Final Report

WSDOT Bridge Preservation Needs Estimation Process Follow-Up Study

Prepared for
Joint Legislative Audit and Review Committee (JLARC)
Washington State Legislature
Contract 19-03

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Prepared by

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Recommendations in this report represent Consultant's professional opinions and do not necessarily reflect the opinions of the Legislative Auditor.

Cover: Wishkah River bascule bridge, US 12 in Aberdeen, Washington.
Keeping Washington's bridges in service requires well-planned preservation as well as mitigation of seismic and climate change risks.
Photo made August 2014 by the author.

Table of Contents

Foreword

In 2015, a study was completed for the Joint Legislative Audit and Review Committee (JLARC) of the Washington State Legislature to review the methods used by the Washington State Department of Transportation (WSDOT) to develop long-term estimates for highway preservation needs. The study found that WSDOT was following best practices completely for pavements but only partially for bridges. The study made a number of recommendations to improve the practices related to bridge preservation needs estimation, and WSDOT concurred with these recommendations.

Subsequent to the initial JLARC study, WSDOT conducted a survey of peer agencies and evaluation of available software to support bridge management. In January 2017 it licensed AASHTOWare Bridge Management, a software package published by the American Association of State Highway and Transportation Officials (AASHTO). With consultant assistance, the Department evaluated alternatives, including in-house development, prepared an implementation plan and commenced the execution of that plan. WSDOT has hired two additional staff to support bridge management, has obtained training from the software vendor, and has participated in industry activities to keep up to date on new capabilities.

The Appendix is a summary prepared by WSDOT of its progress on implementation of the JLARC recommendations, updated in 2017 and 2019.

In July 2018, JLARC directed its staff to conduct a follow-up study to evaluate improvement efforts. The Consultant, Paul D. Thompson, was engaged in March 2019 to provide expert assistance in the form of this report. The central questions of the follow-up study are:

1. What actions has WSDOT taken to address the recommendations in JLARC's 2015 report?
2. Since 2015, are there new best practices for developing long-term estimates for bridge preservation needs? If so, has WSOOT used them as it responds to the recommendations?
3. What actions have WSDOT and OFM taken to improve stakeholders' confidence in preservation estimates?

The initial study noted that implementation of best practices in asset management is a complex multi-year process that benefits from industry standards and industry-developed tools. It does not have a distinct endpoint, but is instead a process of continuous improvement. This follow-on study is therefore an assessment of the results of five years of progress, and of the Department’s plans and preparation for further progress.

Executive Summary

The assessment of bridge preservation needs is a subset of the practice of Transportation Asset Management, a strategic process using data and analysis to sustain the desired level of service, and maximize the accomplishment of agency goals, while minimizing long-term cost and managing risk. The past five years have been a very dynamic period in this field. Federal legislation and regulations established mandatory requirements for Transportation Asset Management Plans and bridge management systems, which include the significant recommendations from the 2015 JLARC report. Industry groups developed improved manuals, training programs, and software to support the planning of bridge preservation. Many state DOTs, including WSDOT, conducted research and business process re-engineering exercises to improve their asset management practices.

With billions of dollars at stake in bridge preservation decision making, many of the industry innovations of the past five years have been oriented toward improved forecasting of conditions and costs, narrowing the range of uncertainty, and creating a more solid and objective basis for significant decisions. Agencies have been implementing tools, including bridge management systems, to support the full range of business processes involved in the planning and delivery of bridge preservation.

For this evaluation, the activities necessary in order to implement the 2015 JLARC report recommendations were divided into seven focus areas, whose organization and content are very similar to the 2015 report, the WSDOT work plan, and more recent industry guidance. These focus areas decompose best-practice long-range bridge needs assessment processes into ingredients that can be objectively described in terms of artifacts such as data, tools, reports, and other evidence of business process execution. These ingredients are widely accepted in the industry even if specific methods and tools for each component may vary from one agency to another.

For each focus area, a narrative is provided of the recent developments in industry best practices, and the specific activities WSDOT has undertaken during the same timeframe, based on written materials provided by WSDOT and interviews with the Bridges and Structures Office and the Capital Program Development and Management Office. The final section of each focus area contains the Consultant's interpretation and evaluation of WSDOT progress for the first five focus areas, and suggested actions for the future in the final two areas. The evaluation is performed in two contexts:

- The extent to which WSDOT progress is keeping up with changes in best practice in other state Departments of Transportation (peer position, expressed as Advanced, Normal, or Behind);
- Change since 2015 in the extent to which WSDOT data and analysis tools are affecting long-range needs assessment reporting (implementation progress, expressed as Full, Partial, or Minimal).

In general, the Consultant concurs with the WSDOT work plan (Appendix of this report) and the 2018 implementation plan (Dye 2018). Their full completion is encouraged. In addition, a number of suggestions are made that could enhance stakeholder confidence in preservation estimates.

Every State DOT is on a journey toward improved asset management practice. Each agency contributes to progress and works at a pace that is limited by industry progress, especially in research, standards, and tools. There is no inherent value judgment in the peer position or the implementation progress. The key point is that WSDOT is on an appropriate track and should continue moving forward.

Summary of progress by focus area

Focus area	Progress report	Evaluation
Data and information systems	WSDOT has appropriate information systems and data consistent with national best practices. In some areas, particularly the longer time series of element condition data and the availability of supplemental risk assessment data, WSDOT is ahead of the progress of most states. It has licensed AASHTOWare Bridge Management (BrM) to perform the necessary analysis. It has established a BrM database and established an automated process for importing bridge inspection data.	Peer position: **Advanced** Progress: **Full**
Forecasting of bridge condition	WSDOT has begun exploratory data analysis to prepare for deterioration and treatment effectiveness modeling. It has developed service life estimates for certain treatments, but these do not consider uncertainty and are not in a form that can be input to BrM. While a few states having best practice are far ahead, WSDOT progress is currently consistent with more than half of agencies on this matter.	Peer position: **Normal** Progress: **Minimal**
Programmatic cost estimation	WSDOT has comprehensive preservation delivery capabilities, and mature documented methods for estimating project costs. These have not yet been input to BrM. While a few states having best practice are far ahead, WSDOT progress is currently consistent with more than half of agencies on this matter.	Peer position: **Normal** Progress: **Minimal**
Analysis of site-based risk	WSDOT has performed significant analyses of high priority hazards and developed suitable mitigation plans for most of them. WSDOT has not yet configured BrM for risk analysis, but is otherwise ahead of most agencies in this area.	Peer position: **Advanced** Progress: **Partial**
Estimation of life cycle cost	WSDOT does not yet have treatment selection and priority-setting methods that include calculations of life cycle cost. It has not yet configured BrM to compute life cycle cost estimates. Completion of the preceding focus areas is necessary to enable life cycle cost calculations.	Peer position: **Normal** Progress: **Minimal**

In their 2019 Transportation Asset Management Plans due June 30, most of the states have included work plans, usually of two or four years in duration, that would enable their bridge management systems to adequately forecast bridge condition, quantify programmatic costs and risks, and compute life cycle costs. WSDOT would need to complete its work plan in order to maintain a Normal or Advanced peer position.

Reporting of bridge preservation needs

Five existing reports of preservation needs estimates were examined, including the Statewide Transportation Improvement Program (STIP), Project Delivery Plan, Regional bridge preservation needs lists, the Gray Notebooks, and the Transportation Asset Management Plan. Bridge preservation needs estimates in these documents were found to be inconsistent, and cannot be reconciled from the information provided. Some of the differences, such as timeframe and level of detail, have clear rationale. For example, the STIP focuses on federally-funded projects over a four-year period, corresponding to federal mandates. Other differences are unclear or inconsistent, such as the extent to which seismic and fish passage costs are included, the degree of inclusion of future needs caused by expected deterioration, and the amount of over-programming that is assumed.

An effort to make the reporting of bridge preservation needs more transparent and consistent would require discussion and agreement among stakeholders and WSDOT on changes to reporting standards and conventions. The following points could form a framework for discussion:

- The Transportation Asset Management Plan (TAMP) is well conceived and positioned to become the primary focal point for long-range estimation of infrastructure preservation needs.
- Strategies to manage the technical complexity of the TAMP may include publication of a separate Technical Report, and/or the use of endnotes similar to the common practice in financial statements. These would enable the main TAMP volume to be relatively brief and high level.
- Preservation needs estimates in the TAMP should be all-inclusive. They should include expected future needs in the ten-year period caused by deterioration, and all risk mitigation needs. They should include all categories of work affecting bridge conditions. Where certain line items are estimated with less confidence, this can be indicated using endnotes.
- When long-term fiscal resources are insufficient to satisfy all long-term preservation needs, specific agency actions should be described and quantified, either a strategy to increase funding in cooperation with the Legislature, or a process to gradually restrict or close bridges that the state is not able to maintain, or other realistic strategies described in actionable detail.
- With the exception of projects requiring a long planning lead time (such as most bridge replacements), the reporting of specific lists of projects should be limited to the STIP timeframe. Needs farther in the future should be reported only by categories of bridges or treatment types. Beyond four years the variability in deterioration rates becomes too significant to support most project-level reporting of needs.
- When separate reports of bridge needs are necessary for specific business processes, they should be accompanied by a reconciliation explaining any differences from what is reported in the TAMP.
- The relationship between funding trends and condition trends is obfuscated in Gray Notebook reports by the effect of work on very large structures such as the SR 520 Bridge and the Alaskan Way Viaduct. This can be ameliorated by reporting these unique structures in a separate category.

Some substantial communication gaps were identified in the process for managing bridge assets. WSDOT officials noted that legislative proposals for WSDOT funding did not appear to reflect the published information about preservation needs. None of the staff interviewed had evidence that legislators were aware of the long-term risks and added costs associated with inadequate preservation, nor was this information clearly presented in any published documents. The Bridge Office reported that it has a limited role in TAMP development at the same time that CPDM reported a more substantial role for the bridge office.

All state DOTs have their communication challenges, so no effort was made to evaluate whether WSDOT's position is ahead or behind other agencies. However, some very good examples of TAMPs now exist from other agencies as cited in this report. In the writing of nine of these TAMPs, the author has found that creation of an effective Working Group helps to improve the quality of collaboration.

All of the successful working groups observed by the author are very active, contributing, even before any writing starts, to agreement on objectives, standards, assumptions, scenario definition, and implementation strategy. The members participate in the actual writing of the document and collaborate on management system analyses. Each working group is intended to follow through to coordinate the implementation of the TAMP, including strategies to increase preservation funding where the TAMP makes the business case to do so. Effectiveness depends in part on making sure each person appointed to the group is reasonably knowledgeable and completely committed to the success of the effort. It also depends on the strong support of senior leadership.

The close working relationships that are formed in the TAMP Working Group are another strong reason why it makes sense to include preservation needs estimation within the TAMP framework.

Asset management is a process of continuous improvement. It is often a matter of discarding old ways of doing business and past miscommunications to rebuild a new and better process going forward.

Summary of suggested actions

1. Complete the work described in the WSDOT Work Plan (Appendix of this report) and implementation plan (Dye 2018).

2. Consider using the TAMP as the focal point and all-inclusive source of bridge preservation needs estimates, with some provisions as suggested in this report for managing complexity and level of detail.

3. Rededicate WSDOT efforts to improve cross-unit collaboration on the TAMP and on all other business processes concerned with transportation asset management, including preservation needs estimation.

1. Introduction

The assessment of bridge preservation needs is a subset of the practice of Transportation Asset Management, a strategic process using data and analysis to sustain the desired level of service, and maximize the accomplishment of agency goals, while minimizing long-term cost and managing risk. The past five years have been a very dynamic period in this field.

- The Federal Highway Administration (FHWA) published a set of rules implementing the 2012 legislation known as the Moving Ahead for Progress in the 21st Century Act (MAP-21). Most important for standardization of best practice were the 2016 rules for Transportation Asset Management Plans, which also addressed minimum requirements for bridge and pavement management systems; and 2017 rules for Performance Management.
- The American Association of State Highway and Transportation Officials (AASHTO) refined its 2013 Manual for Bridge Element Inspection, and every state implemented portions of the manual in response to changes in the National Bridge Inspection Standards.
- AASHTO proceeded with development of its AASHTOWare Bridge Management software (BrM), the successor to Pontis, which implemented many of the FHWA and AASHTO standards to support data collection and management, and decision support.
- FHWA and the National Cooperative Highway Research Program developed several manuals and training programs to help agencies implement best practices.
- Many state Departments of Transportation (DOTs) conducted research to develop or update analytical models of bridge deterioration, treatment effectiveness, unit costs, site-based risk, and other planning tools and metrics to improve the accuracy of their long-range needs estimates.
- Many DOTs conducted self-assessment exercises and business process re-engineering to enable them to implement best practices in transportation asset management, including the improved management of existing bridges.

WSDOT, like all other state DOTs, is deeply involved in the implementation of the new federal rules and industry standards. The Department's work plan, whose most recent version is shown in the Appendix, is closely tied to the timing of a variety of industry activities that support the new rules and standards.

1.1 Study methodology

The activities necessary in order to implement the 2015 JLARC report recommendations were divided into seven focus areas, whose organization and content are very similar to the 2015 report, the WSDOT work plan, and more recent industry guidance. These focus areas decompose best-practice long-range bridge needs assessment processes into ingredients that can be objectively described in terms of artifacts such as data, tools, reports, and other evidence of business process execution. These ingredients are widely accepted in the industry even if specific methods and tools for each component may vary from one agency to another. The focus areas are:

- Data and information systems
- Forecasting of bridge condition
- Cost of bridge work
- Site-based risk

- Estimation of life cycle cost
- Reporting of long-range needs
- Organizational integration

For each focus area, a narrative is provided of the developments in industry best practices during the timeframe since mid-2014, when the research behind the 2015 report was conducted. Following the industry narrative is a discussion of the specific activities WSDOT has undertaken during the same timeframe to implement the recommendations in the 2015 report. These first two sections of each focus area are meant to be factual in nature.

WSDOT provided a large number of documents describing the substantial work that has been accomplished over the past five years. Interviews were conducted with the Bridges and Structures Office and the Capital Program Development and Management Office to gather information and obtain clarification where needed. WSDOT was given an opportunity to review the first draft of these sections, and their comments were incorporated in this Final Report where appropriate.

It should be noted that the study scope as directed by JLARC focuses on developments since the 2015 report, and WSDOT actions to implement the recommendations. Earlier activities and pre-existing business processes are addressed in the 2015 report and are not repeated here except as needed for context and clarity.

The final section of each focus area contains the Consultant's interpretation and evaluation of WSDOT progress for the first five focus areas, and suggestions for the future in the final two areas. The evaluation is performed in two contexts:

- The extent to which WSDOT progress is keeping up with changes in best practice in other state Departments of Transportation (peer position, expressed as Advanced, Normal, or Behind);
- Change since 2015 in the extent to which WSDOT data and analysis tools are affecting long-range needs assessment reporting (implementation progress, expressed as Full, Partial, or Minimal).

In general, the Consultant concurs with the WSDOT work plan and encourages its completion. In addition, a number of suggestions are made that could enhance stakeholder confidence in preservation estimates.

1.2 Industry data sources

Much of the recent industry work to enhance the state of the practice is available online in published form, as referenced at the end of the report. WSDOT conducted a survey of 33 states in September 2016 which summarized practices at that time in the responding agencies. An extensive set of documents describing current practice can be found on several web sites:

Federal Highway Administration (FHWA)

- Asset management: https://www.fhwa.dot.gov/asset/
- Bridge management: https://www.fhwa.dot.gov/bridge/management/
- Bridge inspection: https://www.fhwa.dot.gov/bridge/inspection/
- Bridge preservation: https://www.fhwa.dot.gov/bridge/preservation/

American Association of State Highway and Transportation Officials (AASHTO)

- AASHTO TAM Portal: http://www.tam-portal.com/
  Includes a searchable database of Transportation Asset Management Plans. These plans describe each state's bridge management practices, using a process that is subject to certification by FHWA. The Consultant has been a contributor to nine different TAMPs, in various consulting engagements for the DOTs of Minnesota, Ohio, Nevada, Texas, Louisiana, Alabama, Kansas, Georgia, and Arizona.
- AASHTOWare Bridge Management (BrM) User Group: http://www.brmug.com/drupal7/
  Includes annual BrM usage surveys by Judy Tarwater of AASHTO.

