

## SCAN TEAM REPORT

NCHRP Project 20-68A, Scan 20-01

# Successful Approaches to Utilizing Bridge Management Systems for Strategic Decision Making in Asset Management Plans

*Supported by the*

National Cooperative Highway Research Program

The information contained in this report was prepared as part of NCHRP Project 20-68 U.S. Domestic Scan, National Cooperative Highway Research Program.

**SPECIAL NOTE:** This report **IS NOT** an official publication of the National Cooperative Highway Research Program, Transportation Research Board, or the National Academies of Sciences, Engineering, and Medicine.



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The purpose of each scan, and of Project 20-68A as a whole, is to accelerate beneficial innovation by facilitating information sharing and technology exchange among the states and other transportation agencies and identifying actionable items of common interest. Experience has shown that personal contact with new ideas and their application is a particularly valuable means for such sharing and exchange. A scan entails peer-to-peer discussions between practitioners who have implemented new practices and others who are able to disseminate knowledge of these new practices and their possible benefits to a broad audience of other users. Each scan addresses a single technical topic selected by AASHTO and the NCHRP 20-68A Project Panel. Further information on the NCHRP 20-68A U.S. Domestic Scan program is available at

<https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=1570>

This report was prepared by the scan team for Domestic Scan 20-01, *Successful Approaches to Utilizing Bridge Management Systems for Strategic Decision Making in Asset Management Plans*, whose members are listed below. Scan planning and logistics are managed by Arora and Associates, P.C.; Harry Capers is the Principal Investigator. NCHRP Project 20-68A is guided by a technical project panel and managed by Sid Mohan, NCHRP Program Officer.

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# Disclaimer

The information in this document was taken directly from the submission of the authors. The opinions and conclusions expressed or implied are those of the scan team and are not necessarily those of the Transportation Research Board or its sponsoring agencies. This report has not been reviewed by and is not a report of the Transportation Research Board or the National Academies of Sciences, Engineering, and Medicine.



# Scan 20-01 Successful Approaches to Utilizing Bridge Management Systems for Strategic Decision Making in Asset Management Plans

REQUESTED BY THE

American Association of State Highway and Transportation Officials

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# Abbreviations and Acronyms

<b>AADT</b>	Annual Average Daily Traffic
<b>AASHTO</b>	American Association of State Highway and Transportation Officials
<b>ADT</b>	Average Daily Traffic
<b>BCFS</b>	Bridge Condition Forecasting System (Michigan DOT)
<b>BCI</b>	Bridge Condition Index (Iowa DOT)
<b>BHI</b>	Bridge Health Index (Utah DOT)
<b>BMS</b>	Bridge Management System
<b>BRIM</b>	Bridge Replacement and Improvement Management (MnDOT)
<b>BrM</b>	AASHTOWare™ Bridge Management software
<b>Caltrans</b>	California Department of Transportation
<b>CAN</b>	Change Agent Network
<b>CDOT</b>	Colorado DOT
<b>CFR</b>	Code of Federal Regulations
<b>COTS</b>	Consumer Off-the-Shelf
<b>CTDOT</b>	Connecticut Department of Transportation
<b>DOT</b>	Department of Transportation
<b>dTIMS</b>	Deighton Total Infrastructure Management System
<b>EGIS</b>	Enterprise Geographic Information System (New Mexico DOT)
<b>FAST</b>	Act Fixing America’s Surface Transportation Act
<b>FDOT</b>	Florida Department of Transportation
<b>FHWA</b>	Federal Highway Administration
<b>G/F/P</b>	Good/Fair/Poor
<b>GCR</b>	General Condition Rating
<b>GDOT</b>	Georgia Department of Transportation
<b>GIS</b>	Geographic Information System

<b>HCI</b>	Human Capital Institute
<b>HI</b>	Health Index
<b>HR</b>	Human Resources
<b>IT</b>	Information Technology
<b>MAP-21</b>	Moving Ahead for Progress in the 21st Century Act
<b>MDOT</b>	Michigan Department of Transportation
<b>MDOT SHA</b>	Maryland Department of Transportation State Highway Administration
<b>MnDOT</b>	Minnesota Department of Transportation
<b>MoDOT</b>	Missouri Department of Transportation
<b>NBE</b>	National Bridge Elements
<b>NBI</b>	National Bridge Inventory
<b>NCHRP</b>	National Cooperative Highway Research Program
<b>NDOT</b>	Nevada Department of Transportation
<b>NHDOT</b>	New Hampshire Department of Transportation
<b>NHS</b>	National Highway System
<b>NMDOT</b>	New Mexico Department of Transportation
<b>ODOT</b>	Ohio Department of Transportation
<b>PennDOT</b>	Pennsylvania Department of Transportation
<b>PIN</b>	Personal Identification Number
<b>QA</b>	Quality Assurance
<b>QC</b>	Quality Control
<b>SGR</b>	State of Good Repair Program (VDOT)
<b>SHRM</b>	Society for Human Resource Management
<b>SIIMS</b>	Structure Inventory and Inspection Management System (Iowa DOT)
<b>SME</b>	Subject Matter Expert
<b>STIP</b>	State Transportation Improvement Program
<b>SWM</b>	Strategic Workforce Management
<b>SWMP</b>	Strategic Workforce Management Plan

<b>SWOT</b>	Strengths, Weaknesses, Opportunities, and Threats
<b>TAMP</b>	Transportation Asset Management Plan
<b>TRB</b>	Transportation Research Board
<b>TxDOT</b>	Texas Department of Transportation
<b>UDOT</b>	Utah Department of Transportation
<b>USDOT</b>	U.S. Department of Transportation
<b>USGS</b>	U.S. Geological Survey
<b>VDOT</b>	Virginia Department of Transportation
<b>VTrans</b>	Vermont Agency of Transportation
<b>WMP</b>	Workforce Management Plan
<b>WSDOT</b>	Washington State Department of Transportation

# Executive Summary

Bridge management is about the selection and evaluation of cost-effective programmatic optimal strategies for comprehensive management of bridges and structures. It is concerned with identifying and communicating critical data needs and vulnerability assessments for effective life-cycle cost analysis and management of structures. From a state Department of Transportation asset management perspective, bridges are the next critical asset category after pavements in terms of expenditures. However, bridges represent a significantly greater risk profile than pavements, as road users cannot drive on failed bridges and bridge failures can be catastrophic.

A review of the 2019 Transportation Asset Management Plans (TAMPs) indicated very little documentation on the inclusion of a bridge management system's (BMS) analytic components within the TAMP processes. TAMP processes with analytic components are performance gap identification, life-cycle cost and risk management analysis, and analysis of investment strategies. This disconnect was discussed within the asset management community and within the Federal Highway Administration's Asset Management Expert Task Group. This national scan was an outcome of these discussions and aims to help identify common features and approaches agencies are using to successfully use BMSs within the overall transportation asset management context.

Following the organizational meeting in September 2020, the scan team prepared 82 amplifying questions that focused on understanding the bridge inventory, organizational, and funding structure of the state DOT, identifying the decision support tools, data, performance measures and models used for bridge management; integration of BMS outputs into overall transportation asset management and TAMP; and the sustainability of BMS use and bridge management efforts. A desk scan, including a brief review of the most relevant reports, papers, web resources, the TAMPs submitted by state DOTs prior to June 30, 2019, and a survey of eight state DOTs (Iowa, Louisiana, Michigan, Minnesota, New Mexico, Pennsylvania, Utah, and Virginia) using the amplifying questions was conducted.

Based on the agency interviews and information from TAMPs, most state DOTs were found to be at basic BMS implementation level, based on the BMSWG maturity levels <sup>1</sup> developed by the AASHTO TSP2 Bridge Preservation BMS National Working Group. There were, however, agencies that are at an intermediate level or agencies that have components of their BMS implementation that can be regarded as intermediate. Based on the desk scan findings, the scan team invited nine state DOTs to the virtual workshop conducted during March 4-10, 2021. The invited agencies from the following state DOTs: Connecticut, Florida, Iowa, Michigan, Minnesota, New Mexico, Pennsylvania, Utah, and Virginia.

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1 BMSWG Maturity Levels, Detailed Work Scope by Bridge Management System (BMS) Advancement Tier, AASHTO TSP-2, Bridge Preservation BMS National Working Group:  
<https://tsp2bridge.pavementpreservation.org/files/2018/10/BMS-Working-Group-Attachment-A-Final.pdf>

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A revised set of amplifying questions was sent to the invited agencies and formed the basis of the agencies' virtual workshop presentations and the roundtable discussions. This report summarizes scan findings on data collection and management, performance measures, BMS models, use of BMS for communication, knowledge transfer strategies, and insights from asset management practitioners, as well as key scan findings and recommendations.

The agency presentations show that there is no one-size-fits-all solution or approach in using BMS to support transportation asset management due to the variability in agencies' organizational structures, funding structures, and bridge networks. While some agencies use consumer off-the-shelf technology software systems, others use in-house developed software or spreadsheets, or procedures followed by staff to perform analysis and make decisions. For some agencies, overall bridge management decision making is driven by BMS; for others, BMS partially supports the decision-making framework or TAMP analysis. All scan agencies were strong in inspection data collection and management. Using information based on element condition data in asset management decision making is limited to date; however, some agencies have made progress in this area, including developing agency custom performance measures; establishing agency-defined elements to produce more accurate work recommendations; and recording environments that, in combination with agency-defined elements, should improve deterioration model accuracy in the future. Scan agencies collectively reported challenges in hiring and sustaining qualified staff and noted that they feel understaffed to keep up with increasing needs. Agencies are finding innovative ways to report and track performance and have made significant progress with the TAMP development in their use and implementation of BMS. However, agencies have challenges and needs: improved models (deterioration, costs, and risks), qualified and increased staffing and retention, improved measures/metrics to define bridge performance, placing less emphasis on worst-first programming, and contrasting bridge performance with other assets, to name a few.

The recommendations to better guide and improve the use of BMSs for asset management and TAMP development presented in this report are based on the key scan findings. The scan team compiled a comprehensive list of recommendations to improve the use of BMSs for asset management and TAMP development, that among others, includes the following:

- Task forces with shared membership from state and national bridge, pavement, and asset management groups that meet regularly to come up with a roadmap to improve the use of BMS in asset management decision making
- The necessity of a strategic vision and process to guide BMS implementation and incorporation of BMS information into overall asset management
- The use of additional measures other than condition for analysis and reporting in order to tell a complete story and give more value to least life-cycle cost strategies
- Executive support for hiring qualified staff
- Strategies to maintain agency knowledge
- Research to support BMS implementation



# Introduction

## Background

Asset management (AM) means a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both engineering and economic analysis, based on quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the life cycle of the assets at minimum practicable cost (23 USC <sup>2</sup>, 23 Code of Federal Regulations [CFR] 515 <sup>3</sup>). The asset management approach incorporates an economic assessment of trade-offs among alternative investment options and uses this information to help make cost-effective investment decisions.

A transportation asset management plan (TAMP) is a strategic approach to managing transportation infrastructure assets. It focuses on business processes for resource allocation and utilization with the objective of better decision making based on quality information about assets and well-defined objectives expressed as levels of service or measures of effectiveness. This approach achieves the best performance results for the preservation, improvement, and operation of infrastructure assets given the available resources of a state Department of Transportation (DOT).

In 2012, Congress passed MAP-21 (Moving Ahead for Progress in the 21st Century Act) provisions, which envisioned major improvements to surface transportation, safety, congestion, and freight while providing long-term funding certainty for surface transportation. MAP-21 was less prescriptive in its allocation of funding to different asset classes and replaced the previous prescriptive allocations with the requirement that states develop asset management plans to determine and describe how funding will be allocated. Pavement and bridges located on the National Highway System (NHS) are the only two mandatory asset classes that state DOTs must address in their federally required TAMPs. MAP-21 objectives and requirements were implemented by regulation 23 CFR 515, which provides more detail on how the MAP-21 requirements are to be implemented and satisfied. Nonbinding supplemental guidance is also periodically released to provide further technical detail. Transportation agencies that adopt asset management processes and technologies for managing their pavement and bridge assets, including data-supported asset management plans, will have more success in making a case for increased funding for their assets and will be able to maintain intended flexibilities in their application of federal funding.

Bridge management is about the selection and evaluation of cost-effective programmatic-optimal strategies for comprehensive management of bridges and structures. It is concerned with identifying and communicating critical data needs and vulnerability assessments for effective life-cycle cost analysis and management of structures. From the state DOT asset management perspective, bridges are the

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2 Highways, United States Code, <https://www.govinfo.gov/content/pkg/USCODE-2011-title23/html/USCODE-2011-title23.htm>

3 Asset Management Plans, Transportation Infrastructure Management, Code of Federal Regulations, <https://www.ecfr.gov/current/title-23/chapter-I/subchapter-F/part-515>

next critical asset category after pavements in terms of expenditure. However, bridges represent a significantly greater risk profile than pavements, as road users cannot drive on failed bridges and bridge failures can be catastrophic.

## Scan Objective and Scope

During preliminary efforts for this scan, a review of the 2019 transportation asset management plans (TAMPs) indicated little documentation on the inclusion of bridge management system (BMS) analytic components within the TAMP processes. TAMP processes with analytic components are performance gap identification, life-cycle cost and risk management analysis, and analysis of investment strategies. This disconnect was discussed within the asset management community and within the Federal Highway Administration's (FHWA's) Asset Management Expert Task Group. This national scan was an outcome of these discussions and aims to help identify common features and approaches agencies are using to successfully use BMSs within the overall TAM context.

The scan team investigated agency practices and case studies that illuminate such concerns as:

- Data collection and management
- Performance measure tracking and reporting
- Use of component- and element-level data to track and forecast bridge condition
- Use of BMS data to convey condition information
- Agencies' knowledge transfer strategies to sustain staff qualified to operate their BMS

The primary audience for this report is state transportation agencies; however, local transportation agencies, metropolitan planning organizations, FHWA, and the American Association of State Highway and Transportation Officials (AASHTO) will also benefit from the information provided within this report. It is anticipated that state and local transportation agencies and metropolitan planning organizations in varying stages of BMS use and implementation will be able to use this report to help them further integrate their BMS into TAM decision making. In addition, it is anticipated that AASHTO and FHWA will be able to use this report to further assist agencies in their efforts to use BMS.

## Scan Team and Participants

In September 2020, the scan team met virtually for the initial organizational meeting. Members of the scan team, drawn from city and state DOTs, FHWA, and academia, are given in **Table 1-1**.

Name	Affiliation
Chad A. Allen, AASHTO Chair	City of Seattle, DOT
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Chester Kolota	Maine DOT
Edward Lutgen	Minnesota DOT
Kevin Marshia	Vermont Agency of Transportation
Scott Neubauer	Iowa DOT
Felix Padilla	Florida DOT
Richard W. Runyen	Pennsylvania DOT
C. Todd Springer	Virginia DOT
Paul Vaught	Louisiana DOT and Development
DeWayne Wilson	Washington State DOT
Başak Bektaş, SME	Minnesota State University, Mankato

*Table 1-1: Scan team members*

During the organizational meeting, the team members discussed the team’s approach to the scan and scan logistics in a virtual environment. The scan team then developed preliminary amplifying questions to provide a framework and focus for the most relevant issues and information that would align the scan effort with the scan objective. The scan team members, who were affiliated with different DOTs, each provided an independent list of questions. The team members were also asked to identify agencies that were likely to provide potentially valuable information on different aspects of the BMS implementation and use in transportation AM.

The subject matter expert (SME) processed, grouped, and compiled the amplifying questions and submitted them to different state DOTs as a questionnaire. The amplifying questions (Appendix A) consisted of 82 questions grouped into 10 categories. The questions focused on identifying and understanding the state DOT’s bridge inventory and organizational and funding structure; the decision support tools, data, performance measures, and models used for bridge management; the integration of BMS outputs into overall TAM and TAMP; and the sustainability of BMS use and bridge management efforts. The categories were:

- TAMP/Program-Related Questions
- Organizational Structure and Bridge Network
- Funding Structure
- Decision Support Tools for Bridge Management
- Bridge Management Data Use and Governance
- Performance Measures
- BMS Implementation
- Modeling
- Communication
- Sustainability

A desk scan was conducted that included a brief review of the most relevant reports, papers, web resources; the TAMPs that state DOTs submitted prior to June 30, 2019; and, using the amplifying questions, a survey of eight state DOTs. The state DOTs that were surveyed by online meetings and e-mail communication were Iowa, Louisiana, Michigan, Minnesota, New Mexico, Pennsylvania, Utah, and Virginia.

The SME presented a summary of the desk scan’s process, findings, and the highlights of the state DOT survey findings. Overall, based on the agency interviews and information from TAMPs, most state DOTs were found to be at basic BMS implementation level, based on the BMSWG maturity levels developed by the AASHTO TSP2 Bridge Preservation BMS National Working Group<sup>4</sup>. There were, however, agencies that are at an intermediate level or agencies that have components of their BMS implementation that can be regarded as intermediate. Based on the desk scan findings, the scan team invited nine state DOTs to the virtual workshop conducted from March 4-10, 2021. The invited state DOTs were Connecticut, Florida, Iowa, Michigan, Minnesota, New Mexico, Pennsylvania, Utah, and Virginia.

A revised set of amplifying questions was sent to the invited agencies and formed the basis of the agencies’ virtual workshop presentations and the roundtable discussions. Arora and Associates, P.C., managed scan planning and logistics; Harry Capers was the principal investigator. **Figure 1-1** shows each scan team member’s home state and scan agencies.

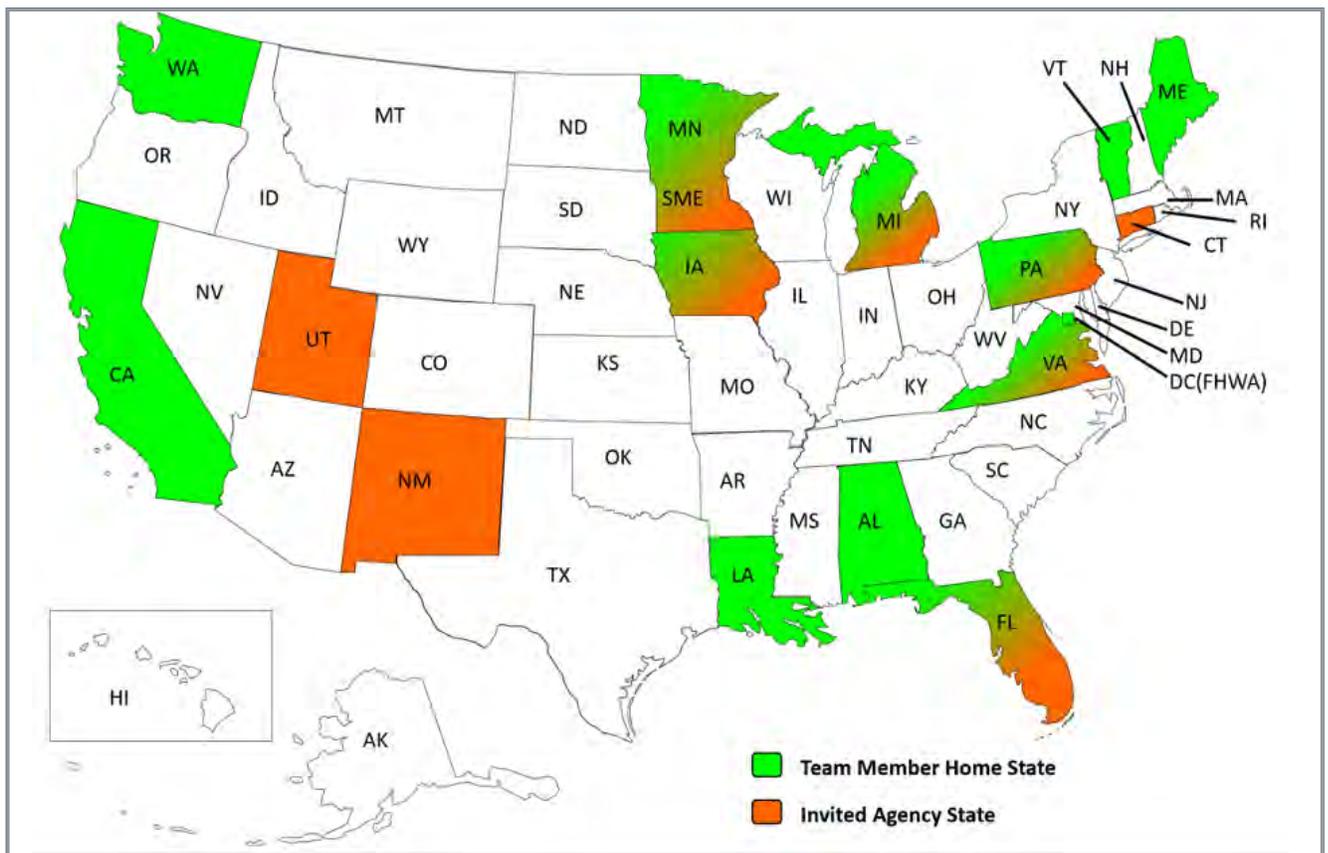


Figure 1-1 Map of team members and invited agency states

4 Bridge Preservation, Transportation System Preservation Technical Services Program (TSP2), American Association of State Highway and Transportation Officials, <https://tsp2bridge.pavementpreservation.org/national-working-groups/>

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Team member contact information is provided in **Appendix B**; scan team members' biographical information is provided in **Appendix C**; and key contacts who contributed to the information presented by the scan agencies are provided in **Appendix D**.



# Overview of Bridge Management Systems and Decision-Making Processes

A BMS is a combination of tools, processes, and procedures to perform AM. This may include a consumer off-the-shelf (COTS) technology software system, in-house software or spreadsheets, or procedures staff members follow to perform analysis and make decisions. The BMSs used by the scan agencies vary and include COTS systems, in-house systems and spreadsheets, and, typically, a combination of these types of BMSs. This chapter gives an overview of the BMSs scan state DOTs use and how the BMSs are utilized for decision making.

## Connecticut

The Connecticut DOT (CTDOT) uses a customized version of InspectTech<sup>5</sup> (Bentley) for its BMS to store and report information on CTDOT's highway bridges, sign supports, and highway buildings<sup>6</sup>. The system consolidates a variety of structure information that was previously stored in multiple repositories. The system includes a link to ProjectWise<sup>7</sup>, which is used as the repository for inspection reports. The CTDOT uses a customized version of dTIMS<sup>8</sup> (Deighton Total Infrastructure Management System) to analyze and project the condition of agency bridges and pavements. The system was implemented in phases beginning in 2013 for bridges and is used solely for analysis. CTDOT uses dTIMS to conduct strategic analysis that estimates future network bridge condition under various investment scenarios<sup>5</sup>. This analysis includes a life-cycle cost optimization that selects a set of bridge treatments to maximize benefits for a given budget, where benefits are based on condition improvement relative to doing nothing. The BMS is also used to produce recommended bridge treatments.

While CTDOT used dTIMS for TAMP analysis, the agency's current project selection practice is reactive, not proactive. Currently, no quantitative decision-making procedure is applied for selected funding levels and/or the distribution of bridge projects throughout the state's four districts. The current selection process is based on the needs of the statewide transportation infrastructure system as a whole. CTDOT is working toward moving to an asset management approach for project selection.

5 InspectTech, Bentley Systems, Incorporated,

[https://prod-bentleycdn.azureedge.net/-/media/files/documents/product-data-sheet/pds\\_inspecttech\\_itr\\_en\\_lr.pdf?la=pt-br&modified=2017071110030](https://prod-bentleycdn.azureedge.net/-/media/files/documents/product-data-sheet/pds_inspecttech_itr_en_lr.pdf?la=pt-br&modified=2017071110030)

6 "Connecticut Department of Transportation, Highway Transportation Asset Management Plan", Connecticut Department of Transportation, 2019, from <https://portal.ct.gov/-/media/DOT/documents/dplansprojectsstudies/plans/Highway-Transportation-Asset-Management-Plan-FHWA-Certified-082819.pdf>

7 ProjectWise/Digital Project Resources, Connecticut Department of Transportation,

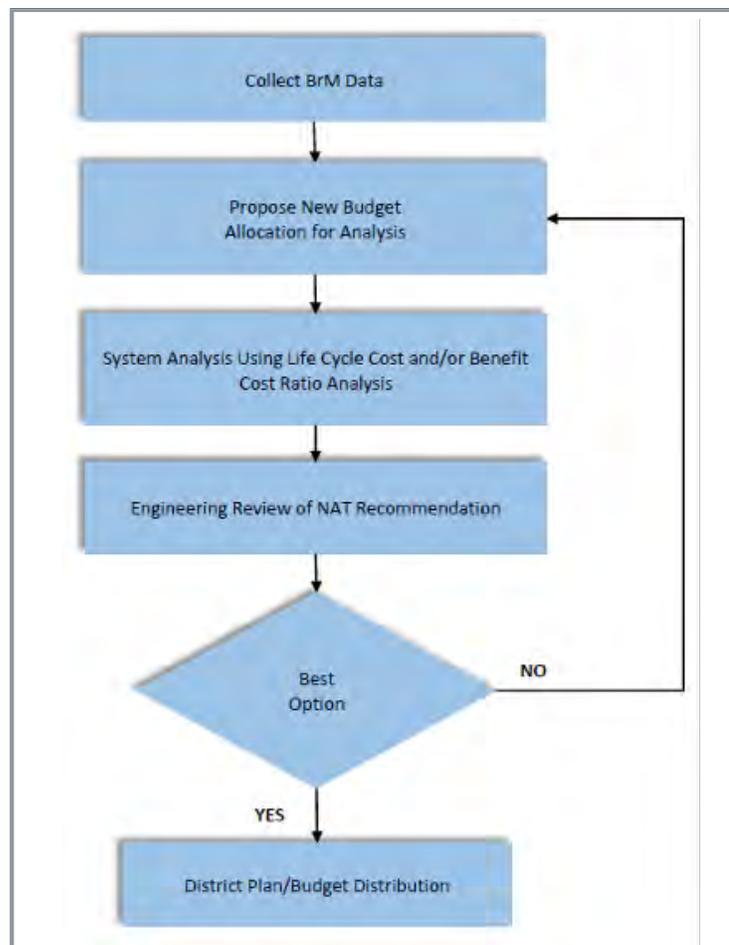
<https://portal.ct.gov/DOT/Engineering-Applications/ProjectwiseDigital-Project-Resources>

8 dTIMS (Deighton Total Infrastructure Management System), Deighton Associates Ltd., <https://www.deighton.com/>

## Florida

Bridge funding allocation at Florida DOT (FDOT) is informed by top-priority risks and its BMS, the AASHTOWare™ Bridge Management<sup>9</sup> (BrM) software, which contains historical bridge data. BrM also stores and processes bridge inventory and condition data for on- and off-system assets; the data is collected during each inspection event and after construction that results in changes to the inventory. This information aids in forecasting future funding estimates based on current inventory and condition data.

FDOT uses customized analysis tools that work with BrM: a network analysis tool and a project-level analysis tool. The project-level analysis tool is used to screen project-level decision making. The project-level decisions made in the tool are then aggregated using the network analysis tool, which also evaluates budget and timing. An overview of the network analysis process for a given budget is given in **Figure 2-1**<sup>10</sup>.



*Figure 2-1 Bridge – System level Performance Analysis (Florida)*

9 AASHTOWare Bridge Management, AASHTOWare, American Association of State Highway and Transportation Officials, <https://www.aashtowarebridge.com/>

10 “Florida Department of Transportation, Transportation Asset Management Plan” Florida Department of Transportation, 2019, from [https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/planning/performance/fdot-transportation-asset-management-plan\\_\(june-28-2019\).pdf?sfvrsn=36c94a6b\\_2](https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/planning/performance/fdot-transportation-asset-management-plan_(june-28-2019).pdf?sfvrsn=36c94a6b_2).

## Iowa

The main bridge management tool Iowa DOT uses is the Structure Inventory and Inspection Management System<sup>11</sup> (SIIMS), which is the single-source location for entering and reviewing condition information on all local and state-owned Iowa bridges. Iowa DOT staff enter recommendations for programming, priority, and cost estimates into SIIMS. Staff meets with each district annually and reviews the recommendations; after the meetings have concluded, Iowa DOT staff compile the high-priority programs. Sometimes there is conflict; however, Iowa DOT staff communicates among the districts and explains what is a high priority and why. Sometimes there is interaction with pavement projects, and it impacts the timing for bridges.

Iowa DOT has used IDS<sup>12</sup> (Infrastructure Data Solutions) software since 2014 as a general planning tool. The software provides outputs on what projects should be done in the 20-year planning period to estimate the general funding level needed.

The IDS software is not used for bridge-level decisions. It is, however, used for scenario comparison for different funding levels (unlimited, current level, and others). The analytical framework is based on the National Bridge Inventory (NBI) General Condition Ratings (GCRs) and other NBI data.

Iowa DOT staff are working on developing BrM to run scenarios at different funding levels and would like to use element condition data to make more granular decisions. Iowa DOT recently hired a full-time person for the BrM implementation.

## Michigan

For collecting, processing, storing, and updating inventory and condition data for bridge assets, Michigan DOT (MDOT) primarily uses the in-house data-collection tool MiBRIDGE<sup>13</sup> user interface for inspectors. Two bridge databases, BrM and MiBRIDGE, along with supplemental Michigan data sets, are used for bridge management functions. MDOT is planning on going with BrM after the new NBI change and will invest in configuring BrM to the agency's inspection needs.

