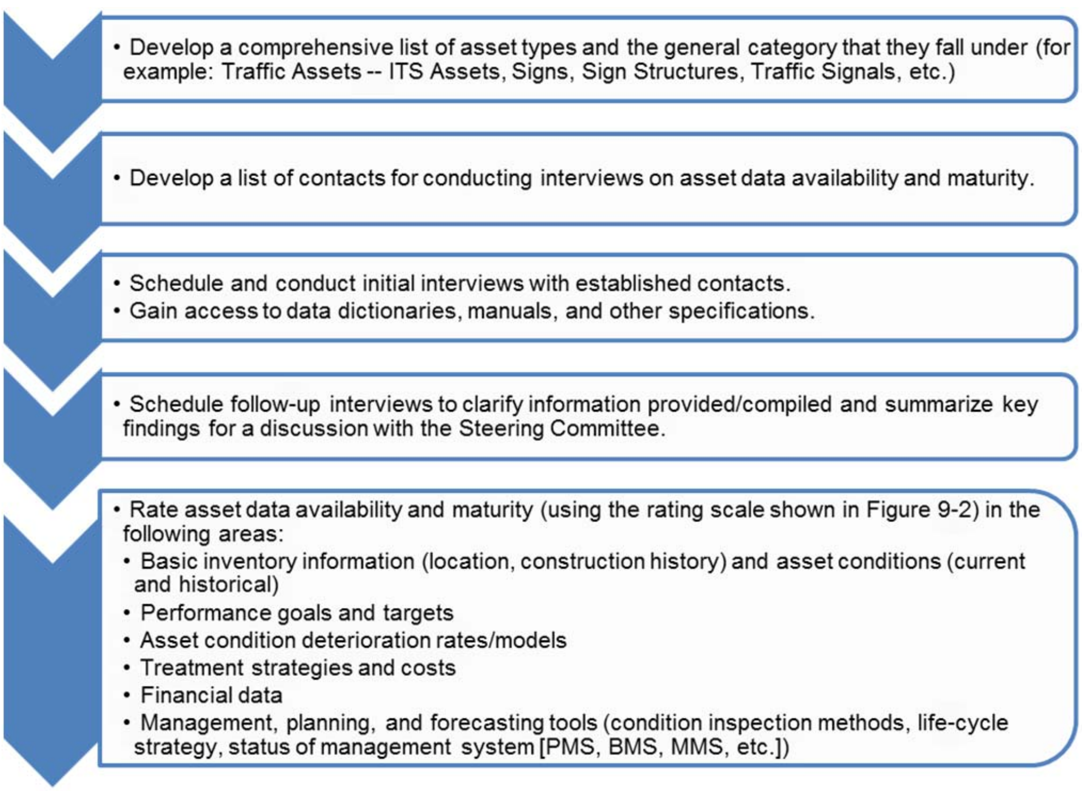


Figure 9-2: Rating Scale for Data Availability and Maturity Assessment

RATING	DESCRIPTION
1	Readily available with minimum manipulation, well-established process, data verified and high-confidence in system
2	Intermediate availability, requires moderate level of manipulation to convert data to a usable format, efforts to improve systems in place
3	Difficult to use data in current format/significant manipulations required, no management system but data tracked through spreadsheets, somewhat documented system
4	Information not readily available/very little data available, no management system in place, complete lack or very little documentation on process
5	Not available/unable to assess, No management system in place

After the data availability and maturity assessments are made, the results should be organized into a matrix (similar to the one shown in Figure 9-3) for comparing the asset categories evaluated.

Figure 9-3: Sample Data Availability and Maturity Level Assessment Summary

ASSET	RATING FOR:					
	BASIC INVENTORY AND CONDITIONS	PERFORMANCE GOALS AND, TARGETS	TREATMENT STRATEGIES AND COSTS	DETERIORATION RATES	FINANCIAL DATA	MANAGEMENT PLANNING, AND FORECASTING
Pavements	1	1	2	2	2	2
Bridges	1	3	3	5	2	4
ITS Assets	2	4	3	5	2	4
Slopes	2	3	3	5	5	5
Guard Rails, Barriers, Impact Attenuators	3	5	3	5	5	4

It should be noted that data availability and maturity cannot be the only driving factors for determination of the final list of assets that will be included in the TAMP; other factors to consider include:

- Level of investment in the assets, including either financial investments or personnel time
- Contribution to the agency's risk levels
- Reporting requirements, legislation, or mandates (e.g. MAP-21 requirements, EPA, GASB, and MnDOT internal requirements)
- Departmental strategic priorities
- Historical practices
- The need to balance transportation partner needs and requests

The final decision regarding the assets to be included should be conducted through a workshop facilitated by the Asset Management Steering Committee and involving members of the asset Work Groups and other MnDOT stakeholders.

GAP ANALYSIS

A gap analysis is a technique that provides an objective and structured process for evaluating current and desired practices and identifying priority actions needed to achieve agency goals. A gap analysis process typically includes a scoring system that allows an agency to rate a specific set of criteria (developed for a specific topic) in order to determine the maturity level for each component included in the assessment.