Transportation Research Board (TRB)

- Bridge management resources: http://www.trb.org/AHD35/AHD35.aspx
- Annual meeting archive: https://sites.google.com/site/trbcommitteeahd35/
  Includes presentations of work in progress by agencies and practitioners to the Bridge Management Committee and its subcommittees. The Consultant is an Emeritus Member of the Committee and Chair of its Subcommittee on Bridge Life Cycle Cost Analysis.

International Association for Bridge Maintenance and Safety (IABMAS)

- Bridge Management Committee: http://www.iabmas.org/
  Includes a periodic worldwide survey of bridge management systems. The Consultant is Vice Chair of this Committee.

National Center for Pavement Preservation (NCPP)

- Bridge preservation partnerships: https://tsp2bridge.pavementpreservation.org/

Joint Legislative Audit and Review Committee (JLARC)

- Final report from 2015: http://leg.wa.gov/jlarc/reports/WSDOTCostEst/pf/default.htm
  The Consultant was a co-author of this report.

Much of the information in this document is synthesized from these sources as well as from work in progress by the author or as reported to the author by other practitioners.

1.3 Role of data, analysis, and judgment

Engineering judgment has always played a significant role in bridge engineering decision making, and continues to do so in best-practice asset management. Over the 20th century in the design of new bridges, best practice evolved from heavy reliance on judgment and experience early in the century, to a hybrid practice using sophisticated engineering design software and quality assurance methods, augmented by judgment, later in the century. In part, this change was motivated by progress in research and data collection of such tremendous volume that it could not be consistently and correctly applied using judgment alone. Agencies varied in how quickly they accepted these changes, but all eventually did.

A similar progression is occurring in asset management. Before the 1980s the long-range assessment of bridge needs and the allocation of funding were performed mainly by judgment in most agencies. With advances in data collection and analysis methods, practitioners noted that judgments about long-range performance and needs were highly subjective and often highly dependent on the experiences and perspectives of each participant. It was very difficult to reconcile competing perspectives, and the credibility of the process was easily brought into question when judgment was applied inconsistently and not backed by data. Agencies then began developing more systematic tools for analyzing data, as a means of improving the consistency and quality of decision making. (O'Connor and Hyman 1989).

Over the past 40 years continuous research and data collection have improved these tools. By 1991 the US Congress had accepted the necessity of bridge management systems in the Intermodal Surface Transportation Efficiency Act. The Federal Highway Administration published an Interim Final Rule addressing six different types of management systems, including bridges, in 1993 (FHWA 1993). This rule mandated all of the tools discussed in the present study. As states attempted to implement these rules, many found that their data were inadequate. The Congress and FHWA relented somewhat in 1996, making the management system rules optional (FHWA 1996).

Nevertheless, many agencies, including WSDOT, proceeded with improvements in best practices. In 1997 the General Accounting Office reported that 48 states were implementing bridge management systems, most commonly the Pontis software developed by the American Association of State Highway and Transportation Officials (Fleming 1997). All of the states continued to improve their bridge data. With these developments achieved and the data greatly improved, FHWA in 2016 again made bridge management systems mandatory (FHWA 2016).

Even with automated support from bridge management systems, engineering judgment continues to play an important role in best practice, especially in the identification of appropriate treatments for a given bridge, and in the assembly of treatments into projects suitable for letting. Other aspects of needs assessment, especially the forecasting of future condition, calculation of life cycle cost, and consistent priority-setting and resource allocation, rely primarily on quantitative analysis in current best practice.

In the present study, as in federal rules and industry guidance documents, it is assumed that engineering judgment plays an important role at the bridge and project levels, and that managerial and political judgment still have an important role in priority-setting and resource allocation. No assessment is made regarding whether one agency has better or worse judgment than another; rather, it is assumed that every agency has the capability to make appropriate judgments. The focus of federal rules and industry guidance is the adoption of best practice data and analysis, where they can improve on older judgment-based methods. That is also the focus of the present study, and is the part of the needs assessment process that WSDOT has committed to improve in response to the 2015 JLARC report.

1.4 Role of uncertainty

Estimation of bridge preservation needs is like any other financial planning exercise in that it entails significant uncertainty. The uncertainty takes two different forms: normal variability of outcomes, which can be tracked and measured as events come to pass ("known unknowns"); and exceptional variability of outcomes, which is very difficult to predict ("unknown unknowns"). Examples of the latter would be the timing of the next big earthquake or the advent of a disruptive new technology. Since billions of dollars are at stake in bridge preservation decisions, expectations are high to reduce uncertainty as much as possible and to account for any reasonable variability that remains.

Figure 1 shows an example of the effects of uncertainty. The graph shows the uncertainty in lifespan of a group of bridge decks that are currently in Fair condition. Some of these decks may reach Poor condition within just two years, while others might last two decades longer. The median remaining life might be 12 years, yet a significant fraction will deteriorate to Poor condition within 10 years. In a 10-year estimate of needs it would be important to make allowance for this "premature deterioration", even though none have yet reached Poor condition.

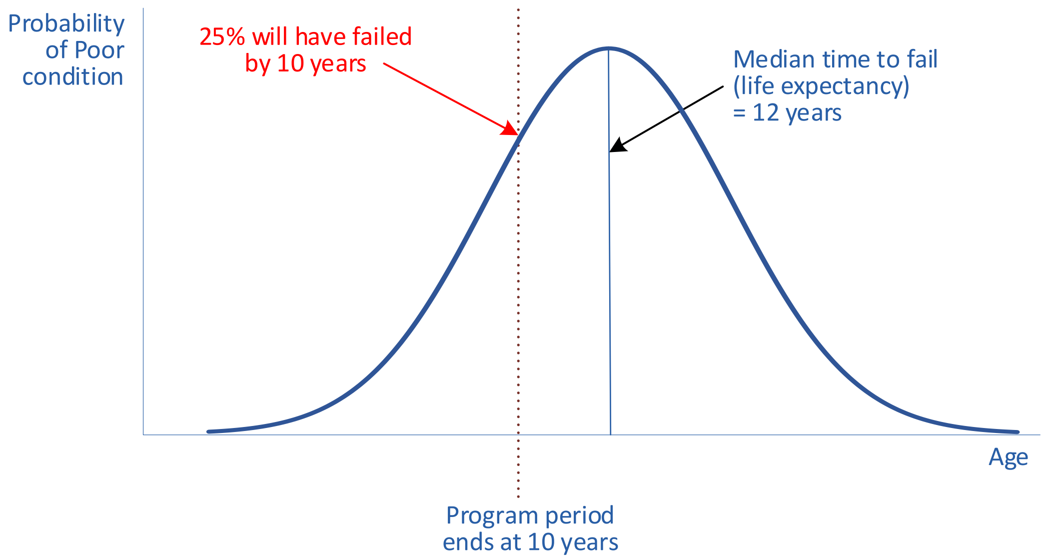

Figure 1. Premature deterioration is a result of uncertainty

In current best practice, bridge management systems account for known uncertainties in deterioration rates by using probabilistic deterioration models, and account for known uncertainties in costs and funding by using sensitivity analysis. Exceptional uncertainties are not analyzed: sometimes they can be accommodated using expert judgment, but usually such unexpected events resist credible judgment as well.

While standardized methodologies do exist for accounting for known uncertainties in bridge management systems, there is no requirement that any specific methodology be used. However, for any non-standard technique to be widely accepted it would need to provide a quantitative estimate of the distribution of variability in outcomes, that is useful and used in decision making. To be credible up to the standards of current best practice it would need be grounded in quantitative data, validated against actual outcomes, and improved over time as more data are gathered.

1.5 Business process perspective

Best practice asset management is a process of continuous improvement. Moreover, it is an organizational process and not a matter of individual effort. In all state DOTs the process is divided into separate procedures that are executed by separate people having different responsibilities and expertise. It is not limited by the capabilities of any one person. Examples of these procedures are:

- Gathering the necessary data in the field;

- Providing secure storage of the data and appropriate access for personnel having a business need for it;
- Ensuring data quality that is consistent and appropriate for its intended uses;
- Developing planning metrics and tools consistent with available data and reflective of known uncertainties;
- Providing information at the appropriate level of detail for agency planning processes, including:
    - Estimation of needed funding levels and negotiation of funding proposals;
    - Estimation of new construction needs;
    - Ensuring consistency with statewide and regional plans;
    - Allocation of resources to competing needs;
    - Establishing and tracking performance targets;
    - Forecasting of future performance;
    - Identification of needs on specific bridges;
    - Priority setting;
    - Development of projects for letting;
    - Delivery of projects.
- Tracking the outcomes of decisions and comparing with forecasts for the purpose of validation;
- Refining planning methods and metrics to incorporate what is learned from past outcomes.

If any of these procedures are to be sustainable and adequately coordinated and managed, they would need to produce tangible products such as information systems, spreadsheets or other data stores, reports, or other types of routine communications. They would need to be backed with manuals, training, and supervisory procedures. When it exists, it is this tangible evidence of a consistent, robust, ongoing set of business procedures that justifies stakeholder confidence in the outputs of the process.

1.6 Key terms and acronyms

AASHTO – American Association of State Highway and Transportation Officials, a non-profit industry group funded primarily by state and federal government agencies, which develops standards, tools, and services available for use by any government agency wishing to adopt them. It is a means by which state governments can pool their resources and share best practices.

Bridge – "A structure including supports erected over a depression or an obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads, and having an opening measured along the center of the roadway of more than 20 feet between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes; it may also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening." (23 CFR 650.305). Federal rules generally use this definition and further restrict it to bridges on public roads. Other applications may include structures having openings of less than 20 feet, or structures supporting fixed assets such as traffic control devices or retained earth.

BMS – Bridge Management System, 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.

BrM – AASHTOWare Bridge Management, a software package published by the American Association of State Highway and Transportation Officials and used by most of the states as their Bridge Management System. Releases up to 5.1.2 (1992-2012) were known as Pontis. The current release is 6.2.

FHWA – Federal Highway Administration, an agency within the U.S. Department of Transportation that supports State and local governments in the design, construction, and maintenance of the Nation's highway system and various federally and tribal owned lands. FHWA is empowered by the United States Congress to develop and administer regulations governing data collection, planning, and other functions related to transportation asset management as applied to highways.

JLARC - Joint Legislative Audit and Review Committee of the Washington State Legislature, the sponsor of this study.

LCCA – Life Cycle Cost Analysis, a method to estimate the long-term costs to maintain a desired level of service on a transportation facility or a network of facilities. It incorporates near-term investments and future investments, considers changes in condition and performance over time, and incorporates the opportunity costs associated with the timing of future investments. In asset management, LCCA usually includes one or more cycles of facility replacement that may be needed in order to sustain the functioning of a complete transportation network. Depending on the context of decision making, it often considers the costs borne by road users and society in the construction and use of the network.

MAP-21 - Moving Ahead for Progress in the 21st Century Act, enacted in 2012. Establishes federal requirements for Transportation Asset Management Plans and Bridge and Pavement Management Systems.

NBI – National Bridge Inventory, the national repository of bridge data that all State Departments of Transportation are required to update by means of the National Bridge Inspection Standards and required annual submittals under 23 CFR 650 Subpart C.

NCHRP – National Cooperative Highway Research Program, a program of the Transportation Research Board. NCHRP administers research in problem areas that affect highway planning, design, construction, operation, and maintenance in the United States.

NHS – National Highway System, the national network of major highways, including all Interstate Highways, that are eligible for funding under the National Highway Performance Program. (23 USC 119). Most federal rules related to asset management apply to the NHS, but some, especially bridge inspection, apply to all public roads across the country. Of the 7,373 bridges in Washington, 2,476 are on the National Highway System. Of these, 2,272 are owned by WSDOT and 204 by local governments (WSDOT 2018).

STIP – Statewide Transportation Improvement Program, a statewide prioritized listing/program of transportation projects covering a period of 4 years that is consistent with the long-range statewide transportation plan, metropolitan transportation plans, metropolitan transportation improvement programs, and statewide Transportation Asset Management Plan, and required for projects to be eligible for funding under 23 USC and 49 USC Chapter 53. (23 CFR 450.104).

TAM - Transportation Asset Management – "… a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both 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 lifecycle of the assets at minimum practicable cost.'' (23 USC 101(a)(2)). Long-range preservation planning is considered to be a part of asset management, and is governed by laws, regulations, and standards developed by government and industry under the umbrella of asset management.

TAMP – Transportation Asset Management Plan, a risk-based plan that describes how the National Highway System will be managed to achieve system performance effectiveness and State DOT targets for asset condition, while managing the risks, in a financially responsible manner, at a minimum practicable cost over the life cycle of its assets (23 CFR 515.7). This is a ten-year plan, required to be made available to the public, and updated at least once every four years.

TRB – Transportation Research Board, a part of the National Academy of Sciences, Engineering, and Medicine. TRB is a non-profit organization that sponsors research in many technical fields important to transportation. It is funded primarily by state and federal government agencies.

WSDOT – Washington State Department of Transportation.

2. Data and information systems

2.1 Best practices

Since the 1970s, states have been required to gather a standardized data set of bridge inventory and biennial inspection data, for submittal to FHWA each April. These are compiled into a National Bridge Inventory (NBI), intended to keep the Congress informed of the conditions and performance of the nation's more than 600,000 bridges (FHWA 1995). Until recently the NBI had only four data items describing bridge condition:

58 – Deck condition rating
59 – Superstructure condition rating
60 – Substructure condition rating
62 – Culvert condition rating

These four items represent separate parts of a structure, with a focus on the primary load-bearing components. Since the NBI Coding Guide is focused on safety rather than on maintenance needs, certain components having significant maintenance costs (such as expansion joints and paint) receive little or no consideration when assigning a condition rating. Each item is recorded using a coding scheme where 9 is excellent condition and 0 is failed and beyond corrective action.

When all of the applicable NBI condition ratings on a given bridge are 7 or above, the bridge is considered to be in Good condition. When any of the applicable NBI condition ratings is 4 or below, the bridge is considered to be in Poor condition. Federal rules enacted in 2017 (after completion of the initial JLARC study) establish a number of network performance measures and transportation asset management rules associated with these Good and Poor designations (FHWA 2017). Most significantly, if the total deck area (in square feet) of National Highway System (NHS) bridges in Poor condition exceeds 10% of the total deck area of all NHS bridges in a state, FHWA can impose sanctions that limit state flexibility in the use of federal funds, in order to direct more funding to the replacement or rehabilitation of such bridges.

Although the FHWA Coding Guide is still mandatory, bridge owners have found that the four NBI condition ratings are insufficient for asset management purposes. They do not provide enough information on the cause of deterioration, to quantify current conditions, forecast future conditions, or select appropriate maintenance actions, and they do not provide enough information on the extent of deterioration for cost estimation.

As a result, nearly all bridge management systems worldwide use a more extensive condition description organized according to elements and condition states (Mirzaei et al 2014). In the United States, most of these systems are based on the AASHTO Manual for Bridge Element Inspection (AASHTO 2019). The guide defines 103 common structural elements and provides objective visual language for recognizing 4 condition states for each element. Inspectors record the quantity or percentage of each element found to be in each condition state.

In the AASHTO element inspections, each element has a set of condition states, which classify the physical conditions found in a field inspection, usually by visual observation by trained personnel. When defining condition states, the difference from one state to the next should make a difference in:

- The type of maintenance or corrective action that may be feasible and effective.
- The cost of maintenance or corrective action.
- The rate of further deterioration.
- Performance of the element as perceived by road users or as it impacts the performance of the asset as a whole. This can incorporate considerations of life cycle cost, mobility, safety, risk, or other performance concerns.

Federal rules mandate the collection and reporting of a subset of 100 of these elements pursuant to 23 USC 144(d)(2). Those NBI elements are shown in Table 1 (FHWA 2014).

