NCHRP 08-36, Task 118
Performance Measures for Infrastructure Preservation

Requested by:

American Association of State Highway and Transportation Officials (AASHTO)
Standing Committee on Planning

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final report

NCHRP 8-36 Task 118: Performance Measures for Infrastructure Preservation

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List of Acronyms

AASHTO	American Association of State Highway and Transportation Officials
AC	asphalt concrete
ASI	Asset Sustainability Index
ASTM	American Society for Testing and Materials
BCA	benefit/cost analysis
Caltrans	California DOT
CORE	commonly recognized, for bridge element inspection data
CRCP	continuously reinforced concrete pavement
DOT	Department of Transportation
EEA	engineering/economic analysis
EIA	economic impact analysis
ESAL	equivalent single axle load
FCI	functional condition index
FHWA	Federal Highway Administration
GASB	Governmental Accounting Standards Board
GRP	gross regional product
HERS	Highway Economic Requirements System
HERS-ST	Highway Economic Requirements System, state version
HI	health index
HPMS	Highway Performance Monitoring System
IRI	International Roughness Index
JPCP	jointed plain concrete pavement
KDOT	Kansas DOT
LCCA	life-cycle cost analysis
LOS	level of service
M&O	maintenance and operations
MAP-21	Moving Ahead for Progress in the 21st Century
MoDOT	Missouri DOT
MPO	metropolitan planning organizations

MTF	Michigan's Transportation Fund
NBI	National Bridge Inventory
NBIAS	National Bridge Investment Analysis System
NHPP	National Highway Performance Program
NHS	National Highway System
NQI	National Quality Initiative
NCHRP	National Cooperative Highway Research Program
PCC	Portland Cement Concrete
PCI	pavement condition index
PHT	Pavement Health Track
PM	preventative maintenance
PMS	Pavement Management System
RSL	Remaining Service Life
RWD	rolling wheel deflectometer
SD	structural deficiency
SHRP	Strategic Highway Research Program
SPM	systematic preventive maintenance
TAMC	Transportation Asset Management Council (Michigan)
VE	value engineering

Executive Summary

Over the past 10 years a tremendous amount of research and best practice summaries have focused on performance measures, data requirements, analytic tools and approaches for integrating measures into a performance management process that supports performance-based decision-making at both the state and regional levels.

There continues to be a challenge in making the case for timely and cost-effective preservation activities encompassing both reactive and preventive maintenance as well as capital investments. Because these activities, and particularly preventive maintenance actions, often should occur when a facility seems to be in a "state of good repair" to nonprofessionals, the challenge of demonstrating and communicating the value of the right sequence of actions over a facility's life cycle can be difficult. In times of significantly constrained resources, delaying preservation activities is often attractive in the short term in order to fund other programs (e.g., safety, mobility, etc.) even though the long-term costs and consequences of such a strategy can be significant. There currently is no "golden measure" that is likely to resolve all of the difficulties in properly evaluating and communicating preservation needs. Every transportation agency is different. Each faces unique challenges in measuring performance and preserving their transportation system.

Three key definitions support understanding of this document. Firstly, the National Cooperative Highway Research Program (NCHRP) Report 551: *Performance Measures and Targets for Transportation Asset Management* defines preservation as follows:

> *Preservation encompasses work to extend the life of existing facilities (and associated hardware and equipment) and to repair damage that impedes mobility or safety. The purpose of system preservation is to retain the existing value of an asset and its ability to perform as designed. Preservation counters the wear and tear of physical infrastructure that occurs over time due to traffic loading, climate, crashes, and aging. It is accomplished through both capital projects and maintenance actions.*

Secondly, state of good repair (SOGR), as defined by Secretary Mary Peters in a July 25, 2008 letter to Congress on this topic, is a condition in which the existing physical assets, both individually and as a system (a) are functioning as designed within their useful service life, (b) are sustained through regular maintenance and replacement programs. SOGR represents just one element of a comprehensive capital investment program that also addresses system capacity and performance. And thirdly, according to the AASHTO Subcommittee on Maintenance, preventive maintenance is a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the

functional condition of the system (without substantially increasing structural capacity). The Federal Highway Administration's (FHWA) *Bridge Preservation Guide* contains additional helpful definitions.

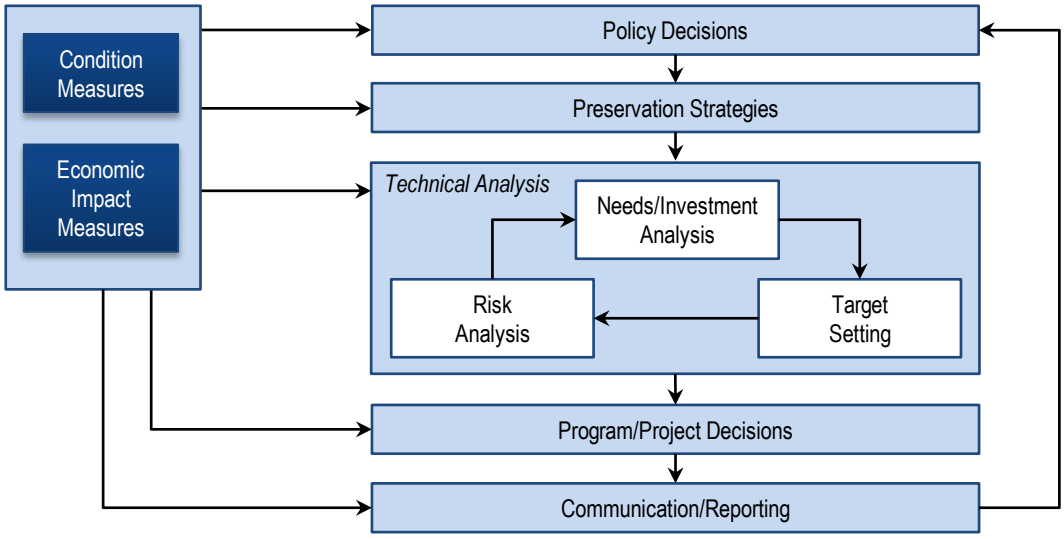
There are several critical interconnected elements that make up effective performance-based preservation programming. The framework developed to showcase all of these elements begins with the high-level policy decisions that shape the actions of agencies and ends with the determination and communication of results. As demonstrated in the diagram, condition and economic impact measures provide guidance in these decisions and every decision along the way to successful preservation.