A recent National Cooperative Highway Research Program project (NCHRP 08-90) resulted in the development of an updated gap analysis spreadsheet tool for asset management. The tool considers MAP-21 requirements and will help state transportation departments identify actions to include in their asset management improvement plans. The gap analysis tool (a) enables an objective assessment of agency practices; (b) introduces a framework for assessing gaps in legislated requirements or core capabilities; (c) provides a tool to facilitate data analysis; and (d) simplifies the analysis and reporting of this information.

The final products from this study are expected to be available in the fall of 2014 through NCHRP[1]. Transportation agencies could potentially use the tool to identify, evaluate, and prioritize areas for improvement through a more structured and streamlined approach.

OTHER PERFORMANCE METRICS

A study published by the FHWA[2] examines a host of proposed performance measures that are centered on an *Asset Sustainability Index* (ASI). The report defines ASI as *a composite metric computed by dividing the amount budgeted on infrastructure maintenance and preservation[3] over time by the amount needed to achieve a specific infrastructure target*. Mathematically, it is:

$$ASI = \frac{Amount\ Budgeted}{Amount\ Needed}$$

An ASI value of 1.0 is considered an ideal scenario when all the needs are accounted for. The ASI can be used in time-series plots to analyze long-term trends, and can also be used as a combined metric to include all the assets being managed by an agency. Or, it can focus on a specific asset category or activity (e.g. pavements, bridges, maintenance) to develop a sustainability ratio metric specific to that asset/activity.

Although the ASI is a relatively simple concept, time-series ASI data can be a very informative metric for long-term (and short-term) planning purposes. An example of how Asset Sustainability Indices can be used to visualize program needs is shown in Figure 9-4.

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[1] NCHRP (2014). Transportation Asset Management Gap Analysis Tool (Web Link)
[2] FHWA (2012). Asset Sustainability Index: A Proposed Measure for Long-Term Performance (Web Link)
[3] The terms "maintenance" and "preservation" are generically used to include routine, reactive, preventive, rehabilitative, and even replacement activities that contribute to the achievement of an infrastructure condition target.

Figure 9-4: Illustration of Asset Sustainability Indices (Output)

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Pavements	0.83	0.82	0.81	0.81	0.80	0.79	0.78	0.77	0.77	0.76
Major Routes	0.80	0.79	0.78	0.78	0.77	0.76	0.75	0.75	0.74	0.73
Arterials	1.00	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91
Collectors	1.00	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91
Pavement Rehabilitation/Replacement	0.40	0.40	0.39	0.39	0.38	0.38	0.38	0.37	0.37	0.37
Pavement Preventive Mainenance	1.00	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91
Bridges	0.90	0.89	0.88	0.87	0.86	0.86	0.85	0.84	0.83	0.82
Preventive Maintenance/Preservation	0.90	0.89	0.88	0.87	0.86	0.86	0.85	0.84	0.83	0.82
Sub and Superstructures	0.87	0.86	0.85	0.84	0.84	0.83	0.82	0.81	0.80	0.79
Decks	0.89	0.88	0.88	0.87	0.86	0.85	0.84	0.83	0.82	0.82
Painting	1.00	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91
Maintenance	0.95	0.94	0.93	0.92	0.91	0.90	0.89	0.89	0.88	0.87
Guardrail	0.95	0.94	0.93	0.92	0.91	0.90	0.89	0.89	0.88	0.87
Pavement Markings	0.95	0.94	0.93	0.92	0.91	0.90	0.89	0.89	0.88	0.87
Drainage	0.95	0.94	0.93	0.92	0.91	0.90	0.89	0.89	0.88	0.87
Signage	0.95	0.94	0.93	0.92	0.91	0.90	0.89	0.89	0.88	0.87
Vegetation/Roadside	0.95	0.94	0.93	0.92	0.91	0.90	0.89	0.89	0.88	0.87
Pavement Surfaces	0.95	0.94	0.93	0.92	0.91	0.90	0.89	0.89	0.88	0.87
Overall ASI	0.88	0.87	0.855	0.84	0.83	0.82	0.81	0.79	0.77	0.75

Each asset/program has its own sustainability index, which can be then be aggregated into an overall ASI for the agency. The agency can then analyze the specific asset(s)/program(s) that strongly impact the overall ASI. This can help the agency and policymakers set priorities as they make investment decisions. Such a performance metric can help track the financial sustainability of agency assets.

Glossary of Terms

GLOSSARY OF TERMS

The primary source of information for this glossary is the *AASHTO Transportation Asset Management Guide: A Focus on Implementation* (AASHTO 2011)

Asset: The physical transportation infrastructure (e.g. travel way, structures, other features and appurtenances, operations systems, and major elements thereof); more generally, can include the full range of resources capable of producing value-added for an agency: human resources, financial capacity, real estate, corporate information, equipment and materials, etc.; an individual, separately-managed component of the infrastructure (e.g. bridge deck, road section surface, streetlight).

Asset Management (AM): A strategic approach to managing transportation infrastructure. It focuses on business processes for resource allocation and utilization with the objective of better decision making based upon quality information and well-defined objectives.