Table 1. National Bridge Inventory (NBI) Elements in the AASHTO Manual for Bridge Element Inspection (AASHTO 2019, FHWA 2014)

Deck elements		Superstructure (continued)		Culverts	
12	Re Concrete Deck	148	Sec Steel Cables	240	Steel Culvert
13	Pre Concrete Deck	149	Otr Secondary Cable	241	Re Conc Culvert
15	Pre Concrete Top Flange	152	Steel Floor Beam	242	Timber Culvert
16	Re Conc Top Flange	154	Prestress Floor Beam	243	Other Culvert
28	Steel Deck - Open Grid	155	Re Conc Floor Beam	244	Masonry Culvert
29	Steel Deck - Conc Fill Grid	156	Timber Floor Beam	245	Pre Concrete Culvert
30	Steel Deck - Orthotropic	157	Other Floor Beam	Joints	
31	Timber Deck	161	Stl Pin Pin/Han both	300	Strip seal joint
38	Re Concrete Slab	162	Stl Gus Plate	301	Pourable joint
54	Timber Slab	Substructure elements		302	Compression joint
60	Other Deck	202	Steel Column	303	Assembly joint with seal
65	Other Slab	203	Other Column	304	Open joint
Superstructure elements		204	Pre Conc Column	305	Assembly joint without seal
102	Steel Clsd Box Gird	205	Re Conc Column	306	Other joint
104	Pre Clsd Box Girder	206	Timber Column	Bearings	
105	Re Clsd Box Girder	207	Stl Tower	310	Elastomeric Bearing
106	Othr Clsd Web/Box Girder	208	Timber Trestle	311	Moveable Bearing
107	Steel Opn Girder/Beam	210	Re Conc Pier Wall	312	Enclosed Bearing
109	Pre Opn Conc Girder/Beam	211	Other Pier Wall	313	Fixed Bearing
110	Re Conc Opn Girder/Beam	212	Timber Pier Wall	314	Pot Bearing
111	Timber Open Girder	213	Masonry Pier Wall	315	Disk Bearing
112	Other Open Girder/Beam	215	Re Conc Abutment	316	Other Bearing
113	Steel Stringer	216	Timber Abutment	Railings	
115	Pre Conc Stringer	217	Masonry Abutment	330	Metal Bridge Railing
116	Re Conc Stringer	218	Other Abutments	331	Re Conc Bridge Railing
117	Timber Stringer	219	Stl Abutment	332	Timb Bridge Railing
118	Other Stringer	220	Re Conc Sub Pile Cap/Ftg	333	Other Bridge Railing
120	Steel Truss	225	Steel Pile	334	Masry Bdge Rling
135	Timber Truss	226	Pre Conc Pile	Protective systems	
136	Other Truss	227	Re Conc Pile	510	Wearing surfaces
141	Stl Arch	228	Timber Pile	515	Steel protective coating
142	Other Arch	229	Other Pile	521	Concrete protective coating
143	Pre Conc Arch	231	Steel Pier Cap		
144	Re Conc Arch	233	Pre Conc Pier Cap		
145	Masonry Arch	234	Re Conc Pier Cap		
146	Timber Arch	235	Timber Pier Cap		
147	Stl Main Cables	236	Other Pier Cap		

Although the rules for NBI elements were published in 2014, the first mandatory submittal of these data was in 2015, after completion of the initial JLARC report.

The AASHTO manual provides four condition states per element for increasing levels of severity of each of the following defects: delaminations, spalls, and patched areas; exposed rebar or prestressing tendons; efflorescence and rust staining; corrosion; cracking (distinguishing concrete, steel and timber), load capacity, collision damage; damaged connections; timber decay; timber checks; abrasion;

distortion; settlement; scour; mortar breakdown; masonry displacement; restricted movement or misalignment of bearings; bulging, splitting, or tearing of elastomeric bearings; loss of bearing area; debris impaction; and damage to expansion joint hardware or deck interface. All of these defects are to be considered by the bridge inspector when assigning an element condition state. As an example, Table 2 shows the defect descriptions that go into the assessment of the condition states of a reinforced concrete deck.

Table 2. Definition of condition states – Element 12, Reinforced concrete deck (AASHTO 2019)

Defects	CS 1 GOOD	CS 2 FAIR	CS 3 POOR	CS 4 SEVERE
Delamination/Spall/ Patched Area (1080)	None.	Delaminated. Spall 1 in. or less deep or 6 in. or less in diameter. Patched area that is sound.	Spall greater than 1 in. deep or greater than 6 in. diameter. Patched area that is unsound or showing distress. Does not warrant structural review.	The condition warrants a structural review to determine the effect on strength or serviceability of the element or bridge; OR a structural review has been completed and the defects impact strength or serviceability of the element or bridge.
Exposed Rebar (1090)	None.	Present without measurable section loss.	Present with measurable section loss but does not warrant structural review.	
Efflorescence/Rust Staining (1120)	None.	Surface white without build-up or leaching without rust staining.	Heavy build-up with rust staining.	
Cracking (RC) (1130)	Insignificant cracks or moderate-width cracks that have been sealed.	Unsealed moderate-width cracks, or unsealed moderate pattern (map) cracking.	Wide cracks or heavy pattern (map) cracking.	
Abrasion/Wear (PSC/RC) (1190)	No abrasion or wearing.	Abrasion or wearing has exposed coarse aggregate but the aggregate remains secure in the concrete.	Coarse aggregate is loose or has popped out of the concrete matrix due to abrasion or wear.	
Settlement (4000)	None.	Exists within tolerable limits or arrested with no observed structural distress.	Exceeds tolerable limits but does not warrant structural review.	
Scour (6000)	None.	Exists within tolerable limits or has been arrested with effective countermeasures.	Exceeds tolerable limits but is less than the critical limits determined by scour evaluation and does not warrant structural review.	
Damage (7000)	Not applicable.	The element has impact damage. The specific damage caused by the impact has been captured in CS 2 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in CS 3 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in CS 4 under the appropriate material defect entry.

FHWA Division Bridge Engineers in each state administer annual compliance reviews to ensure that each state is gathering and reporting accurate and complete bridge inspection data for the National Bridge Inventory (FHWA 2017). Compliance is assessed using a set of 23 metrics, as follows:

1: Bridge inspection organization
2: Qualifications – Program Manager
3: Qualifications – Team Leader(s)
4: Qualifications – Load Rating Engineer
5: Qualifications – Underwater Bridge Inspection Diver
6: Inspection frequency – Routine – Lower risk bridges
7: Frequency – Routine – Higher risk bridges
8: Frequency – Underwater – Lower risk bridges
9: Frequency – Underwater – Higher risk bridges
10: Frequency – Fracture Critical Member
11: Frequency – Frequency criteria
12: Procedures – Quality Inspections
13: Procedures – Load Rating
14: Procedures – Post or Restrict
15: Procedures – Bridge Files
16: Procedures – Fracture Critical Members
17: Procedures – Underwater
18: Procedures – Scour
19: Procedures – Complex Bridges
20: Procedures – Quality Control / Quality Assurance
21: Procedures – Critical Findings
22: Inventory – Prepare and Maintain
23: Inventory – Timely Updating of Data

After completion of the compliance review, a letter is sent to the state Department of Transportation to report the results. If any issues were found, the Department may be required to submit a Plan of Action to correct any deficiencies found and improve the process going forward.

The compliance review process has received minor updates since the initial JLARC report, but is largely unchanged.

2.2 WSDOT practice

WSDOT has appropriate information systems and extensive data of sufficient quality to support the estimation of long-term bridge preservation needs. It has licensed AASHTOWare Bridge Management (BrM) to perform the necessary analysis. It has established a BrM database and established an automated process for importing bridge inspection data.

2.2.1 Information systems

Prior to its acquisition of AASHTOWare Bridge Management, WSDOT had already implemented a connected set of in-house information systems for management of its bridge inventory and inspections. Significant modules include (WSDOT 2019):

- **BEISt** –Bridge Engineering Information System. The WSDOT internal website that holds electronic bridge files.
- **BridgeWorks** – The software application that is used to record, process and report bridge inspections and which updates data in the inventory databases.
- **Bridge File** – A file containing historic and current information about a bridge, and meeting the intent of Chapter 2 of the AASHTO Manual for Bridge Evaluation (AASHTO 2018).
- **WSBIS** - Washington State Bridge Inventory System – The aggregation of structure inventory, and appraisal data collected and used to fulfill the requirements of the National Bridge Inspection Standards and additional data used to manage the state and local bridge inventories.

WSDOT also maintains databases with additional data related to steel bridge painting, concrete bridge decks and overlays, expansion joints, scour, seismic retrofit and bridge repairs.

These systems are relatively modern in the technology used, and have undergone quality assurance under the Federal Highway Administration system of metrics (FHWA 2017). As part of the implementation of AASHTOWare Bridge Management (BrM), WSDOT staff created an automated one-way linkage to periodically update the BrM database with data from WSBIS. This enables control of the updating of BrM analyses to ensure that the data are current when needed.

2.2.2 Element inspection

WSDOT was one of the early agencies to implement a system of bridge element inspection similar to the AASHTO Manual for Bridge Element Inspection (AASHTO 2019). The WSDOT process is comprehensive in surveying all of the structural elements that can generate preservation and maintenance needs (WSDOT 2019, Chapter 4). Bridge deck elements have been inspected using a consistent set of definitions since 2012, when the deck soffit was identified as a separate element. Recording of elements that have been repaired was made uniform with a set of changes in condition state language in about 2010. Other elements have remained consistent for an even longer period of time, as far back as the mid-1990s.

The Department's element catalog was especially innovative in covering bridge sidewalks and pedestrian railings; expansion joint components; floating bridge components; seismic restrainers; deck overlays; and protective coatings on steel elements. More recent versions of the AASHTO Element Manual have followed Washington's lead in adding deck surfaces, steel coatings, and other protective elements.

WSDOT bridge inspectors use this element level condition data when making repair recommendations, especially for priority one maintenance items. Some of the elements, particularly deck overlays and paint system elements, are used to assist the inspector's judgment in identifying current preservation needs, and to document these needs.

Because WSDOT's element inspection process pre-dates FHWA's National Bridge Inventory Element inspection requirements (FHWA 2014), it does not precisely match the definitions governing federal bridge data submittals: the classification of elements is more detailed than FHWA requires, but the definitions of condition states are less precise, because they do not explicitly classify the individual defects that make up a condition state definition in the federal and AASHTO specifications. The mapping of WSDOT condition states to federal condition states is not exactly 1:1, although it is close.

WSDOT decided to preserve the value of its historical inspection data by maintaining its existing element inspection process, and instead developed a conversion procedure to translate its element conditions to match the federal standard for reporting purposes. FHWA has not objected to this procedure. The differences in definition do not appear to have any negative effect on the estimation of long-term preservation needs.

2.2.3 Federal Quality Assurance Reviews

FHWA periodically conducts a Quality Assurance Review (QAR) of each state's bridge inspection process to ensure conformance with the National Bridge Inspection Standards (FHWA 2019). In the QAR results reported by FHWA to WSDOT in January of 2019, several deficiencies were documented:

- Metric 13 – Load rating procedures
- Metric 14 – Procedures to post or restrict bridges
- Metric 15 – Bridge files (relating to record-keeping on certain local agency structures)
- Metric 18 – Scour-critical inspection procedure (relating to certain local agency structures)

WSDOT submitted Plans of Corrective Action to FHWA in February and March of 2019. On review of the specifics of these issues, it is fair to say that none of them have any bearing on the estimation of long-term preservation needs for state-owned structures.

2.2.4 Data on site-based risks

The national bridge inspection standards include a limited set of data items related to the risk of transportation service disruption. Examples include load-carrying capacity, scour classifications, and a flag indicating whether fracture-critical inspections are required. WSDOT has identified certain hazards for a more detailed assessment on bridges where screening criteria are met:

- **Seismic** – WSDOT created a database in the 1990s to develop a bridge seismic retrofit program. Following a Cascadia earthquake drill in 2016, WSDOT worked with the state Department of Emergency Management and others to identify lifeline routes in the Puget Sound region that are regarded as critical to keep open in the event of a major earthquake. These have been screened based on structure characteristics, seismic risk, and traffic volume, for a more detailed analysis of seismic resilience. The results of these assessments are preserved in order to support decisions on retrofit or replacement of vulnerable structures.
- **Scour** – Bridges having foundations in water may be susceptible to erosion and other damage that can compromise structural capacity or increase the risk of flood damage. WSDOT inspectors

record descriptions of observed scour. In some cases special underwater inspections by divers are scheduled. This information is tracked over time by WSDOT inspectors and asset managers to support decisions about mitigation or replacement of vulnerable structures. WSDOT has created a database to generate reports and establish a prioritized list of future needs on the scour critical bridges.

- **Over-clearance** – Following the tragic collapse of the I-5 Skagit River bridge in 2013, WSDOT developed a risk mitigation plan for 63 bridges that may be vulnerable to over-height truck collisions. In many cases it was feasible to modify the sway bracing on these structures to increase the vertical over-clearance, thus reducing the risk of such collisions. Revised data on vertical clearance have been maintained by WSDOT to support the oversize truck permit process. WSDOT summarized details and costs to raise the vertical clearance on steel truss bridges in a report published thru the WSDOT Research Office (Swett and Bedi 2017).
- **Under-clearance** - WSDOT has also conducted a more limited assessment of certain bridges for impaired under-clearance. This is regarded as a lower risk and is not a comprehensive statewide program at this time.

2.3 Evaluation

WSDOT data and information systems are consistent with national best practices. No significant deficiencies were found. In some areas, particularly the longer time series of element condition data and the availability of supplemental risk assessment data, WSDOT is ahead of the progress of most states.

Peer position: Advanced

Implementation progress: Full

2.3.1 Information systems

WSDOT has all of the necessary data and information system capabilities to support best practice assessment of bridge needs. This is the same finding as was made in the 2015 JLARC report. WSDOT has taken steps since 2015 to modernize its information technology infrastructure, and has documented the current status in its Bridge Inspection Manual (WSDOT 2019).

In 2017 WSDOT licensed the AASHTOWare Bridge Management (BrM) Software. It has developed a procedure to import bridge data into the BrM database from WSBIS to ensure that the data are current when needed. It is not uncommon for agencies to use a data warehouse or other enterprise data repository for inventory and inspection data, and then import the data into a bridge management system for analysis when needed.

In 2018 an AASHTO survey (Tarwater 2018) reported that 35 state DOTs were storing bridge inspection data in BrM, in more than half of these cases by importing or replicating from external software. WSDOT practice is therefore in line with common industry practice in this area.

2.3.2 Element inspection

The WSDOT element inspection process is comprehensive in surveying all of the structural elements that can generate preservation and maintenance needs. The 2015 JLARC report noted that WSDOT was significantly ahead of other states on the implementation of element level data collection, mainly because of its monitoring of coatings, wearing surfaces and other elements that require significant maintenance funding. Subsequently all other states have caught up, under mandatory federal rules for element level bridge data reporting. The implication of this WSDOT advantage in 2019 is that WSDOT has far more data available for bridge element deterioration modeling than most states.

2.3.3 Federal Quality Assurance Reviews

Deficiencies found by FHWA in its January 2019 QAR report are not unusual and do not have any bearing on the estimation of long-term preservation needs for state-owned structures.

2.3.4 Data on site-based risks

WSDOT has identified certain hazards for a more detailed assessment on bridges where screening criteria are met. A considerable amount of progress was made in this area since 2015. A comprehensive national survey of risk data has not been conducted, but by going beyond FHWA requirements WSDOT is very likely ahead of most states in its data resources available for risk analysis.

3. Forecasting of bridge condition

3.1 Best practices

Deterioration of bridges has inherent uncertainty because many of the factors affecting the rate of decay are hidden and difficult to measure. Most important is the chemical transformation of construction materials under the influence of contaminants in the air and water; corrosion of steel hidden within concrete structural elements; and micro-cracks too small to be visible with the naked eye. Deterioration rates and the effectiveness of repairs can vary widely among bridges for a variety of reasons:

- Since most bridges are assembled in the field, and concrete elements are often cast in the field, weather, construction site conditions, material quality, and contractor skill often affect the longevity of the structure in ways that are difficult to predict or mitigate.
- Even for elements fabricated under factory conditions, variations occur in design characteristics, material properties, transportation, and erection that affect durability.
- Operating conditions including freeze/thaw, rainfall, temperature changes, heavy truck traffic, air and water pollution, and especially the use of deicing chemicals all affect the longevity of bridge elements.
- Deterioration of certain elements can affect other elements. In particular, damage to deck wearing surfaces, expansion joint seals, and paint systems expose the underlying structure to accelerated deterioration.

General patterns of deterioration are manifest when tracking large populations of bridges over time. While significant uncertainty exists in forecasts of deterioration on individual structures, for financial planning purposes bridge managers forecast the general rate at which conditions change and new preservation needs arise in an inventory as a whole. Such forecasts are the essential basis for long-range estimates of bridge preservation needs.