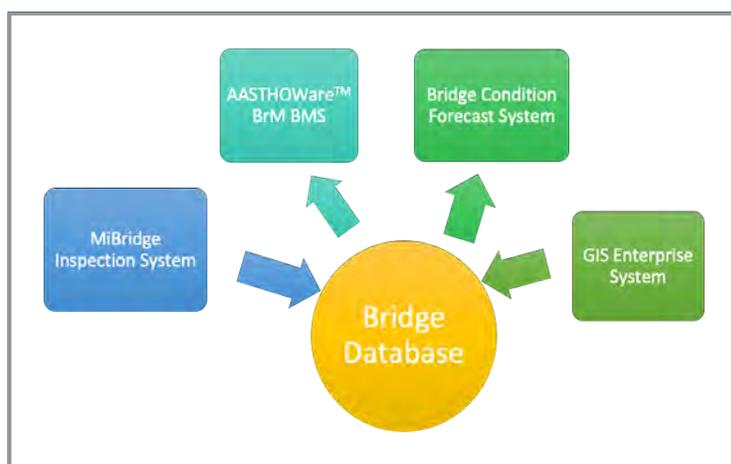


Figure 2-2 Bridge data systems (Michigan)

11 SIIMS, Iowa Department of Transportation, <https://iowadot.gov/siims>

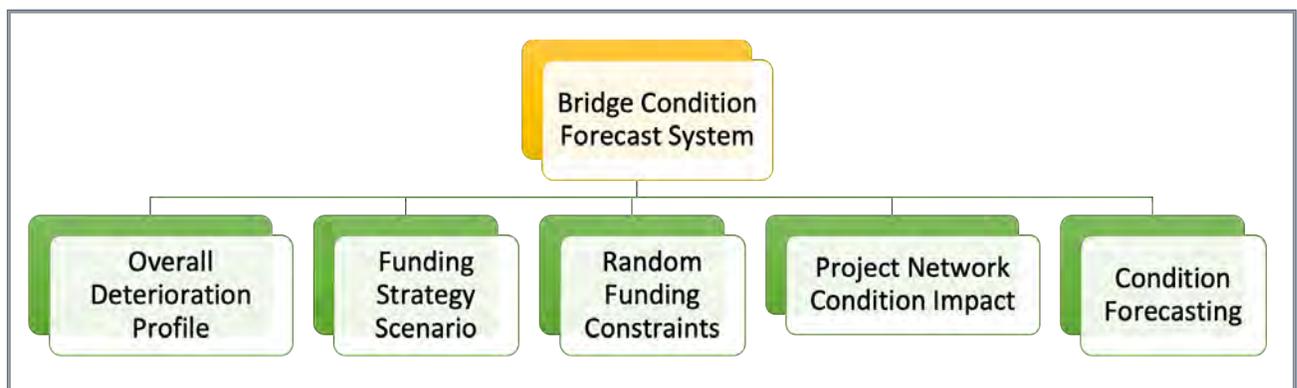
12 IDS (Infrastructure Data Solutions), <https://ids.consulting/>

13 MiBRIDGE, Michigan Department of Transportation, <https://www.michigan.gov/mdot/programs/bridges-and-structures/mibridge>

MDOT has a spreadsheet bridge condition forecasting system (BCFS), which is a tool for forecasting deterioration for bridge assets that uses Markovian models for GCRs. Occasionally, MDOT adds element data analysis but hopes to do more in future years with more element data inspections.

MDOT did a study a while ago on life-cycle analysis to determine the benefit-cost over the life cycle of assets to evaluate alternative actions. This led to the creation of a deck preservation matrix. The agency uses these guidelines since most cost-effective decisions align with this matrix. It also has a spreadsheet that does life-cycle cost analysis at a bridge level.

Decks primarily drive decision making. For identifying short- and long-term budget needs for managing the condition of bridge assets, the agency uses BCFS for primarily budget needs, budgets, and type of work. The BCFS includes custom deterioration profiles, multiple funding scenarios, and constraints; it also shows projected condition (**Figure 2-3**). MDOT adjusts the budget and funding-level needs for scenario analysis. Primarily it is looking 10 years out; however, it will also do longer range analysis when needed.



*Figure 2-3 Components of the Michigan bridge condition forecasting system*

For selecting projects, MDOT has a project process where it identifies goals divided by individual regions. MDOT's highway call for projects is an integrated, annual, year-long process that includes coordination with numerous programs and requires a departmentwide partnership effort. The call-for-projects process ensures that progress toward department goals is being made while providing an opportunity for program adjustments if they are deemed necessary. Regions are responsible for selecting projects; they centrally review how these projects impact long-term performance by coordinating with pavement projects.

MDOT uses its BMS to communicate the data to public. The open data portal for the geographic information system (GIS) on Michigan.gov has the current condition of each of the state's bridges. MDOT also has similar GIS for metropolitan planning organizations that own NHS bridges. MDOT integrates its BMS with programming and inspection systems; GIS support personnel populated the portal with relevant data.

In addition to the above-described tools, MDOT also has a risk analysis tool. The agency adds weights to different fields of vulnerability and criticality to map different levels of risk (e.g., scour risk).

The asset management functions multiple MDOT offices perform to manage the bridge network can be summarized with these steps:

- Goals and objectives are established.
- System inventory and condition data are collected.
- The condition data is analyzed and rates of deterioration are computed.
- Performance measures and standards are set or reaffirmed.
- Gaps in performance and risk factors are evaluated.
- Life-cycle network analysis is developed using forecasting tools.
- Investment strategies are implemented through programs, project selection, and practices.
- The process and system are monitored and adjusted.

In terms of how its BMS fit into other systems that are used for pavement management and overall asset management, MDOT reported that individual programs are made but that there is communication between pavement and bridge to adjust projects based on impact to traffic. MDOT has an ongoing customization project with BrM to add pavement functionality. Once that happens, the goal is cross-asset optimization and probably adding culverts.

## Minnesota

Minnesota DOT's (MnDOT's) Bridge Replacement and Improvement Management (BRIM) system is a BMS developed in-house and used for forecasting bridge condition, considering improvement from future projects. MnDOT uses Bentley InspectTech<sup>5</sup>, rebranded Structure Information Management System, as the interface to collect bridge inventory and inspection data. MnDOT then copies this data back into agency databases to support the customized reporting and analysis tools and to support the use of BrM<sup>14</sup>.



Figure 2-4 Bridge management systems (Minnesota)

14 "Minnesota DOT, Transportation Asset Management Plan," Minnesota Department of Transportation, 2019, from <https://www.dot.state.mn.us/assetmanagement/pdf/tamp/tamp.pdf>

BRIM's treatment logic provides a recommended work type, timeframe, and cost for each bridge. This logic also considers factors such as bridge width, vertical clearance, design live load, risks, and historical design details. The treatment options include a mixture of preservation, rehabilitation, and replacement alternatives that consider the remaining life in the bridge. The timings of these treatments are based on condition and predicted deterioration. Bridge experts in the districts and the Bridge Office review the output each year. The treatment logic can be varied to compare various repair strategies. The BRIM work type logic and deterioration modeling assumes that routine preventive maintenance treatments are being performed with frequencies established in the Bridge Maintenance Manual<sup>14</sup>.

Currently, the BMS assists MnDOT upper staff in understanding future predicted conditions based on different funding scenarios. Based on performance targets and other needs or department initiatives, budgets for specific bridge programs are developed based on available resources. MnDOT is working on improving the BRIM system's predictions for network-level planning to better coordinate functional needs and corridor projects.

### New Mexico

Bridge project selection at New Mexico DOT (NMDOT) begins at the Central Office with priority lists based on inspection data. The agency currently looks at the following to create the priority list: deck, superstructure, substructure GCRs, health index (HI), bearing conditions, joint conditions, and approach slab conditions. The Bridge Bureau then meets with the districts and goes over the lists and re-prioritizes based on "boots-on-ground" knowledge.

NMDOT currently uses two BMS tools. The first one, based on spreadsheets, uses NBI GCRs (i.e., deck, superstructure, substructure, and culvert) for forecasting and project selection. The agency also uses BrM for inventory management and is working toward using it to support project selection. The prioritization list from the spreadsheets is later refined to include more rehabilitation. The agency uses a benefit cost ratio to establish priorities. Benefits are measured by the ability to improve the NBI GCRs. Different components are weighted using different percentages. A critical objective for the bridge network is improving Fair condition bridges to Good condition.

### Pennsylvania

For collecting, processing, storing, and updating inventory and condition data for bridge assets, Pennsylvania DOT (PennDOT) has an in-house BMS, which houses bridge inventory and inspection element data for all assets, tunnels, signs, etc. Because PennDOT developed its BMS in house rather than buy an off-the-shelf system, its BMS works with the agency's systems, interacting with both project management and construction management.

For forecasting deterioration for bridge assets, PennDOT uses BridgeCare, a bridge asset management system that utilizes deterministic deterioration models for NBI components (i.e., deck, superstructure, substructure, and culvert). **Figure 2-5** is a screenshot of the BridgeCare user interface for scenario runs. (PennDOT plans to move to element-level analysis in the future.) This product was developed in-house and is open-source, enterprise-level software. BridgeCare develops recommendations per asset per year using decision trees that guide the treatment selection based on lowest life-cycle cost (**Figure 2-6**).

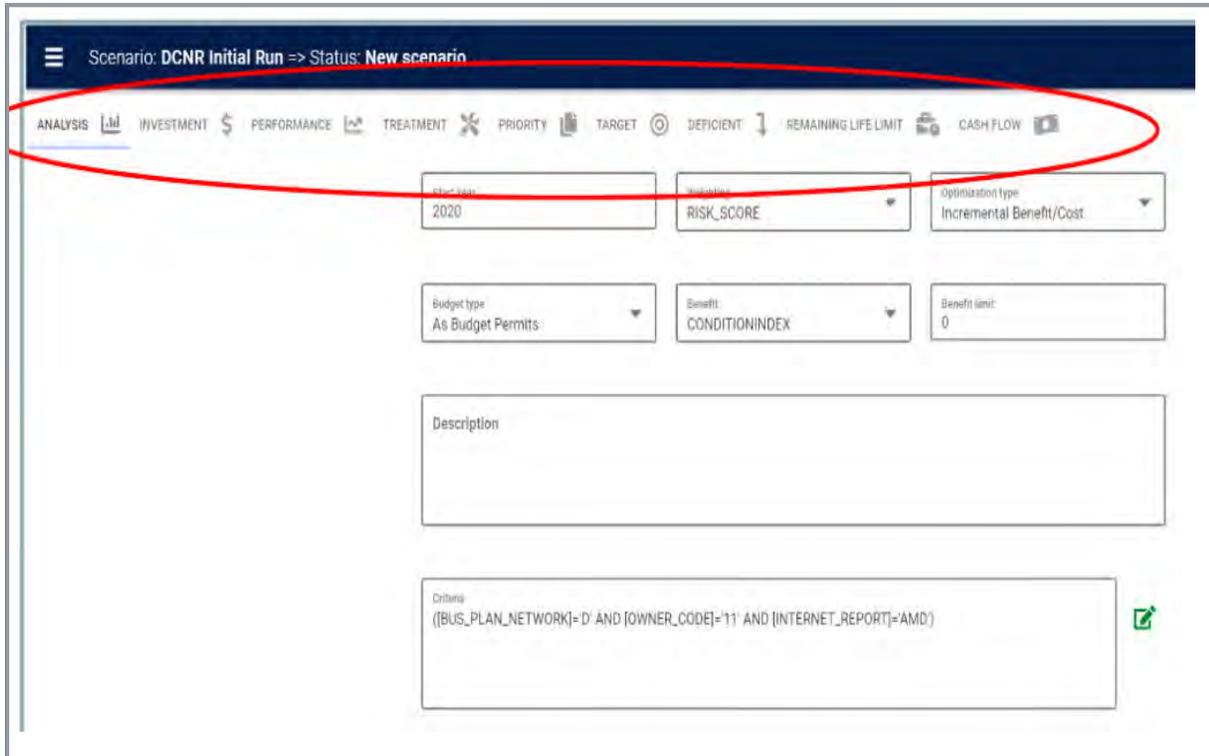


Figure 2-5 BridgeCare scenario interface (Pennsylvania)

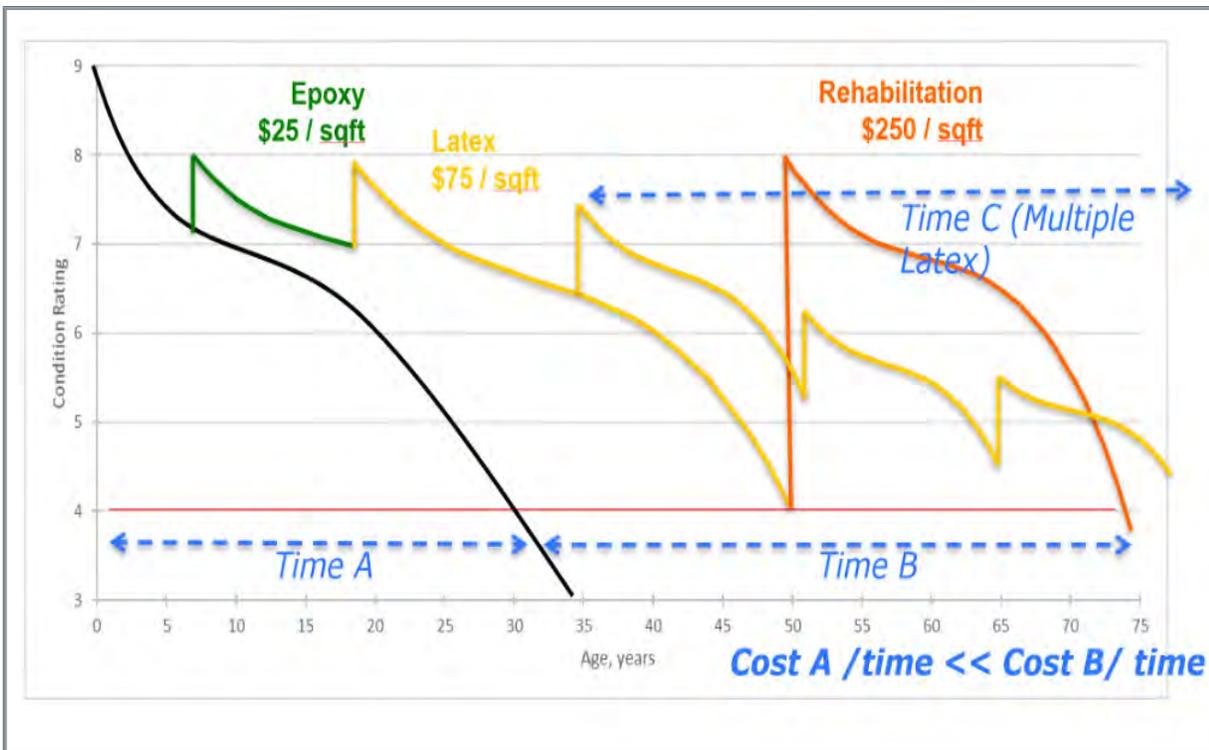


Figure 2-6 Lowest life-cycle cost treatments by age for Pennsylvania bridge decks

PennDOT has different deterioration models for six bridge and six culvert families, as well as additional variables in these families. BridgeCare multi-objective decision analysis also uses benefit cost analysis and describes deterioration models. For determining short- and long-term budget needs, PennDOT again uses BridgeCare multi-objective decision analysis. Although FHWA requires four- and 10-year analysis, PennDOT finds that four- and 12-year analysis more useful for its planning process.

From PennDOT's perspective, software-recommended treatments cannot be modeled as a project. The agency takes recommended treatments, includes any additional relevant constraints, and creates projects. PennDOT finds that the process helps identify high-risk structures.

Part of PennDOT's risk analysis hinges on its BMS system. The agency counts on the inspectors to provide the data for identifying high-risk structures. Maintenance needs are added to the BMS, and the system creates automatic updates for these needs. The BMS is the system of record and inspection, while BridgeCare is the analytical tool that uses the data from BMS. PennDOT also has the same setup for pavements. The Roadway Management System, which uses stations and lengths, serves as the system of record. PennDOT also has enterprise-level dTIMS that shares recommended pavement treatment information with other agency offices. PennDOT used RoadCare for TAMP analysis. Pavement staff makes all pavement decisions; however, RoadCare was utilized for TAMP projections. dTIMS and RoadCare models are essentially the same.

## Virginia

Virginia DOT (VDOT) collects and records data in an inspection report using a Word file, then enters the data into BrM for the remaining items. VDOT plans to develop comprehensive digital bridge inspection and reporting software that will collect data, which then will be routed into BrM. In-house tools (Python, Excel) and BrM are used to meet other BMS requirements and functions. For quantifying project performance measures, VDOT uses a combination of BrM, in-house spreadsheets, and an in-house Python tool for prioritization. It also has performance dashboards, which do not currently interact with the agency's highway maintenance management system (but may in the future) and its critical findings and tracking SharePoint site. For pavement management, VDOT uses Pavement Manager (Agile Assets), which does not interact with bridge management tools.

VDOT's State of Good Repair (SGR) Program<sup>15</sup> has a bridge prioritization formula<sup>16</sup> comprising five factors that measure importance, condition, redundancy, structure capacity, and cost-effectiveness (**Figure 2-6**). Each of these factors is multiplied by varying weighting coefficients. In the SGR project selection process, each district is sent a scoring spreadsheet for its SGR-eligible structures to be filled out and submitted to the central office. Four of the five factors, which are based on condition and inventory data from BrM, are prepopulated by the Central Office; however, districts can update the cost-effectiveness factor based on costs and district needs. VDOT has three other major funding programs for bridge work: Maintenance and Operations funds, Special Structures program, and the Building Resilient Infrastructure and Communities grants.

<sup>15</sup> State of Good Repair (SGR) Program, Virginia Department of Transportation, <https://www.virginiadot.org/projects/state-of-good-repair/>

<sup>16</sup> State of Good Repair (SGR) Program Bridge Prioritization Formula, Structure and Bridge Division, Virginia Department of Transportation, [https://www.virginiadot.org/business/resources/bridge/SGR\\_PrioritizationFormula\\_Description\\_08-31-2018.pdf](https://www.virginiadot.org/business/resources/bridge/SGR_PrioritizationFormula_Description_08-31-2018.pdf)

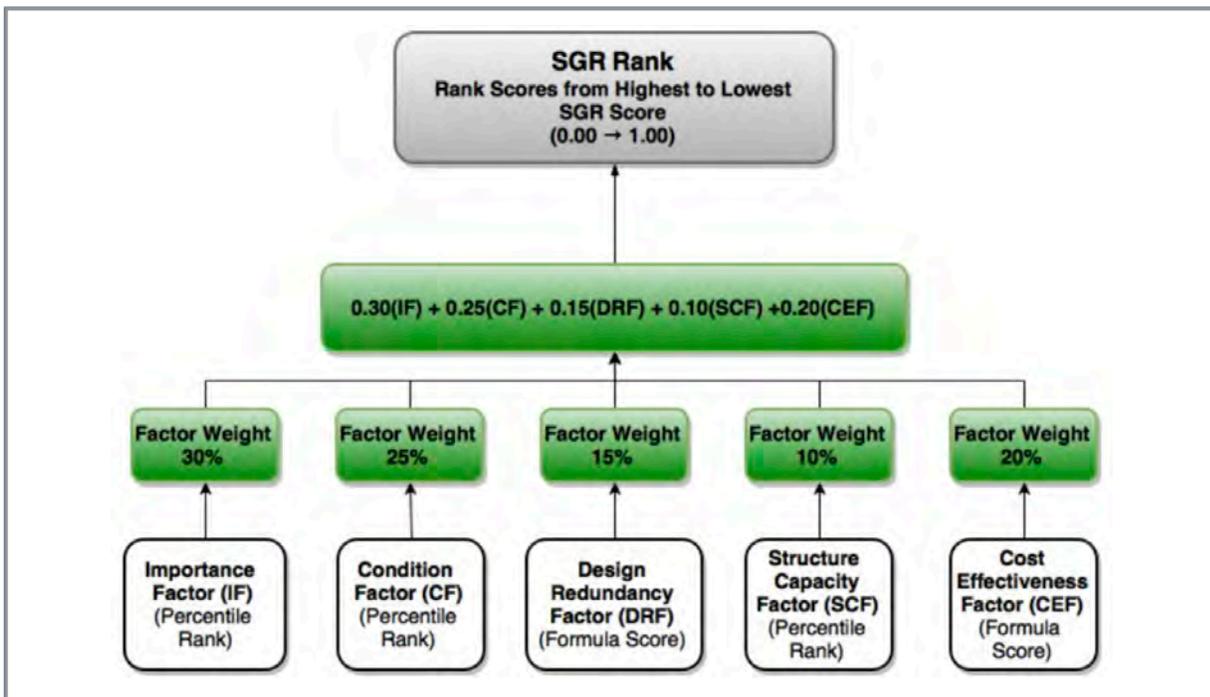


Figure 2-7 State of Good Repair Program bridge prioritization formula components (Virginia)

The SGR prioritization is used for identifying major rehabilitation and replacement projects. The five multiple-weighted objectives are in the following categories:

- Design Redundancy Factor – Representing hazard and traffic load risks through scour criticality, seismic vulnerability, fracture criticality, and structures with fatigue-prone details subfactors
- Structure Capacity Factor – Representing serviceability limitations through weight restrictions, vertical clearance (for roadway or railroad below), and deck width subfactors
- Importance Factor – Indicating the importance of the carried route through annual average daily traffic (AADT), truck AADT, future AADT, bypass impact factor, NHS, and Corridor of Statewide Significance subfactors
- Condition Factor – Indicating the overall physical condition through the subfactors of deck rating, superstructure rating, substructure rating, culvert rating, and element condition-states (in future)
- Cost Effectiveness Factor – Indicating the cost-effectiveness of the required work on the bridge through the replacement cost of the structure and the cost of the required work subfactors

VDOT is currently working on a resource allocation tool that will use a multi-objective decision-making algorithm. The objective function will encompass NBI GCRs and life-cycle cost. Risks are not being incorporated but the agency may consider scour and impact risk in the future.

## Utah

Within the Utah DOT (UDOT) structure, bridges are handled by a statewide division; project prioritization is handled on a statewide, not regional, assessment. The Structures Division coordinates priorities with individual regions for inclusion of bridge work into region-sponsored projects.

UDOT uses inspectX<sup>17</sup>, a custom inspection tool, for data collection. inspectX links to BrM for data transfer; the inspection data is stored in BrM. Prioritization is based on an internally developed Bridge Health Index (BHI) and a decision matrix using internal spreadsheets. UDOT is currently evaluating BrM Optimizer. The agency does inspection scheduling and assigning through inspectX. Work candidate recommendations from National Bridge Inspection Standards inspections are entered into inspectX and BrM. UDOT also uses GIS for bridge locations and key information and Google DataStudio for performance dashboards. An internally developed ePM is used for project data tied to specific bridges and is used to track project schedule and expenditures per bridge. **Figure 2-8** presents data systems that constitute UDOT's bridge data warehouse.

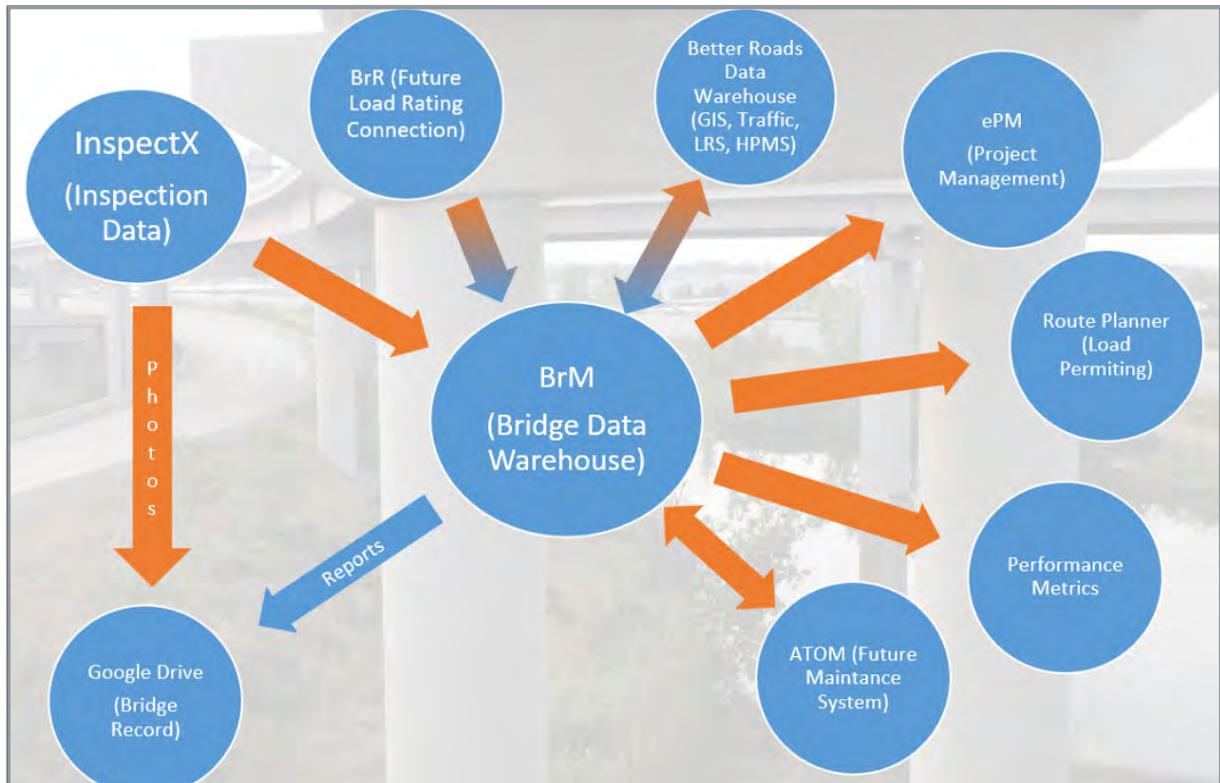


Figure 2-8 Bridge Data Warehouse (Utah)

<sup>17</sup> inspectX, AssetIntel, <https://www.bridge-intel.com/inspectx>



# Data Collection and Management

Quality data and efficient data systems are core elements of asset management. In terms of bridge inspection data collection and database system implementation, scan agencies are mature, with established systems and practices. All scan agencies are strong in inspection, asset inventories, and inspection data collection and data systems that store and process data. Using information systems and dashboards to track and communicate performance measures internally and externally is becoming commonplace. Agencies realize the benefits of and aim for centralized data systems when possible. Inspection data collection tools and databases vary among agencies and provide custom solutions that are tailored to agency preferences.

Data attributes, particularly data items defined by the National Bridge Inspection Standards under the NBI, are consistent across agencies, with the exception of element-level data collection. Not all agencies collect data for element defects and environments. Iowa, Utah, Florida, and Connecticut were among the agencies that collect defect data. Use of environments for element-level data also varied across agencies; however, agencies are interested in using environments in future for different deterioration models for varied environments. With established data-collection practices, agencies currently focus on continuously improving data quality, translating data into useful information, and refining the list of data attributes that they should keep or start collecting.

Most agencies established quality control (QC) and quality assurance (QA) processes aligned with the National Bridge Inspection Standards. Some agencies also have automated data quality checks and QA practices to continuously improve their inspection programs and data quality.

In Utah, collaborative peer reviews, during which inspectors assess one structure or component and then discuss the results, are part of the QC/QA process and training efforts (**Figure 3-1**).

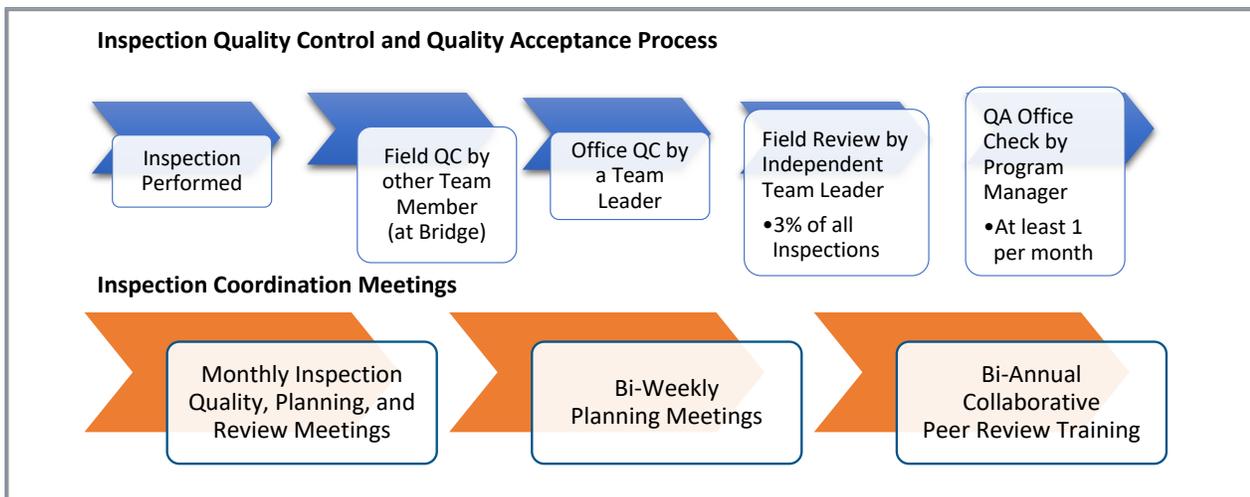


Figure 3-1 Quality control/quality assurance process (Utah)

Collaborative peer review training occurs at least on one bridge inspection per year. A team of peers assembled with the team leader and the subject inspection team to participate in a team-oriented re-inspection. The team collaborates to develop appropriate component ratings and to identify elements and condition states from a blank inspection data sheet (discussion of appropriate ratings is ongoing during the inspection); reviews the original report; discusses the report in detail among the team members; and generates a report documenting the results of the review, which is stored in the bridge file<sup>18</sup>.