Asset Management System: An integrated set of procedures, tools, software, and data intended to support proactive management decision making regarding the preservation, improvement, and replacement of assets.

Capital Investment: A type of investment that generally involves construction or major repair; includes the construction of new assets, reconstruction or replacement of existing assets, structural and functional improvements to existing assets, and rehabilitation of existing assets; when precision is required, capital refers to work that is funded under the agency's capital budget according to agency policy.

Deterioration Model: A mathematical model to predict the future condition of an asset or asset element, if no action, or only un-programmed maintenance, is performed.

Direct Costs: Costs of an agency activity that are directly related to the quantity of work (e.g. labor, material, equipment usage, contract pay items).

Equivalent Uniform Annual Cost (EUAC): Net present value, converted to an annuity (uniform annual monetary amount) or perpetuity.

Expected Outcomes: These are forecasted outcomes based on predictive modeling.

Gap Analysis: A tool for drilling down into the detail of the transportation asset management processes which uses the maturity model as its scale.

Health Index: Weighted average computed over the elements of an asset and a set of condition criteria, of the percent of each element that satisfies each criterion. It may be described by terms such as bridge condition rating or index, or pavement condition rating or index.

Indirect Costs: The cost of implementing a programmed activity, including direct and indirect costs. In capital budgeting analyses, initial cost is interpreted as the direct reduction in available budget as a result of a commitment to the activity.

Level of Service (LOS): Qualitative measures related to the public's perception of asset condition or of agency services; used to express current and target values for maintenance and operations activities.

Life Cycle: A length of time that spans the stages of asset construction, operation, maintenance, rehabilitation, and reconstruction or disposal/abandonment; when associated with analyses, refers to a length of time sufficient to span these several stages and to capture the costs, benefits, and long-term performance impacts of different investment options.

Life-Cycle Cost: Net present value (or equivalent uniform annual cost) of the sequence of monetary costs and benefits in a life-cycle activity profile. In the context of a life-cycle cost analysis, LCC should be defined as to the types of costs it includes; for example whether un-programmed maintenance or user costs (or both) are included, as well as inflationary assumptions about the cost stream.

Maturity Model: A concept used to specify the relative position of the agency for each transportation asset management process.

Performance: Characteristic of an asset that reflects its functionality or its serviceability as perceived by transportation users; may be related to condition.

Performance Gap: The gap between an asset's current condition/performance and a defined target or threshold value; implies need for work.

Performance Measure: An indicator, preferably quantitative, of service provided by the transportation system to users; the service may be gauged in several ways (e.g. quality of ride, efficiency and safety of traffic movements, services at rest areas, quality of system condition, etc.).

Periodic Maintenance: Maintenance or repair activity that is conducted on a fixed schedule according to manufacturer recommendations, research recommendations, or a maintenance intervention strategy (e.g. light bulb replacement, vehicle maintenance).

Plan Outcomes: These describe performance outcomes that are consistent with MnDOT financially constrained spending priorities. *Targets* and *Plan Outcomes* are not mutually exclusive.

Preservation: Actions to deter or correct deterioration of an asset to extend its useful life; does not entail structural or operational improvement of an existing asset beyond its originally designed strength or capacity.

Preventive Maintenance: Proactive maintenance approach that is applied while the asset is still in good condition; extends asset life by preventing the onset or growth (propagation) of distress.

Prioritization: Arrangement of investment candidates in descending order according to their importance to the agency mission (usually represented by an objective function or benefit measure) in relation to their initial cost.

Reactive Maintenance: Emergency or other un-programmed time-sensitive maintenance or repair that arises as a response to observed defects or performance problems (e.g. small bridge deck repairs, traffic signal repairs, incident response).

Rehabilitation: An event consisting of multiple treatments intended to correct physical or functional defects that impair the satisfaction of a level of service standard that the asset may previously have satisfied. It may include replacement of parts of the asset but not the entire asset, and is generally understood to be more significant in scale than a repair.

Repair: Treatment applied in order to correct a physical or functional defect that impairs the satisfaction of a level of service standard that the asset may previously have satisfied. Repairs are usually understood as intermediate in scale between maintenance and rehabilitation. Specific instances of repairs may be programmed or un-programmed according to agency policy.

Replacement: Disposal of an existing asset and substitution of a new asset serving the same functional requirements and possibly additional requirements in the same location; replacement-in-kind is a type of replacement where the new asset is substantially similar in function to the old asset, following the principle of modern engineering equivalence.

Risk (of an asset): The possibility of adverse consequences related to an asset from natural or man-made hazards. Generally consists of the likelihood of the hazard, the consequences of the hazard to the asset, and the impact of asset damage or malfunction on the mission of the asset or on life, property, or the environment.

Routine Maintenance: Un-programmed, non-urgent maintenance activities undertaken by crews that are scheduled on a daily, weekly, or monthly basis (e.g. street cleaning, drainage inspection and maintenance, bridge washing).

Strategic: A view of assets that is policy-based, performance-driven, long-term, and comprehensive.

Targets: A fixed benchmark against which MnDOT evaluates past, present, and future performance.