Because of the inherent uncertainty, all bridge management systems, including BrM, model deterioration in the form of a probability distribution. Rates of deterioration and action effectiveness are expressed as transition probabilities. BrM requires its forecasting models to be entered in a particular form that is compatible with these models, and published methodologies exist for developing these metrics from inspection data. The model has two parts, as depicted in Figure 2:

- Deterioration paths (blue) estimate the downward movements among condition states from year to year, if no agency action is taken.
- Preservation paths (red) estimate the upward movements among condition states when an agency conducts a preservation or rehabilitation action.

For convenience, deterioration models are typically expressed in terms of the median number of years to transition from each condition state to the next-worse state. The relative size of upward and downward movements determines the overall change in condition. If the red and blue movements are balanced, then network condition remains unchanged.

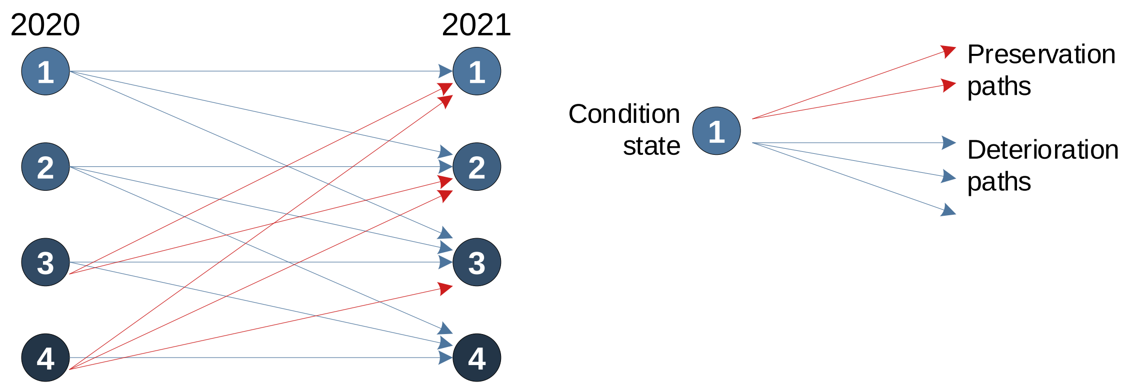

Figure 2. Changes in condition estimated by a forecasting model (1 is best condition state, and 4 is worst)

In principle each element in the inventory has its own deterioration model. Certain elements, such as expansion joints, deteriorate quickly, while others, such as bridge abutments, deteriorate very slowly. The differences in deterioration rates do not correspond to the traditional distinction between deck, superstructure, and substructure; hence, the more detailed element level is necessary. In practice, agencies develop models for groups of elements that are expected to deteriorate at similar rates.

Table 3 shows an example of a deterioration model developed for the FHWA's National Bridge Investment Analysis System (NBIAS), which is used by the FHWA Office of Policy for periodic Reports to the Congress on national bridge needs. This was developed using statistical analysis of element inspection data gathered from a panel of 15 states. The table shows the model for a cool, wet climate typical of the western lowlands of Washington. A different model would apply to cold, dry regions such as Eastern Washington. The transition times reported in the model can be converted mathematically to transition probabilities, which indicate how much of the inventory has historically deteriorated each year.

Since the models quantify year-to-year changes in condition, they can be developed using a relatively small amount of data, two inspection cycles (four years) at a minimum. However the models are more reliable if developed using a longer time series, since general climate and operating conditions can vary from year to year, particularly the use of corrosive deicing chemicals.

According to a series of annual AASHTO surveys reported to the User Group of AASHTO's Bridge Management System (the most recent in 2018), about half of the states have developed deterioration models for element condition data, most based on expert judgment but several based on statistical analysis of bridge inspection data. Development of deterioration models declined immediately after the 2013 publication of a significantly revised AASHTO Manual for Bridge Element Inspection, because of incompatibility of the old and new element definitions. As of 2019, however, there has been a jump in the number of agencies using statistical analysis on their recent inspection data. Some of the states now have more than 4 years of data in the new format, which is sufficient for the most common bridge elements.

As of spring 2019, the following Departments of Transportation have performed recent research to populate their bridge management systems, or have such research in progress: Florida, New York, Alabama, Kansas, New Jersey, Iowa, Virginia, Montana, South Dakota, South Carolina, Oklahoma, Delaware, Illinois, Indiana, Pennsylvania, Idaho, and Georgia. The federal NBIAS model is also available for any state and is currently used by Arizona in its bridge management system. A comprehensive guide to applicable methodologies can be found in NCHRP Report 713 (Thompson, et al 2012).

Table 3. FHWA's NBIAS deterioration model for cool, wet climate zone (median years to transition from each condition state to the next-worse state, by element)

Element group		Median years from state to state 1 to 2	2 to 3	3 to 4
A1	Concrete deck	7	14	14
A2	Concrete slab	5	17	10
A4	Steel deck	8	4	5
A5	Timber deck/slab	6	6	12
B1	Strip seal expansion joint	16	6	6
B2	Pourable joint seal	7	4	4
B3	Compression joint seal	7	6	6
B4	Assembly joint/seal	14	9	9
B5	Open expansion joint	13	9	9
C1	Uncoated metal rail	10	16	32
C2	Coated metal rail	18	13	12
C3	Reinforced concrete railing	26	21	16
C4	Timber railing	18	5	5
C5	Other railing	21	7	7
D1	Unpainted steel super/substructure	13	23	23
D2	Painted steel superstructure	14	20	7
D6	Prestressed concrete superstructure	39	23	9
D7	Reinforced concrete superstructure	14	23	14
D8	Timber superstructure	24	14	8
E1	Elastomeric bearings	54	11	11
E2	Metal bearings	16	19	19
F1	Painted steel substructure	11	17	6
F3	Concrete column/pile	22	20	21
F5	Concrete abutment	29	33	17
F6	Concrete cap	40	42	20
F8	Timber substructure	10	18	9
G1	Reinforced concrete culverts	21	24	30
G2	Metal and other culverts	7	10	18
P1	Deck wearing surface	6	19	11
P2	Protective coating	10	7	5

Federal regulations require that deterioration models be identified in Transportation Asset Management Plans (23 CFR 515.7(b)(2)) and be used in Bridge Management Systems (23 CFR 515.17(b)). As agencies implement these requirements, the utilization rate should increase to 100% over time.

Effectiveness of preservation work is estimated using the same methods as bridge element deterioration, as the fraction of deteriorated elements that are improved to a target condition state by application of a treatment, as in the red preservation paths indicated above in Figure 2. Bridge management models tend to be relatively insensitive to effectiveness within reasonable ranges of the improvement factors. When treatment methods are found to be unreliable in improving conditions, agencies tend to discontinue their use or find more effective substitutes. Thus, expert judgment is often used to derive effectiveness rates.

3.2 WSDOT practice

WSDOT has completed exploratory data analysis and entered some initial transition times into BrM. These are a positive step toward the ability to generate initial needs estimates from the bridge management system.

3.2.1 Deterioration models

WSDOT has a long history of consistent element condition data dating to the mid-1990s, suitable for use in developing deterioration models. Using this information, some consultant support, and expert judgment, the Department has developed service life estimates for certain elements or treatments, particularly bridge decks and overlays, expansion joints, concrete columns, and steel bridge coatings.

An unpublished January 2019 document provided by WSDOT, "WSDOT Steel Bridge Painting – 10 Year Needs" provides estimated average life expectancies of coating systems under six different scenarios, from 20 to 35 years. Paint systems are found to last about five years longer in Eastern Washington than in Western Washington. These lifespans are reported to be considerably longer than the historical intervals of 10-12 years between overcoatings when lead-based paint was used.

For any given bridge, actual decisions about whether to repaint are based on conditions observed in the field by bridge inspectors. As is the case for all types of bridge repairs, there can be significant variation from bridge to bridge in the amount of time that elapses before recoating must be scheduled.

With new staff members hired in 2018, WSDOT has completed a more comprehensive process of quantifying bridge element deterioration rates. The current status may be characterized as exploratory data analysis. This determines the suitability of data and reasonableness of observed changes in condition, and provides an initial set of transition times to enable preliminary usage of the BrM models.

3.2.2 Treatment effectiveness

The AASHTOWare Bridge Management Software contains a feature known as Benefit Groups for estimating the improvement in condition that may result from bridge preservation actions. This is especially important for accurate estimation of life cycle costs, since improvements in condition postpone the time when further action will be needed. As delivered, BrM has only a very limited set of Benefit Groups, leaving it to each agency to fully populate the model. WSDOT has received some training for this activity but has not yet begun the work to fully configure the software.

3.2.3 Consideration of variability

While WSDOT has extensive data suitable for developing these models, it has not yet begun the formal model estimation process using statistical methods that account for variability in deterioration rates within the inventory. Deterioration rates used in the reports provided by WSDOT do not quantify uncertainty or use quantified uncertainty as part of the reporting of needs.

3.3 Evaluation

Condition forecasting models are mandatory under federal rules, and nearly all state DOTs, including WSDOT, are documenting work plans to satisfy this requirement as part of their 2019 Transportation Asset Management Plans. While a few states having best practice are far ahead, WSDOT progress is currently consistent with more than half of agencies on this matter. Based on the experiences of other agencies, a more rigorous statistical analysis is advised to make the BrM results fully reliable.

Peer position: Normal

Implementation progress: Minimal

3.3.1 Deterioration models

This study identified 17 state DOTs that have analyzed their recent (since 2014) element condition data to develop the probabilistic deterioration models required for BrM. Previously, about half of the states had developed deterioration models for an earlier element inspection process using AASHTO's Pontis bridge management software. Most of the rest have at least experimented with judgment-based models, or have conducted exploratory data analysis as a precursor to configuring BrM, as WSDOT has done. WSDOT progress is therefore in line with the progress of other states.

It is noted that development and usage of deterioration models in bridge management systems and transportation asset management plans is mandatory under federal rules, so the utilization rate is expected to approach 100% over time.

With a longer time series of consistent element inspection data than most other states, WSDOT's database is more than sufficient for formal statistical analysis of bridge element deterioration transition times that fully reflect the variability normally found in the inventory.

WSDOT's peer position as "normal" is based on its plan to have its deterioration and treatment effectiveness models fully developed for BrM within the next two years. A majority of states are in the same position. Only after completion of a formal statistical analysis can its progress be characterized as best practice in this area.

3.3.2 Treatment effectiveness

WSDOT has not yet begun the process of developing probabilistic treatment effectiveness models, in the form of Benefit Groups, that are necessary for BrM implementation. This is consistent with progress in a majority of agencies at this time.

3.3.3 Consideration of variability

All of the deterioration rates documented by WSDOT thus far have been expressed in a deterministic form, such as average service life of elements or treatments. WSDOT has indicated that it recognizes the importance of uncertainty in the forecasting of future conditions, but has not yet developed models that reflect this variability. All of the forecasting models required in BrM are in a probabilistic form that does account for variability.

4. Programmatic cost estimation

4.1 Best practices

In bridge management analyses, unit costs are used with current condition and with forecasts of future condition to convert condition information into predicted future costs. This is essential for life cycle cost analysis and also for consistent network-wide estimation of preservation and maintenance needs. The unit costs must be expressed in dollars per deteriorated outcome units — i.e. the same units that are used in element inspection, in order to relate them directly to inspection data. Two ways to do this are:

- Statistical analysis of capital and maintenance work accomplishment data, in combination with bridge element condition and quantity data, to derive typical unit costs.
- Expert judgment. Agencies that either do not have suitable work accomplishment data, or have not yet analyzed their data, often use an expert judgment elicitation process to develop approximate unit costs to use when estimating future bridge needs. This is a viable alternative and can be accurate if based on validated project cost estimation procedures.

For both of these approaches, it is normal to rely on an agency's estimators to review analysis results and make appropriate adjustments to account for typical conditions and uncertainties encountered in programmatic cost estimation. Some agencies go further and compare their cost metrics with peer agencies having comparable delivery capabilities, as in Table 4. The analyst then evaluates differences in bridge types and work classifications to understand the differences among agencies to assess the reliability of the unit cost estimates.

In the period since 2015, FHWA rule-making and certification guidance regarding bridge treatments has been shaped by both existing rules and an FHWA Bridge Preservation Guide (FHWA 2018). NCHRP Project 14-36 is completing a proposed AASHTO Guide for Bridge Preservation Actions, which if approved by AASHTO will be published later in 2019. A common taxonomy for bridge treatments is:

- **Initial Construction** – Complete construction of a new bridge structure on a new alignment.
- **Replacement** – Removal of an existing bridge and construction of a replacement bridge to serve the same alignment as the removed bridge. Since replacements are often necessitated by traffic growth or other functional requirements, there are often additional costs associated with bridge expansion and approach roads above and below the structure.
- **Rehabilitation** - Major work required to restore or increase the structural integrity of a bridge, as well as improvements to function, capacity, resilience, or safety.
    - Partial or complete replacement of deck or wearing surface
    - Partial or complete replacement of bridge railing
    - Retrofit of fatigue-prone steel details
    - Retrofit of fracture critical members to add redundancy
    - Seismic retrofits, such as superstructure restraint or wrapping of vulnerable columns
    - Partial or complete replacement of superstructure
    - Bridge strengthening or widening
    - Bridge jacking to reset bearings or increase vertical clearance
- **Preservation** - Actions or strategies that prevent, delay, or reduce deterioration of bridges or bridge elements, typically causing an improvement in element conditions.
    - Seal or replace a leaking deck joint
    - Removal of deck joints where feasible

  - Rehabilitation or replacement of deck drains
  - Application of thin overlays on bridge decks
  - Repair or restoration of major structural elements such as beams, piers, or culverts
  - Painting of steel elements (total, zone, or spot painting)
  - Installation or repair of scour countermeasures
  - Repair of slope paving
- **Maintenance** – Condition-based or interval-based activities that do not require engineering or multi-year programming, usually determined by inspectors or local crews. These typically do not improve condition measures but serve to delay deterioration.
  - Bridge cleaning
  - Application of deck sealant
  - Repair of bridge rail deterioration or collision damage
  - Minor deck spall repairs or deck crack sealing as needed
  - Approach slab repairs or mudjacking
  - Cleaning of scuppers and expansion joints as needed
  - Lubrication of bearings and pins
  - Sealing of substructure caps and bearing seats
  - Arrest of steel fatigue cracks, as needed
  - Removal of channel or culvert debris as needed
  - Cleaning of brush from under or around bridges as needed

Table 4. Example cost analysis from Alabama

Total by treatment (all in 2015 dollars)							
	Cost ($)	Allocated cost *	Average annual $	Report count	Cost per report	Compare with	
Operations	3,180,925						
Overhead	2,443,089						
Misc	169,013						
Inspection	16,158,604	17,221,502	4,305,376	8209	2,098		
Routine	12,153,084	12,952,503	3,238,126	4557	2,842		
Deck repair	2,858,845	3,046,898	761,724	176	17,312	25,122	MN
Rail repair	964,937	1,028,409	257,102	145	7,092	23,800	TX
Joint repair	1,541,495	1,642,894	410,723	310	5,300	5,590	TX
Super repair	2,493,739	2,657,775	664,444	204	13,028	40,000	MN
Bearing repair	1,145,145	1,220,472	305,118	136	8,974	40,000	NV
Sub repair	1,069,709	1,140,073	285,018	270	4,222	20,637	TX
Slope repair	748,419	797,649	199,412	122	6,538	5,300	TX
Culvert repair	576,243	614,148	153,537	44	13,958	12,100	MN
Total	45,503,249	42,322,324	90,580,581	14,173			

* Overhead and Misc are allocated among the routine and corrective treatments, and Operations is omitted.

Painting costs from other states:
TxDOT had about 300,000/bridge for painting
Ohio had about 200,000/bridge
MnDOT had 377,500/bridge

It is important for the cost of each project developed in a bridge management system to include all cost factors that must be covered under the program budget to be analyzed. Normally this includes indirect costs such as traffic control, engineering, mobilization, demolition, environmental mitigation, and land acquisition.

Indirect costs are not generally proportional to the quantity of work to be done. For example, a work zone must be established for any deck repair project, and the cost of a traffic control installation is roughly the same whether the repairs affect 10% of the deck (in random locations) or 50%. Agencies account for this in one of two different ways:

- Estimate an approximate fixed cost of such work items based on known characteristics of the bridge (such as traffic volume and number of lanes) and the type of work to be done; or
- Estimate indirect costs as a percentage of direct costs, but configure treatment feasibility criteria to prevent the generation of small projects, so that an assumption of linear indirect costs is more reasonable.

BrM can support either of these approaches.