UDOT's team quantifies the consistency of inspection results by comparing the results of the collaboratively developed bridge inspection report with the original inspection results. The comparison provides a means for identifying areas where improvements are needed for specific inspection teams and summarizes the results from multiple reviews to identify programmatic improvements. With this strategy, they sometimes mix up a team of inspectors as part of their training and to improve consistency. UDOT has found that this strategy helps develop consensus; the inspectors favor the process and find it beneficial. Data quality has also improved since the agency implemented this strategy.

Monthly inspection quality, planning, and review meetings are also part of the UDOT bridge management QC/QA process. The meeting attendees plan upcoming inspections and review unresolved issues from the previous month. The entire bridge inspection staff and the bridge management engineer attend the meetings, where the following issues are discussed:

- Schedules and workloads
- Labor, equipment, and other resources
- Safety concerns
- Upcoming bridge inspections and issues of concern
- Previous-month inspections
- Critical findings
- Bridges with condition ratings changing above or below NBI 4
- Open peer discussion of case studies and questions

When scan agencies were asked whether they were collecting all the data attributes that they need for TAMP analysis or BMS modeling, some responded that they identified additional data needs during TAMP development or while developing and implementing BMSs. For example, PennDOT started tracking cost and time of maintenance work to improve deterioration and cost models that it uses in its Bridge Asset Management System, referred to as BridgeCare. PennDOT plans to use the cost and work history data in future to refine its models.

MnDOT has collected bridge maintenance data for more than 10 years and has a database that is both rich and accessible. The data includes attributes such as the bridges work has been performed on, the date the work was performed, the elements the work was performed on, treatment type, quantity,

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<sup>18</sup> "Bridge Management Manual," Utah Department of Transportation, 2017, from [https://www.udot.utah.gov/main\\_old/uconowner.gf?n=35942524323318753](https://www.udot.utah.gov/main_old/uconowner.gf?n=35942524323318753)

cost, and actuals. MnDOT believes that the data will be valuable for determining action effectiveness models as well as agency-custom deterioration models (element or component level). It also initiated a research project recently to utilize the data to develop treatment efficiency models and cost-effectiveness decision trees.

UDOT is another agency that is working toward improving data collection for attributes such as cost data from actual bridge work expenditures, documentation of deck overlay dates, and documentation of nonstandard materials (to determine if they impact deterioration rates).

Multiple agencies mentioned that they are working toward better defining and modeling preservation within their BMSs. Scan agencies frequently brought up building and communicating a preservation culture and developing the modeling framework within their BMS as part of their next steps in BMS implementation. Agencies recognize that collecting and archiving bridge work data, including necessary attributes that will enable development of custom treatment efficiency and deterioration models, is a valuable effort that will improve BMS models and implementation.

Multiple scan agencies are using GIS in various ways for data management and to improve internal and external communication. For instance, Georilla is MnDOT's internal web-map application that is currently being used by approximately 700 unique visitors each month to mash-up asset, project, and activity information to make better data-driven decisions (Figure 3-2). The application combines data on multiple assets, such as bridges and structures, drainage infrastructure, geotechnical assets, lighting, public utilities, pavement signs, and signals, as well as maintenance system work orders. This helps MnDOT personnel coordinate project decisions better and by providing a visual medium for communication.

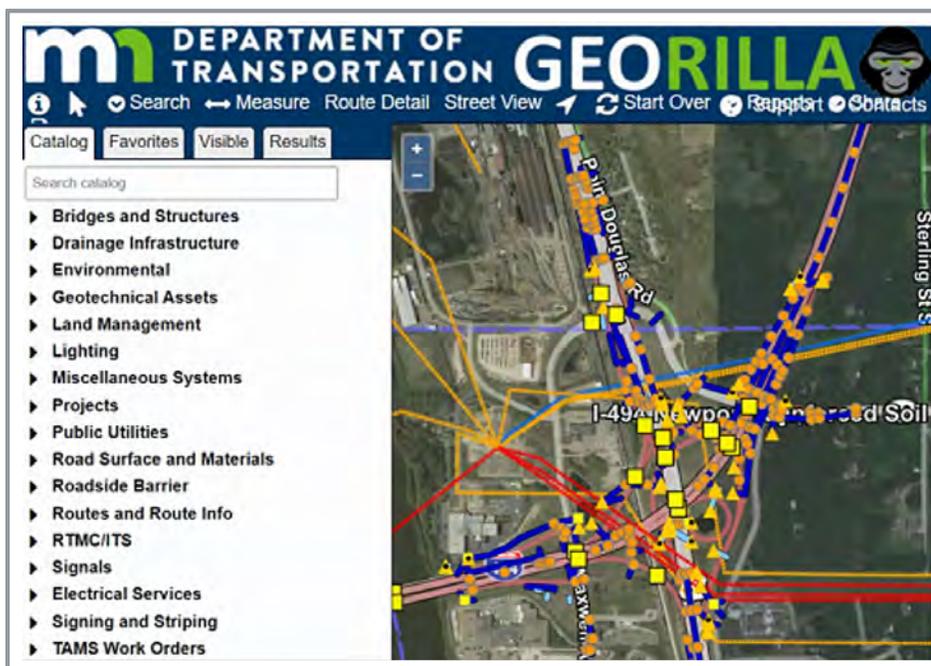


Figure 3-2 Georilla web-map application (Minnesota)

Two other agencies that utilize GIS to better coordinate and schedule projects are CTDOT and UDOT. CTDOT added three bridge work-type definitions (removal, breakout project, and no work proposed) to the FHWA bridge work types (**Table 3-1**). CTDOT currently requires that all bridge work types and work codes be recorded. In the future, work types and codes will be required for all projects (e.g., highway and traffic projects) for all roadway bridges. Using GIS, polygons for project limits are drawn geospatially to check for bridge work in proximity. CTDOT uses the information from these geospatial polygons to improve project scheduling and to increase cost savings from coordinating such projects that are close to each other.

Work type	Description
Initial Construction (NEW)	This work type is for a new roadway bridge on a new roadway system. This category does not include new roadway bridges that replace existing roadway bridges. (FHWA Work Type)
Maintenance (MNT)	This work type is for maintenance and repair work on a roadway bridge. This category is to be used predominantly by the Bureau of Highway Operations. (FHWA Work Type)
Preservation (PRS)	This work type is for the preservation of a roadway bridge to keep it in a state of good repair. The proposed work on the roadway bridge maintains (does not raise) the condition rating(s) of the component/elements. (FHWA Work Type)
Rehabilitation (HRB)	This work type is for the rehabilitation of an existing roadway bridge. This category does not include new roadway bridges that replace existing roadway bridges. (FHWA Work Type)
Reconstruction (RPL)	This work type is for a full roadway bridge replacement of an existing roadway bridge. (FHWA Work Type)
Remove (RMV)	This work type is for a roadway bridge that is being removed and not replaced. (CTDOT Work Type)
Breakout Project (BOP)	This work type is for breakout work required for utility or environmental needs. (CTDOT Work Type)
No Work Proposed (NWP)	This work type is for a roadway bridge that is within the limits of a project but has no work proposed for it. (CTDOT Work Type)

*Table 3-1 Bridge work-type descriptions (Connecticut)*

After holding a series of workshops to evaluate risks, UDOT developed a corridor approach and an external-facing GIS dashboard that has individual maps that:

- Identify assets
- Identify threats
- Determine user costs
- Provide value to the assets
- Identify criticality of the assets
- Set a risk priority
- Develop a return on investment

UDOT plans to evaluate risks for inclusion in projects during the scoping phase to determine if they should be mitigated for during scheduled projects. A map layer in UDOT’s mapping center (UPLAN) has been created to display the location and project information for all projects that use emergency funds. The map<sup>19</sup> is updated daily through a connection to the ePM system (Figure 3-3). The web dashboard also has map layers that show data on agency-defined risks (Figure 3-4) and an accompanying layer that combines the cost and risk data into return-on-investment information (Figure 3-5).

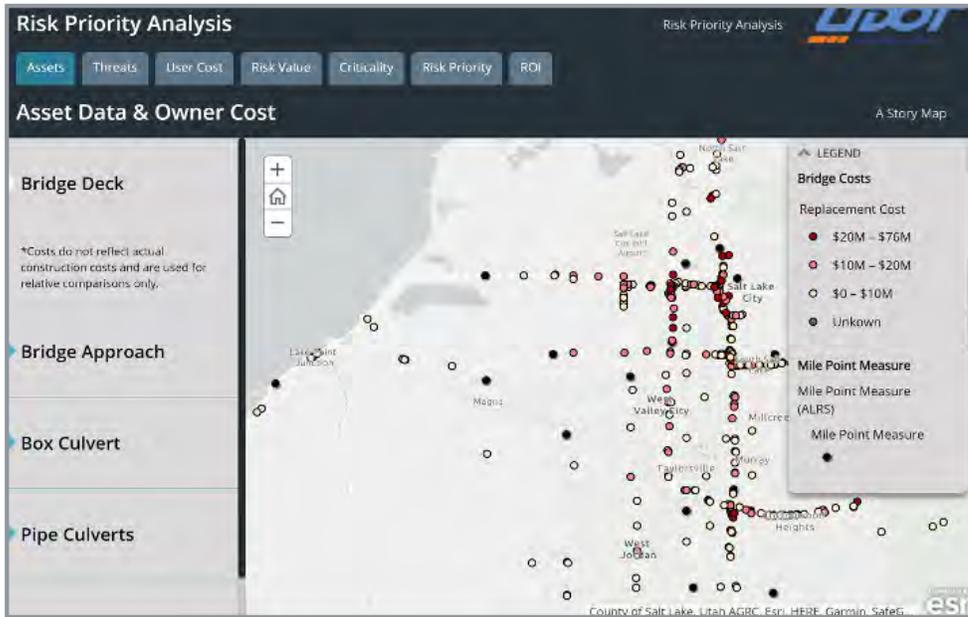


Figure 3-3 Risk priority analysis web dashboard asset data and owner costs (Utah)

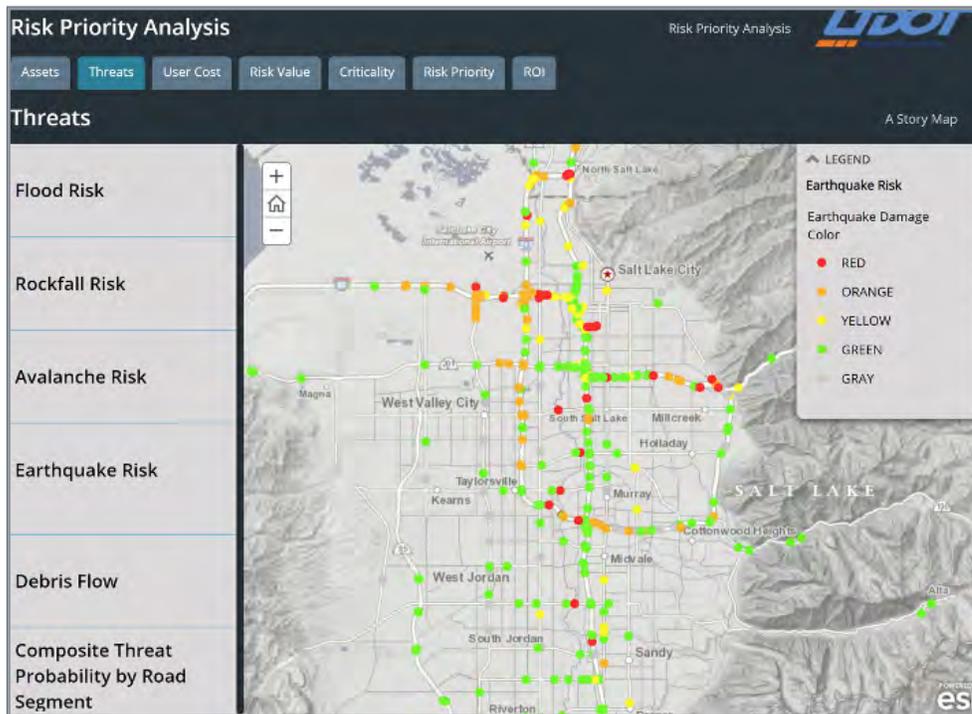


Figure 3-4 Risk priority analysis web dashboard risks (Utah)

19 “Risk Priority Analysis Map,” Utah Department of Transportation, 2021, Retrieved July 3, 2021, from <https://uplan.maps.arcgis.com/apps/MapSeries/index.html?appid=fab82e27ca6047fc855bb97976ea0d41>





# Performance Measures

Federal bridge condition performance measures heavily influence state DOT planning efforts and project selection. The condition of bridges carrying the NHS, which includes on- and off-ramps connected to the NHS, are classified as Good, Fair, or Poor (G/F/P) based on the NBI GCRs, NBI items 58 - Deck, 59 - Superstructure, 60 - Substructure, and 62 - Culverts. For the purposes of national performance measures under the National Highway Performance Program, the method of assessment to determine the classification of a bridge is the minimum of condition rating method (i.e., the condition ratings for lowest rating of a bridge's three NBI items, 58 - Deck, 59 - Superstructure, and 60 - Substructure). For culverts, the rating of its NBI item (62 - Culverts) determines its classification. Federal bridge performance measures are percentage of NHS bridges by deck area in Good condition and percentage of NHS bridges by deck area in Poor condition.

One observation from the scan was the difference between the performance measures used within BMSs or for bridge management decisions and the performance measures used for Transportation Performance Management and TAMPs. While the federal bridge condition performance measures heavily govern Transportation Performance Management/TAMPs, bridge managers also use other performance measures, such as Fair or Severe condition. The difference between the performance measures used in TAMPs and used in BMSs by bridge managers may lead to coordination issues between agency TAMP implementation and bridge management.

During scan presentations and discussions, multiple scan state DOTs brought up the importance of the Fair condition category as a performance measure to better target life-cycle planning and bridge preservation for structures in this condition category. Currently, Fair condition is not part of federal bridge performance measures; therefore, TAMPs do not need to include or address planning efforts for the structures in this category.

This chapter presents examples of scan agency approaches to performance measures within the agency bridge and asset management context. The bridge performance measures agencies use heavily rely on condition, aligned with the federal bridge performance measures. This chapter also includes scan agency approaches to risk management and modeling, although risk management is a standalone component of asset management and TAMPs. Selected scan agency practices for measuring, documenting, and communicating risks for bridge management are presented. When relevant, agency plans for performance measures and risk management are also included.

## Condition

The bridge performance measures scan agencies use focus on condition and are based mostly on NBI GCRs. However, agencies have additional condition measures, definitions, or indices that go beyond federal bridge performance measures (i.e., percent of NHS bridge deck area in Good and Poor condition) that they use for different purposes and include bridge element condition data, albeit limited, and other NBI data items within bridge performance measures.

MDOT defines Severe condition based on NBI GCRs as structures that have an NBI GCR equal to or less than three (NBI GCR  $\leq$  3). The agency subdivides the Poor condition into Poor (NBI GCR = 4) and Severe (NBI GCR  $<$  4) and reports condition using this classification in the Michigan Transportation Asset Management Council's annual report on Michigan's roads and bridges<sup>20</sup>. This additional classification helped MDOT and the Michigan Transportation Asset Management Council highlight groups of structures with urgent needs, such as the number of structures on the local system that are in Severe condition. For example, the graph in **Figure 4-1**, which is from the aforementioned annual report, illustrates the relative percentage of bridges in Poor and Severe condition for 2019. The same graph also highlights that the 2019 percentage of Poor and Severe bridges in Michigan are relatively higher than in other Great Lakes states and the national average.

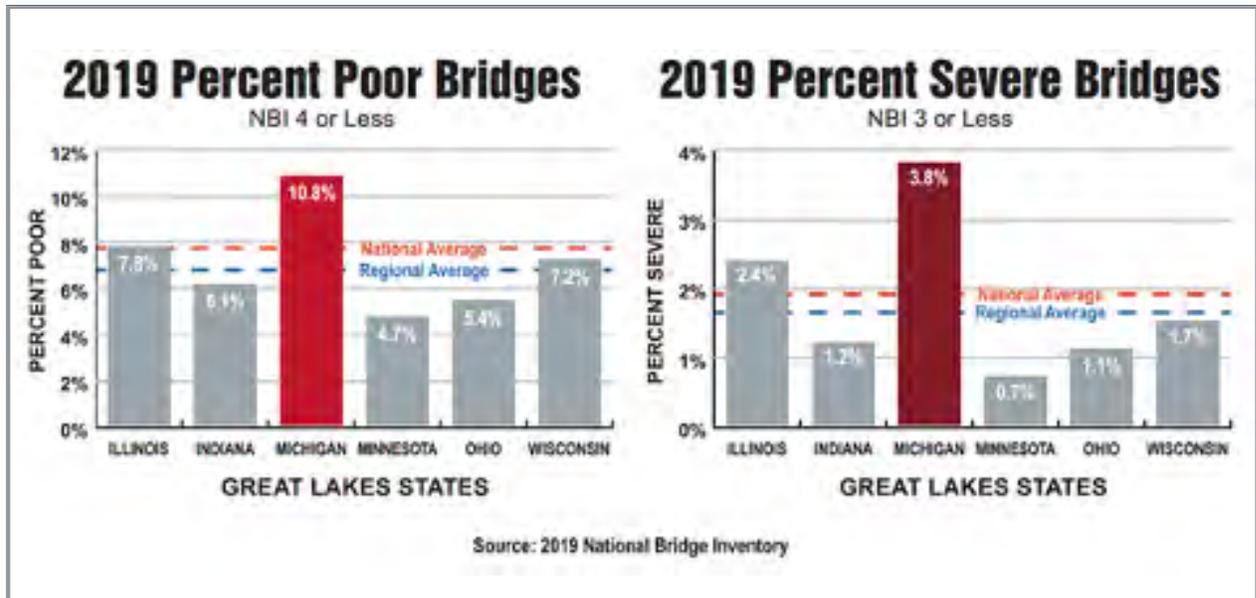


Figure 4-1 Bridges in the Severe condition category (Michigan)

Multiple scan state DOTs also developed custom condition indices. This chapter presents examples from Vermont, Utah, Connecticut, and Iowa.

### Vermont

VDOT established performance measures and targets for bridges and pavements during its 2019 comprehensive review; however, no performance measures for movable bridges and tunnels were readily available. The VDOT commissioner directed the Structure & Bridge Division to develop an HI to measure the condition and health of tunnels and movable bridges and for use as a performance measure. VDOT continues to work on this HI and would like to expand its use to all structures.

The HI is a calculated index measuring the current overall condition of a structure on a 0 to 100 scale, with 100 corresponding to an ideal (new) structure. The HI for each element of a structure is calculated with detailed condition data from inspections and is modified by design life (age), functional

<sup>20</sup> Michigan's 2020 Roads & Bridges Annual Report, Michigan Transportation Asset Management Council (TAMC), 2020, [https://www.michigan.gov/documents/tamc/2020\\_TAMC\\_Roads\\_Bridges\\_Annual\\_Report\\_WEB\\_723484\\_7.pdf](https://www.michigan.gov/documents/tamc/2020_TAMC_Roads_Bridges_Annual_Report_WEB_723484_7.pdf)

performance (design adequacy), and operational performance (risk consequence).

The overall HI for each structure is calculated using the weighted average of the element HIs (weighted by safety and importance). The HI for special structures aligns with the methodology used to calculate the HI for conventional bridges. Currently, VDOT uses the HI to measure the relative health of individual movable bridges and tunnels and individual systems (i.e., mechanical, electrical, structural, and house) for a given category of special structure. In the near future, the agency would like to maximize benefits with limited funds by using the HIT and the project prioritization formula for scenario analyses of the 50-year long-term plan. In the long term, VDOT would like to use the HI to determine which treatments provide optimal life-cycle value and possibly replace its project prioritization formula (Figure 2-7) with the HI.

Figure 4-2 is an illustrative example of VDOT’s future use of the HI for determining treatments that provide optimal life-cycle value. The figure also shows HI thresholds for Excellent and Severe conditions (preliminary scale), in addition to G/F/P conditions. The use of Excellent and Severe conditions is another example of additional condition categories to G/F/P (G-F), similar to MDOT’s use of the Severe condition category.

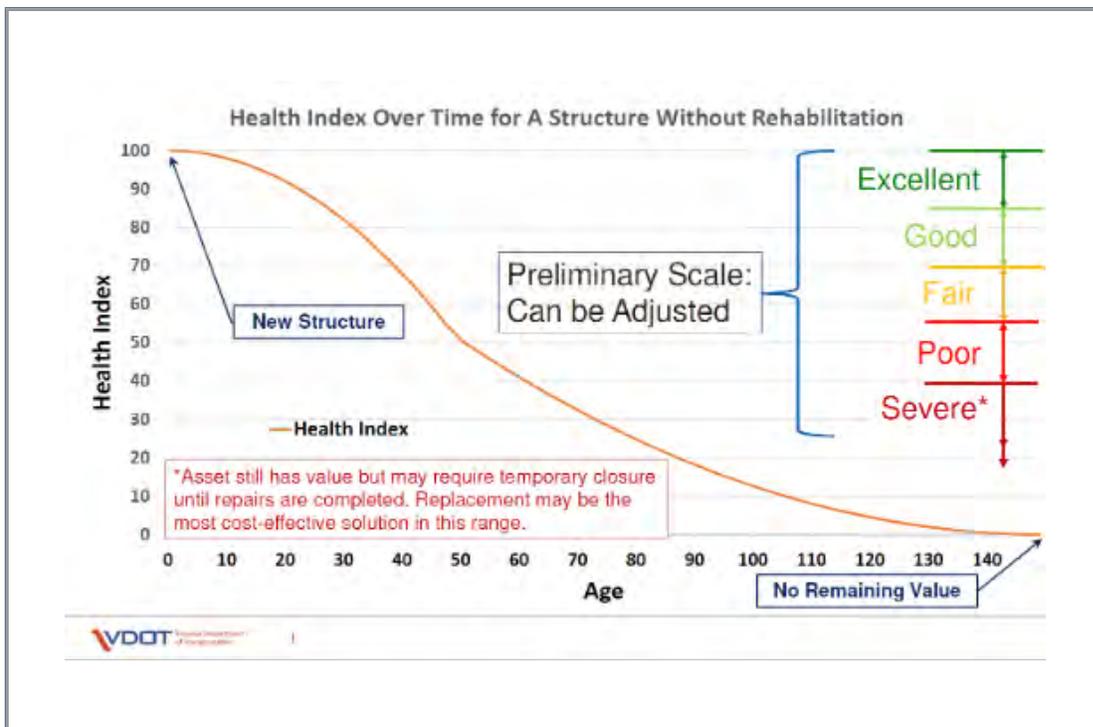


Figure 4-2 Health index and use of Severe category (Vermont)

## Utah

UDOT Bridge Management developed a Bridge Health Index (BHI), which it defines as a measure to describe the overall condition of each bridge that is used as a structural performance measure and for work effort prioritization<sup>21</sup>. UDOT’s BHI is also the bridge performance measure used for its TAMP and is based on element condition data.

The BHI is a weighted index of three separate scores (deck, superstructure, and substructure), which are weighted to underscore the importance of each category in overall bridge health. The weighting of these categories is as follows:

$$\text{BHI} = (\text{Deck Score} \times 0.40) + (\text{Superstructure Score} \times 0.35) + (\text{Substructure Score} \times 0.25)$$

UDOT weights the health of deck elements higher because the elements contribute to preserving many other areas of the structure. An HI score is calculated for each element as a ratio of the value of the element in the element’s current condition to the value of the element in the best possible condition. Each of the three category scores is then calculated as a weighted average of the HIs of the bridge category elements, where elements are weighted by the total quantity of the element and its relative importance. The category score is calculated for the deck, superstructure, and substructure before combining the resulting scores into a final BHI.

UDOT uses BHI to prioritize bridge replacement and rehabilitation projects statewide. HIs for individual elements are used to identify projects for preservation treatments or for targeted projects (e.g., deck overlays). **Figure 4-3** shows UDOT bridge performance measures, targets, and condition for NHS, non-NHS, and local governments as of March 2019. The target for NHS bridges is a BHI of 85, for state-owned non-NHS bridges a BHI of 80, and for local government bridges a BHI of 75. Visual references to BHI values are provided in **Figure 4-4**.



Figure 4-3 Bridge health index targets<sup>21</sup> (Utah)

21 Utah Transportation Asset Management Plan, Utah Department of Transportation, 2019, [https://www.udot.utah.gov/main\\_old/uconowner.gf?n=15892110208531307](https://www.udot.utah.gov/main_old/uconowner.gf?n=15892110208531307)

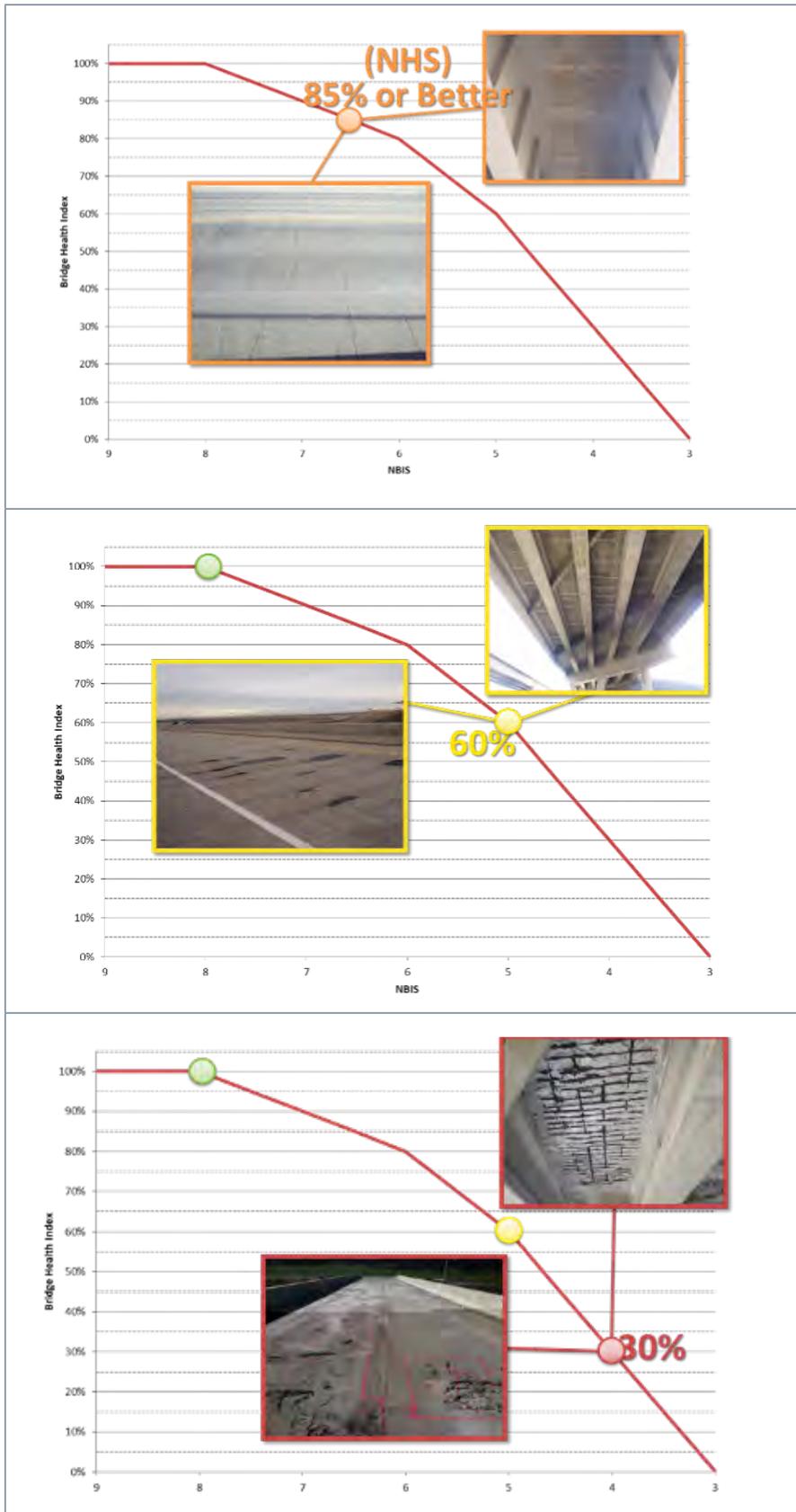


Figure 4-4 Bridge health index targets<sup>21</sup> (Utah)

## Connecticut

The CT BHI comprises mostly NBI GCRs but also selected bridge element conditions. The Connecticut BHI is a performance measure calculated and used within the dTIMS software and is utilized in network-level optimization. **Table 4-1** presents the components of the Connecticut BHI and their associated weights. Treatment benefits for the agency's TAMP strategy analysis are measured by improvement in the BHI.

Item	Weight points
Deck (58)	15
Superstructure (59)	15
Substructure (60)	15
Structural Evaluation (67)	10
Deck Geometry (68)	5
Underclearances (69)	5
Waterway Adequacy (71)	5
Approach Alignment (72)	4
Structure Open/Posted/Closed (41)	2
Paint (BRI-18)	5
Bearings (NBE)	5
Girders (NBE)	5
Joints (NBE)	5
Wearing Surface (BRI-18)	4
<b>Total</b>	<b>100</b>

*Table 4-1 Bridge health index components and weights (Connecticut)*

## Iowa

Iowa DOT developed its Bridge Condition Index (BCI), which is modified from the FHWA's Sufficiency Rating<sup>22</sup>, to create a custom index that is more aligned with agency priorities. The BCI, which is based primarily on NBI GCRs, combines into a single index a bridge's condition, its ability to provide adequate service, and how essential it is for the traveling public. The BCI reflects the bridge's overall condition, considering its structural condition, load-carrying capacity, horizontal and vertical clearances, width, traffic levels, type of roadway it serves, and the length of out-of-distance travel if the bridge were closed. The BCI is reported on a 100-point scale, with 100 representing the best condition possible. A bridge rated 50 or higher is considered to be in a state of good repair.