4.2 WSDOT practice

WSDOT has comprehensive preservation delivery capabilities, and mature documented methods for preparing engineer's estimates for project costs on specific individual bridges. These are not in the same form as what would be required for network level planning in BrM and have not been input to BrM.

4.2.1 Preservation delivery capabilities

WSDOT is found to have a full complement of preservation delivery capabilities, using its own forces or contractors. Under the P2 Strategic Preservation Program, WSDOT has been able to develop innovative approaches for structures unique to WSDOT, such as crack-sealing procedures for concrete floating bridge pontoons.

Administration of structure preservation is described in the Transportation Structures Preservation Manual (WSDOT 2018). Certain procedures are described in the WSDOT Maintenance Manual (WSDOT 2019, Chapter 5).

4.2.2 Treatment feasibility criteria

The AASHTOWare Bridge Management software has a set of pages devoted to defining actions, including criteria for when the actions are to be applied. Actions can be initiated as a part of the inspection process, or can be generated automatically by the software. The automatic creation of actions is especially important for estimation of life cycle costs. As delivered, BrM has a limited set of actions, suitable for network-level planning. Agencies have the option to produce a much more detailed and targeted preservation strategy. WSDOT staff have had some training for this feature, but have not yet worked with it.

4.2.3 Development of unit costs

Like all state Departments of Transportation, WSDOT has a staff capability to prepare engineer's estimates for bridge preservation projects that it initiates either for its own forces or for contractors. To keep this capability up-to-date, the agency has internal databases of work status and accomplishments, including the Capital Program Management System (CPSM), the Transportation Executive Information System (TEIS), and the Construction Contract Information System (CCIS). For work by internal crews, the systems track resource usage of labor, materials, and equipment. For work by contractors, the systems have project costs as paid to the contractor.

The Bridge Management Engineer periodically accesses this information to update cost metrics used for planning purposes. It is envisioned that the same process will be used in order to populate unit costs in BrM, but this process has not yet begun. Recent procedures and unit costs for many types of work can be found in Chapter 12 of the WSDOT Bridge Design Manual (WSDOT 2018). Many of these costs are not expressed in the same measurement units as the element quantities used in the bridge inspection process, so WSDOT staff will need to develop typical deteriorated quantities in order to convert unit costs to a form that is usable in BrM.

4.2.4 Indirect costs

WSDOT has not yet developed indirect cost models for BrM.

4.3 Evaluation

While a few states having best practice are far ahead, WSDOT progress is currently consistent with more than half of agencies on this matter. Completion of the WSDOT work plan for the BrM cost model is a prerequisite to effective implementation of BrM for long-range estimation of bridge preservation needs.

Peer position: Normal

Implementation progress: Minimal

4.3.1 Preservation delivery capabilities

WSDOT practice is consistent with a majority of state DOTs.

4.3.2 Treatment feasibility criteria

WSDOT staff have had some training for this feature of BrM, but have not yet worked with it. While a few agencies have developed comprehensive preservation strategies, WSDOT progress is consistent with the current level of progress of a majority of agencies.

4.3.3 Development of unit costs

Like all state Departments of Transportation, WSDOT has a staff capability to prepare engineer's estimates for bridge preservation projects that it initiates either for its own forces or for contractors. BrM requires unit costs that differ from most project level cost estimation, compatible with network level business processes such as budgeting and resource allocation. Unit costs must be expressed in the same measurement units as are found in element inspection, and must be expressed in dollars per deteriorated quantity rather than total quantity. WSDOT has not yet entered such cost factors into BrM. While a few states are far ahead on this matter, WSDOT progress is not unusual at the present time.

Characterization of WSDOT's peer position as "normal" is based on its plan to have its cost models fully developed for BrM within the next two years. A majority of states are in the same position. Only after completion of this step can it be characterized as best practice in this area.

4.3.4 Indirect costs

WSDOT has not yet developed indirect cost models for BrM.

5. Analysis of site-based risk

5.1 Best practices

In asset management, site-based risk is most often analyzed as the likelihood and consequences of an unexpected event causing a disruption of network performance at a given site. Network performance is interpreted as any combination of cost, safety, mobility, or environmental sustainability, and a disruption is an event that impairs performance for a significant length of time. Examples of disruptions would be:

- A flood that destroys a bridge;
- A flood that threatens to damage a bridge, the threat great enough that officials decide to close the bridge temporarily for safety reasons;
- A ship or oversize vehicle strikes a bridge;
- An earthquake damages bridges over a wide geographic area;
- A truck driver loses control and strikes a bridge railing.
- A truck or train fire damages a bridge.

All bridges have some amount of inherent risk associated with them, but most do not warrant additional risk mitigation action beyond what was provided in their original design. Design standards are structured in order to provide a uniform acceptable level of risk across the network. However, a variety of events can cause a reassessment of risk, which may warrant additional mitigation. For example:

- Changes in stream flow cause unexpected scour at bridge foundations, or make high water more likely;
- Improved understanding of seismic events exposes vulnerability that was not identified at the time a bridge was built;
- Research on bridge rail crashworthiness renders certain older designs obsolete;
- Increases in traffic volume elevate the risk of disruption;
- Deteriorated condition increases the likelihood of damage due to overload or fatigue.

Bridge owners routinely monitor these changes and may add or remove bridges from consideration for retrofits or other mitigation measures. Certain changes, especially improved understanding of seismic events and the effects of climate change, may increase the risk on a large number of bridges all at once. Given fiscal limitations, it becomes necessary to prioritize mitigation measures along with other preservation needs for the same limited funds. Federal rules regarding Transportation Asset Management Plans have several requirements related to risk management (23 CFR 515.7(c):

> *(c) A State DOT shall establish a process for developing a risk management plan. This process shall, at a minimum, produce the following information:*
>
> > *(1) Identification of risks that can affect condition of NHS pavements and bridges and the performance of the NHS, including risks associated with current and future environmental conditions, such as extreme weather events, climate change, seismic activity, and risks related to recurring damage and costs as identified through the evaluation of facilities repeated damaged by emergency events carried out under part 667 of this title. Examples of other risk categories*

include financial risks such as budget uncertainty; operational risks such as asset failure; and strategic risks such as environmental compliance.

(2) An assessment of the identified risks in terms of the likelihood of their occurrence and their impact and consequence if they do occur;

(3) An evaluation and prioritization of the identified risks;

(4) A mitigation plan for addressing the top priority risks;

(5) An approach for monitoring the top priority risks.

Many of the risks listed in paragraph 1 are site-based risks that can be analyzed using bridge management system data to produce the information needed for long-term needs assessment purposes.

Recent software systems such as AASHTOWare Bridge Management have functions that can be configured to prioritize risks in a systematic way. NCHRP Project 20-07(378) developed an unpublished set of models that can be used in a bridge management system to support this capability, for 16 different types of hazards including earthquake, landslide, storm surge, high wind, flood, scour, wildfire, temperature extremes, permafrost instability, overload, over-height collision, truck collision, vessel collision, sabotage, advanced deterioration, and fatigue. Figure 3 shows the summary worksheet for this methodology, supported by additional worksheets for each hazard and consequence that an agency chooses to consider. NCHRP Project 08-118, due to begin in 2019, is intended to formalize and further develop some of these methods, which are also being used for geotechnical asset management in Alaska, Montana, Colorado, and Western Federal Lands agencies. All of this is a relatively recent development that has occurred mostly after the 2015 JLARC report.

NCHRP 20-07 (378) Risk Analysis

Sheet B - Project summary

Bridge ID	**010001**		
Alternative	**Do nothing**	Deck area (sq.ft)	20,000
Program year	**2017**	Program cost ($000)	12,345

Roadways	On structure				Under structure			
Func class	11 - Urban interstate				14 - Urban other principal arterial			
Utilization	ADT	54,000	Trucks	5.50%	ADT	21,000	Trucks	3.00%
Roadway	Length (ft)	200	MPH	55	Length (ft)	100	MPH	45
Detour	Miles	2.1	MPH	45	Miles	1.0	MPH	45

From BMS data. If multiple roadways, use the total ADT and most significant roadway, projected to program year.
Length on-structure is bridge length. Length under-structure is bridge width..

Hazard scenarios		Consequences ($000)				Likelihood			Risk
ID	**Scenario**	**Cost**	**Safety**	**Mobility**	**Environment**	**Extreme**	**Disruption**	**Weight**	**Cost ($k)**
1	Eq-100	12,345	50	6,000	600	1.00%	5.00%	1.00	9.50
2	Fl-100a	12,345	50	6,000	600	1.00%	10.00%	1.00	19.00
3	Fl-100b	100	0	2,000	200	1.00%	20.00%	1.00	4.60
4	Fl-500	12,345	50	6,000	600	0.20%	50.00%	1.00	19.00
5	OH-13.5	100	70	200	40	--	5.00%	1.00	20.50
6	AD-0.9	50	0	200	40	--	10.00%	1.00	29.00
7	Fracture	12,345	0	6,000	600	--	0.50%	1.00	94.73
8								1.00	0.00
9								1.00	0.00
10								1.00	0.00

Use worksheet A to define the hazard scenarios and performance criteria.
See Section 3.5 for supporting computations of consequences.
See the Sections 3.3 and 3.4 for likelihood computations.

Risk cost and vulnerability	Cost	Safety	Mobility	Environment
Struc weight	20,000	75,000	134,400	134,400
Criteria weight	1.00	1.00	1.00	1.00
Risk cost ($k)	102.79	3.63	79.00	10.90
Vulnerability	5.1394	0.0483	0.5878	0.0811

See Section 3.2 for these computations.

Risk analysis results	
Maximum unit risk cost:	100.00
Vulnerability index:	0.0586
Utility:	**94.14**
Social cost of risk ($000):	**196.31**

Figure 3. Prototype worksheet for bridge risk analysis (NCHRP Project 20-07(378))

5.2 WSDOT practice

WSDOT has performed significant analyses of high priority hazards and developed suitable mitigation plans for most of them. These are not yet configured into the logic of BrM.

5.2.1 Identification of hazards

WSDOT has evaluated potential site-based hazards affecting bridges and has identified the ones of highest priority for risk mitigation. These are as follows, listed in priority order:

- Bridge deterioration. Bridges rated in Poor condition according to the federal performance metrics are viewed as most likely to cause service disruptions in the form of load posting, vehicle damage, or forced closure. According to the June 2018 edition of the Gray Notebook, 7.5% of WSDOT bridges (by deck area) are in poor condition. This number has been improving in recent years, largely because of certain mega-projects such as the SR 520 floating bridge replacement and the closure of the Alaskan Way viaduct. There has been little reporting of progress on the much more numerous bridges of more modest size.
- Construction quality. As noted above, variability in construction quality is a significant factor in the uncertainty in rates of bridge deterioration. Premature deterioration forces emergency repairs and more frequent preservation actions, whose work zones disrupt the flow of traffic.
- Bridge flooding and scour. When bridge foundations occur in moving water, they are susceptible to erosion of material supporting the bridge. This leaves them vulnerable to flood damage, so they require regular monitoring. Climate change, by introducing unforeseen variability in sea level and stream flows, creates flooding events and scour that may not have been anticipated by designers.
- Earthquakes. Since the 1990s WSDOT has had a program to analyze and retrofit bridges that may be vulnerable to earthquakes, whether generated by the Seattle Fault, the larger South Whidbey Island Fault system, or the Cascadia Subduction Zone. Nearly $200 million in retrofits has been completed so far, but future needs may approach $1 billion. WSDOT is conducting research focused on Cascadia earthquake risk to determine the most cost-effective approaches to risk mitigation over the very large geographic area that could be affected.
- Over-height truck collisions. The 2013 collapse of the Skagit River I-5 bridge demonstrated the potential consequences of this hazard. WSDOT has developed criteria and designs for raising the sway bracing on steel thru-trusses, and for under-crossings of prestressed concrete structures. Emergency collision repairs are extremely disruptive and costly, compared to the costs of planned mitigation actions.
- Steel expansion joints. The steel armoring on bridge expansion joints takes extreme loadings from heavy truck traffic. If worked loose, these materials can damage vehicles and disrupt traffic, an event that is noticeability frequent on major elevated routes such as Interstate 5 through Seattle.

5.2.2 Likelihood of service disruption

WSDOT has a considerable amount of actual or potential data that can inform estimates of the likelihood of service disruption from each of the prioritized hazards. With this information, BrM has the capability to combine risk mitigation benefits with life cycle cost benefits as a means of integrated prioritization of all preservation needs. In particular:

- As discussed previously, bridge element deterioration models quantify the likelihood of deterioration each year across the inventory. WSDOT has started an exploratory process for developing these models.
- Analysis of deterioration patterns has helped WSDOT to identify construction quality issues and implement corrective action. Such investigations are planned to continue.
- Technologies for scour monitoring have benefited from active research by universities and private vendors. WSDOT has maintained a summary of historic bridge failures, from which the economic impact of scour and flooding can be estimated.
- Seismic acceleration maps are maintained nationwide by the US Geological Survey, and regularly updated. Active research is underway to better estimate the structural response of various bridge configurations in the WSDOT inventory.
- A priority list of thru-truss retrofits for vertical clearance has already been established. Clearances and traffic volumes on these structures are readily available.

The consequences of service disruption depend on traffic volume, detour length, and emergency repair costs, all of which are already readily available.

5.2.3 Risk mitigation capabilities

For most of the prioritized hazards, WSDOT has already developed appropriate mitigation measures. This is especially the case for actions that respond to normal bridge deterioration. For construction quality and certain seismic hazards, active research is underway and will need to continue, as these are cutting edge problems that are faced by many agencies.

WSDOT has encountered a number of difficulties with mitigation of scour and flooding hazards, which are steadily increasing in new locations due to climate change. Many sites are not easily amenable to conventional scour mitigation because of lack of access and environmental sensitivity. Officials have noted that in many cases it is necessary to compare mitigation approaches with total bridge replacement. Longer-span bridges, which have become steadily more economical, can be built with foundations well clear of the water. In some cases WSDOT has found that this alternative can be more attractive from both the economic and environmental perspectives.

5.3 Evaluation

Most state DOTs have not yet developed models for BrM or other tools to identify and prioritize risks in a systematic way. WSDOT has not yet configured BrM for risk analysis, but is otherwise ahead of most agencies in this area.

Peer position: Advanced

Implementation progress: Partial

5.3.1 Identification of hazards

WSDOT has evaluated potential site-based hazards affecting bridges and has identified the ones of highest priority for risk mitigation. Additional work will be required in order to configure BrM to make use of this information, but WSDOT is significantly ahead of most agencies in their readiness to do so.

5.3.2 Likelihood and consequences of service disruption

WSDOT has a considerable amount of actual or potential data that can inform estimates of the likelihood and consequences of service disruption from each of the prioritized hazards. With this information, BrM has the capability to combine risk mitigation benefits with life cycle cost benefits as a means of integrated prioritization of all preservation needs. Additional work will be required in order to configure BrM to make use of this information, but WSDOT is significantly ahead of most agencies in their readiness to do so.

5.3.3 Risk mitigation capabilities

WSDOT’s risk mitigation capabilities are consistent with most other state DOTs, and appropriate for its needs.

6. Estimation of life cycle cost

6.1 Best practices

It is necessary for preservation needs estimates to be fiscally constrained, to accurately account for future needs due to deterioration and to develop realistic 10-year forecasts of condition and performance outcomes. However, unlike the four-year fiscal scenario considered in the STIP, the ten-year analysis for the needs estimate should consider a wider range of fiscal scenarios. The current 10-year financial plan is just one scenario. Over that time frame funding is uncertain, and the senior leadership of most agencies would want to strategize to actively improve the agency's fiscal health over that period.

Consistent with federal rules for the TAMP, many agencies define a "state of good repair" for their bridge inventory as the overall condition level that can be sustained at minimum long-term cost. For life cycle planning purposes and for needs estimation, one of the fiscal scenarios to be developed is the funding level, and resulting condition, that best satisfies the definition of a state of good repair. This may be more or less than the current financial plan.

Because of fiscal constraints it is necessary to set priorities among competing needs. If the minimization of life cycle cost is an agency objective, then estimates of the long-term cost impacts of investments should play a part in the criteria for prioritization. This is one of the primary functions expected of a bridge management system in federal rules and in best practice.

In recent years, bridge materials and construction methods have vastly improved, enough so that the standard design life calibrated in AASHTO bridge design manuals for new bridges has increased from 50 years to 75 years. However, most of the existing bridges in Washington were built before that period of innovation, and some are already past their original design life. The reason these bridges continue to serve the public safely, is the preservation program.

Figure 4 shows the effects of preservation schematically. The lines in the chart show typical condition (in terms of percent Good) over a 100-year period:

- The dotted line is uninterrupted deterioration. If left unrepaired, the bridge would eventually have to be closed.
- The solid orange line shows the situation where the bridge is replaced after conditions become intolerable. A replacement cost is incurred, represented by the orange bar.
- The solid green line shows the effects of a preservation program. In this case, preservation or rehabilitation work is performed on an interval of about 20 years, and routine maintenance is also performed. The costs of these activities are shown using green bars. The bridge still has to be replaced eventually, but this large cost is significantly postponed.

Postponement of large costs is always of value, as it stretches the benefit of the significant investment made in these bridges, and it reduces overall costs in the long run. It is a universal convention to evaluate this benefit using a discount rate, typically around 2% per year. In effect, the importance of a large expenditure declines by this amount for each year that the cost can be delayed, since the money saved can then be used for higher-priority investments. The cost bars in Figure 4 become smaller over time because of this discounting. The process of estimating the total size of these costs is called life cycle cost analysis (LCCA). The difference in life cycle cost between the orange bar and the green bars is the life cycle benefit of preservation. If the total length of the green bars is less than the orange bar, then the preservation program is cost-effective for that bridge.

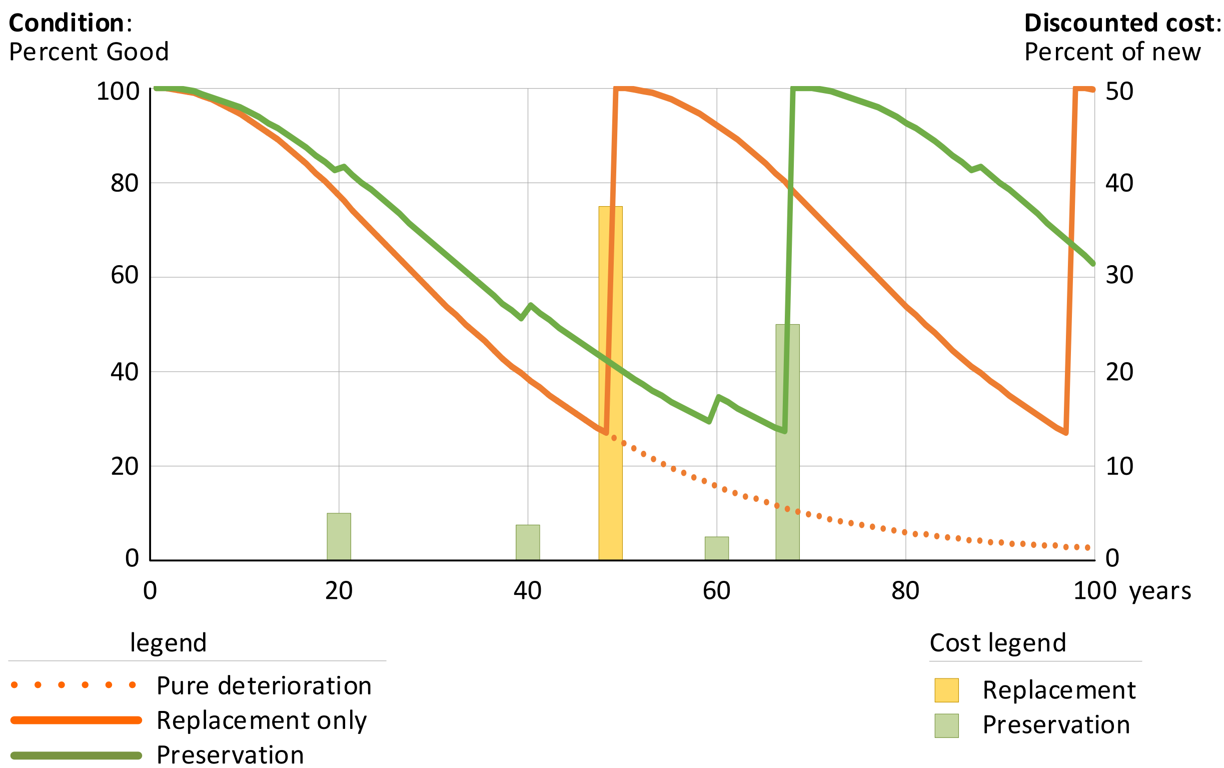

Figure 4. Effects of the preservation program on bridge condition and cost

Given the long lifespan of bridges, uncertainty in the rate of deterioration, and the conservative discount rate used by most agencies for asset management, the analysis period considered in the life cycle cost calculation is usually up to 200 years. This may incorporate multiple cycles of preservation and reconstruction. This differs from traditional practice in bridge design where a higher discount rate and shorter analysis period are typical, as discussed in the following paragraphs.

Within the broad transportation community, life cycle cost analysis is a well-known methodology used since the 1980s for bridge management and even earlier for pavement management (Hawk 2003). It is frequently understood as a component of project design, relying on detailed information about the configuration and materials of a single facility to forecast future costs of the facility and compare design alternatives. In asset management, there is a superficial similarity to project design in the need to forecast performance over a long period of time, and the need to explicitly model inter-temporal tradeoffs in the form of a discount rate. However, the requirements of asset management make a big difference. For example:

- Asset management focuses mostly on existing facilities and explores alternative strategies to maintain service. They start with a facility as-is, in its imperfect state.
- Most asset management applications require that life cycle cost analysis be applied in a consistent way to the entirety of an inventory, or a significant subset of it.

- As a result of the previous point, asset management demands data that can be economically gathered and updated for all the assets in the inventory. Planning metrics such as deterioration rates and unit costs also must sufficiently reflect the diversity of assets in the inventory.
- In asset management, the inherent uncertainty in forecasts of future conditions and costs is significant in the forecasting of annual funding and resource needs. For any given group of seemingly identical assets, future costs will tend to spread out over time because of differing rates of deterioration among the assets in the group. Within any given time window only a fraction of the assets in the group will be ready for preservation work.
- Unlike design applications, it is common for asset management applications to consider replacement as an integral part of the long-term future of a given transportation link. For this reason, many practitioners prefer the term “long-term cost analysis” rather than “life cycle cost analysis” to clarify that strategies may include replacement and the subsequent life of a replacement asset.
- Risk plays a different role in asset management than in project design. While design decisions have long-lasting impacts over the whole life of a facility, asset management decisions have impacts of shorter duration (e.g. from one preservation action until the next one) on individual facilities and offer more flexibility in scoping and timing. Decisions often change from year to year due to changes in resources, changes in condition, and competing demands for funding. Operational flexibility means lower financial risks, which are almost universally reflected in the use of lower discount rates for asset management, in comparison to project design applications.
- Because of both of the previous two points, asset management tools often forecast conditions and costs over a longer period of time than project design applications. Replacement costs are large, and therefore a longer period of discounting is necessary before the timing of replacement has a sufficiently small impact on near-term decisions. Lower discount rates exacerbate this effect.

In bridge management systems, life cycle cost affects whether a given project is cost-effective, and also affects the relative priority of the project within funding constraints. Some agencies make these determinations separately: cost-effectiveness may be determined generically as a part of the development of decision rules for preservation work, while life cycle costs are explicitly calculated for each bridge as a part of priority-setting.

All transportation agencies use LCCA within their design processes for major structures, very often performed by consultants. The usage of LCCA for bridge management has varied over time. A 2010 FHWA survey found that, at that time, 38% of state DOTs had been using this methodology, mostly within AASHTO’s Pontis bridge management system (FHWA 2010). Michigan and Florida had custom-developed spreadsheet applications for this purpose. As of 2015, an AASHTO survey had found usage dropping off somewhat to 31%. At that time more than half the Pontis licensees had transitioned to AASHTO’s most recent version of Pontis, which it called AASHTOWare Bridge Management (BrM), which at that time had very limited LCCA capability.

LCCA usage was steady at 32% in 2018 as agencies waited for completion of the LCCA functionality in BrM. For the federally-mandated 2018 Transportation Asset Management Plan (TAMP), several states (including Florida, Michigan, Minnesota, Ohio, Nevada, Texas, Alabama, and Louisiana) used spreadsheet-based life cycle cost models with their BrM data in order to develop the Life Cycle Planning component of the document. Also in 2018, Kentucky used a spreadsheet LCCA with BrM data to construct its $700 million Bridging Kentucky program for preservation and replacement of 1000 of its minor bridges. By identifying cost-effective preservation opportunities, the analysis found significant cost savings amounting to 41% of the program, which enabled expansion of the program to at least 153 additional, larger bridges.

A more complete set of LCCA functionality in BrM was finally released in September 2018. Starting with the 2019 TAMP, due June 30, 2019, state DOTs are required to use bridge management systems to perform life cycle cost analysis (23 CFR 515.7(b)(4) and 23 CFR 515.17(c), FHWA 2016). Because of the short period of time between the BrM release and the TAMP, most agencies have not been able to fully implement this new software. It is common therefore for agencies to describe their implementation progress and submit a work plan for full implementation. Eventually if all states are compliant with 23 CFR 515.17, LCCA usage will necessarily increase to 100%.

6.2 WSDOT practice

WSDOT does not yet have treatment selection and priority-setting methods that include calculations of life cycle cost. BrM has this capability but is not yet configured by WSDOT to do this.

6.2.1 Analysis parameters

BrM, when fully implemented in WSDOT, will be able to perform life cycle cost calculations. The Department will need to select values for various modeling parameters, including a discount rate, analysis period, and inflation rate. These parameters have already been selected for pavement management and could be used also for bridge management. However, since bridges have much longer lifespans than pavements, it is appropriate to select a longer analysis period for bridges.

BrM can be configured to combine life cycle cost with risk using either a utility approach or a user cost approach. In the case of a utility approach, it is necessary to configure functions for scaling, amalgamation, and weighting, to balance the various objectives of cost, safety, mobility, and sustainability while managing risk. For a user cost approach, it is necessary to select unit user costs for travel time, vehicle operating cost, and accidents. The AASHTO Red Book (AASHTO 2010) is a common source for these unit costs.

6.2.2 Agency and user cost calculations

Once the various analytical inputs are fully developed, WSDOT will be able to use BrM to compute life cycle costs as a means of prioritizing all preservation needs. This activity is not yet started for BrM. A few examples exist within WSDOT of a more focused life cycle cost analysis, such as the evaluation of rehabilitation vs replacement alternatives, based on total agency cost of ownership, for ten bridges on the SR 153 corridor.

WSDOT's 2018 Transportation Asset Management Plan (WSDOT 2018, page 69) indicates a plan to use a software package known as Decision Lens for prioritizing the various subcategories of the transportation Improvement and Preservation capital programs, using the Analytic Hierarchy Process (AHP) to judge their relative importance in the budget. Subsequent work by the Capital Program Development and Management Office has determined that this might not be the best way to proceed with priority-setting, although the tool continues to be useful for other purposes. WSDOT plans to evaluate bridge management system outputs to determine whether that will be a more suitable way forward.

6.3 Evaluation

WSDOT has not yet set up BrM to perform life cycle cost calculations. In addition to the items discussed in this section, the activities discussed above for condition forecasting and cost estimation would need to be completed to enable BrM to perform life cycle cost calculations.

Peer position: Normal

Implementation progress: Minimal

6.3.1 Analysis parameters

The Department will need to select values for various modeling parameters, including a discount rate, analysis period, and inflation rate. Additional parameters will be needed for the priority-setting functions of BrM, in the form of utility factors and/or user cost factors. WSDOT has not yet selected these parameters.

6.3.2 Agency and user life cycle cost calculations

The industry adoption rate for life cycle cost analysis in bridge management hovered around one-third for many years in multiple surveys from 2010 to 2018. Calculation of life cycle cost is a mandatory capability for bridge management systems and for the Transportation Asset Management Plan under recent federal rules. Therefore, the implementation rate is expected to approach 100% over time.

Characterization of WSDOT's peer position as “normal” is based on its plan to have its life cycle cost models in BrM fully operational within the next two years. A majority of states are in the same position. Only after completion of this step can it be characterized as best practice in this area.

7. Implementation process

7.1 Bridge Management Systems

To carry out these needs assessment steps consistently and reliably, state Departments of Transportation use bridge databases and an accompanying set of automated analysis procedures. Together, these tools are called a Bridge Management System (BMS; Thompson and Hyman 1992, Markow and Hyman 2009).

Since 1994, most of the states have pooled their bridge management system development efforts into an AASHTO project known as Pontis. Forty-six of the states licensed Pontis at one time or another, and 40 were using it as of 2015. Pontis had all of the analysis features described here, but this doesn't necessarily indicate that all of the states were using these capabilities. A 2010 survey (FHWA 2010) summarized the state of bridge management system analysis as follows:

- Bridge deterioration: 46% used Pontis and 17% used their own custom tools, for a total of 63%.
- Identification of needs: 39% used Pontis and 40% used custom tools, for a total of 79%.
- Life cycle cost: 38% of states considered life cycle cost in bridge management decision-making.
- Bridge preservation costs: 52% had a database of these costs.

Further analysis of the Pontis usage statistics showed that the states which had successfully implemented Pontis had large inventories under centralized management. States with smaller inventories and decentralized management were not as successful. Since 2011 AASHTO has been conducting a project to upgrade Pontis to make it more suitable for a broader range of state DOTs. The new release, which has been re-branded as "AASHTOWare Bridge Management" was released in several phases beginning in 2015.

The period from 2012 to 2018 saw a slight decline in utilization of BMS for management decision support, although usage remained steady for data collection. Federal legislation known as the Moving Ahead for Progress in the 21st Century Act (MAP-21) enacted in 2012, established a broad set of asset management requirements for pavements and bridges on the National Highway System, in addition to various requirements about system performance monitoring and reporting. MAP-21 was not specific about management systems or methodologies, but was interpreted to require implementation of bridge management systems for management decision support. During this time there was considerable uncertainty about what capabilities would be required in a BMS, even though AASHTO had already published guidance (Thompson and Hyman 1992, Gordon et al 2011). MAP-21 empowered FHWA to develop regulations to implement the legislation.

The federal rule-making process in response to MAP-21 extended from 2012 to 2017. As is typical in such processes, FHWA published a draft rule as a Notice of Proposed Rulemaking, then solicited comments. Requirements governing bridge management systems were included within a Rule for Transportation Asset Management Plans, which was finalized and published in the Federal Register on October 24, 2016 (FHWA 2016). The Final Rule for Performance Management Measures, which include bridge condition measurement, was published on January 18, 2017 (FHWA 2017). The section governing bridge management systems, 23 CFR 515.17, is as follows in its entirety:

§ 515.17 Minimum standards for developing and operating bridge and pavement management systems

Pursuant to 23 U.S.C.150(c)(3)(A)(i), this section establishes the minimum standards States must use for developing and operating bridge and pavement management systems. State DOT bridge and pavement management systems are not subject to FHWA certification under § 515.13. Bridge and pavement management systems shall include, at a minimum, documented procedures for:

(a) Collecting, processing, storing, and updating inventory and condition data for all NHS pavement and bridge assets.

(b) Forecasting deterioration for all NHS pavement and 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 NHS pavement and bridge assets;

(d) Identifying short- and long-term budget needs for managing the condition of all NHS pavement and bridge assets;

(e) Determining the strategies for identifying potential NHS pavement and bridge projects that maximize overall program benefits within the financial constraints.; and

(f) Recommending programs and implementation schedules to manage the condition of NHS pavement and bridge assets within policy and budget constraints.

These regulations do not specify any particular software or methodology to be used, but instead specify capabilities that a state DOT must have in one way or another. Now that the uncertainty surrounding federal rule-making has been resolved, agencies are proceeding with BMS implementation. Since AASHTO has invested more than $10 million of pooled state resources in the development of the AASHTOWare Bridge Management system (BrM), the majority of states have indicated their intention to implement this software. Figure 5 shows the BrM licensees as of September 2018.

The map in Figure 5 reflects the status of license fee payments as of September. Additional agencies (e.g. Montana, Nevada, Georgia, Ohio) have since concluded their licensing arrangements and are using the system. Not all of these agencies intend to fully implement the capabilities of BrM. Some, such as California, Nevada, New York, Texas, and Georgia, have existing software systems for bridge inventory and condition data that they intend to continue to use, so they may decide to implement only selected analysis features of BrM. Others, such as Florida, Minnesota, and Michigan, use the BrM data management features but have existing spreadsheet-based decision support software for budgeting and strategic planning that they intend to maintain. A few, particularly New York and Ohio, have not yet decided whether to implement all of BrM or develop their own software for parts of the necessary functionality.