The Iowa BCI helps the agency prioritize recommended projects and serves as a performance measure in addition to G/F/P (**Figure 4-5**). Iowa DOT also uses the BCI (**Figure 4-6**) in its state of good repair definition<sup>23</sup>. The index exists within the IDS Bridge Optimizer<sup>24</sup> program as a measure to compare scenario outputs.

22 Recording and Coding Guide for the Structure Inventory and Appraisal of the Nations Bridges, Federal Highway Administration, Washington D.C., 1995, <https://www.fhwa.dot.gov/bridge/mtguide.pdf>

23 2019-2028 Transportation Asset Management Plan, Iowa Department of Transportation, 73, 2019. [https://iowadot.gov/systems\\_planning/fpmam/IowaDOT-TAMP-2019.pdf](https://iowadot.gov/systems_planning/fpmam/IowaDOT-TAMP-2019.pdf)

24 Bridge Optimizer™, IDS (Infrastructure Data Solutions), <https://ids.consulting/solutions/bridge-optimizer/>

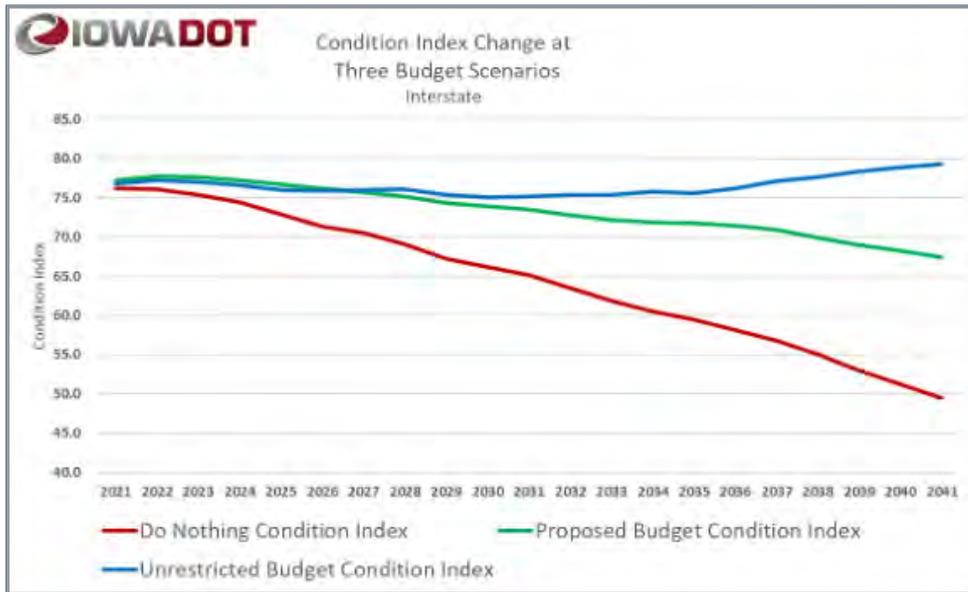


Figure 4-5 Bridge scenario analysis with the Bridge Condition Index (Iowa)

Owner	System	Count	Deck Area (ft <sup>2</sup> )	Good	Fair	Poor	BCI < 50
Iowa DOT	NHS	2,561	33,350,027	48.9%	49.1%	2.1%	106
	Non-NHS	1,598	12,087,103	51.7%	47.0%	1.3%	54
	<b>Total</b>	<b>4,159</b>	<b>45,437,130</b>	<b>49.6%</b>	<b>48.5%</b>	<b>1.8%</b>	<b>160</b>
Other	NHS	41	927,412	47.8%	40.6%	11.6%	
	<b>Total</b>	<b>41</b>	<b>927,412</b>	<b>47.8%</b>	<b>40.6%</b>	<b>11.6%</b>	
All	NHS	2,602	34,277,439	48.9%	48.8%	2.3%	
	<b>Total</b>	<b>4,200</b>	<b>46,364,542</b>	<b>49.6%</b>	<b>48.4%</b>	<b>2.0%</b>	

Note: there are more than 19,000 locally owned bridges in Iowa that are not on the NHS. Those assets are not included in the IAMP.

Figure 4-6 Bridge Condition Index in Iowa DOT's Transportation Asset Management Plan

Iowa DOT also uses decimal GCRs in its decision framework and models developed for IDS Bridge Optimizer and in its interpretation of the results. This practice of using GCR as a quantitative continuous parameter rather than as a discrete parameter is to address the long time spent in some NBI GCRs and the differences in relative perceptions of condition when a bridge enters an NBI GCR and when a bridge has stayed in that GCR for a while. VDOT also follows this approach in some of its analysis and models. This practice was of interest in scan discussions, with other DOTs commenting on its potential use.

## Minnesota

MnDOT noted that NBI GCRs have limitations since their limited granularity does not always allow for “credit” on specific work types (e.g., preservation) and inclusion into the NBI GCRs. MnDOT would like to use element condition ratings as performance measures once they are mature enough. The agency is currently working on preventive maintenance performance measures and has draft measures and targets (Table 4-2).

Category	Measure	Target	LOS A	LOS B	LOS C	LOS D
Flushing	Bridges flushed on time (annually)	A	90%	70%	60%	50%
			95%	85%	65%	50%
Crack Sealing	Bridges crack sealed on-time by square foot of deck area (5-year frequency)	A	95%	92%	88%	85%
Poured Joint Sealing	Bridges with poured joints sealed on-time by linear foot of poured joint (8-year frequency)	A	95%	92%	88%	85%
Expansion Joints	Strip seal and modular joints in Good and Fair condition by linear foot of joint	A	95%	94%	92%	90%

Table 4-2 Draft bridge preventive maintenance performance measures (Minnesota)

## Florida

FDOT has a performance-based maintenance and preservation program supported by bridge element performance measures for bridge decks, deck joints, steel protective coating systems, and concrete slope protective systems. Overall, FDOT has ascribed to a high-condition standard, which might not be applicable to all state DOTs. The bridge preservation strategy in Florida aims to ensure the functionality of “protection elements” over the long term and preservation of “core/structural” elements throughout the entire life of the bridge. Bridge element performance measures are based on both element and defect condition, have network targets for each measure, and are listed below:

- Bridge Deck
  - Reinforced Concrete: At least 95% of deck area is in CS1 / CS2 with less than 1% of area including Exposed Rebar (1090) and Cracking (1130) defects.
  - Prestressed Concrete: At least 95% of deck area is in CS1 / CS2 with less than 1% of area including Exposed Rebar (1090), Exposed Prestressing (1100), and Cracking (1110) defects.
  - Steel: At least 95% of deck area is in CS1 / CS2 with less than 1% of area including Corrosion (1000) and Connection (1020) defects.
- Deck Joints
  - Deck Joints (Steel Bridges): At least 95% of deck joint length is in CS1 / CS2 with less than 1% of length including conditions allowing leakage (multiple defect types).
  - Deck Joints (All Bridges): At least 90% of deck joint length is in CS1 / CS2 with less than 5% of length including Metal Damage (2370) defects.
- Steel Protective Coating Systems
  - Steel Protective System: At least 95% of protective system area is in CS1 / CS2 with less than 1% of area including Peeling/Bubbling/Cracking (3420) and significant Effectiveness (3440) defects.
- Concrete Slope Protective Systems
  - Concrete Slope Protection: At least 95% of slope protection area is in CS1 / CS2 with less than 1% of area including Exposed Rebar (1090), Cracking (1130), and significant Seal (2330) and Settlement (4000) defects.

These performance measures are reported in and tracked by the FDOT Bridge Performance Report (Figure 4-7). The performance measures are also used to manage turnpike maintenance with five maintenance zones. In Zone 1, maintenance is done by work order driven regional repair contracts, while Zones 2 through 5 are managed through asset maintenance contracts. Bridge performance measures are used for reporting and coordination between FDOT and asset management contractors by publishing data monthly, tracking condition trends, and producing detailed reports to support repair programs.

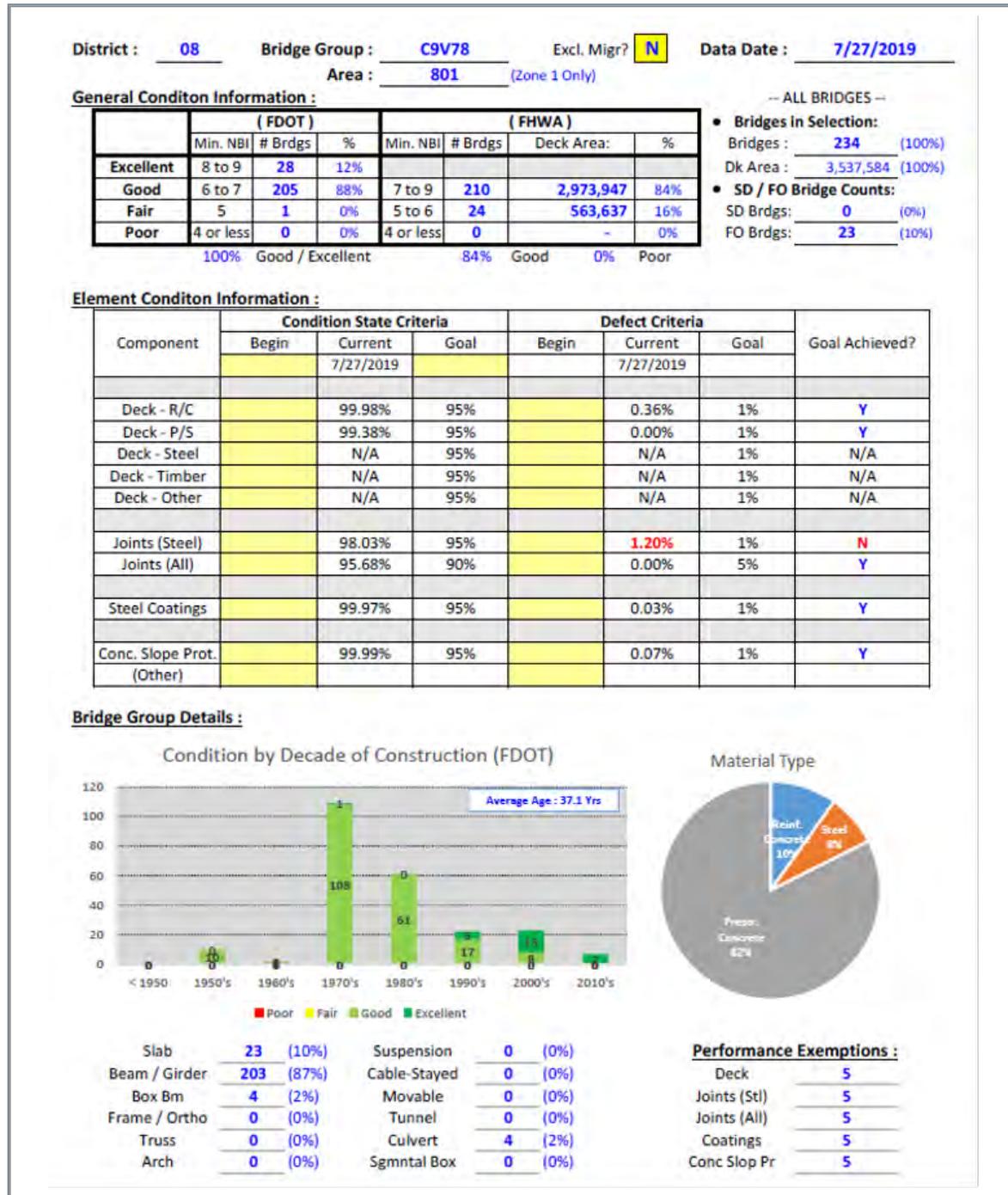


Figure 4-7 Bridge performance report (Florida)

## Risk

Although risk is not defined as a performance measure within all scan DOT TAMPs, selected practices on measuring, documenting, and communicating risk are presented in this chapter. Identifying and collecting data on risk and using risk models for TAMP analysis were limited. For most agencies, risk management, linking bridge risks to the overall asset management framework, and inclusion of agency asset management risks in BMS modeling are areas for improvement.

### Michigan

MDOT has a performance measure to mitigate scour risks within its call-for-projects process. Within its five-year process, one performance measure is to mitigate 20% of scour-critical interstate bridges. MDOT monitors progress each year toward achieving this goal. The agency has a scour assessment spreadsheet to determine the highest risk bridges based on vulnerability and criticality. For vulnerability factors, MDOT looks at scour rating, footing type, number of substructure units, soil type, scour remediation, presence of scour, and waterway adequacy. For criticality factors, it looks at highway classification, traffic volume, detour length, deck area, and economic importance. **Figure 4-8** presents progress on this performance measure by region, while **Figure 4-9** presents the actual and projected number of scour-critical bridges on Michigan interstate roads.

Performance Measure	Region						
	Bay	Grand	Metro	North	Southwest	Superior	University
Mitigate 20 Percent of Scour Critical Interstate Bridges	↑	↑	↑	Goal Met	↑	Goal Met	↑
↑ Target number programmed during CFP ↓ Target number programmed ↓ Less than target programmed							

Figure 4-8 Progress in scour-related performance measure (Michigan)

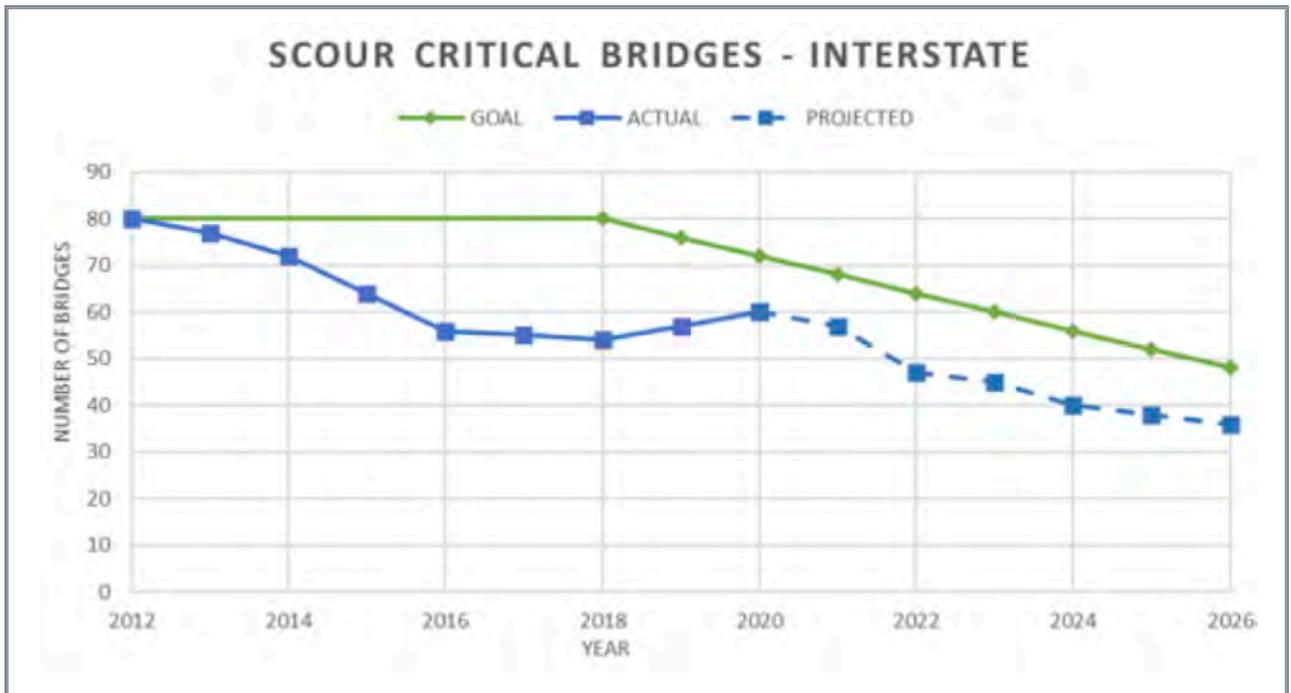


Figure 4-9 Actual and projected number of scour-critical bridges (Michigan)

**4-10** MDOT has two other call-for-projects performance measures that address structure risks, one for

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Serious and Critical bridges and the other for fracture-critical bridges. The agency tries to program serious and critical bridges in the five-year plan or ask for justification if they are not programmed. MDOT tries to keep fracture-critical bridges in Good or Fair condition and has a requirement to keep fracture-critical elements in Good or Fair condition.

## Utah

UDOT is tracking risks and emergency response projects by using GIS to spatially view the risks. The UDOT risk priority analysis and GIS maps are discussed in detail in Chapter 3.

## Minnesota

MnDOT Asset Work Groups identify bridge (and pavement) risks, starting off by compiling a list of possible network-level risks associated with properly managing the asset class. Then each identified risk is given a likelihood score (rare, unlikely, possible, or likely) and a consequence score (minor, moderate, major, or catastrophic). These decisions are then documented within the TAMP and managed in the prioritized fashion. Future TAMPs will revisit these risks, ensuring an application of an appropriate level of mitigation strategies, revising scores, or adding to and subtracting from the list of identified risks.

MnDOT has a process for identifying risks and strategies for mitigating top-priority risks through its Bridge Planning Index. This index weighs the risks associated with the condition and fatigue of the bridge structure, potential damage from flooding and trucks, and impacts of detours. The BMS (known as BRIM in Minnesota) calculates the index and integrates it into the project selection scoring process.

BRIM has a three-step process based on risk. The three modules are:

- Resiliency (**Figure 4-10**) uses engineering judgement to assign the probability and consequence of service interruption given current bridge inventory and inspection data. Factors include different types of materials, age, condition, traffic, overlay data, scour susceptibility, fatigue details, load capacity, geometry, and deck condition.
- Improvement (**Figure 4-11**) predicts network-level future work type scopes, timeframe, and cost using deterioration models for 20 years beyond the State Transportation Improvement Program (STIP).
- Expert Review (**Figure 4-12**), puts all BRIM predictions in front of district review, the staff who perform scoping and safety inspections. This allows network-level predictions to be dialed into project-specific work scopes for appropriate funding.

Sometimes corridor-driven pavement projects will drive upcoming bridge work. These corridor-driven projects are merged with bridge condition need projects within the BRIM first time period candidates for final selection as STIP projects.

A decision tree within BRIM recommends actions based on several factors. This logic is derived from years of institutional knowledge of cost-effective strategies to maintain bridges. The decision tree recommends both an action and time period. A district bridge engineer must review this decision and can override the decision with knowledge not available to the software.

OVERWEIGHT TRUCKS											
Operating HS		Case 0 MnDOT network					Case 1 MnDOT network				
Range	Up To	A	B	C	D	E	A	B	C	D	E
99.0 HS45+	9999	100	100	100	100	100	100	100	100	100	100
1.3 HS 40 - 44	45	90	90	100	100	100	85	85	95	95	95
1.2 HS 35 - 39	39.9999	80	80	90	100	100	75	75	85	95	95
1.1 HS 30 - 34	35	60	60	80	90	90	55	55	75	85	85
1.0 HS 25 - 29	30	40	40	60	80	80	35	35	55	75	75
0.9 HS 20 - 24	24.9999	20	20	50	60	60	15	15	45	55	55
0.8 HS 15 - 19	19.9999	0	0	20	20	20	0	0	15	15	15
0.7 < HS 15	14.9999	0	0	0	0	0	0	0	0	0	0

Figure 4-10 Bridge Replacement and Improvement Management Resilience module (Minnesota)

Bridge replacement and rehabilitation grid								
Indicated action								
Year built	Deck type	Struct Deficient	Deck cond <= 5			Deck cond = 6		
			ADT>10k	4-10k	<4k	ADT>10k	4-10k	<4k
2005+	Any	OPM	ReOvly	ReOvly	ReOvly	ReOvly	ReOvly	ReOvly
1977-03 (H)	Has conc ovly	Replace	Redeck	Redeck	Redeck	ReOvly	ReOvly	ReOvly
	No conc ovly	Replace	Redeck	Redeck	Redeck	Overlay	Overlay	Overlay
1970-76 (J)	Epoxy bars	Replace	Replace	Redeck	Redeck	Redeck	OPM	OPM
	Has conc ovly	Replace	Replace	Redeck	Redeck	Replace	Redeck	Redeck
<1970 (K)	Yr deck 1977+	Replace	Replace	Replace	Replace	Replace	Replace	Replace
	Yr deck <1977	Replace	Replace	Replace	Replace	Replace	Replace	Replace

Red cells indicate invalid actions (according to the list at right)

Indicated period								
Year built	Deck type	Struct Deficient	Deck cond <= 5			Deck cond = 6		
			ADT>10k	4-10k	<4k	ADT>10k	4-10k	<4k
2005+	Any		2032-41	2032-41	2032-41	2042-47	2042-47	2042-47
1977-03 (H)	Has conc ovly	2026-31	2032-41	2032-41	2042-47	2026-31	2026-31	2032-41
	No conc ovly	2026-31	2032-41	2032-41	2042-47	2026-31	2026-31	2032-41
1970-76 (J)	Epoxy bars	2026-31	2042-47	2026-31	2032-41	2042-47		
	Has conc ovly	2026-31	2026-31	2026-31	2032-41	2032-41	2032-41	2042-47
<1970 (K)	Yr deck 1977+	2026-31	2026-31	2026-31	2026-31	2026-31	2032-41	2042-47
	Yr deck <1977	2026-31	2026-31	2026-31	2026-31	2026-31	2026-31	2032-41

Figure 4-11 Bridge Replacement and Improvement Management Improvement module (Minnesota)

Project Selection Policy												
Bridge Project Selection												
Bridge Score Considered	Project ID or Bridge List	Project Comments	CHIP Score	CHIP Year Scored	Engineer over-ride				Final decision		STIP Exclude costs?	CHIP
					Action	Period	Action	Period	Action	Period		
SPscore	PSPprojectID	PSPprojectcomments	CHIPscore	CHIPYrs	gridact	gridper	enrgract	enryrea	action	period	exclcos	CHIP
	3409-19	Let, awarded		2012	Replace	2026-31			Replace	2026-31	2021	
	6403-37	Reflects BRIM period.		2012	Replace	2026-31	ReOvly		ReOvly	2026-31	2022	
	5902-25	To coordinate with a District road project. A		2018	Replace	2032-41	Superstr	2026-31	Superstr	2026-31	2024	
20	3701-91	Bridge is currently load posted.		2018	Replace	2032-41		2026-31	Replace	2026-31		2025
65	5103-91	Reflects BRIM period.			Replace	2026-31			Replace	2026-31		2026
55	4701-33	Substructure movement and low inventory r		2018	Replace	2032-41		2026-31	Replace	2026-31		2026
55		Due to pier cap condition, the District recor		2019	Replace	2032-41		2026-31	Replace	2026-31		2028

Figure 4-12 Bridge Replacement and Improvement Management Expert Review module (Minnesota)

## Pennsylvania

PennDOT notes that risk can only be analyzed within context. Many mitigation strategies exist within the DOT business structure. In PennDOT’s approach, enterprise risk is expressed numerically and uniformly across assets. The agency has a bridge risk formula (Equation 4 1) that computes a risk factor by combining multiple bridge-level risks. Bridge risk is part of PennDOT’s BridgeCare multi-objective decision analysis logic.

$$\text{Bridge Risk} = (\sqrt{\text{deck area} * \text{ADT}}) * F_s * F_{fc} * F_{det} * F_{adtt} * F_{flood}$$

Equation 4 1

Where:

- **F<sub>fc</sub>** – Fracture Critical Factor  
If FC Rating is less than 5 the  $F_{fc} = 1.4$ , otherwise  $F_{fc} = 1$
- **F<sub>det</sub>** – Detour Length Factor  
If Detour > 30 the  $F_{det} = 2$ , if Detour >= 10 the  $F_{det} = 1.5$ , otherwise  $F_{det} = 1$
- **F<sub>adtt</sub>** – Average Daily Truck Traffic Factor  
If ADTT > 20% the  $F_{adtt} = 2$ , if ADTT >= 10 the  $F_{adtt} = 1.5$ , otherwise  $F_{adtt} = 1$
- **F<sub>flood</sub>** – Flood Closure Factor  
If the bridge has been overtopped, the  $F_{flood} = 3$ , if the bridge has been closed for flooding,  $F_{flood} = 1.5$ , otherwise  $F_{flood} = 1$



# Bridge Management System Models

Various models and algorithms support performance measurement, condition forecasting, resource allocation, life-cycle management, and risk management within a BMS or within an agency's bridge management processes. Scan agencies gave presentations on the current status of their models and discussed future plans, which were enlightened by the TAMP development or ongoing improvement efforts within the state DOTs. BMS models from scan discussions, which are presented in this chapter, are categorized under deterioration models, life-cycle cost models, decision trees, and element to component condition conversion.

## Deterioration Models

Throughout the scan discussions and presentations, scan participants emphasized the need for robust deterioration models for bridge management analysis. While some agencies are using GCR deterioration models and find them sufficient for their TAMP purposes, most scan state DOTs reported that they are developing element deterioration models or have plans to do so in future. Another observation from the scan on deterioration models was the difference in models some scan DOTs used for TAMP development (mostly GCR deterioration models) and BMSs (use of element deterioration models but also GCR deterioration models). Overall, all scan agencies recognize the need for using component and element-level deterioration models that are more granular and that factor condition, age, and environmental factors.

Iowa has custom GCR deterioration models that were developed based on the state's historic condition data in the IDS Bridge Optimizer program. The deterioration models change based on factors presented in **Table 5-1** and bridge condition history to provide custom deterioration models for Iowa bridges.

Deterioration factors	NBI item number
Age	Derived from Item 27, Item 90, and Item 106
Average Daily Traffic (ADT)	Item 29
Annual Average Daily Traffic	Item 109
Length of Maximum Span	Item 48
Number of Lanes	Item 28A
Deck Protection (Type of Wearing Surface)	Item 108A
Deck Protection	Item 108C
Design Load	Item 31
Skew Angle	Item 34

*Table 5-1 General Condition Rating deterioration model factors (Iowa)*

MnDOT uses BRIM for forecasting future bridge deck condition. BRIM uses a deterministic deterioration model developed from research that studied historical MnDOT deck NBI GCR inspection data (**Figure 5-1**). Seven deterioration curves are based on district; AADT; superstructure type; and deck features, such as rebar type, wearing surface type, and depth of cover. MnDOT assigns a deterioration curve to each bridge and uses the curve to forecast future condition, considering improvement from future projects in the agency’s four-year STIP and 10-year Capital Highway Investment Plan.

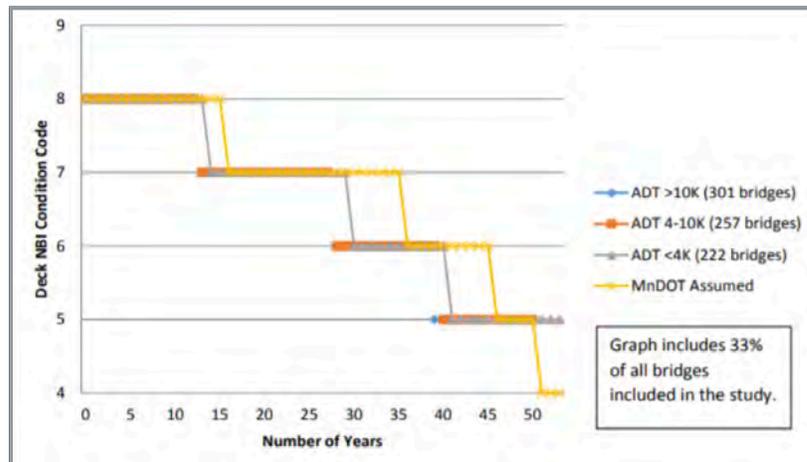


Figure 5-1 Deck deterioration models for bridges built before 1975 without epoxy-coated bars and with a concrete overlay (Minnesota)

MDOT has Markovian GCR deterioration models within the BCFS (**Figure 5-2**) to do component-level deterioration. It also uses spreadsheets to find deterioration rates and repeats the process every five years to update its models. MDOT is in the process of using more element-level deterioration in BrM and spreadsheets now that the agency has more inspections of the element data collected with the AASHTO Manual for Bridge Element Inspection<sup>25</sup>. The BCFS models are the backbone of MDOT’s analysis to compare funding levels, types of work, and deterioration for short- and long-term needs.

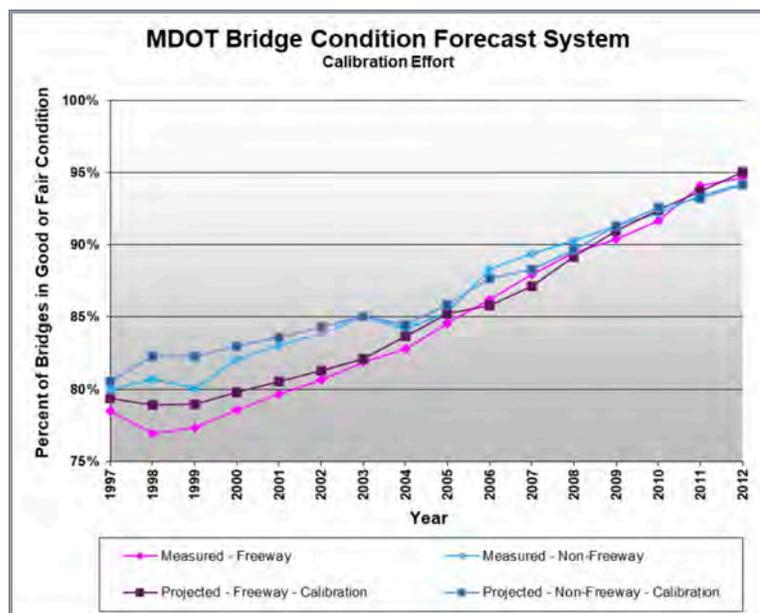


Figure 5-2 Bridge condition forecast system (Michigan)

CTDOT worked with Deighton to analyze the agency’s bridge inspection data from 1992 to 2019 to develop GCR deterioration models to use within dTIMS. There are three deterioration curve families. The middle curve is for bridges performing about average, the upper curve is for bridges that are in better-than-average condition for their age, and the lower curve is for bridges doing worse than expected. CTDOT has one curve for each initial GCR, then the middle, upper, and lower groupings (Figure 5-3), which adds up to 27 curves for each component family. In total, CTDOT has more than 2,000 curves, which factors structure type and material, structure condition relative to age, and initial NBI GCR.