Since alternative commercial sources exist for inventory and inspection software, and planning functions can be supported using spreadsheet tools, it is possible that there may be agencies that ultimately decide not to implement any of BrM. None have yet made a firm commitment to this path, however.

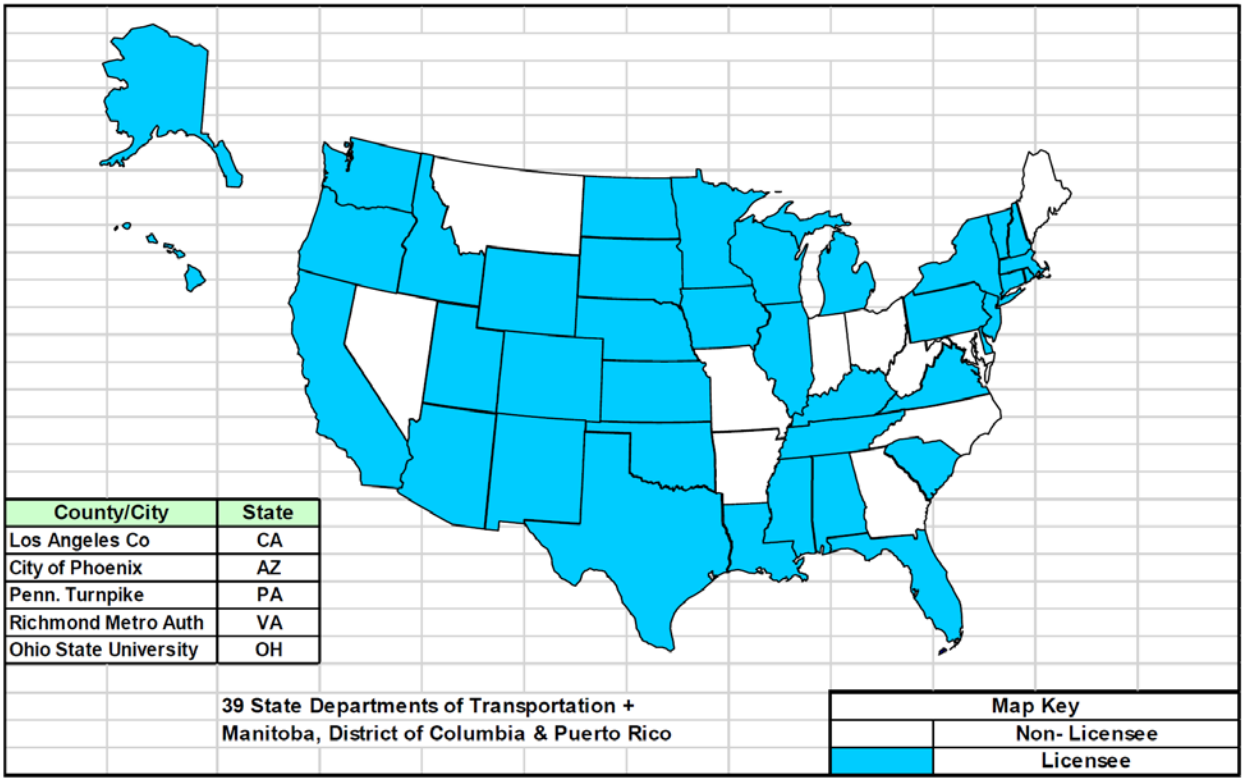

Figure 5. AASHTOWare Bridge Management licensees (2018). At least four additional states (Montana, Nevada, Georgia, Ohio) have joined since the time when this map was presented by AASHTO.

In the vast majority of agencies implementing BrM, the pace of implementation is governed by two constraints:

- A comprehensive set of life cycle planning features in BrM was released in September 2018. A few beta-tester agencies had access to it earlier in 2018.
- Most of the agencies attempting to quickly implement the planning capabilities are doing this in the context of the federally-mandated Transportation Asset Management Plan which is due on June 30, 2019.

As a result of these timing constraints, most of the states are in the same position as WSDOT in their implementation efforts. Exceptions are those states, such as Florida, that had already implemented their own planning tools and had updated them for compatibility with new bridge inspection standards after 2014.

7.2 WSDOT implementation status

WSDOT has confirmed the gaps identified in the initial JLARC report, has developed an appropriate work plan, and has begun executing that plan. An update to the plan is anticipated as part of the 2019 Transportation Asset Management Plan.

Suggested actions: Proceed with the execution of the documented work plan.

WSDOT's Transportation Asset Management Plan (TAMP, WSDOT 2018) provides a comprehensive framework of transportation system goals and objectives, as well as the organization and process necessary to achieve these goals. It brings into alignment federal laws and regulations, state laws, and Executive Orders related to the management of the state's transportation assets.

Following the initial JLARC report, WSDOT in 2016 conducted a self-assessment of its Transportation Asset Management capabilities, motivated by Volume 2 of the AASHTO Transportation Asset Management Guide (Gordon et al 2011). In comparison to pavement management, its bridge management capabilities were rated by WSDOT staff as considerably behind, particularly in the areas of history of work activities, performance measures, life cycle management, and risk assessment. This tended to confirm the same issues found in the initial JLARC study and helped in prioritizing the Department's response.

An April 2018 report prepared for WSDOT detailed a two-year implementation plan for AASHTOWare Bridge Management (Dye 2018). WSDOT began at once to implement this plan. As of this writing, the plan is somewhat behind the schedule described in the report, primarily because the bridge management software from AASHTO is not yet fully functional. This aspect of the schedule is largely outside WSDOT's control.

Because of strong support from most of the states and FHWA, WSDOT believes the AASHTO software is still the solution most likely to succeed, to support long-term estimation of bridge preservation needs as well as for other aspects of bridge asset management. Having hired two new staff to conduct the implementation process, the Department is proceeding with configuration and development tasks that are possible at this stage. Development of deterioration models, cost models, and business rules are near-term priorities.

WSDOT outlined its ten-year plan and near-term activities, for both pavements and bridges, in the 2018 TAMP. The plan includes a section (pages 64-70) specifically addressing the implementation of the JLARC 2015 recommendations, the main theme being the implementation of BrM. WSDOT is planning to update its work plan as a part of the 2019 Transportation Asset Management Plan, due to be submitted to FHWA by June 30, 2019.

7.3 WSDOT reporting of long-range needs

WSDOT reports long-range preservation needs in several formats, but none are comprehensive or consistent. All state DOTs have some means of communicating long-range needs to their stakeholders and legislators. Transportation Asset Management Plans (TAMPs), because of their nationwide standardization and necessary explanation of context, goals, and methods, are viewed by many agencies as a promising means of reporting needs in a consistent way over time. This would be done specifically within the Life Cycle Planning and Investment Planning chapters of the TAMP.

Suggested actions: Focus on the TAMP as the primary means of reporting long-range preservation needs. When other documents report the same information for other purposes, provide a reconciliation to enable readers to understand the differences among the reports. Always provide a complete summary of what needs are included and what needs are excluded. Maintain a more active working group to avoid future communication gaps and enable a stronger implementation strategy.

7.3.1 Current reports of bridge preservation needs

WSDOT currently develops the following reports that present future bridge preservation needs (links to the most recent versions are given in footnotes):

Statewide Transportation Improvement Program (STIP)[1] – A four-year fiscally-constrained program focused on the use of federal funds. Although most WSDOT bridge work uses some amount of federal funding, many projects do not, particularly preservation work. Non-federal projects generally do not appear in the STIP. The current STIP includes about 1,500 transportation projects utilizing $3.9 billion in federal funds expected in 2019-2022.

Project Delivery Plan[2] – A ten-year plan that is more comprehensive than the STIP, because it includes projects that do not rely on federal funds. It is roughly fiscally-constrained for the first three biennia. After that, identified projects decline in size and number, as there does not appear to be a process to try to anticipate the projects that may arise due to future deterioration. Projects listed after the third biennium are regarded as speculative and subject to change. The current version is a snapshot as of 23 August 2018. Bridge preservation projects are in section P2.

Regional bridge preservation needs lists[3] – These undated lists (apparently modified most recently in August 2015) contain a snapshot of bridge preservation needs in the categories of border bridges, scour repair, deck work, general structural repairs, painting, replacement & rehabilitation, and seismic retrofit, with separate spreadsheet files for each of the six regions. Each line in the file is identified with a specific bridge. About 9% of the nearly 1000 projects listed have a planned work year, ranging from 2016 to 2025. Nearly all of the projects have a cost estimate, which is a rough "placeholder" estimate in many cases (particularly large seismic retrofits). The total cost of all the projects listed is more than $2.5 billion. Although the total is large, it still is not comprehensive. It does not include large planned or proposed megaprojects such as the SR 520 "Rest of the West" nor the I-5 Columbia River Crossing. More

[1] https://www.wsdot.wa.gov/LocalPrograms/ProgramMgmt/STIP.htm
[2] https://www.wsdot.wa.gov/construction-planning/project-delivery-plan
[3] https://www.wsdot.wa.gov/bridge/structures/preservation

importantly, all the needs are based on current condition, so there is no allowance for expected future needs caused by normal deterioration.

Gray Notebooks[4] – WSDOT publishes a quarterly performance and accountability report known as the Gray Notebook. A report on bridges is featured in June of each year, the most recent in edition 70, dated June 2018. The report contains a variety of summary statistics on conditions and needs. In 2018 the highlighted topics include: current conditions and recent trends, including comparisons to goals; aging of the bridge inventory; growth of the inventory; the bridge inspection process; and load posting of bridges. A section on bridge asset management separately addresses movable bridges, concrete bridge decks, replacement and rehabilitation needs; painting of steel bridges; the program to reduce over-height truck impacts; and the seismic retrofit program. Within and between the various work categories, the format and assumptions vary somewhat from program to program and year to year.

Transportation Asset Management Plan (TAMP)[5] – Under federal rules (23 CFR 515), WSDOT and all state Departments of Transportation are required to develop a plan for maintaining a state of good repair of at least the pavements and bridges on the National Highway System. WSDOT has extended this scope to include all state-owned pavements and bridges (on and off the National Highway System), and has expressed the intention to eventually extend the scope to additional classes of infrastructure assets. The first TAMP was delivered as required in April 2018, and the second one is due on June 30, 2019. The TAMP is required to be updated on an interval of no more than four years. The 2018 version of the TAMP contains a partial summary of ten-year needs on page 31 within the chapter on Life Cycle Planning, and it has an estimate of annual funding, preservation needs, and funding gap on page 53. In future versions each agency is required to document condition goals which minimize life cycle cost. It must describe a strategy and investment plan to accomplish this and other goals, including safety, mobility, and environmental sustainability, while managing risk.

The STIP and the Gray Notebooks, as published today, existed in substantially the same form at the time of the initial JLARC study in 2014. The Project Delivery Plan, regional needs lists, and TAMP are new. An informal listing of unfunded needs known as the "Orange Book" did exist in 2014 and does not exist today. The WSDOT Transportation Asset Management Plan (WSDOT 2018, page 61) indicates that this list was updated in 2015 and mentions a plan to publish another update in 2018. However, WSDOT staff have indicated that there are currently no plans to do this.

A few additional documents, oriented toward internal or more technical usage, are prepared and updated within WSDOT to anticipate certain types of needs. Some of these documents do consider future deterioration, in that they incorporate estimates of typical lifespans of certain elements, particularly paint systems. These treat the inventory as a going concern that generates new preservation and renewal needs on a periodic basis. Although the analysis does not consider uncertainty and premature deterioration, it is an important step in making future needs estimates more realistic.

As a result of this type of analysis, WSDOT published in Gray Notebook Edition 62 (June 2016) an estimate of additional needs forecast to arise over 10 years because of deterioration for bridge element repairs, expansion joint preservation, concrete deck preservation, steel painting, bridge rehabilitation & replacement, and scour. In that year, current needs were estimated at $1.2 billion (excluding seismic

[4] https://www.wsdot.wa.gov/accountability/gray-notebook/home
[5] https://www.wsdot.wa.gov/about/assetmanagement/statewide-asset-management-plan

and certain other needs), with additional needs from deterioration at $1.5 billion, for a total of $2.7 billion. That analysis was not updated in the same form for the 2017 and 2018 Gray Notebooks. It is unclear whether any of these forecast needs are included in the more recent editions or in the TAMP.

For the fiscally-constrained needs estimates in the STIP and the Project Delivery Plan, priority-setting is done mainly within the Bridge Office. While the Capital Program Development and Management (CPDM) Office nominally has responsibility for systemwide funding allocation, which implies a role in prioritization, no reports or other artifacts were found to indicate that any significant negotiation occurs. All of the participants noted that they were unaware of any negotiation with legislative staff about funding allocation or priority setting. Passages in the Gray Notebook and internal documents indicate that the main criteria for priority setting are condition, traffic volume, the bridge's role in the transportation network, detour length or difficulty, bridge age, and structural characteristics affecting risk. Life cycle cost is currently not calculated for priority setting.

7.3.2 Communication gaps

Some substantial communication gaps were identified in the process for managing bridge assets. WSDOT officials noted that legislative proposals for WSDOT funding did not appear to reflect the published information about preservation needs. None of the staff interviewed had evidence that legislators were aware of the long-term risks and added costs associated with inadequate preservation, nor was this information clearly presented in any published documents. The published information, on examination, appeared inconsistent and sometimes contradictory. For example:

- The Gray Notebook shows a gradual improvement in condition even as it describes substantial unmet preservation needs.
- The Project Delivery Plan is described as over-programmed for Roadway Preservation (P1) but not for Bridge Preservation (P2).
- The various sources differ in what seismic needs appear to be included. In many cases it is unclear what is included and what is excluded.
- Some of the sources show a decline in needs over time, because of the exclusion of new needs caused by deterioration. This is confusing to stakeholders as they see these numbers increase from year to year.

A satisfactory explanation exists for all of these matters, but the need for a relatively technical explanation makes the information difficult for non-technical stakeholders to use. In addition, there is a significant risk that the upcoming 2019 Transportation Asset Management Plan, and the process for producing future updates to the TAMP, may duplicate (at best) or contradict (at worst) existing channels for reporting bridge preservation needs, such as the Gray Notebook.

These documents produce needs estimates that are not consistent and cannot be reconciled from the information provided. Some of the differences, such as timeframe and level of detail, have clear rationale. For example, the STIP focuses on federally-funded projects over a four-year period, corresponding to federal mandates. Other differences are unclear or inconsistent, such as the extent to which seismic and fish passage costs are included, the degree of inclusion of future needs caused by expected deterioration, and the amount of over-programming that is assumed.

To resolve or prevent communication gaps in the preparation of the TAMP, all of the state DOTs with which the author has been engaged have formed cross-agency Working Groups. All of these working groups have the participation of offices concerned with Planning and Programming, Bridge Management, and Pavement Management, as well as other units concerned with planning, finance, and delivery of preservation and maintenance.

All of these working groups are very active, contributing, even before any writing starts, to agreement on objectives, standards, assumptions, scenario definition, and implementation strategy. The members participate in the actual writing of the document. Each working group is intended to follow through to coordinate the implementation of the TAMP, including strategies to increase preservation funding where the TAMP makes the business case to do so. In most cases these working groups have been very effective, but this depends on making sure each person appointed to the group is reasonably knowledgeable and completely committed to the success of the effort. It also depends on the strong support of senior leadership.