For example, concrete box culvert is in family CULVERT01. If a culvert is in average condition for its age, it is assigned to the middle curve set (MC). If the starting culvert rating = 6, a culvert will be assigned to the CULVERT01\_MC\_6 curve. The starting point on that curve is adjusted based on the number of years since the structure was built or reconstructed (bridge age):

$$(0.5 * (\text{Bridge\_Age}+100)/100 * \text{Initial Life (e.g., Bridge Age = 30, Initial Life = 20, then } 0.5 * 130/100*20 = 13)$$

The starting point on CULVERT01\_MC\_6 curve will be advanced 13 years, so the culvert will transition to 5 in only seven years, instead of the default 20 years.

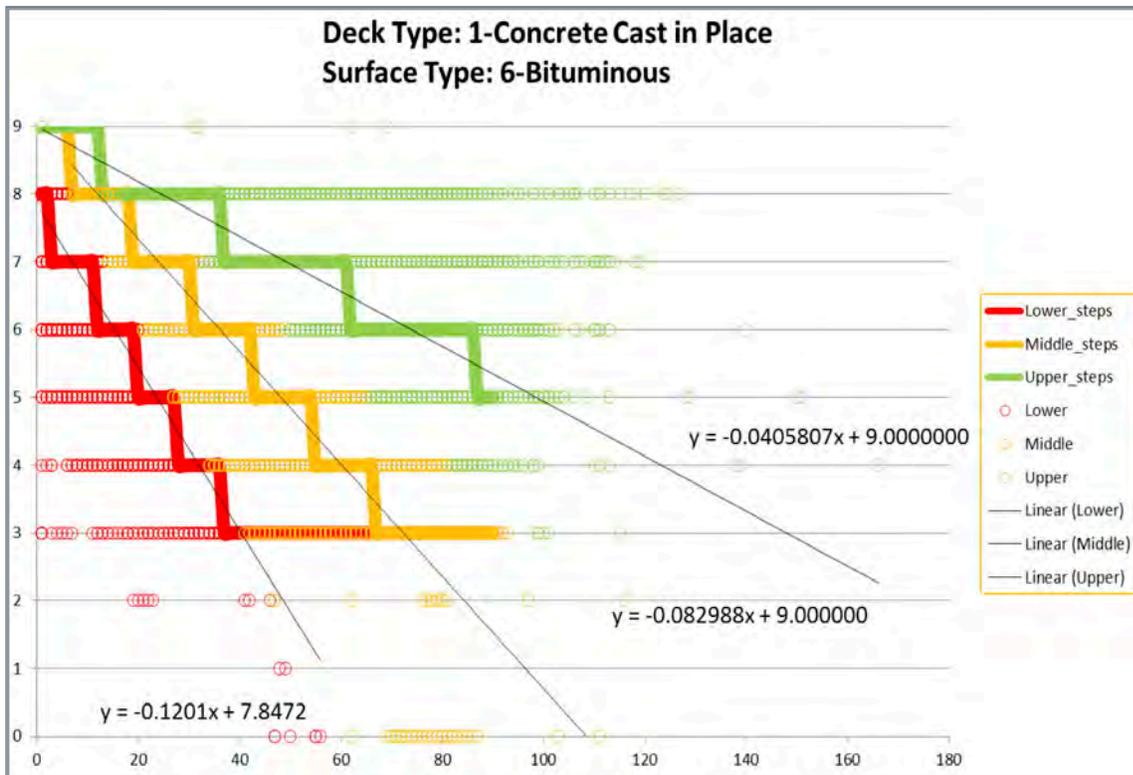


Figure 5-3 General Condition Rating deterioration curves for concrete cast-in-place decks with bituminous overlays (Connecticut)

CTDOT also modeled transition probabilities for its NBEs. Figure 5-4 shows its current transition probability matrix for the open steel girder element. Both GCR and NBE deterioration models are used in dTIMS for bridge scenario analysis.

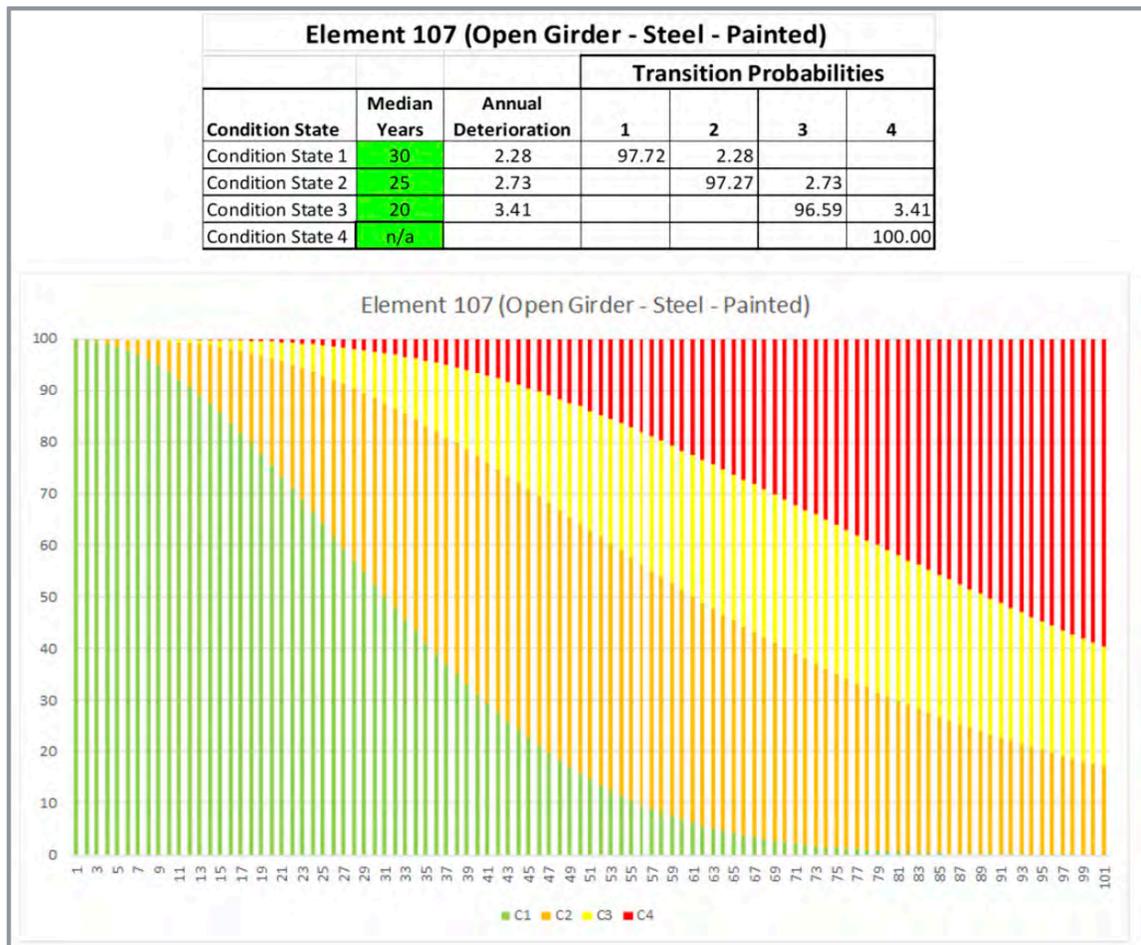


Figure 5-4 Transition probability matrix and resulting transitions for the open steel girder element (Connecticut)

PennDOT has developed bridge deterioration models to be used in conjunction with BridgeCare. After lengthy investigation, PennDOT ultimately decided to pursue deterministic modeling rather than probabilistic modeling for its bridge deterioration modeling methodology. Because it wanted to be able to predict discrete values in the future per structure, PennDOT opted for deterministic modeling. The model predicts future condition ratings based on the stepped nature of the 10 condition ratings and the rates at which bridges move through previous condition ratings. PennDOT created general sets of deterioration curves per bridge family to represent these rates of deterioration through previous condition ratings. The agency currently has 924 bridge and culvert deterioration models under 84 bridge and culvert families.

The deterministic modeling approach was considered to make best use of PennDOT’s bridge condition data and was the only methodology that could support individualized treatment recommendations and also be understandable by key stakeholders, including PennDOT’s district engineers and bridge engineers. The deterioration analysis was conducted using condition rating duration prediction. This prediction method determines the statistical duration in years that bridges spend at each condition rating, using the 0 to 9 rating scale of the National Bridge Inspection Standards. This procedure is followed to create deterioration curves for each bridge component (deck, superstructure, substructure, and culvert). The method includes the following general steps:



Figure 5-6 Deterioration model update Interface (Pennsylvania)

FDOT uses Markovian element deterioration models in its custom BMS analysis tools and for TAMP analysis. FDOT has a long-standing tradition of implementing research into practice<sup>26, 27, 28, 29, 30</sup>. The agency's PLAT is entirely element-driven and is supported by continual research on deterioration, unit cost, and risk models for Florida bridge elements.

Florida element deterioration models are Markovian models that are modified from the initial Pontis models<sup>26</sup>. The deterioration models were first developed based on AASHTO's Commonly Recognized Elements and updated in 2016 to address the changes in the elements.

26 Sobanjo J O and P D Thompson (2001), Development of Agency Maintenance, Repair & Rehabilitation (MR&R) Cost Data for Florida's Bridge Management System, State Maintenance Office, Florida Department of Transportation: 287,

<http://www.pdth.com/images/fdotagcy.pdf>

27 Thompson PD, JO Sobanjo and R Kerr (2003), "Florida DOT Project-Level Bridge Management Models," *Journal of Bridge Engineering* 8(6):345-352, [http://dx.doi.org/10.1061/\(ASCE\)1084-0702\(2003\)8:6\(345\)](http://dx.doi.org/10.1061/(ASCE)1084-0702(2003)8:6(345))

28 Sobanjo JO and PD Thompson (2007), "Decision Support for Bridge Programming and Budgeting," State Maintenance Office, Florida Department of Transportation, <https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/research/reports/fdot-bd543-09-rpt.pdf>

29 Sobanjo J (2011), "Estimating the Timing of Rehabilitation and Replacement of Bridge Elements," *Transportation Research Record: Journal of the Transportation Research Board* 2220(-1):48-56, <http://dx.doi.org/10.3141/2220-06>

30 Sobanjo JO and PD Thompson (2013), "Development of Risk Models for Florida's Bridge Management System," State Maintenance Office, Florida Department of Transportation, <https://rosap.nrl.bts.gov/view/dot/26017>

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## Life-Cycle Cost

Modeling and inclusion of life-cycle costs into BMS and TAMP analysis vary across agencies. Selected examples of life-cycle cost models and approaches from scan DOTs are included below.

### Virginia

VDOT has an under-development Python tool for which the objective function is going to be a weighted utility function of:

- Long-term average of average GCR weighted by importance factor
- GCR weighted by importance factor at a target year
- Life-cycle cost

VDOT is currently not incorporating any risks but may consider scour and impact risk in the future. Its deterioration models are Weibull distribution for component-level deterioration and hybrid Markov-Weibull models for element-level deterioration. VDOT plans to consider life cycle in the BMS analysis. Its decision trees are a combination of expert elicitation and past bridge performance. The agency uses historical data from previous bids and financial information from past projects for its work cost values. It also has a preservation policy that is used in BMS analysis. The output from BMS analysis is used at a very high level for funding bridges, determining overall inventory needs assessment, TAM target setting and review, and potentially to lobby for additional funding based on long-term forecasts of inventory condition.

When VDOT has differences between what the bridge management program recommends for projects versus what it actually needs/wants to do, the agency finds an overall reason for the projects being selected (considering the optimization engine and inputs such as cost, benefits, deterioration, and others) and compares that with the state of practice and expert elicitation.

### Michigan

MDOT has a bridge deck preservation matrix (**Figure 5-7**) that was developed based on life-cycle cost analysis. This matrix was found to give similar answers for a majority of bridges; therefore, individual life-cycle cost analysis is only done for special cases. When individual life-cycle cost analysis is needed, MDOT uses spreadsheets. MDOT plans to use life-cycle cost analysis within BrM in the future once the configuration is complete.

BRIDGE DECK PRESERVATION MATRIX – DECKS WITH UNCOATED “BLACK” REBAR							
DECK CONDITION STATE				REPAIR OPTIONS	POTENTIAL RESULT TO DECK BSIR		ANTICIPATED FIX LIFE
Top Surface		Bottom Surface			Top Surface BSIR #58a	Bottom Surface BSIR #58b	
BSIR #58a	Deficiencies % (a)	BSIR #58b	Deficiencies % (b)				
≥ 5	N/A	N/A	N/A	Hold (c) / Seal Cracks	No Change	No Change	N/A
				Silane			5 years
				Healer Sealer (d)			8 to 10 years
	≤ 10%	≥ 6	≤ 2%	Epoxy Overlay (f)	8, 9	No Change	15 to 20 years
≤ 10%	≥ 4	≤ 25%	Deck Patch (e, j)	6, 7, 8	No Change	5 to 10 years	
4 or 5	10% to 25%	≥ 5	≤ 10%	Deep Concrete Overlay (h, j)	8, 9	No Change	25 to 30 years
		4	10% to 25%	Shallow Concrete Overlay (h, i, j)	8, 9	No Change	20 to 25 years
				HMA Overlay with water-proofing membrane (f, i)	8, 9	No Change	8 to 10 years
		2 or 3	> 25%	HMA Cap (g, i)	8, 9	No Change	2 to 4 years
≤ 3	>25%	≥ 6	< 2%	Deep Concrete Overlay (h, j)	8, 9	No Change	20 to 25 years
		4 or 5	2% to 25%	Shallow Concrete Overlay (h, i, j)	8, 9	No Change	10 years
				HMA Overlay with water-proofing membrane (f, i)	8, 9	No Change	5 to 7 years
		2 or 3	>25%	HMA Cap (g, i)	8, 9	No Change	1 to 3 years
				Replacement with Epoxy Coated or Stainless Rebar Deck	9	9	60+ years

Figure 5-7 Bridge deck preservation matrix (Michigan)

## Connecticut

CTDOT utilizes life-cycle cost analysis through dTIMS. The treatment selection algorithm creates an incremental benefit cost plot (Figure 5-8) of possible treatment strategies and selects strategies at the top of the Pareto frontier.



Figure 5-8 Example incremental benefit cost plot (Connecticut)



Bridge Painting (steel superstructure) – Full Bridge		
Attribute	Criteria	Consequence
Deck		No change
Superstructure		Ceiling + 1
Substructure		No change
Deck Wearing Surface		No change
6B36 Paint Condition		9
6B37 Paint (Extent)		N

NOTES:

- 1) "Ceiling" is the highest seeded value of any particular condition rating. For example, a bridge component with a seeded value of 7.13 has a "Ceiling" seeded value of 7.99.
- 2) After this treatment is performed, BridgeCare will not allow for additional treatments or this treatment to be performed again in the simulation according to the following schedule:
  - c. Years before any treatment = 5
  - d. Years before same treatment = 25

Figure 5-10 Example bridge treatment consequence table (Pennsylvania)

The following treatments are currently being utilized in PennDOT BridgeCare analyses:

- Epoxy Overlay
- Structural Overlay
- Bituminous Overlay
- Bridge Painting (steel superstructure) – Full Bridge
- Bridge Painting (steel superstructure) – Joint/Spot/Zone Painting
- Deck Replacement
- Substructure Rehabilitation
- Superstructure Replacement/Rehabilitation
- Bridge Replacement
- Culvert Rehabilitation
- Culvert and Small Bridge (< 3') Replacement
- County Maintenance – Deck Work
- County Maintenance – Superstructure Work
- County Maintenance – Substructure Work

Due to variability in structure type, size, business plan network, traffic volumes, condition, risk, and other characteristics, the treatments listed above contain several sets of rules to accommodate these differences. The treatment selection logic is displayed in two formats: flowcharts and summary tables. Consequences are the seeded condition rating changes that are expected to occur as a result of specific bridge treatments being selected during the BridgeCare analysis. Additionally, a table is provided that shows the prescribed unit costs associated with each treatment type selected. The consequences and unit costs shown in the tables are the consequences and costs that the central office currently utilizes in its BridgeCare simulations.

## Connecticut

CTDOT treatments have defined triggers, resets (benefits), costs, and follow-on treatments for their treatments within its BMS, which constitute decision trees plus costs for their treatments. A CTDOT treatment may be major (may be applied alone) or ancillary (only applied in conjunction with a major treatment). Treatments modeled by CTDOT are:

- Bridge/Culvert Replacement (major)
- Culvert Repair (major)
- Rehab Project (contractor or BRU, placeholder major for ancillaries):
  - Superstructure Replacement (ancillary)
  - Superstructure Repair: Girder or Overall (ancillary)
  - Deck Replacement (ancillary)
  - Deck Repair (ancillary)
  - Substructure Repair (ancillary)
  - Bearing Replacement (ancillary)
  - Wearing Surface Replacement (ancillary)
  - Paint Replacement (ancillary)
  - Paint Repair (ancillary)
  - Joint Replacement (ancillary)

**Figure 5-11** shows an example trigger for superstructure replacement. The trigger uses both GCRs, other NBI items, and select element conditions. It also checks first for a committed project, then checks trigger conditions.

```
IF(IS_COMMITTED() and
(Bridges->COM_TRT = 'str_STR_MTCE_Contractor' OR Bridges->COM_TRT = 'str_STR_MTCE')
AND YR = Bridges->COM_YEAR,
Bridges->COM_TRT_1 = 'str_anc_Superstructure_Replace' or
Bridges->COM_TRT_2 = 'str_anc_Superstructure_Replace' or
Bridges->COM_TRT_3 = 'str_anc_Superstructure_Replace' or
Bridges->COM_TRT_4 = 'str_anc_Superstructure_Replace' or
Bridges->COM_TRT_5 = 'str_anc_Superstructure_Replace',
str_abf_OBJ_Superstructure AND
(str_AAV_SUPER_RATING <= 4.0
OR (str_AAV_ELEM_107_CS3 + str_AAV_ELEM_107_CS4 > 15.0)
OR (str_AAV_ELEM_109_CS3 + str_AAV_ELEM_109_CS4 > 15.0)
OR (str_AAV_ELEM_110_CS3 + str_AAV_ELEM_110_CS4 > 15.0)
OR (str_AAV_ELEM_111_CS3 + str_AAV_ELEM_111_CS4 > 15.0)
OR (str_AAV_ELEM_112_CS3 + str_AAV_ELEM_112_CS4 > 15.0))
AND
str_AAV_SUB_RATING >= 4.0 AND
str_CDAV_SCOUR_CRITICAL <> '0' AND
str_CDAV_SCOUR_CRITICAL <> '1' AND
str_CDAV_SCOUR_CRITICAL <> '2' AND
str_CDAV_SCOUR_CRITICAL <> '3')
```

*Figure 5-11* superstructure replacement trigger (Connecticut)

## Element to Component Condition Conversion

Element to component condition conversion is a general challenge for state DOTs that are implementing or working toward implementing BMSs, which are typically built on an element data framework. Since the federal bridge condition performance measures are based on GCRs, converting element condition forecasts that come from element-based analysis or investment strategy development to GCRs have potential uses for agencies that use a BMS with an element framework. Element to GCR conversion research in the U.S. goes back to late 1990s . Since then, different algorithms that tried to improve the predictive accuracy of the translation or mapping have been proposed<sup>31, 32, 33, 34, 35</sup>.

Some state DOTs have also customized available algorithms or adjusted mapping thresholds based on their data and experiences. The BrM software has conversion integrated into its analysis and includes the FHWA conversion profile, as well as the flexibility for agencies to create custom profiles. However, state DOTs need an algorithm or application integrated into BMS analysis with high predictive accuracy between element condition data and GCRs. Observations on element-to-GCR conversion from the scan presentations and discussions are presented below.

### Utah

UDOT uses a BHI that includes both element and component conditions; therefore, element-to-component conversion has uses in its BMS and analysis that support bridge management and TAMP development. UDOT uses the following guidelines for element-to-component condition conversion:

- NBI 8: Very Good Condition – No problems noted (No CS 2)
- NBI 7: Good Condition – Some minor problems (< 10-15% CS 2; No CS 3)
- NBI 6: Satisfactory Condition – Structural elements show some minor deterioration (10 – 60 % CS 2; 1 – 10 % CS 3)
- NBI 5: Fair Condition – All primary structural elements are sound but may have some minor section loss, cracking, spalling, or scour (>50-60% CS 2; >10% CS 3; < 5% CS 4)

### Florida

FDOT customized the NBI Translator and uses it to map element condition data to NBI GCRs. Translated NBI GCRs are used for predicting network-level NBI conditions in NAT outputs. This tool has built-in dashboards and creates reports and graphs for program outcomes for performance measures, such as percent Good/Excellent, HI, paint HI, and life-cycle benefits.

31 Hearn, G, J Cavallin, and DM Frangopol, (1997), Generation of NBI Condition Ratings from Condition reports for Commonly Recognized (CoRe) Elements, University of Colorado at Boulder:52

32 Al-Wazeer A, C Nutakor and B Harris (2007). "Comparison of Neural Network Method Versus National Bridge Inventory Translator in Predicting Bridge Condition Ratings." *TRB 86th Annual Meeting Compendium of Papers* CD-ROM Paper #07-0572

33 Sobanjo JO, PD Thompson, R Kerr, (2008). "Element-to-Component Translation of Bridge Condition Ratings." *Transportation Research Board Annual Meeting 2008 Compendium of Papers* DVD Paper #08-3149

34 Bektas B, A Carriquiry and O Smadi (2012). "Using Classification Trees for Predicting National Bridge Inventory Condition Ratings." *Journal of Infrastructure Systems* 19(4): 425-433, [http://dx.doi.org/10.1061/\(ASCE\)IS.1943-555X.0000143](http://dx.doi.org/10.1061/(ASCE)IS.1943-555X.0000143)

35 Bektaş BA (2017). "Use of Recursive Partitioning to Predict National Bridge Inventory Condition Ratings from National Bridge Elements Condition Data." *Transportation Research Record* 2612(1): 29-38, <https://journals.sagepub.com/doi/abs/10.3141/2612-04>

## Virginia

VDOT has done internal research on the conversion and reported a national need for research and development of conversion profiles or algorithms with better predictive accuracy. The agency’s preliminary study to enhance the accuracy of the existing models provided insight on the type of conversion that it would like to have to support resource allocation, capital budgeting, increased consistency between element condition and GCRs, and other asset management functions.

VDOT tried to calibrate element weights and boundary percentages (thresholds) in the GCR conversion profile (matrix) using an evolutionary genetic algorithm combined with expert elicitation. The accuracy of predictions for Virginia bridge condition data improved by 50% compared to the existing default model in the BrM software. The following analysis steps were followed for this study:

- Extracted component-level GCR data and the corresponding element-level condition-state percentages
- Assigned VDOT’s elements (155 elements) to each of the deck, superstructure, substructure, and culvert components
- Evaluated the accuracy of the existing methods in BrM (**Table 5-2**)
- Calibrated element weights and GCR profile boundaries for one district, using an optimization feature of Excel and expert elicitation
- Optimized element weights and GCR profile boundaries for a statewide conversion model using the calibrated values from one district (**Table 5-3**)

		Equivalent condition-state method	
		Measurement unit type	Measurement unit type
GCR-NBI Conversion Profile	FHWA	30%** (74%***)	17%** (59%***)
	BrM Default	33%** (81%**)	18%** (59%***)

*Table 5-2 Accuracy of predicted bridge-level General Condition Rating for all Virginia DOT bridges\**

- \* Based on July 1, 2019, historic data
- \*\* Corresponds to exact GCR prediction
- \*\*\* Corresponds to ±1 GCR prediction

	One district	All VDOT structures
Deck	59%* (92%**)	45%* (90%**)
Superstructure	58%* (93%**)	45%* (90%**)
Substructure	56%* (94%**)	50%* (94%**)
Culvert	54%* (94%**)	50%* (92%**)

*Table 5-3 Accuracy of predicted General Condition Rating for all Virginia DOT structures and selected district*

- \* Corresponds to exact GCR prediction
- \*\* Corresponds to ±1 GCR prediction

Optimized element weights in the deck component (**Table 5-4**), optimized boundaries of the deck conversion profile (**Figure 5-12**), and the number of inspected versus predicted GCRs (**Figure 5-13**) are provided below.

Frequency of element in deck components	Element number	Element name	Optimized weights
46%	12	Concrete reinforced deck	7.5
0%	13	Prestressed concrete deck	3.6
5%	15	Prestressed/reinforced concrete top flange	20
6%	16	Reinforced concrete top flange	2
0%	28	Open grid steel deck	6
0%	29	Concrete filled grid steel deck	1.6
0%	30	Corrugated/orthotropic/etc. deck	5
18%	31	Timber deck	30
22%	38	Concrete reinforced slab	10
0%	39	Other slab	2.6
0%	54	Timber slab	30
0%	60	Other deck	4.6
3%	65	Other slab	4
5%	300	Strip seal expansion joint	20
23%	301	Pourable joint seal	20
20%	302	Compression joint seal	5
2%	303	Assembly joint with seal	50
1%	304	Open expansion joint	1
1%	305	Assembly joint without seal	25
0%	306	Other joint	18
0%	320	Prestressed concrete approach slab	0.6
27%	321	Concrete approach slab	0.6
46%	330	Metal bridge railing	10
63%	331	Concrete bridge railing	10
8%	332	Timber bridge railing	22
3%	333	Other bridge railing	14
0%	334	Masonry bridge railing	12
74%	510	Wearing surfaces	5
31%	515	Steel protective coating	0.2
18%	520	Concrete reinforcing steel protection system	15
7%	521	Concrete protective coating	0.2
7%	801	Sidewalk	11
17%	802	Deck drains	200
2%	843	Link slab	7
1%	844	Slab extension	7
36%	845	Joint effectiveness	550
0%	886	Beam/girder ends or bearings-steel protective coating	5.6

Table 5-4 Optimized element weights in the deck component (Virginia)

Calibrated for Decks based on weights and boundaries-Manually improved				
GCR	Condition state percentages			
	CS1 %	CS2 %	CS3 %	CS4 %
9		0.0%	0.0%	0.0%
8		0.1%	0.0%	0.0%
7		25.0%	15.0%	1.9%
6		100.0%	32.0%	10.0%
5			55.0%	22.0%
4			100.0%	65.0%
3				100.0%
2	-	-	-	-
1	-	-	-	-

Figure 5-12 Optimized boundaries for decks (Virginia)

Count of Converted NBI Column Labels								Accurate predicted GCRs	
GCR From Inspection	4	5	6	7	8	9	Grand Total		
4	6	2	6	3			17	35%	
5	1	13	49	39	1		103	13%	
6		5	119	142	1	3	270	44%	
7		2	2	67	515	5	38	629	82%
8				3	75	5	34	117	4%
9						17		17	100%
N				2	3		5		
<b>Grand Total</b>	<b>9</b>	<b>22</b>	<b>244</b>	<b>776</b>	<b>11</b>	<b>96</b>	<b>1158</b>		
Percentage of total accurate predicted GCRs (GCR range between 3-9)	59%								
±1 Accuracy	92%								

Figure 5-13 Number of inspected versus predicted GCRs for decks (Virginia)

VDOT believes that the accuracy of conversion profiles can be enhanced by refining the profiles based parameters such as deck type, material, and wearing surface; superstructure type and material; and substructure/culvert type and material combined with scour condition, and also considering agency-developed elements. VDOT recommends developing two conversion profiles:

- **In-practice:** What is actually occurring based on data analytics (influence of non-primary elements, may over-emphasize localized issues, diversity in rating practices from districts, consultant, inspector, etc.)
- **Ideal:** What should be occurring based on the strict interpretation of the NBI coding guide



# Use of Bridge Management Systems for Communication

Scan state DOTs use different formats (e.g., dashboards, reports, and scenario analysis) and information with different levels of complexity or detail to communicate with varying stakeholders (e.g., bridge management group, executive managers, legislators, and road users), using the data in their BMS or other agency data repositories. This chapter includes example formats and types of information that the scan DOTs use for communication.

GIS is used and/or integrated with BMSs to view, report, or analyze selected structures. GIS is also used to both process data (e.g., viewing and filtering bridge data sets internally for bridge management business processes) and communicate bridge network performance or asset management efforts with external users (e.g., through dashboards). Examples of GIS use in data collection and management can also be found in Chapter 2.

## New Mexico

New Mexico's Enterprise GIS (EGIS) takes data from multiple sources and puts it into one program for everyone to view. Bridge data from the BrM software is uploaded directly into EGIS weekly. EGIS Viewer is easy to query based on many different criteria related to projects, bridges, pavement, traffic, and roadway data, and helps bridge managers and engineers view and analyze data by combining the attributes from multiple data resources when needed. The tools also help the agency visually present information from analysis and query results. In **Figure 6-1**, a screenshot of EGIS Viewer shows all prestressed concrete bridges in the state with an overall condition rating of Good.

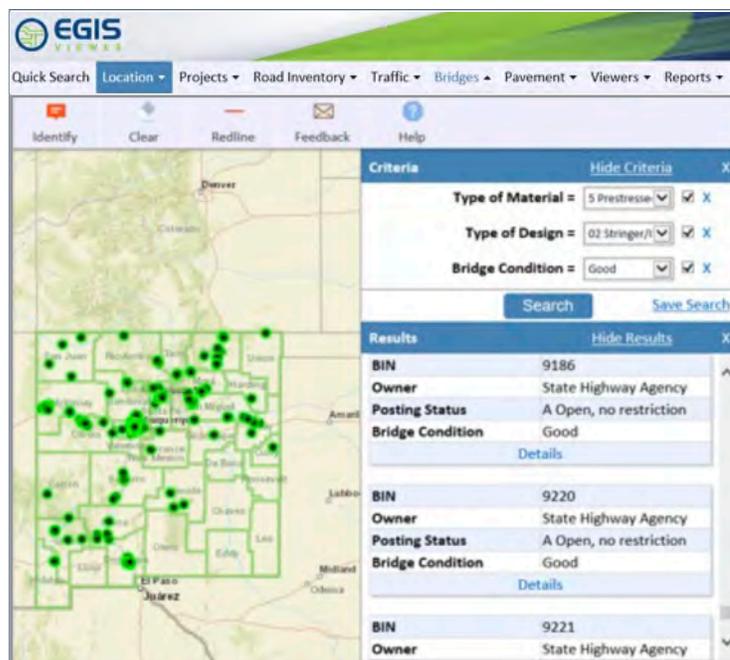


Figure 6-1 Enterprise Geographic Information System Viewer (New Mexico)

## Michigan

MDOT has an external-facing, active dashboard that shows condition metrics, performance measure status, and descriptive statistics for all and select structures<sup>36</sup>. From the same web page, users can also view and retrieve data on all Michigan bridges, see a dedicated map for Poor bridges (including those that are in Severe condition), and view posted and closed bridges. Michigan.gov also has dashboards that show trend analyses, bridge forecasts, and bridge comparisons.

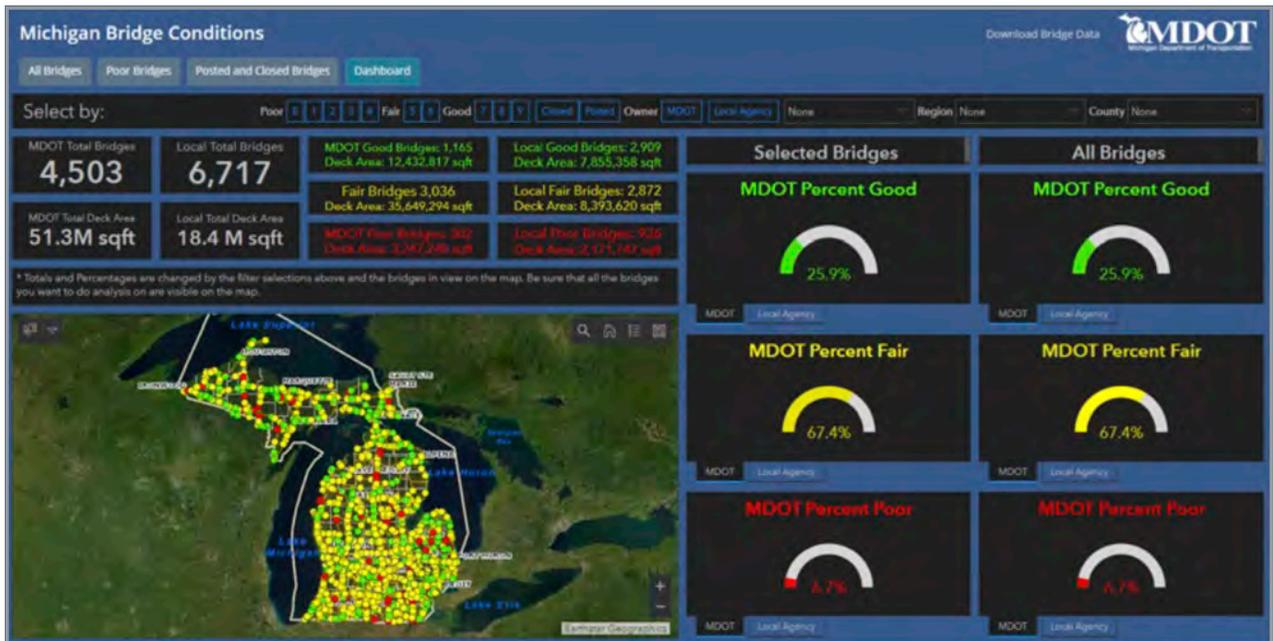


Figure 6-2 Bridge condition dashboard (Michigan)

## Minnesota

MnDOT has a performance website<sup>37</sup>, “Minnesota Go Performance Dashboard,” that presents information on the performance measures and status of different components and the impacts of the overall transportation system (i.e., safety, environment, customers, aviation, transit, bicycle/pedestrian, freight/rail, bridges, workforce, and roads). Bridge condition and inspection performance measures are reported externally here (Figure 6-3). Before the dashboard was created, the agency published a performance scorecard and annual report, which included bridge condition under the category of Operational Excellence: System Stewardship.

MnDOT reports that transparently communicating budget scenario projections to upper staff and the legislature is key to telling a compelling funding story. The Bridge Office is constantly delivering a message that it has an upcoming bridge bubble that it needs to manage. As the interstate was expanded west through the state in the 1960s, those bridges now are coming due for repair and replacement. MnDOT uses charts showing the age of bridges (Figure 6-4) to communicate the upcoming need. (A condition-by-decade graph prepared by UDOT communicates a similar message (Figure 6-5).) MnDOT also develops an unfunded needs map from BRIM output to help communicate the backlog in the current funding scenario.

<sup>36</sup> “Michigan DOT Bridge Conditions Dashboard,” Michigan Department of Transportation, 2021, from <https://mdot.maps.arcgis.com/apps/MapSeries/index.html?appid=fb70725b2be04dc7b01703d0b6c91bb6>).

<sup>37</sup> Minnesota DOT Performance Website,” Minnesota Department of Transportation, 2021, from <https://performance.minnesotago.org/>).



## Bridge Condition

Why is this important?

How do I print?

NHS Bridge Condition

Non-NHS Bridge Condition

### NHS Bridge Deck Area Condition

#### About

Bridge condition is assigned during inspections performed at least every two years on all state highway bridges. Ratings combine deck, substructure, and superstructure evaluations. Bridges rated "poor" are safe to drive on, but they are near the point where significant investment in repair or replacement is necessary. The cost and disruption of repairing or replacing large, heavily used bridges are also greater compared to bridges that are smaller and less traveled.

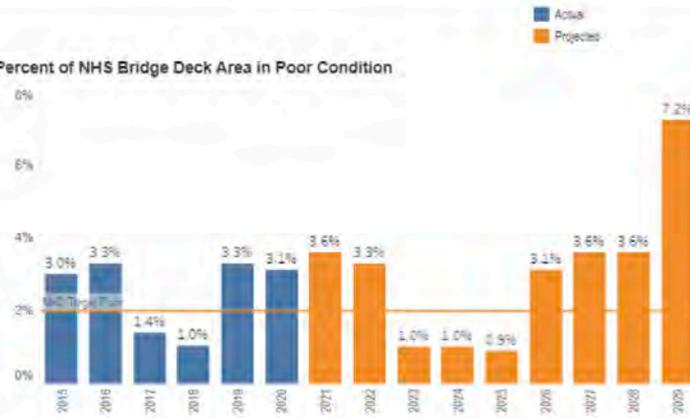
#### Recent Trends

The percent of deck area in poor condition exceeded the target in 2019 when a set of very large twin bridges (representing 2.1% of the total NHS deck area), fell into poor condition. These bridges are scheduled for repair work in 2023. The percent of deck area in good condition fell below the target and is now 32.4%. This sharp decline can be largely attributed to MnDOT's effort to increase the quality and standards of inspection efforts, resulting in more accurate assessments of condition. As shown by the forecasts, the conditions are expected to level off, but with a slight upward trend back toward the target.

#### Where We Want To Go

Current performance targets were set by historical trends. MnDOT is instead researching ways to set new targets based on life cycle cost optimization analysis. These new targets will then guide MnDOT toward making investments that aim to maximize the life of our structures.

Percent of NHS Bridge Deck Area in Poor Condition



Percent of NHS Bridge Deck Area in Good Condition



Figure 6-3 Bridge Condition dashboard<sup>37</sup> (Minnesota)

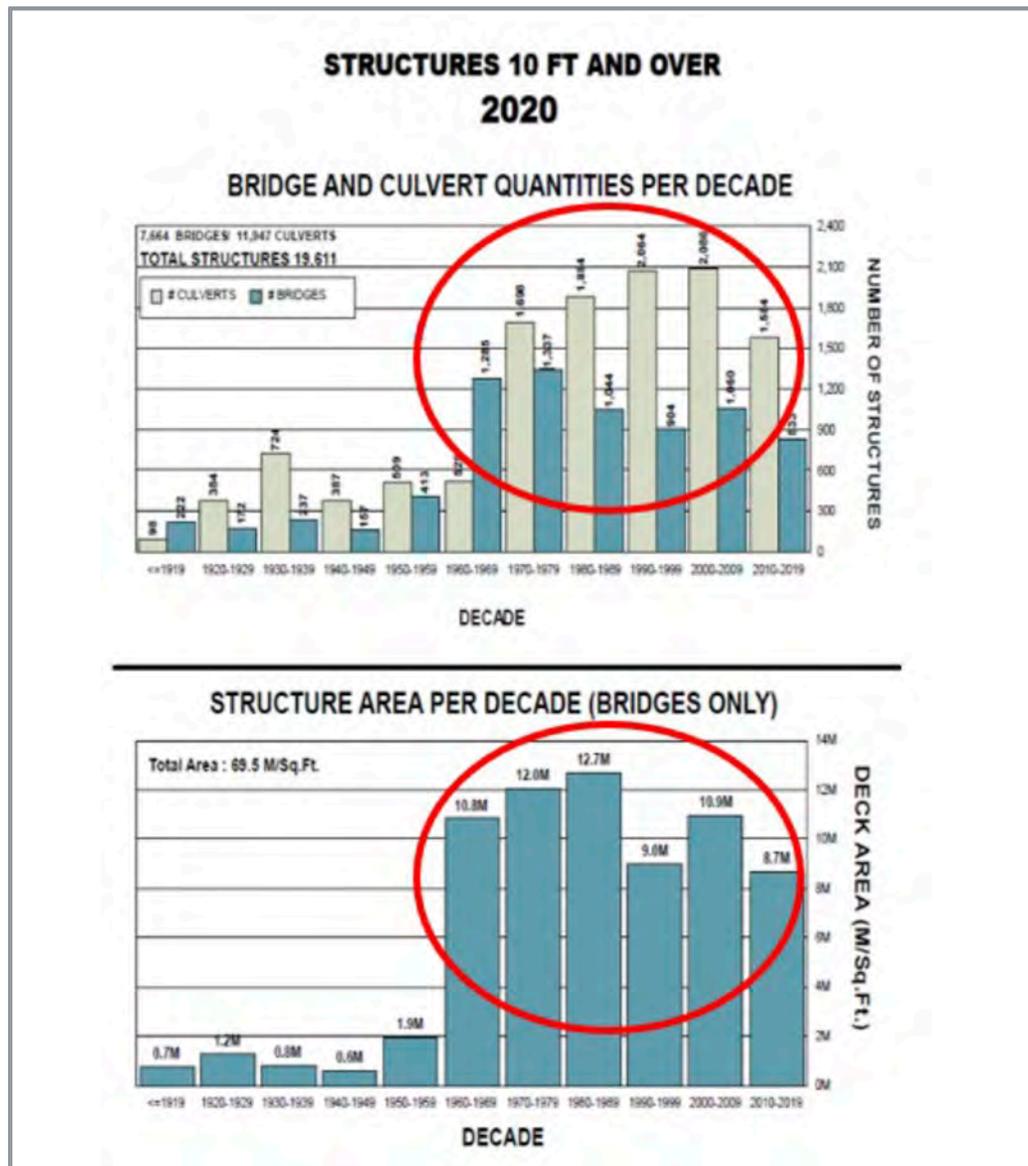


Figure 6-4 Bridge and culvert areas by decade (Minnesota)

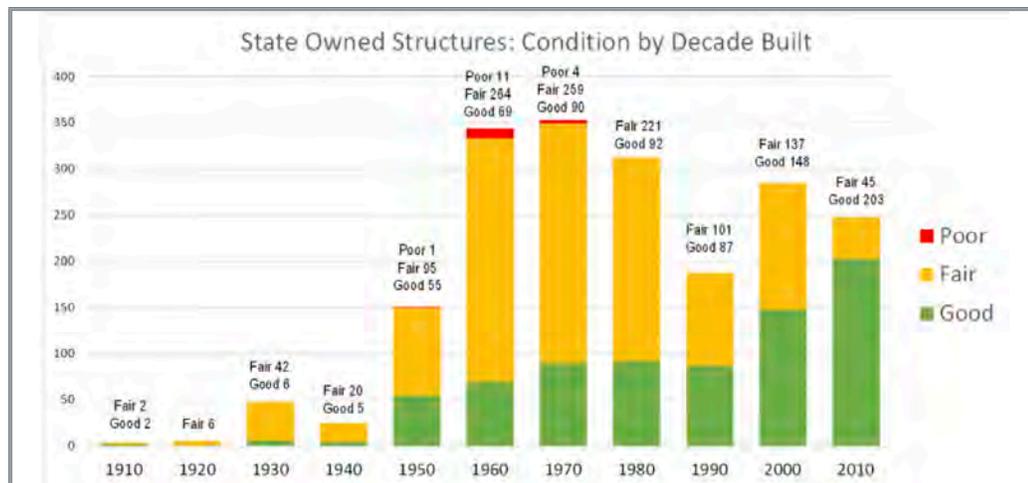


Figure 6-5 Condition by decade built (Utah)

An annual bridge report is a common format that state DOTs use (**Figure 6-6**) for communicating detailed information on state bridges. Typically, information on bridge groups and classification, condition status and age by group, bridge performance measures and targets, and bridge work (e.g., rehabilitation and replacement) plans for the relevant planning horizons are included in these reports and posted on agency websites as a reference for multiple stakeholders.



Figure 6-6 Annual bridge reports from Minnesota, Utah, and Michigan

Multiple scan state DOTs reported that conveying technical information in plain language to laypeople, upper management, and legislators and in a brief manner (e.g., one-pagers with visuals) is a successful strategy. Visuals and graphs that combine multiple measures and values efficiently are also found to be useful communication vehicles. For example, MDOT’s bridge cycle-of-life graph (Figure 6-7) combines information on current, target, and predicted G/F/P conditions as well as transitions between conditions in one graph, instead of presenting the same information in several hard-to-follow paragraphs. Similarly, Figure 6-8 communicates efficiently the per-capita investment differences on state roads between Great Lakes states. In Figure 6-9, a PennDOT one-pager with visuals is used to communicate why investing in bridge preservation is cost effective.

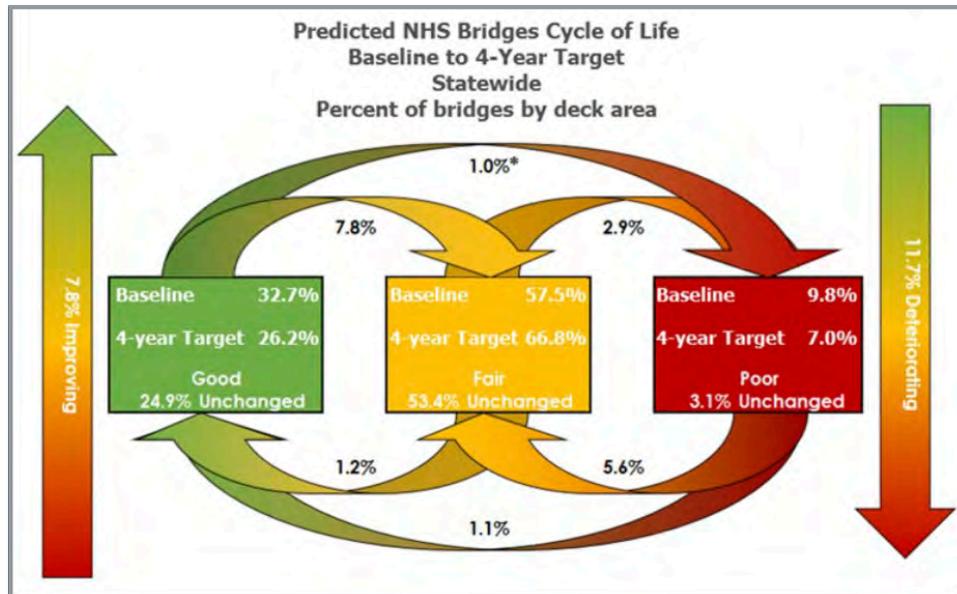


Figure 6-7 Bridge cycle-of-life graph (Michigan)



Figure 6-8 Great Lakes states’ per-capita road investment (Michigan)

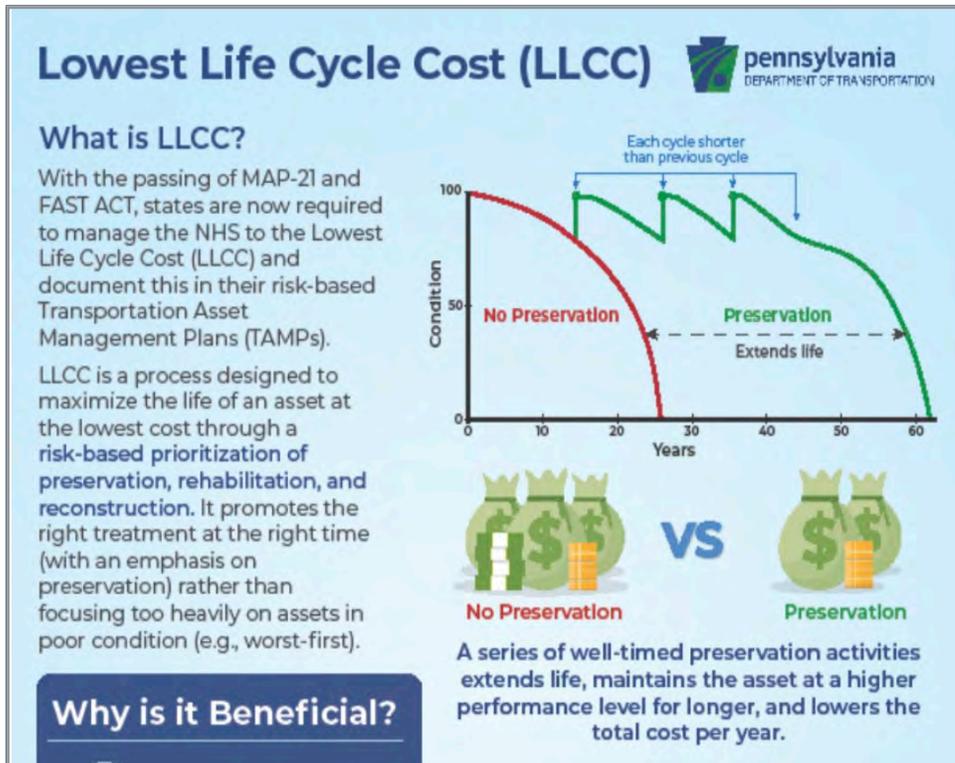


Figure 6-9 One-pager on lowest life-cycle cost (Pennsylvania)

Another powerful use of BMSs for communication is using scenario analysis results to engage decision makers. When communicating BMS analysis, the VDOT Bridge Management Team tries to explain the process for different types of audiences. For example, for the Bridge Management Group the team presents details and complicated procedures; however, for the executive managers, the team might only use a simple summary table. BMS scenario outcomes generated from the VDOT BMS have been used to engage with agency leadership and the legislature on appropriate budgeting levels, performance targets, or needs. For example, state legislators approved VDOT's 50-year strategic plan for bridges.

Scan state DOTs, including Virginia, Connecticut, Iowa, and Michigan, noted the importance of using long-term (20- to 50-year) analysis results to properly support life-cycle cost analysis, financial planning, assessment of investment strategies, and performance gap identification. A 10-year period analysis that satisfies the minimum duration requirement for a state DOT's financial plan to implement the TAMP for 23 CFR 515.9(e) may not sufficiently inform long-term financial plans and asset management strategies.

CTDOT uses a 30-year scenario analysis for some of its TAMP analysis (**Figure 6-10**). Iowa DOT uses a 20 year scenario analysis for TAMP analysis and for communicating with legislators. Scenario analysis helped the latter agency tremendously in increasing the overall bridge budget. It was able to present to the commission what its needs are and show the need for increasing expenditure.

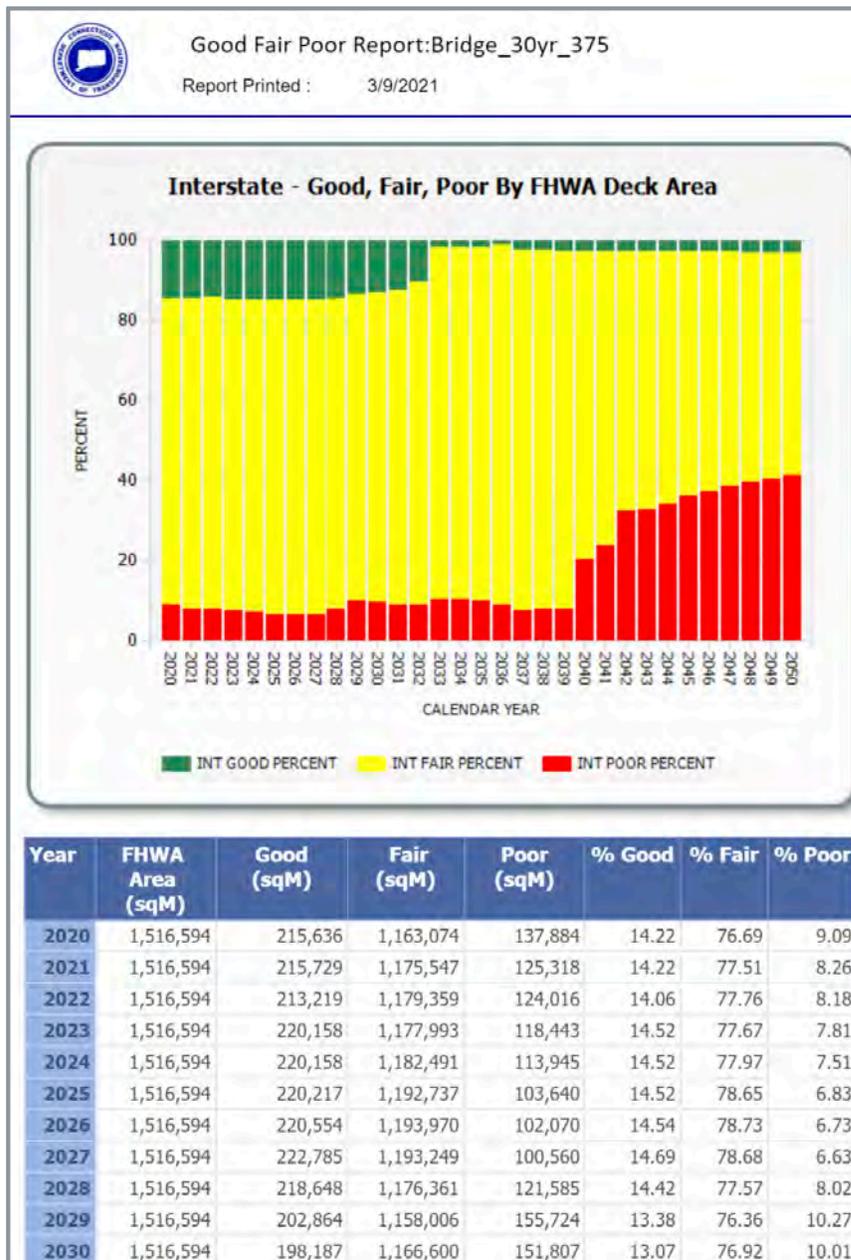


Figure 6-10 Thirty-year scenario analysis results (Connecticut)

Results from MDOT’s 30-year analysis (Figure 6-11) show how overall condition has changed relative to the funding that the agency has received. MDOT reports that the fluctuations in funding are a result of additional funding from sources such as the Reinvestment Act of 2009, the American Recovery and Reinvestment Act, Oberstar, and Rebuild Michigan, as well as funding shifts from one year to another to align bridge work with road corridor projects. The graph shows that that Michigan network bridge condition is projected to decline. Per its TAMP, Michigan has a \$32 million annual gap for its NHS bridges to achieve a state of good repair (95% are in Good or Fair condition). MDOT communicates its goals and performance measures primarily as part of the annual call-for-projects process. Its external goals are reported on the public MDOT and FHWA websites.

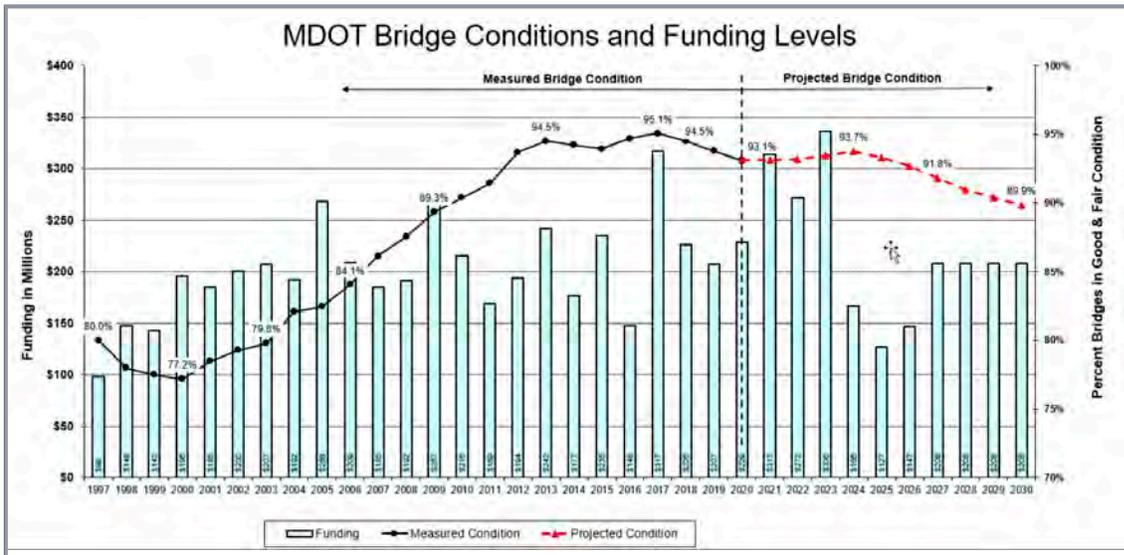


Figure 6-11 Thirty-year funding and projected condition graph (Michigan)

UDOT has also effectively used scenario outcomes generated from its BMS to engage with agency leadership and the legislature on appropriate budgeting levels, performance targets, or needs. By developing internal models of bridge condition projections based on funding levels, UDOT structures funding increased from \$15 million to \$48 million over a four-year time span. The funding came from other assets that were exceeding performance targets and from a gas tax increase.



# Knowledge Transfer Strategies

Without exception, hiring and keeping enough people to operate BMSs, support TAMP analysis, and carry out all other bridge management functions is a major challenge for scan state DOTs. Every scan DOT reported that they currently do not have enough people to support all bridge-management processes and continue efforts for their improvement plans. Multiple agencies reported that the BMS functions were a collateral assignment to one employee. Some of these agencies have added or are adding a full-time equivalent dedicated to implementing and operating their BMS and supporting the TAMP and other investment planning and reporting functions, including the data analytics and model-development functions.

VDOT commented that finding and hiring people who have both bridge/structure knowledge and knowledge on data analytics (referred to as “unicorns”), has been a struggle. Overall, agencies find it challenging to hire and keep the right people with the right expertise. Most DOTs have a very small number of staff and usually lack the time or people to explore and learn new methods. BMSs are complex and require people with experience in data science and engineering. More training in these areas is of great interest to agency staff.

It is common for state DOTs to lose personnel through retirements and transitions to private sector. Most state DOTs cannot even advertise for a position before that person leaves, which creates a big problem in transferring knowledge and expertise. Most often, the newcomer needs to go through a steep learning curve, creating discontinuities in the business process and discouraging new hires. FDOT practice allows the agency to double-fill a position for nine months, allowing the newcomer to learn from the incumbent. For such strategies, however, upper management must be committed to support staffing and resources.

Documentation that explains agency bridge management processes in a way that easily conveys the information in a digestible format (e.g., Bridge Management Manuals from Utah and Michigan DOTs) is reported to be successful in knowledge transfer and communication. However, finding time to create this documentation requires a commitment. Succession planning and documentation are critical for the sustainability of agency knowledge and business processes.



# Insights from Asset Management Practitioners

Following the scan effort, the scan team prepared a series of questions and sent them to asset management contacts from the participating scan agencies. The intention of these questions was to gain additional asset-management perspectives from within these scan agencies since the majority of the scan team members were bridge management professionals.