7.3.3 Potential improvements in reporting of needs

To some extent, an effort to make the reporting of bridge preservation needs more transparent and consistent would require discussion and agreement among stakeholders and WSDOT on changes to reporting standards and conventions. The following points could form a framework for discussion:

- The federal Transportation Asset Management Plan (TAMP) is required of every state DOT, must cover at least ten years, and has certain methodological requirements consistent with best practice in the estimation of long-range bridge preservation needs, including the full implementation of a bridge management system. WSDOT could use the TAMP as a focus of reporting of long-range needs in the Investment Plan chapter. Many state DOTs have stated, in their 2018 TAMPs, their intention to do this.
- To enable the TAMP to support state business requirements in addition to federal requirements, most states exceed federal requirements by including within the scope of the TAMP state-owned pavements and bridges that are not on the National Highway System. WSDOT already has done this in the 2018 TAMP.
- For the TAMP to serve this purpose, a portion of the TAMP could be presented in a non-technical form similar to what is provided now in the Gray Notebook. Several state DOTs have published their TAMPs in two volumes, an executive summary and a technical volume, to reach two different audiences. Many can be found on AASHTO's TAM Portal[6]. WSDOT's 2018 TAMP stated the intention to do this, but did not follow through.
- Many legislators are more familiar with financial statements than with engineering or planning reports. In financial statements it is common to use endnotes to explain significant factors affecting the interpretation of the numbers presented. While this is not often seen in TAMPs, there is no prohibition on this if it helps improve stakeholder understanding. For example, if the cost of seismic retrofit of bridges on Interstate 5 through Seattle is known only as an approximation, this best available estimate can be reported as part of the needs estimate, with an endnote explaining the limitations of that estimate, the range of uncertainty, and the steps that would be needed in order to refine it.
- The life cycle planning chapter of the TAMP would present the methodology for determining preservation needs, including deterioration, costs, risk mitigation, and treatment selection

[6] http://www.tam-portal.com/

criteria. This also could be divided between technical presentation and non-technical summary. It would need to be clearly stated that the needs estimate in the investment plan includes a forecast of future needs (within the ten year timeframe) caused by future deterioration.

- An important element of the life cycle planning chapter of the TAMP is an estimate of the optimal condition of the inventory that can be maintained at minimum long-term cost. Many state DOTs in their 2019 TAMPs are referring to this condition level as a "long-term state of good repair." This is calculated using a fiscally-constrained scenario where life cycle cost is computed and used for priority setting along with consideration of risk. Alternative fiscal scenarios are evaluated and compared to determine which one minimizes long term cost, and to illustrate the long-term cost implications of higher or lower near-term funding levels. Some agencies distinguish different routes by network importance or functional class, although that distinction is more common with pavements than with bridges. The annual cost of attaining and/or maintaining this condition level is then the baseline cost of keeping the existing inventory in service and offsetting normal deterioration. The annual cost of maintaining a state of good repair becomes a line item in the TAMP investment plan.
- If the life cycle planning analysis shows that funding is insufficient to achieve a condition that minimizes long-term costs, then the difference in condition is a type of performance gap. The TAMP rules call for a chapter that describes the alternatives available to remedy performance gaps. Examples of such alternatives may include:
    - Increase funding for preservation, in which case the TAMP would discuss how this would be done, whether through increased revenue or by reallocation from other uses.
    - Tolerate worse-than-optimal conditions, in which case the TAMP would discuss the additional long-term costs and risks to be faced by the agency and the public.
    - Restrict or close certain bridges, in which case the TAMP would discuss how many bridges would be affected, the criteria to be used, and how this would be decided.

  The key is to explain all alternatives in a specific actionable way, so stakeholders will more readily visualize the implications of inadequate preservation funding.
- It is very important to clearly state what types of needs are included. This is especially important for seismic and scour retrofits, other risk mitigation, fish passage and other functional improvements, bridges and culverts too small to be reported in the structure inventory, and other work categories that have not been clearly stated in the past. If certain categories of work are unfunded, the types and amount of this work should also be clearly stated. In this way, the needs estimate can be made all-inclusive.
- The TAMP does not list projects individually; it merely reports needs in broad categories. The STIP provides a means of listing projects individually. Some state DOTs extend the STIP to cover non-federal projects or timeframes longer than four years, but WSDOT uses the Project Delivery Plan and regional bridge preservation needs lists for this purpose. If two or more separate project lists are maintained, best practice would provide a reconciliation of total and category costs among the reports so it is clear that they are consistent with each other, or to explain any inconsistencies.
- Beyond the four-year time horizon of the STIP, variability of deterioration rates becomes significant, making it more difficult to forecast the scope and timing of preservation work on specific bridges. Therefore such needs should be stated in categories and not by individual

projects. Bridge replacement and major rehabilitation may require a longer planning lead time at the project level.

- It has been noted that the relationship between preservation needs, funding, and condition has been obfuscated in the Gray Notebook by the influence of very large bridges such as the SR 520 bridge and the Alaskan Way Viaduct. This leads, for example, to the situation where the text of the Gray Notebook reports that preservation is under-funded while graphics show steadily improving overall conditions, a mixed message that confuses readers and undermines the effort to fund preservation adequately. To avoid this problem in the future, certain large bridges could be called out into a separate "sub-group" whose costs and condition targets are tracked separately. This approach is specifically allowed under federal TAMP rules (for example, 23 CFR 515.7(b)).

While FHWA has a number of specific requirements for the process of developing the TAMP, it largely leaves it up to each agency to decide exactly how it will use the document and to determine how best to implement the plan. Under 23 CFR 515.13, FHWA certifies the process of developing the TAMP, but does not certify the TAMP itself. Its consistency review is a determination of whether the state DOT is carrying out the plan that the state DOT itself specified. FHWA does not require that the TAMP be the focus of long-term preservation needs reporting, and does not certify it for that purpose, but there is nothing in the TAMP rules that would prevent it from being used in this way. Indeed, the TAMP framework is designed to reinforce best practices in this area, and many agencies are using it for exactly this purpose. If WSDOT were to develop a separate document that thoroughly describes its preservation needs, such a document would be duplicative of the TAMP. It would make sense to combine these highly inter-related reports.

7.4 Organizational integration

Having possession of a Bridge Management System with necessary data and planning metrics, constitutes the first phase of accurate long-term needs estimation. The next phase is the integration of this tool into all relevant routine business processes of the agency. AASHTO has published extensive guidance on this topic (Markow and Hyman 2009, Gordon et al 2011). The accuracy and relevance of an estimate of needs depends on assurance that, if provided with sufficient resources, the agency can and will deliver the expected transportation system performance implied by those needs, at minimum long-term cost. The following business processes are especially relevant:

Development of preservation budgets of sufficient size to minimize long-term cost. This entails the determination of which preservation strategies are most cost-effective from a life cycle perspective; forecasting of the most likely total magnitude of preservation work that can optimally be done within the ten-year horizon, taking deterioration and uncertainty into account; communicating this total magnitude to appropriate decision makers in the Executive and Legislative branches of state government in a timely way; and securing authority and resources to fully execute the preservation program. As a financial planning exercise, this process requires a determination of total expected preservation costs but does not necessarily require identification of the specific projects or bridges, especially for needs beyond the time frame of the Statewide Transportation Improvement Program. Evidence of this process would be reports documenting, for each significant treatment category, criteria for treatment selection, unit cost, estimated effect on condition, and estimation of the savings in life cycle cost under identified conditions; or equivalent capabilities within a Bridge Management System.

Effective incorporation of risk mitigation in the preservation budget. Infrastructure expenditures that increase the resilience of the network in the face of seismic risk, climate change, and other hazards are an integral part of the total investment necessary to sustain network performance over the long-term. This entails activities similar to those listed in the previous paragraph for preservation work and is properly a part of the same budgeting process.

Establishment of performance targets. The most cost-effective preservation activities are applied when infrastructure assets are in relatively good condition, and become infeasible if assets are allowed to deteriorate too far. When an asset is kept in condition that enables the most optimal preservation strategy to be applied, and condition does not by itself impair satisfaction of the asset's functional requirements, it is said to be in a State of Good Repair. An inventory of assets is in a State of Good Repair if the overall condition of the network is such that the agency is able to sustain a State of Good Repair on all individual assets where long-term continuation of service is justified. Federal rules require each state DOT to specify its desired State of Good Repair, the process for determining it, and the remedial strategy for closing any existing performance gaps (23 CFR 515.7(a)). Federal performance management rules also provide targets for aspects of performance other than condition (FHWA 2017).

Project development. The agency's ability to deliver the target levels of performance with the provided resources, starts with its ability to reliably identify and program all projects necessary to sustain the State of Good Repair. The process of identifying cost-effective preservation treatments should also provide criteria for recognizing opportunities to apply these treatments, and ensure that each project fully covers all preservation and risk mitigation needs in the most cost-effective manner.

Priority setting. Since funding is often inadequate to address all needs, agencies need a way to prioritize projects. If long-term costs are to be minimized, the priority-setting process requires a way to quantify long-term cost savings, including the user and non-user costs associated with site-based risk, so resources are applied first to the projects having the greatest benefit. In most agencies, priority-setting is conducted as a planning or finance function, which draws its necessary data on costs and benefits of projects from an engineering or maintenance function. As a result, evidence of an effective priority setting process includes not only a project cost estimate, but estimates of improvements in performance and life cycle cost savings. This is something that agencies expect as an essential function of their bridge management systems in support of routine decision making (Markow and Hyman 2009).

These processes depend on the credibility of planning metrics such as deterioration rates and unit costs. The credibility of these metrics, in turn, depends on an ongoing business process to measure these metrics, to assure their quality, and to adjust the planning process when the metrics are found to change. In best practice these metrics are not a matter of judgment or guesswork: they are tracked systematically using quantitative databases and statistical methods, comparable to what would be used for any other significant financial planning process where billions of dollars are at stake.

It is very common for agencies to encounter resistance to change when implementing improvements to asset management processes. Generally a considerable amount of training and senior leadership support is necessary in order to build a performance-oriented culture and establish accountability for improved practices. WSDOT is taking appropriate steps and should persist in its follow-through to implement the reforms it has identified.

The federal asset management rules (23 CFR 515.19) offer a suggested (though not mandatory) set of implementation steps which are elaborated in more detail in the AASHTO Transportation Asset Management Guide (Gordon et al 2011):

§ 515.19 Organizational integration of asset management.

(a) The purpose of this section is to describe how a State DOT may integrate asset management into its organizational mission, culture and capabilities at all levels. The activities described in paragraphs (b) through (d) of this section are not requirements.

(b) A State DOT should establish organizational strategic goals and include the goals in its organizational strategic implementation plans with an explanation as to how asset management will help it to achieve those goals.

(c) A State DOT should conduct a periodic self-assessment of the agency's capabilities to conduct asset management, as well as its current efforts in implementing an asset management plan. The self-assessment should consider, at a minimum, the adequacy of the State DOT's strategic goals and policies with respect to asset management, whether asset management is considered in the agency's planning and programming of resources, including development of the STIP; whether the agency is implementing appropriate program delivery processes, such as consideration of alternative project delivery mechanisms, effective program management, and cost tracking and estimating; and whether the agency is implementing adequate data collection and analysis policies to support an effective asset management program.

(d) Based on the results of the self-assessment, the State DOT should conduct a gap analysis to determine which areas of its asset management process require improvement. In conducting a gap analysis, the State DOT should:

> *(1) Determine the level of organizational performance effort needed to achieve the objectives of asset management;*
>
> *(2) Determine the performance gaps between the existing level of performance effort and the needed level of performance effort; and*
>
> *(3) Develop strategies to close the identified organizational performance gaps and define the period of time over which the gap is to be closed.*

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Appendix. WSDOT Progress Report on JLARC Recommendations

WSDOT's Plan to Improve Reliability of Long-Term Bridge Cost Estimates
January 2019 Update to 2017 JLARC Audit

JLARC Recommendation 14-5(1): Improve Bridge Estimates: WSDOT should use best practices to make its bridge estimates as reliable as its pavement estimates.			
Item	**Action Steps**	**Status**	**Progress**
A	Research asset management systems, and deterioration and life cycle cost models by conducting literature review and surveying peer states.	Completed 10/1/2017.	November 2017 Update • WSDOT surveyed AASHTO members in 2016 and Western Preservation Partnership states in 2017 about their bridge asset management systems. • Bridge Asset Management staff attended an AASHTO sponsored BrM conference in the fall of 2017 to network with other states and learn about bridge asset management software. January 2019 Update • Bridge Asset Management Engineer attended a FHWA sponsored Bridge Management Peer exchange in Salt Lake City Utah in April 2018 that included 13 western states. • Bridge Asset Management staff attended an AASHTO sponsored BrM conference in the fall of 2018 to network with other states and learn about bridge asset management software.
B	Using results from item A and staff knowledge, analyze historical bridge element data to model deterioration rates and life-cycle costs for some bridge elements.	In progress. Estimated completion 7/1/2020.	November 2017 Update • WSDOT performed in-house analysis of data to develop deterioration rates for some bridge elements, including bridge deck, and coating systems. • In the 2017-19 biennium, WSDOT, in partnership with Saint Martin's University, is conducting research to develop deterioration rate curves for reinforced concrete bridge columns specific to WSDOT bridges. • As of November 2017, Bridge and Structures staff is following up with states on their survey responses including inquiring about Oregon DOT's implementation progress of their Bridge Management System. January 2019 Update • Bridge and Structures staff met with Oregon DOT staff in 2017 to discuss their Bridge Management System implementation progress.

			• Utilized an Intern in 2018 to review inspection data and document details on many of the WSDOT Bridge Elements. • In the process of reviewing historical bridge inspection data for each of the 152 bridge element types to develop deterioration rates. • Future effort to review construction contract costs from past projects to develop costs for repair or replacement of each of the 152 bridge elements.
C	Evaluate options and availability for purchasing a bridge management system based on: (1) results from items A and B; (2) staff judgment of the pros and cons of the available software; and (3) cost.	Completed. 12/1/2018.	November 2017 Update • WSDOT obtain AASHTO's newest version of its generic bridge management software in January 2017. • The Bridge and Structures Office is hiring a new data specialist to evaluate the new software to determine if WSDOT should customize the generic software with Washington's bridge data or develop an in-house software package. WSDOT staff will interview for this position in December 2017. January 2019 Update • The Bridge and Structures Office hired two additional employees in 2018 to evaluate and implement the AASHTO BrM Bridge Management software. • WSDOT completed a Research project with Dye Management Group to summarize a plan to implement a bridge management system. • Made periodic updates to AASHTO BrM to stay current with latest version releases. Renewed our BrM license for the coming fiscal year. • Working to establish a meeting between Bentley (AASHTO BrM vendor) and WSDOT to further discuss full BrM implementation.
D	Develop a list of bridges most vulnerable to natural and man-made hazards and report progress on reducing risk to these bridges.	Completed 8/31/2015.	November 2017 Update Bridge preservation web page has the statewide and regional bridge needs lists based upon preservation category. The Bridge Office updates annually and on demand by request. January 2019 Update

			• Bridge Office has published a report on the cost to raise the vertical clearance on its Steel Truss bridges (WA_RD 876.1). • WSDOT completed a risk assessment required by the FHWA for the Transportation Asset Management plan. • Bridge Risk lists will be updated each biennium as part of WSDOT's 10 year Asset Management Plan.

JLARC Recommendation 14-5(2): WSDOT and OFM should develop a process to improve stakeholders' confidence in its highway estimates.			
Item	**Action Steps**	**Status**	**Progress**
A	Thoroughly document long-term need estimates including key assumptions and uncertainties.	In progress. Estimated completion 7/1/2019	November 2017 Update • 10-year needs estimate developed and summarized annually (every August) in the Gray Notebook. WSDOT published the most current bridges annual report in June 2017 (GNB edition 66). • The Bridge and Structures Office will document key assumptions that underlay these estimates as they develop bridge management system specifications. January 2019 Update • WSDOT published the most current bridge needs in the GNB edition 70 report from the quarter ending in June 2018. • Assumptions on 10 year needs will be documented as part of the FHWA required Transportation Asset Management Plan by 7/1/2019.
B	Communicate with legislative stakeholders routinely about estimates.	Completed 11/7/2017. .	November 2017 Update • The Bridge and Structure Engineer presented plan to the Joint Transportation Committee at its November 2015 meeting. WSDOT will provide future plan updates as requested. In coordination with OFM, every biennium update the Chairs of the House Senate and Joint Transportation Committees with WSDOT's long-term bridge preservation cost estimates, which will help inform legislators how much bridge preservation work can be accomplished at a given funding level.

C	Ensure a robust internal and external review process for long-term preservation estimates that protects them from being influenced by outside pressures.	Completed.	November 2017 Update **Estimate Review**: The Bridge Office and CPDM will continue to collaboratively develop long-term preservation estimates. Specifically: 1. Bridge Asset Management group reviews bridge condition reports and estimates when bridges need to be painted, repaired, and/or decks need replacement. 2. Bridge Asset Management group along with CPDM price the future cost of the preservation work to derive a final list. 3. The Bridge Office annually updates this list. Other lists are developed on demand by those wanting a different time scale or type of repair class. These estimates are prepared independently by WSDOT subject matter experts and are available for use in legislative budget decisions.