Asset management contacts from Connecticut, Iowa, Minnesota, New Mexico, and Utah responded to questions about:

- How their BMS supports transportation asset management
- The relationship between the TAMP requirements and the use of BMS
- The utilization of BMS for the CFR 667 requirements
- The establishment of funding levels for bridge and pavement assets
- The influence of the TAMP process on the bridge program
- The connections between TAMP and BMS efforts
- The use of BMS in investment decisions
- The agency process to develop a performance-based planning and programming (life-cycle planning) approach

Based on the agency responses received from the asset management SMEs, information for setting performance management targets, TAMP life-cycle planning requirements, and TAMP investment scenarios are typically provided by the bridge management staff at the agencies. Agencies have some variability in the way they define these groups or teams. BMSs are used in various ways to gather or analyze agency data to provide these inputs, particularly to investigate the impact of alternative funding scenarios on the bridge network over time.

TAMP risk management is typically not directly linked to BMS and falls under the agency asset management umbrella with exceptions. For example, MnDOT's BMS predicts future bridge condition by system type, which is used in setting performance targets. Using BRIM (MnDOT's BMS), projects are selected using decision trees and then prioritized by risk. Risk is built into the BMS, which MnDOT uses in planning and programming for projects. TAMP investment scenarios, as well as investment scenarios used in the Minnesota State Highway Investment Plan, are developed using BMS' recommendations pertaining to capital and maintenance needs over the next 10 and 20 years. UDOT's BMS analysis also incorporates risk for setting performance goals and targets.

Scan information indicates that agencies do not appear to use BMSs to address the 23 CFR Part 667 requirements directly. Agencies typically have other tracking efforts for determining locations where the FHWA Emergency Relief funding was used. Iowa DOT identifies locations where the FHWA Emergency Relief funding is used in its project scoping system. As projects are being scoped and reviewed for the National Environmental Policy Act, it can check any potential repeated Emergency Relief events in the vicinity. MnDOT stores all emergency relief data in a financial system, from which it is then extracted, converted to spatial data in GIS, and analyzed through spatial analysis tools.

NMDOT currently uses its maintenance management system, STIP, FHWA Financial Management and Information Systems, and district input to identify any locations twice damaged by emergency events. It has recently prioritized increasing vertical clearance on bridges that have been repeatedly damaged by impacts from over-height loads.

## Funding

Agencies were also asked how they described their internal processes to establish funding levels for bridges and pavement. The scan team inquired if the available funding came from the TAMP, BMS analysis, a combination of both, or a separate analysis. The responses varied, and while BMS analysis informed the funding levels for some agencies, analysis outputs were utilized rather to inform future investment direction.

CTDOT noted that it establishes funding levels for assets using a combination of the TAMP process, existing current funding, and asset-management systems. Results from asset management systems for varied investment levels were incorporated into the TAMP.

Iowa DOT has six funding programs within its highway program, which are typically informed by historical spending. The agency developed a 20-year interstate plan to be more deliberate about investments in their interstate routes; stewardship funding now more closely matches that plan. Over the last five years, Iowa DOT has also used the analysis from its bridge and pavement management systems to communicate with management and the Transportation Commission (which approves the agency's annual five-year program) the need for investment in stewardship. The agency was able to double its investment in non-interstate bridge modernization, which is for bridge preservation, rehabilitation, and replacement.

MnDOT established its funding levels through the Minnesota State Highway Investment Plan process (internal development and public engagement), discussing different priorities for investment, which included investment to reach various pavement and bridge condition outcomes at the end of 20 years. Both the pavement and bridge management systems inform the various levels of investment to reach those 20-year outcomes.

NMDOT allocates funding to each of its six districts using formulas that factor in total lane miles and square feet of bridge deck into its funding equation. Each district then establishes its own funding level for bridges and pavements based on the data and resultant spreadsheet analyses. The districts use their BMS to create these spreadsheets.

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The funding levels at UDOT are based on individual requests received as part of its STIP process and are based on the BMS analyses and prioritization processes that its Structures Division used to develop its asset management plan.

## TAMP Influence

The respondent agencies also reported that their TAMPs influenced their bridge programs for the better. At CTDOT, the need for reporting data through the TAMP and annual TAMP implementation documentation has aligned with better analysis and summarization of bridge condition data and feedback on treatment performance. Further evaluation of bridge performance has provided the opportunity for Iowa DOT to focus on specific bridge treatments, administration of treatments, and life-cycle costs and efficiencies. The agency reported that its TAMP helped it realize that it needs to devote more resources to bridge management; thus, it worked toward increasing staff for bridge management efforts. The BMS analysis helped the agency secure increased bridge funding based on a presentation highlighting the need for significant investment for a wave of aging structures.

At MnDOT, the TAMP identified the need for the bridge program to move from a worst-first approach to a more proactive asset management approach. Once MnDOT identified the need to devote more resources to that effort, it created an asset management engineer position. Additionally, the agency is moving to element-based performance targets to represent the condition of its bridges more accurately.

The TAMP has required that NMDOT move toward data-driven project selection, which has increased the importance of having quality data in the agency's BMS database.

UDOT reported that the TAMP has provided it with a forum to ask better questions and to better evaluate its processes. The agency's goal now is to make the TAMP more robust and integrated with the other asset groups so that internal reports and information are easier to provide.

## TAMP and BMS Connections

Another inquiry the scan team made was about the communications and any beneficial connections between the DOTs' TAMP and their internal BMS processes. CTDOT designated an asset steward for each asset and worked with the agency's Asset Management Group to ensure that the TAMP is being implemented and all required TAM data is documented annually. The asset steward for bridges provides to the TAMP bridge condition data, which comes from the BMS, and BMS projections are included in the TAMP.

Iowa DOT put a structure in place that encourages communication and learning. The TAM Governance Structure and multidisciplinary Bridge and Pavement Management Committees meet monthly and have representation from both the central and the district offices. These committees work with the TAM Implementation Team and the agency's executive management team on program funding recommendations.

At MnDOT, the TAMP development efforts have required continuous communication between staff in both the asset management (investment planning) and bridge offices. The NMDOT Asset Management Bureau has been working with the Bridge Bureau on establishing a bridge data quality management plan, strategic data business plan, and TAMP procedures to meet the TAMP requirements.

UDOT reported that the TAMP is built on the strategies and approaches of each individual group, including Structures. It would like to further improve communication between its TAMP and BMS efforts.

## Investment Decisions

Another area that the scan team wanted input on from the asset management SMEs was how specific investment decisions (i.e., how much money to spend on treatment types) were being made at the agencies and whether the agencies' BMSs were utilized in this process. What the team discovered was that while the BMS may inform investment decisions on a larger scale for some agencies, this remains an area of future improvement for many others.

CTDOT noted that most of the funding since the 2018 TAMP has been invested in rehabilitation and reconstruction treatments to address the high percentage of Poor bridges; these decisions often relied on engineering judgement. Preservation investments have been limited due to lack of additional resources and cost-effective delivery methods. CTDOT is starting to make the shift toward increased preservation programs and is using life-cycle data to make these decisions. The agency noted, however, that using the BMS in the decision-making process still needs to be vetted.

One of Iowa DOT's current challenges is that the BMS is not really connected downstream to project-level treatments. The NBI Optimizer system recommends treatments; however, those are not even considered when Iowa DOT decides what bridge work to program. However, the data from SIIMS (i.e., inspection data) are used to select and develop projects. As its BMS continues to mature, Iowa DOT hopes to see more agreement between the work it does and the BMS recommendations.

For MnDOT, the decision-making processes are a combined effort between the agency's internal development and public engagement process, its project selection policy, its Capitol Highway Investment Plan, and its STIP. The BMS helps guide decisions between these plans and programs.

The UDOT Structures Group uses BMS to model its needs and funding strategies. It evaluates the results of that modeling as a committee, outlines its own (i.e., Structures) projects, and delivers them within its own budget. This budget is requested through UDOT's STIP process at the end of each year along with all other funding requests from the other asset owners. The Structures Group makes the final decision and then senior management reviews, revises, and approves the budget. Those funding recommendations are then made to UDOT's Transportation Commission.

## Performance-Based Planning

The final question inquired how the asset management team works with the BMS owners and the bridge asset owners to develop a performance-based planning and programming (life-cycle planning) approach. This appears to be an area that most agencies are trying to improve upon.

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CTDOT focused on decreasing the Poor deck area to get the percentage of Poor bridges below the 10% minimum condition level until 2021. Currently the bridge asset liaison in the Asset Management Group is working with staff from Bridge Management to develop a bridge joint preservation program using a life-cycle planning approach. Once the bridge joint program is established, CTDOT plans to then develop other bridge performance-based programs based on life-cycle planning.

For its revised TAMP to be published in 2022, MnDOT formed a TAMP Bridge Work Group that includes staff from Investment Planning, Asset Management, the Bridge Office (BMS and asset experts), the Metro district, a greater Minnesota district, and the FHWA Division Office. MnDOT's TAMP is primarily developed in-house, although the agency hired a consultant to assist in the TAMP's life-cycle planning portion. MnDOT has been using performance-based planning for many years and has refined it through the TAMP process since the agency's pilot TAMP in 2014. The BMS is a key function of TAMP and other plan development.

At NMDOT, life-cycle planning is performed at the bridge level to ensure that the correct bridge is selected in the correct situation. The UDOT Structures Group develops its own planning and programming strategies and is currently reviewing methods to determine performance-based metrics and life-cycle planning.



# Key Findings

The agency presentations show that there is no one-size-fits-all solution or approach in using BMS to support transportation asset management due to the variability in agencies' organizational structures, funding structures, and bridge networks. While some agencies use COTS software systems, others use software or spreadsheets developed in-house or procedures followed by staff to perform analysis and make decisions. For some agencies, BMS drives overall bridge management decision making, while for others BMS partially supports the decision-making framework or TAMP analysis.

All scan agencies were strong in inspection data collection and management. Using information based on element condition data in asset management decision making is limited to date. However, some agencies have made progress in this area, including developing custom performance measures, establishing agency-defined elements to produce more accurate work recommendations, and recording environments that, in combination with agency-defined elements, should improve the accuracy of future deterioration modeling.

Scan agencies collectively reported challenges in hiring and sustaining qualified staff and noted that they feel understaffed to keep up with increasing needs. Agencies are finding innovative ways to report and track performance and have made significant progress with the TAMP development in their use and implementation of BMS. However, agencies have challenges and needs: improved models (deterioration, costs, and risks), qualified and increased staffing and retention, improved measures/metrics to define bridge performance, placing less emphasis on worst-first programming, and contrasting bridge performance with other assets, to name a few.

## Data Collection and Management

One of the keystones of asset management is quality data. Knowing what you have, where it is located, and what condition it is in are foundational elements of any asset management system. This scan discovered that agencies are strong in inspection and inspection data collection. Where some agencies varied included how the data was used to evaluate bridge risks and develop deterioration, cost, and action effectiveness models and how the bridge data was used to inform overall asset management decisions. Most agencies established QC/QA processes. Some agencies also had automated data quality checks and QA practices to continuously improve their inspection programs and data quality.

Agencies that either developed or were involved in the development of their own deterioration models or BMS tools invested in data quality and saw big improvements. Similarly, these agencies also started collecting or are working to improve the collection of bridge work data (data on the timing and cost of maintenance, preservation, rehabilitation, and replacement work) since they realized they needed this data to improve bridge management models and framework for deterioration models, treatment efficiency/impact models, and decision trees. However, use of bridge element models in TAMP analysis

was limited. Agencies typically utilized NBI component-level GCR models for TAMP analysis and noted that they were developing bridge element models. One of the reasons states use GCR models is because federal performance measures are based on GCRs.

Although they may typically use custom inspection tools and databases, most agencies collect similar data attributes, except for element defects and environments. Few agencies are collecting data on environments and defects; however, most scan agencies see the value in both and are interested in defining how best to collect these attributes for their use.

Some agencies are assessing and categorizing bridge hazards, risk magnitudes, and emergency response projects. It should be noted, however, that FHWA 23 CFR 667 requires tracking of repairs and reconstruction from events associated with an emergency declaration; not all states are impacted by this.

Some agencies are also using GIS to spatially view the data on risks. Identifying and collecting data on risk attributes was limited, however, and is an area for improvement for most agencies.

Agencies note that they are not collecting all the data that they need, as informed by the TAMP development over the recent years.

## Performance Measure Tracking and Reporting

Agencies have their custom ways of tracking and reporting performance measures, which are mostly condition driven. Bridge managers typically have additional agency-level performance measures as well as federal performance measures (% Good and % Poor by NHS deck area). Most agencies noted that they report out on the federal performance measures and that meeting the statewide performance level had more leverage in their decision-making processes. Also, there can be advantages to using simpler measures for communication, tracking, and forecasting, and using more comprehensive (but sometimes less intuitive) measures for optimization of allocations and project program development.

Agencies note that G/F/P does not cover all bridge conditions for bridge management needs. Some agencies define a Severe condition to accompany Poor condition to highlight the difference in condition and planning needs for these two groups of structures. Another reason to use the Severe condition is for use in contrasting against other assets (e.g., such as pavement) that do not have the same consequences when they reach Severe categories (e.g., potentially disrupting the transportation system by closing a bridge). Some are considering defining a cusp condition to accompany the Fair condition to highlight the quantity that may move to Poor in the nearer future.

Some agencies also commented that the federal measures do not give sufficient value for some cost-effective work. This includes preservation work or even deck rehabilitation or replacement that moves a deck to Good but leaves the superstructure or substructure in Fair condition to provide for consistent remaining service life across all components (deck, superstructure, and substructure). Similarly, many bridges are Poor due to the deck alone; the measure values can be improved by performing deck rehabilitation and replacement alone, while the remaining service life of the other components may be much less than that of the new deck. Element-based performance measures can

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be used in supplement to mitigate some of these limitations. A few agencies also have element-based performance measures that they utilize for project-level decisions, such as selecting or triggering preservation actions and reporting preservation outcomes.

Internal- or external-facing dashboards are great tools for tracking, reporting, and communicating performance measures. Visibility of data and dashboards increases the chances of obtaining and sustaining necessary bridge funds. Most dashboards are GIS-based and show the information visually.

One of the overarching goals of asset management is to promote data-driven, performance-based, and risk-based decisions. A limited number of presenting states showed progress in influencing risk-based decisions within their bridge management systems and programs.

Agencies that use a bridge HI based on element condition data had their custom ways of defining the index. Managing to a bridge HI appears to be an opportunity to improve decision making for maintenance/preservation work since element data may inform such decisions better and provide reportable outcomes of preservation work.

Some agencies are using supplemental indices to assist in allocation and management of assets. These indices may not serve as measures that can be used in forecasting and optimization but can assist in establishing needs or performing trade off analyses between bridge work types or asset classes. One agency interviewed has an annual maintenance allocation goal that is presented as cents per square foot of bridges by deck area. One agency is investigating the use of an overlay asset sustainability index, which is as an average total replacement cost per year to sustain existing overlays and computed using the total area of overlays, the average unit cost for replacement, and the average overlay service life. Similar measures may be applied to other protective systems. Several agencies have or are developing performance measures for tracking maintenance needs and performing specific types of maintenance (e.g., crack sealing and joint repair).

## **Use of Component- and Element-Level Data to Track and Forecast Bridge Condition**

Most agencies are using component-level data (percentage of deck area that is Good and Poor) to forecast bridge condition and guide bridge management analysis. Agencies acknowledge the value of using element data for the same purposes and intend to do so in future.

Making the right treatment on the right asset at the right time and at the lowest practicable costs is a tenet of asset management. Asset management is not only about maintenance—it encompasses the entire life cycle of an asset. Bridges are a critical and complex transportation asset. Complex in that how bridges deteriorate is often characterized in different ways. Several presenting agencies have used decimal GCRs in their analysis to account for the change in condition in time within a GCR, which was noted as a good practice that could be used by other agencies. Decimal GCRs also incorporate that the different components might be rated differently. This practice may help prioritize which assets should receive treatments before another asset in similar condition and may benefit states with a large number of Fair bridges. It also provides for better understanding of overall trend and forecast, which

are harder to decipher when looking at changes to G/F/P in combination, which is not represented by a singular number and considers only the lowest rated component of a bridge, disregarding the condition of other components. As states align their bridge management practices to resemble asset management best practices more closely (i.e., less emphasis on bridge replacement and more emphasis on condition-based and cyclic maintenance), the number of Fair bridges might grow, which could make the practice of decimal GCR even more important.

Agencies recognize the need for having multiple deterioration curves for components and elements that factor variability in condition, age, environment, or other significant variables.

Some agencies use element condition data to track condition and program maintenance needs. As states consider the positive benefits of instituting asset management best practices into their bridge management systems, the desire to make the right treatment on the right asset becomes even stronger. Understanding which assets and which elements an agency desires to fund maintenance or rehabilitation programs for will be best supported when the appropriate element-level data is available to analyze risks and be used in performance-based decision-making.

Performance metrics, bridge work costs, and actions all need to be aligned and calibrated to properly model and present bridge management needs.

Element-level analysis is a necessity to trigger bridge work that addresses bridge elements (e.g., joints, paint, and bearings) systematically. There is a national need to correlate element condition to GCRs with improved accuracy. This is a challenge and common need for all agencies.

There is a national/regional need to define the value of preservation in terms of reduction in life-cycle cost and/or extension in service life. This is said with the understanding that an accurate definition of value will be influenced by cost, treatment type, treatment technology/specifications, member design type and condition, and many other variables; therefore, the definition is regionally specific.

## **Use of Bridge Management System Data to Convey Condition Information**

Using GIS to convey condition or project information has potential uses, such as supporting cross-asset project decisions or improved corridor management. Layering structural condition, element condition, maintenance needs, potential/planned projects, and past projects with work performed can lead to improved decisions.

Agencies had examples of great charts/visuals that communicate both condition and change in condition trends (e.g., cycle of life).

To understand which structures are deteriorating under which conditions and environments, models that account for such variability and reporting condition for different groups of structures based on that variability are needed.

The scan uncovered many different opportunities for bridge and asset management professionals to increase coordination and collaboration. Some agencies had great success in communicating with

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decision makers using BMS scenario analyses. They were able to make a case for increased funding and inform decision makers of future needs. An example of such communication was the cycle-of-life graphic that many presenting agencies had adopted. This is an example of a communication opportunity that asset management could utilize when discussing not only bridges, but also other asset classes.

## Agencies' Knowledge Transfer Strategies

Hiring and retaining qualified staff to operate BMSs is a shared challenge for all agencies. Agencies define the personnel needed to support bridge management functions as unicorns—people who need to have multidisciplinary knowledge, such as design, project management, data analytics, and optimization. Agencies feel understaffed, while a limited number of people can facilitate the development and implementation of TAMP. While the focus of most the conversation was on staffing to support BMS, it was noted that asset management teams face similar risks. Both bridge and asset management professionals noted the need for unicorns, which leads to further discussion surrounding the training and knowledge that can be transferred and shared within and between each team. Also challenging is the fact that individuals with data science experience/interest often are not wholly committed to the bridge discipline and are attractive to other, higher-salary disciplines and employers.

Commitment from upper management is needed to support strategies, such as double filling (i.e., the person who is ready to retire trains the incoming person for a while), which will improve knowledge transfer. Benefits abound for asset and bridge management teams that commit to working together to solve funding and programming risks. Cross-training teams and increased working meetings are effective ways to increase collaboration and are most helpful in promoting safe and complete streets through effective corridor management.

Agencies need time and opportunities for training and exploring BMSs, which are complex tools and require a learning curve. It takes time and experience to become familiar and comfortable with these tools.

Documentation is key for knowledge transfer. Bridge management manuals and decision trees were great examples of documentation. However, documentation is not a top priority when agencies are understaffed and have difficulty keeping up with their current workloads. Lack of documentation and lack of strategies for knowledge transfer cause loss of agency knowledge with retirements.

Changes in data specifications and systems, while sometimes necessary, require time and resources to manage from already understaffed offices. These changes also lead to discontinuity in data sets (e.g., changes in inspection methodologies and data attributes).

## Other Observations

Asset managers on the panel noted the need for increased communication, coordination, and collaboration between the bridge and asset management teams.

There are multiple agencies in which the BMS functions were a collateral assignment to one employee. Some of these agencies have added or are adding a full-time equivalent dedicated to implementing and

operating their BMS and supporting the TAMP and other investment planning and reporting functions, including the data analytics and model development functions.

Many agencies are still trying to properly capture and incorporate their maintenance and preservation activities into bridge management. Most of the states reported that they are working on this; however, this seems to be a national gap. Increased collaboration with asset management could help transfer the knowledge of the requirements associated with the Federal Consistency Determination required by the TAMP legislation. In turn, improved incorporation of maintenance and preservation activities into bridge management will help bridge managers communicate their maintenance needs, which can be used to leverage future (and increased) funding.

To be compliant with the language stipulating the federally required consistency determination, an agency must predict spending across different work types. Agencies allocate varying percentages of their funding to different bridge work categories (e.g., initial construction, maintenance, preservation, rehabilitation, and reconstruction). Each year the agency measures how much of its funding it spent in each of these categories. The levels appear to depend on agency culture and vision rather than on data analytics. Some agencies had great success with increased levels of preservation by doing work on more structures and shifting Fair structures to Good.

Agencies recommend starting simple in BMS implementation and managing early expectations. Agencies that are new to implementation are suggested to progress one step at a time, document, and have a progressive plan. The granularity of deterioration, action type, cost, and action effectiveness modeling can develop over time and in concert, resulting in equivalent data availability and quality across the different BMS inputs.

Some agencies had great success in initiating research and using the research findings to advance their BMS modeling.

Establishing a strategic implementation plan for overall transportation asset management at the agency may be a great strategy to better coordinate management of separate assets and better align individual programs with agency goals.

Cross-asset allocation is still a big challenge from multiple perspectives. Often the importance of bridges to public safety is not captured in the performance measures used for cross-asset trade-off comparisons. Asset classes have different life cycles, different risk profiles, and different capital and maintenance outlays, and their condition levels have different impacts on mobility and the economy. A framework that compares the assets at all of these levels needs to be developed and needs to be a multi-objective and a multi-asset optimizing framework. Cross-asset allocation also needs to be done in a way that policy makers and executives can understand and be supportive of decisions that might deviate from past precedence.

Pavement and corridor projects can dictate bridge project selection and move spending from optimal. To reconcile this issue, a few bridge offices pursue partial reimbursement to compensate for their decreased buying power. Additionally, there is merit to considering total bridge and pavement benefit-cost, including life-cycle benefit—first cost when selecting projects with combined asset classes.

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Specific investment decisions, such as expenditures on treatment types, are not informed by BMSs on a bridge-level. Rather, information from BMS analysis informs network-level expenditures for future investment. Although the TAMP development at the agencies initiated collaborative work among the asset management team, the BMS owners, and the bridge asset owners to develop a performance-based planning and programming (life-cycle planning) approach, this appears to be an area on which most agencies are trying to improve. Agencies reported that TAMP development improved communication between asset management and bridge management teams and influenced their bridge programs for the better. However, the process also provided areas of improvement for BMS implementation, integration of BMS to asset management processes at the agencies, and improved communication and collaboration between the asset management and bridge management professionals.



# Recommendations

This chapter presents recommendations to better guide and improve the use of BMSs for asset management and TAMP development based on key scan findings.

- State and national bridge, pavement, and asset management groups should coordinate and form task forces with shared membership or meet regularly to come up with a roadmap to improve the use of BMS in asset management decision making and better coordinate BMS use within asset management.
- Agencies need to have a strategic vision and process to guide BMS and incorporate BMS information into overall asset management. Agencies that coordinate at a strategic level have better success.
- Agencies that still tend to follow worst-first strategy due to their focus or their attention on percent Poor should explore the use of additional measures for analysis and reporting to tell a complete story, more comprehensively represent changes over time, and give more value to least life-cycle cost strategies. Average general condition rating and element HI serve as examples of supplemental measures. Measures that directly include life-cycle cost need to be further explored.
- Executives should support hiring qualified staff, adopting strategies to maintain agency knowledge, and conducting research to support BMS implementation.
- Agencies should start exploring element condition data to identify, track, and model bridge work.
- Data on cost and impact of bridge work needs to be systematically documented.
- Agencies should explore longer-term analysis and scenario planning (beyond federal requirements) to inform long-term financial planning and improved communication with elected officials. Long-term forecasts of performance measures and analysis results are needed to show long-term investment impacts and inform long-term financial investment needs.
- Future data needs should be discussed and planned based on the recent TAMP development experience. Agencies should identify additional data needs that can be used to improve the BMS modeling framework or consider refinement if data items are no longer helping with bridge management decision making.
- National and state research is needed on a variety of topics to improve BMS modeling. The main research topics are deterioration modeling, cost modeling, life-cycle cost modeling, preservation value/effectiveness, element-to-GCR conversion, element-based performance measures/health indices development, risk modeling, and alternative performance measure development to better facilitate cross-asset resource allocation.
- Quality data is needed for good decision-making. Agencies should consider adapting good practices of QC and QA or add to existing practice.

- Asset and bridge management professionals need close coordination and stronger collaboration to communicate a unified risk and performance-based message to secure funding to ensure future sustainability.
- Agencies should consider asset and bridge teams to perform internal cross-training to promote understanding, reduce silos, and enhance communication and knowledge transfer.
- Nationally, there is a need to better identify, quantify, and compare risks; develop performance measures for risk that can compare in trade-off decisions with condition-based measures; and integrate risk into an agency's asset management processes. Risks are in general not well-informed. Continued effort, dedication, attention, and research are necessary to improve data and models of likelihood and consequence while examining the role that asset vulnerability has in risk escalation. One of the benefits of performance management relevant to tracking and reporting is that these organization-wide efforts provide an opportunity to communicate a relatable story. Bridge management and their systems are part of that story. Through increased coordination and stronger collaboration with asset management professionals, the "bridge story" can be elevated and championed by additional teams within the agency. In turn, this will increase internal knowledge and understanding and help inform the discussion regarding how much to invest in pavements versus bridges. Bridges link pavements, present critical connection points in transportation networks, and have different safety requirements. Performance measures that will enable cross-asset allocation should recognize these differences.
- Further infusion of asset management principles and performance measures within the current bridge management paradigm could support exploration of bridge sustainability indices, bridge consumption ratios, and bridge sustainability ratios. Coupled with an understanding of how bridge assets are valued and risk profiles may provide the communication horsepower to compete with pavements for funding. Additionally, supplemental indices based in asset valuation can inform cross-asset allocation. For example, comparisons of replacement value (total cost to replace and asset class) across asset classes and/or a ratio of current value and replacement value can help inform whether cross-asset allocation is equitable. As stated previously, multiple measure often need to be used in concert.
- In reality, bridge management professionals are asset management professionals. Asset management professionals are tasked with overall asset management, which includes bridges. Each group flies at a different level and has different perspectives. Agencies that can coordinate the "flight paths" will mature at an increased rate. Both entities must work together as a unified air traffic controller to share data across any pre-existing silos, confer on the development of performance targets, and communicate an effective bridge story together to ensure and secure the most sustainable funding scenario possible.

## Dissemination and Implementation Strategy

The scan team compiled a preliminary list of state and national conferences at which to present the scan findings. Presentations are planned at state conferences, such as the Maine Transportation Conference. Presentations are also planned at national conferences, such as the Transportation Research Board Annual Meeting and the AASHTO Bridge Preservation Technical Committee and Bridge Evaluation Technical Committee. Additionally, the scan team will investigate avenues for presenting workshops and webinars and submitting articles to journals.

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The implementation plan is constantly developing; however, the plan as it existed at the scan's conclusion is shown below. Many of the recommended actions were initiated directly following the scan meeting and are ongoing.

### Currently Planned Dissemination Activities

- **Federal Highway Administration** – Engage with the Asset Management Expert Task Group
- **Transportation Research Board** – Produce a webinar with the National Cooperative Highway Research Program (NCHRP) in partnership with the NCHRP 20-01 Domestic Scan Team and scan workshop presenters
- **Presentations** of the scan results at national, state, and local organization meetings, including:
  - AASHTO T-18 – Bridge Management, Evaluation, and Rehabilitation
  - Maine Transportation Conference
  - AASHTO Transportation System Preservation Technical Services Program (TSP 2)
  - AASHTO Annual Bridge Management/Bridge Management User Group Meeting
  - AASHTO T-9 – Bridge Preservation Technical Committee
  - FHWA Bridge Preservation Expert Task Group
  - FHWA Long-Term Bridge Performance Program
  - National Conference on Transportation Asset Management (a joint meeting of the AASHTO Subcommittee on Asset Management and the TRB Transportation Asset Management Committee AJE30)
- **Future workshops** to be developed include:
  - An NCHRP 20-44 implementation proposal to further disseminate findings through a peer exchange targeted to integrate bridge management with asset management
  - A proposal for a workshop to be presented at the 2023 TRB Annual Meeting



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# Appendix A: Amplifying Questions

## TAMP/Program-Related Questions

1. What are the major lessons learned from the TAMP development process? Did you make any changes to bridge management data and your BMS? If so, please share these changes.
2. How are bridge risks getting into and addressed within your TAMP?
3. After beginning your TAMP development, have there been any data items previously uncollected that you have started collecting (e.g., new inspection field, project costs, project history)? If so what data items?
4. What were the major challenges you faced regarding your BMS configuration and implementation once you started developing your TAMP? Could you address them all?
5. At your agency, is there a formal or informal group or process that makes sure that bridge management functions and BMS implementation are aligned with the agency TAMP and asset management objectives? If so, please elaborate. If not, please discuss your thoughts on whether that would be useful.
6. How do your BMS recommendations support TAMP development and are the recommendations readily transferable for the following:
  - a. Performing life-cycle planning defined as the process to estimate the cost of managing an asset class or asset sub-group over its whole life with consideration for minimizing cost while preserving or improving the condition. Is minimizing network-level life-cycle cost or long-term cost considered?
  - b. Identifying investment strategy by major work types of maintenance, preservation, rehabilitation, reconstruction (replacement), and initial construction (new construction). Address relative to analyzing alternative investments by work type, translating actions configured in BMS to the major work types, other.
  - c. Identifying risks and strategies for mitigating top priority risks.
  - d. Identifying desired state of good repair long-term goals.
  - e. Identifying strategies that best achieve state of good repair goals at the minimum practicable cost.
7. Are there any areas of communication, internally or externally, you would like to improve, based on your TAMP development experience?

## Organizational Structure and Bridge Network

1. In your organizational structure, where are asset management and bridge management located? How do they interact? Please elaborate on whether bridge management, maintenance, inspection, and project delivery functions are centralized or decentralized.

2. Explain how your organizational structure and business processes allow (or do not allow) for BMS recommendations to inform statewide project selection. Address central, regional/district level processes and the vetting of BMS recommendations against boots-on-ground knowledge and recommendations.
3. How easy is it for the agency's bridge asset management team to work with the inspection team to change what data is collected in the field? How does bridge management communicate with other divisions for bridge management data needs and can bridge management influence data collection? Any examples?
4. Describe current staffing allocated for BMS implementation, maintenance, and use. Exclude staffing dedicated solely to inspection-related support, data collection, and review.
  - a. Include and describe all associated staffing located within database administration/IT, bridge, and/or asset management disciplines. Describe the number of full or partial full-time equivalents (FTEs). More refined breakdowns are acceptable.
  - b. Describe responsibilities (BMS implementation, maintenance, use, etc.) for each staff member and percent of allocated time.
  - c. Describe any contract services that supplement agency staffing.
5. What do you estimate is your agency's ideal BMS staffing and percent of allocated time?
6. Explain how your organizational structure and business processes allow (or do not allow) for BMS analyses to assist in determining your bridge program budget and sub-program allocations. Where in your organization and how are these decisions made (sub-programs may be representative of different work types or objectives, ex. maintenance, preservation, rehabilitation, replacement, risk mitigation, functional improvements)?
7. Questions on the size and condition of the bridge network:
  - a. How many structures do you have in your network?
  - b. How many bridges > 20 ft (6.1 m) are your responsibility?
  - c. How many bridges < 20 ft (6.1 m) are your responsibility?
  - d. How many of your agency bridges are on the NHS?
  - e. How many bridges are currently Poor (structurally deficient)?
  - f. How many bridges are posted?

## Funding Structure

1. Does your state have separate funding sources for different types of bridge projects? If so, how do you use your bridge management system to account for each funding source? Is there overlap between funding sources?

2. What is the breakdown of bridge funding by work type (maintenance, preservation, rehabilitation, replacement, risk mitigation, other)?
3. Does political jurisdiction or administrative unit impact the breakdown of major bridge projects in the budget? If so, please discuss.
4. What is the current annual allocation of funding for bridge improvements? How has it changed in the last five years? What are your expectations of/concerns about funding levels in the next five years?
5. Do you administer funding in your state as a competition (silo) between pavements and bridges or do you try to administer them in conjunction with each other, creating a team approach that attempts to optimize the entire budget as opposed to the siloed budgeting approach, and is this analysis handled in an application, spreadsheet, or manually by subject matter experts?

## Decision Support Tools for Bridge Management

1. A BMS is a combination of tools, processes, and procedures to perform asset management. This may include a consumer off-the-shelf technology (COTS) software system, in-house software or spreadsheets, or procedures followed by staff to perform analysis and make decisions. For the following BMS requirements, indicate what combination of tools/processes your state uses to meet the requirements.
  - a. Collecting, processing, storing, and updating inventory and condition data for bridge assets.
  - b. Forecasting deterioration for bridge assets;
  - c. Determining the benefit-cost over the life cycle of assets to evaluate alternative actions (including no action decisions), for managing the condition of bridge assets;
  - d. Identifying short- and long-term budget needs for managing the condition of bridge assets;
  - e. Determining the strategies for identifying potential bridge projects that maximize overall program benefits within the financial constraints.; and
  - f. Recommending programs and implementation schedules to manage the condition of bridge assets within policy and budget constraints.
2. Do you perform other, high-level, important functions with your BMS that you would like to mention? Please identify if these are done with COTS software, in-house software or spreadsheets, or staff.
3. What systems are used for pavement management and overall asset management? How does your BMS fit into these tools?

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## Bridge Management Data Use and Governance

1. What are the main sources of data that are used for bridge management? Elaborate on your use of National Bridge Inventory data items, General Condition Ratings (GCRs), element condition data (National Bridge Elements, Bridge Management Elements, Agency Defined Elements, and defects), and other data utilized for bridge management. Please include links to any agency manuals and highlight any that you find are especially beneficial to asset management. Please discuss how these elements impact decision-making.
2. How are you handling NBI GCR-based performance measures since most BMSs are using element-level data? How are you comparing your NBI data to your element level?
3. Do you have a data warehouse for bridge asset management information or an enterprise information management effort underway at your DOT? If so, have these efforts improved your data/information management or coordination with other areas of the DOT? What new challenges/opportunities have you experienced?
4. Considering that the information required for a BMS comes from several disparate systems (i.e., bridge inspection, traffic, project history, maintenance work history), have you developed any innovative methods (“automated”) for collecting, compiling, and importing that data into the BMS?
5. Do you have data to support the development of the below items for BMS implementation? Have you used them to develop these items or have plans to do so? Please describe the data types that your agency has available to develop/define these items and the sufficiency of each data type. Please also elaborate if you have gone through any effort to improve data collection and use regarding these items:
  - a. for development of deterioration models
  - b. for defining action types used by your agency
  - c. for defining action costs
  - d. for defining action triggers or decision trees/rules
  - e. for defining action benefits/effectiveness
  - f. other data types used by your BMS
6. Have you made any changes to your data governance procedures in result (data that is collected, format of collection, data translation methods, quality assurance to improve accuracy, etc.)? Are there data quality issues that you have identified? If so, please elaborate.
7. For each data type describe the data mining and analysis procedure required to arrive at the inputs for your BMS configuration. Is that process readily repeatable for occasional updating of the BMS configuration?

8. Would you say that your agency/department has buy-in on data-driven decision making, or does it rely more on expert opinion? If data-driven decision making is more accepted, what things have you done to develop organizational confidence in that?
9. Do you have a quality control process for things like conflicting data or inspector bias?
10. Are historic decisions analyzed and shared with agency personnel in order to improve the BMS? If so, how?

## Performance Measures

1. Describe your program goals, objectives, and or performance measures. Do you have any external/internal classification for them? How are they reported?
2. What do you use as an overall measure of the current condition or health of bridges? Do you forecast the same measure(s) for planning?
3. Do you have any performance measures for bridge risks such as scour, sea level rise, and seismic activity?
4. Do you have a measure of progress in achieving bridge condition performance targets set in the prior year?
5. What performance measures if any are included in your BMS configuration that is used for network-level analyses and optimization? If you have multiple goals, objectives and/or performance measures, how does your BMS prioritize between measures during project selection?
6. (Please respond if your answer to the previous question does not cover this.) How do you connect your goals/objectives/performance measures with the project selection process? How do you report on the connection between the goals and project selection?
7. Is your agency using its BMS to assist in identifying performance measure targets that reflect a selected/optimal investment strategy?
8. If long-term goals have been established for your agency's performance measures, how were they decided (judgment/preference, future forecasting, optimization recommendations, other)? Which staff were involved, and which had the final decision?
9. How often do you review your program goals, objectives and or performance measures?

## BMS Implementation

1. What is one area (or more) that you feel your BMS performs well?
2. Is there anything that you would definitely recommend agencies to do in their BMS implementation? Anything they should avoid?
3. Can you elaborate on your BMS implementation efforts, what were the sequential steps you have followed thus far to implement and configure your BMS?

4. Were all BMS implementation efforts done internally? Have you hired consultants or had research projects to help with the implementation?
5. At what stage of BMS implementation and use would you characterize your agency as being? (Please see BMSWG maturity levels for your reference.) Compare to 5 years ago. Compare to where you want to be in 5 and 10 years.
6. Describe expected obstacles to achieving where you want to be in 5 and 10 years with BMS implementation and use.
7. What are the top three challenges or opportunities you would like to address to improve your BMS if resources were not an issue?
8. How would you rate the analysis run outputs relative to what you need to inform budget allocation and project selection?
9. How well do the outputs agree with judgment or institutional preferences? Answer relative to different output types: future condition/performance forecasts, budget allocation to different work types, recommended projects, and recommended project scope and actions.
10. In what ways have you used your BMS to support agency decision-making thus far? Compare that to where you would like that to be 5 and 10 years from now.
11. How many years do you run your bridge analysis to predict your needs moving forward; what is ideal for you?
12. Can you use the BMS program outputs directly or do you need to refine the results?

## Modeling

1. Have you incorporated bridge risks into your BMS actions and benefits? Which risks are considered? Are they budgeted separately and how are budgets determined?
2. How is the optimization or program planning algorithm process performed by your BMS?
3. What type of deterioration models are being utilized? Please discuss models for both NBI GCRs, and elements (if any). Please elaborate on how the models were developed (e.g., expert elicitation, in-house analysis, or research).
4. Do you collect defect information for elements? Were you able to get any input for condition forecasting or bridge management from defects? In other words, are they worth the effort?
5. Do you utilize your BMS to identify, prioritize, select, and track bridge functional improvement actions (widening, strengthening, raising)? If so, how?
6. Do you utilize life-cycle planning? If so, how? How do you incorporate life-cycle planning into the development and implementation of your asset management plan?
7. Have you done any validation of your BMS models (i.e., deterioration models, forecasts of bridge conditions, or forecasts of future needs)?

8. Do you convert element condition to component ratings for use in your BMS? If so, do you have a custom method (or matrix) or are you using the default conversion provided in your BMS?
9. Are the decision trees in your BMS based on expert elicitation or analyses of past bridge performance?
10. How have you determined the bridge work costs in your BMS?
11. Have you done any sensitivity analyses of your initial BMS program results to reconfigure your models/parameters (e.g., deterioration models, cost values, or decision trees)?
12. Are you currently utilizing your BMS for agency maintenance activities or is it strictly used for project selection?
13. Does your agency have a bridge preservation policy? If so, is the policy reflected/modeled in your BMS?
14. To what extent do you use the output from your bridge management program?
  - a. Do you use it to identify individual bridge projects?
  - b. Do you use it for determining an overall inventory needs assessment?
  - c. Do you use it for TAMP target setting and review?
  - d. Do you use it to lobby for additional funding based on long-term forecasts of inventory condition?
15. How do you reconcile what the bridge management program recommends for projects versus what you actually need/want to do?

## Communication

1. How does your agency document its bridge management policies and processes and communicate them?
2. Please provide examples of the most useful reports, tables, charts, maps, PowerPoint presentations, screenshots, or other material you provide to the executive management team for purposes of bridge decision making.
3. Do you have a public-facing dashboard for bridge asset information? If so, what information is included?
4. Do you have an internal-only dashboard for bridge asset information? If so, what information is included?
5. Please share the three best examples of how you are communicating externally.

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6. Asset analysis can be a very complicated process. Bridges are no exception: they can be analyzed at the component level, element level, or a hybrid model and the various types of treatments, their triggers, and their costs. Are your analysts able to convey in plain language to business partners and executives how their analyses work? If so, how?
  7. Have scenario outcomes generated from your bridge management system been used to engage with agency leadership or the legislature on appropriate budgeting levels, performance targets, or needs? How and would you be able to provide examples?

## Sustainability

1. Describe any training your agency has received on BMS. What are the major topic areas for which you believe training would be useful?
2. Do you have any best practices for training or to maintaining alignment between the users and/or implementers of the BMS?
3. What support from national or regional organizations/programs (e.g., government, research, or industry) would be helpful?
4. How do you see BMS analyses informing cross-performance area/cross-asset location? What is needed to accomplish that?
5. What major software enhancements or changes would you like to see made by BMS vendors?
6. Do you have a noteworthy process or experience that you think will be beneficial for other agencies to be aware of? Describe in brief.
7. What methodologies/strategies are you finding most successful for transferring knowledge? What strategies are in place to ensure transfer of knowledge from personnel leaving the agency to current personnel?



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# Appendix B: Scan Team Contact Information

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# Appendix C: Scan Team Biographical Sketches

**CHAD ALLEN** (Team Chair) is the Asset & Performance Management Program manager for the Seattle Department of Transportation (SDOT) and has been with the agency since 2020. He recently completed a 30-year career with the Vermont Agency of Transportation (VTrans). When he left VTrans, the bridge inspection team was under his guidance and leadership and the team was in the midst of several key digital transformation initiatives, including modernizing the data collection and reporting processes and configuring the new asset management system to include roadway structure assets. Now with SDOT, Allen is focused on improving the overall condition and financial sustainability of Seattle's assets. He is working with the SDOT Roadway Structures team and its many different partners to develop a comprehensive risk register that will be used to establish an implementation roadmap to reduce risk, increase performance, and enhance its overall asset management maturity. These risk-management deliverables will increase SDOT's strategic decision-making capabilities and provide the Structures Team with a platform to communicate its obstacles and challenges alongside mobility issues, increasing SDOT's situational awareness while also informing future budget and levy discussions. Allen has served as a member of several AASHTO committees and subcommittees and has been active in supporting many different NCRHP research and scanning efforts. He is a graduate of the University of Vermont University with bachelor's and master's degrees in civil engineering. He is a licensed professional engineer in Vermont.

**ERIC CHRISTIE** is the deputy state maintenance engineer for the Alabama Department of Transportation (ALDOT). In this role, he is responsible for the oversight of bridge maintenance, bridge scour, bridge management, load rating, oversize/overweight permits and ALDOT's maintenance management system. He also serves as the program manager for ALDOT's Bridge and Tunnel Inspection Programs. Christie is a graduate of The University of Alabama with a bachelor's degree in civil engineering. He is a licensed professional engineer in Alabama. Christie serves as the vice-chair of the AASHTOWare Bridge Task Force. Christie is also the vice-chair of the AASHTO Committee on Bridges and Structures Technical Committee T-18 for Bridge Management, Evaluation, and Rehabilitation and is a member of Technical Committee T 19 for Software and Technology.

**DEREK CONSTABLE** is a Bridge Management engineer with the FHWA's Office of Bridges and Structures. He serves as the primary representative on matters related to the management of bridges and structures, which includes the strategies, practices, data, and tools used to assist in the assessment and management of structures. He contributes to local and national programs, research, technology deployment, and training initiatives and provides direction for systematically managing structural assets efficiently and cost-effectively. He has also served in bridge positions with the FHWA Pennsylvania Division, FHWA Maryland Division, Federal Lands Highway Office, and New York State DOT and is a member of the TRB Committee on Bridge Management. Constable is a licensed professional engineer and holds bachelor's and master's degrees in civil and structural engineering from The Cooper Union for the Advancement of Science and Art in New York City.

**BECKIE CURTIS** is the deputy chief Bridge Engineer for the Michigan Department of Transportation (MDOT). She is the division administrator for the Office of Structure Preservation and Management, whose primary objectives are to align and strengthen MDOT's functions related to bridge asset management, bridge performance measures, the National Bridge Inspection Program, ancillary

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structure asset management, bridge preservation, and bridge emergency response. She is currently serving as the chair of the Michigan Transportation Asset Management Council Bridge Committee, which seeks to improve the state of practice for bridge asset management at the state and local levels. She is a member of the AASTHOWare Bridge Management Task Force. Curtis received a bachelor's degree in civil engineering from Michigan State University and received a master's degree in engineering from the University of Michigan. She is a licensed professional engineer.

**MICHAEL JOHNSON** is the Caltrans State Asset Management engineer and has been with Caltrans for 30 years. In his current capacity, he is responsible for leading the implementation of asset management and the development of the State Highway Operation and Protection Program. This program is a \$4.5 billion annual program of projects that address rehabilitation and operation needs for the state-owned transportation system. Johnson holds a bachelor's degree in civil engineering and a master's degree in structural engineering, both from California State University, Sacramento. He has held numerous national positions with the Transportation Research Board, AASHTO, and FHWA Expert Task Groups. Johnson has published numerous papers in the areas of bridge inspection, bridge management, and asset management.

**CHESTER KOLOTA** is the Bridge Management engineer for the Maine Department of Transportation (MaineDOT). In this role, he is responsible for the management of MaineDOT bridges and other structures, which includes the development of the Bridge Work Plan, optimization of bridge investments, evaluation of bridge load ratings, and administration of the bridge asset management system. Before joining MaineDOT in 2015, Kolota served as the structural engineer for the FHWA New Jersey Division for seven years, and as a structural engineer in the Bridge Inspection and Management Program and in Bridge Design for the FHWA Federal Lands Bridge Office in Virginia. Kolota received a bachelor's degree in civil engineering from the University of Maine in 2001, and a bachelor's degree in physics from Binghamton University in 1994. He is a licensed professional engineer in Maine.

**EDWARD A LUTGEN** is the Bridge Construction and Maintenance engineer for Minnesota Department of Transportation (MnDOT). He is a civil engineering graduate from the University of Minnesota and a licensed professional engineer in Minnesota. Lutgen has over 25 years of bridge experience, including design, construction, safety inspection, steel fabrication, geotechnical, operations, bridge data management, preservation, bridge program planning, maintenance, and load ratings. In his current role, he manages the Bridge Asset Management, Load Ratings, Construction, Scoping, Structural Metals, Fabrication Methods, and Safety Inspection units in the MnDOT Bridge Office. In addition, he is the Bridge Inspection Program manager for Minnesota. Lutgen is a member of several AASHTO committees, including T9 (Bridge Preservation), T16 (Timber), and T18 (Bridge Management, Evaluation, and Rehabilitation), the Bridge Preservation Expert Task Group, and Long-Term Bridge Preservation.

**KEVIN MARSHIA** is the director of Asset Management for the Vermont Agency of Transportation (VTrans). The Asset Management Bureau is responsible for the data collection, analysis, risk management, and performance measures for all state highway assets, which includes the development and maintenance of the state's pavement management and bridge management systems. He has been a member a number of AASHTO committees and councils during his 20 years with VTrans. He currently chairs the AASHTO Committee on Nonmotorized Transportation. Marshia holds a bachelor's degree in civil engineering from the University of Vermont.

**SCOTT NEUBAUER** has been the Bridge Maintenance and Inspection engineer for the Iowa Department of Transportation (Iowa DOT) for the past 9 years and has worked in the agency's Office of Bridges and Structures for 27 years. His tenure in the Bridge Office has included work as a bridge designer, superload engineer, load rating engineer, and maintenance and inspection engineer. His current position is responsible for bridge inspection and maintenance needs evaluation, which includes development and use of the inspection data collection system, bridge management system, and bridge evaluation software to provide project needs for the department's five-year program. He has been involved in NCHRP projects involving bridge load rating issues, bridge approach distress, bridge posting practices, and bridge element data assessment. Neubauer is a graduate of Iowa State University with a bachelor's degree in construction engineering. He is a licensed professional engineer in the state of Iowa.

**FELIX PADILLA** is the State Bridge Inspection engineer in Structure Operation Section at the Florida Department of Transportation (FDOT). He began his career with the New York State Department of Transportation in 2006 after earning his bachelor's degree in civil engineer and moving from the Dominican Republic. After working on bridge design in New York for five years, he moved to the consultant world and worked at HNTB doing bridge design and inspections for the next four years. In 2015, he began working for FDOT in its Structures Design Office before finally moving to the Maintenance Office two years ago. Currently, he's the Sate Bridge Inspection engineer and is responsible for setting policy and resolving any outstanding issues in FDOT's Bridge Inspection Program.

**RICHARD RUNYEN** is the Bridge Inspection Section chief for the Pennsylvania Department of Transportation (PennDOT) in Harrisburg. In this position, he acts as the state's bridge and tunnel program manager. He develops, administers, and ensures compliance of the state's bridge and tunnel inspection standards, policies, and procedures. His responsibilities include developing and updating PennDOT's inspection manual, coding manual, and quality assurance manual. Since joining PennDOT in 2010, Runyen has worked in both a District Engineering Office and PennDOT's Central Office, serving in several positions, many involving bridge inspection and management. He graduated from Villanova University and holds bachelor's and a master's degrees in civil engineering. He is a licensed professional engineer in Pennsylvania and serves on AASHTO's Committee on Bridges and Structures, holding a position on the T-18 Subcommittee for Bridge Management, Evaluation and Rehabilitation.

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**C. TODD SPRINGER** has over 28 years of experience in the design, preservation, management, and delivery of transportation projects and programs involving bridges and related structures. He is currently a program manager with the Structure and Bridge Division of Virginia Department of Transportation (VDOT). VDOT owns and maintains the vast majority of the 21k+ bridges and culverts in the commonwealth of VA, as well as several large tunnels, movable bridges, ancillary structures, retaining walls, and soundwalls. These assets are valued in excess of \$50 billion, with annual maintenance and construction programs budgeted in excess of \$400 million. Springer oversees the implementation of the \$1 billion+ six-year improvement plan for bridge projects involving the rehabilitation or replacement of bridges, helps to develop state and federal asset management plans for bridges and structures, and implements state and federal performance management metrics. VDOT's maintenance practices need to be especially strategic given the relatively limited funding to maintain, for example, bridges or culverts being 50 years old on average and most of these structures having a service life of 50 years. His team works to do the following for these assets: maximize/extend service life, minimize life-cycle costs, minimize risk, determine predictive indicators of performance, and determine the most effective maintenance and construction practices. Some of Springer's significant roles include being the program manager for structures and bridges for the \$5 billion Virginia Mega Projects Program involved five mega projects in Northern Virginia; Bridge Technology Practice lead for Transportation in North America for CH2M Hill (since merged with Jacobs); and design manager for reconstruction of coastal highways for the Sri Lanka Tsunami Reconstruction Program for USAID.

**PAUL VAUGHT** is an assistant administrator in the Bridge and Structural Design Section of the Louisiana Department of Transportation and Development, where he has worked since 2003. He currently serves as the Bridge Preservation Program manager and is responsible for funding oversight of bridge rehabilitation and replacement capital improvement projects, with a total annual budget approaching \$200 million. In that role, he is responsible for identifying projects for funding and chairing the associated project selection committee. Vaught also serves as a project manager and bridge task manager for complex bridge projects and is the Major and Movable Bridge coordinator for post-disaster damage assessment. He received his bachelor's degree in civil engineering from Louisiana State University and is a licensed professional engineer in Louisiana.

**DeWAYNE WILSON** is Currently Bridge Area Engineer, Missoula, Bridge Bureau of Montana Department of Transportation. DeWayne was the bridge asset management engineer for the Washington State Department of Transportation (WSDOT). His primary duties include supervision of the Asset Management Unit, which is tasked with identifying and prioritizing the preservation needs for the 3,300 state-owned bridges. He works with others in the WSDOT Bridge Office to identify initial scopes of work for the bridge preservation projects, including concrete bridge deck rehabilitations that may use hydromilling scarification. He has been with WSDOT for 36 years, having done bridge inspections and managing the department's Bridge Deck Rehabilitation Program. He has been in his current position for 15 years. He holds a bachelor's degree in civil engineering and is a licensed professional engineering in the state of Washington.

**DR. BAŞAK BEKTAŞ** is an assistant professor of civil engineering at Minnesota State University. Her interdisciplinary background includes a master's degree in industrial engineering with a focus on systems management. Her research experience is on infrastructure asset management with a focus on bridges, bridge preservation, pavement management, performance measurement, asset performance modeling, risk and reliability analysis, engineering economic analysis, and transportation safety. Bektaş has served as the Principal Investigator on projects that addressed asset management and preservation with the Federal Highway Administration, the U.S. Department of Transportation, the National Cooperative Highway Research Program, the Iowa Department of Transportation, the Iowa Highway Research Board, the Minnesota Department of Transportation, and the Wisconsin Department of Transportation. She chairs the Transportation Research Board AKT50 Bridge and Structures Management Committee, is a founding member of the AKT60 Bridge Preservation Committee, and is a member of the Federal Highway Administration Bridge Preservation Expert Task Group. Bektaş is experienced in applying statistical methods and data mining to a variety of transportation problems and her asset management research has had included quality control, management, and analysis of various data sets. She also teaches courses on structural engineering, transportation engineering, infrastructure asset management, and engineering economics.



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# Appendix E: Glossary

**AASHTO Manual for Bridge Element Inspection** – Published first in 2011 and updated in 2013, this manual builds on, updates, and enhances AASHTO’s Commonly Recognized Elements through improvements such as changes in the measurement units of decks and slabs, development of a bearing surface element, standardization of the number of elements states, addition of elements constructed of innovative materials, and development of protective coating elements for concrete and steel, as well as deck protection systems.

**AASHTOWare™ Bridge Management software (BrM)** – Bridge Management software system sponsored by the Federal Highway Administration and owned by American Association of State Highway and Transportation Officials. Formerly known as Pontis.

**Agency-Developed Elements (ADEs)** – Custom elements in accordance with the defined element framework that may be sub-elements of National Bridge Elements or Bridge Management Elements or may be agency-defined elements without ties to the National Bridge Elements or Bridge Management Elements<sup>39</sup>.

**Asset Management** – A strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the life cycle of the assets at minimum practicable cost. (23 U.S.C. 101(a)(2), MAP-21 § 1103)

**Bridge Management** – Bridge management is a core bridge discipline that focuses on making informed and effective decisions on the operation, maintenance, preservation, replacement, and improvement of bridges within a bridge inventory. Bridge management decision making is highly dependent on relevant and quality data and on methodologies and tools for analyzing that data across an inventory of bridges<sup>38</sup>.

**Bridge Management Elements** – Components of bridges such as joints, wearing surfaces, protective coatings systems, and deck/slab protection systems that are typically managed by agencies utilizing Bridge Management Elements<sup>39</sup>.

**Bridge Management System (BMS)** – Formal procedures and methods for gathering and analyzing bridge data for the purpose of predicting future bridge conditions, estimating network maintenance and improvement needs, determining optimal policies, and recommending projects and schedules within budget and policy constraints. A BMS includes a network-level computerized database and decision support tool that supplies analyses and summaries of the data, uses models and algorithms to make predictions and recommendations, provides the means by which alternative policies and programs may be efficiently considered, and facilitates the ongoing collection, processing, and updating of necessary data.

**Bridge Preservation** – Actions or strategies that prevent, delay, or reduce deterioration of bridges or bridge elements; restore the function of existing bridges; keep bridges in good condition; and extend their life. Preservation actions may be preventive or condition-driven<sup>41</sup>.

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<sup>38</sup> FHWA, 2020, from <https://www.fhwa.dot.gov/bridge/management/>

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**Commonly Recognized (CoRe) Elements for Bridge Inspection** – The AASHTO Guide for CoRe Structural Elements was published in 1997 and adopted by FHWA and AASHTO as the preferred standard to collect bridge element condition information. The guide precedes the AASHTO Manual for Bridge Element Inspection.

**Element Condition States (CSs)** – Defect descriptions and severity with guidelines to the inspector for determining defect severity and condition assessment for a bridge element <sup>39</sup>.

**General Condition Ratings (GCRs)** – Condition ratings used to describe the existing, in-place bridge or culvert as compared to the as-built condition. Evaluation is for the materials related, physical condition of the deck (National Bridge Inventory Item 58), superstructure (Item 59), and substructure (Item 60) components of a bridge. Culverts are also rated and coded for overall condition evaluation (Item 62)<sup>40</sup>.

**Life Cycle Cost Analysis (LCCA)** – Process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs, such as maintenance, user costs, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment (Transportation Equity Act for the 21<sup>st</sup> Century).

**Maintenance** – Work that is performed to maintain the condition of the bridges or respond to specific conditions or events that restore the highway system to a functional state of operations <sup>41</sup>.

**National Bridge Elements (NBEs)** – Primary structural components of bridges necessary to determine the overall condition and safety of the primary load-carrying members<sup>38</sup>.

**National Bridge Inspection Standards (NBIS)** – Federal regulations establishing requirements for inspection procedures, frequency of inspections, qualifications of personnel, inspection reports, and preparation and maintenance of a state bridge inventory. The NBIS apply to all structures defined as bridges located on all public roads.

**National Bridge Inventory (NBI)** – A collection of information (database) of the nation's bridges located on public roads, including Interstate highways, U.S. highways, state and county roads, and publicly accessible bridges on federal lands. The inventory presents a state-by-state summary analysis of the number, location, and general condition of highway bridges within each state. Collection of NBI data is authorized by statute 23 U.S.C. 144 (National Bridge and Tunnel Inventory and Inspection Standards) and implemented by regulation 23 CFR 650.301 et seq<sup>42</sup>.

**Nondestructive Evaluation (NDE)** – A means of analyzing and assessing the condition of various structural components of in-service highway infrastructure assets—pavement, bridges, and tunnels—without impairing their future usefulness.

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<sup>39</sup> Manual for Bridge Element Inspection, American Association of State Highway and Transportation Officials, 2013

<sup>40</sup> Recording and Coding Guide for the Structure Inventory and Appraisal of the Nations Bridges, Federal Highway Administration, 1995, Washington D.C.

<sup>41</sup> Bridge Preservation Guide: Maintaining a Resilient Infrastructure to Preserve Mobility United States. Federal Highway Administration, 2018

<sup>42</sup> Public Disclosure of National Bridge Inventory (NBI) Data, Federal Highway Administration, 2007, <https://www.fhwa.dot.gov/bridge/nbi/20070517.cfm>

**Pontis** – Application software for managing highway bridges and other structures. Now known as AASHTOWare Bridge Management (BrM) software.

**Quality assurance (QA)** – The use of sampling and other measures to ensure the adequacy of quality control procedures to verify or measure the quality level of the entire bridge inspection and load rating program (23 CFR § 650).

**Quality control (QC)** – Procedures that are intended to maintain the quality of a bridge inspection and load rating at or above a specified level (23 CFR § 650).