This Report includes a Best Practices Review and Summary Section where several of these key elements are explored in greater detail, including:

- Condition-based measures for preservation;
- Economic impact measures;
- Need/investment analysis and measures;
- Target setting and measures;
- Risk analysis and measures; and
- Communication/reporting of measures.

Significant emphasis is placed on the development and application of preservation measures, the focus of this research. The table below provides a summary of the reviewed preservation measures.

Framework for Performance-Based Preservation Programming



Summary of Reviewed Measures

Measure Type	Example	Outcome/Usefulness of Measures
Direct Condition Measures	• IRI for pavements • Sufficiency rating for bridges • NBI condition ratings	Provides understanding of system condition and performance, provides baseline for additional data-driven analysis
Remaining Service Life (RSL)	• RSL for pavements, reported in years until replacement is needed • RSL for bridges, usually a function of age and condition, reported in years until replacement is needed	Makes link to asset performance, provides understanding of future investment needs
Customer-Driven and User Perspective	• Customer survey and/or outreach results	Can be tied to outputs (such as miles of pavement repaved) to quantify cause and effect, improves accountability and targeted investment towards elements the customers find important
Life-Cycle Cost	• Remaining service life • Life-cycle cost analysis • Life expectancy analysis	Supports identifying the most cost-effective strategy (e.g., replacement, maintenance/preservation activities) among alternatives
Avoided Cost	• Relationship between asset level of service, required maintenance work, and cost consequences of delayed maintenance • Cost of poor pavement condition in terms of vehicle operating costs and costs to restore pavement to good condition	Describes the implications for implementing projects or programs, quantify the impacts of deviating from a least life-cycle cost approach
Sustainability Index	• Asset sustainability index, a high-level composite assessment of asset condition for pavement, bridge, and maintenance	Provides an indicator of the gap or surplus between need and investment, helps indicate the degree to which investment is adequate or inadequate
Benefit/Cost/ Performance-Cost	• Utility function as a measure of benefit • Budget scenarios and effects on infrastructure condition • Benefit cost to assess asset investment options	Supports choosing between alternatives, testing feasibility of options, comparing programming scenarios
Economic Development Impact	• Employment is widely used and understood • Personal income • Property values	Illustrates the experience by users as well as transportation's contribution to the general economy

Some of these measures will satisfy several of the elements found in the framework for performance-based preservation programming. For example, simple condition measures can effectively support needs/investment analysis,

target setting, and risk analysis. They are easy to communicate with the public. However, they do not always support the best programming decisions as they provide no insight into potential future performance.

Measures such as avoided cost and life-cycle cost can better support forward-looking preservation decisions, but require analysis resources and they are difficult to communicate. Some measures, such as economic development impacts, can tell a good story but are difficult to use as a base for comparing alternatives, being difficult to quantify for smaller-scale decisions.

Given that no one measure satisfies all of the agency needs, agencies can find value in coupling measure types. For example, combining simple condition measures with benefit/cost/performance-cost measures will give an agency good capacity in nearly all areas. Measures that performance well in needs/ investment analysis (such as remaining service life or an asset sustainability index) can be supplemented with measures that are useful in communicating the value of preservation (such as customer satisfaction or economic development impacts).

This Report provides a roadmap with some guidance on highest priorities for agencies to successfully apply performance-based preservation programming. The roadmap is broken into three tiers. Every transportation agency has a different level of maturity in data collection and analysis, asset management, performance management, target setting, and other activities which support performance-based preservation programming. The tiers are intended to provide guidance to those agencies with limited maturity, those with moderate maturity, and those with significant maturity in performance-based preservation programming.

Agencies with Limited Maturity in Performance-Based Preservation Programming

This tier covers agencies that may be new to performance management and asset management. They have limited comprehensive data on asset condition and inventory available. They rely on historical funding allocations for maintenance and preservation and address maintenance needs on a "worst-first" basis. They lack significant tools, resources, or capacity to complete sophisticated data-driven decision-making.

Agencies with limited maturity in performance-based preservation programming should:

- **Strengthen asset inventory and condition data resources.** These data will drive all subsequent analysis and decision-making.
- **Compile and report condition measures for major assets.** With a comprehensive condition inventory of major assets such as pavement and bridges, agencies can compile system-level statistics. This can make the case for preservation and set a foundation for target setting.

- **Set targets based on system-level asset condition.** Target setting can link preservation and maintenance activities to future results and provide achievable goals to reach for. Agencies can formally adopt and publicize targets or chose to only internally and/or informally recognize targets. The important step is linking preservation activities to future asset conditions. MAP-21 contains new requirements for target setting.
- **Track expenditures and results for communication with the public and decision-makers.** Once agencies have asset inventory and condition data, they can strengthen their understanding of how investment affects condition. Over time this will help agencies develop a cause-and-effect story of preservation.

Agencies with Moderate Maturity in Performance-Based Preservation Programming

This tier covers agencies with some experience in performance management and asset management. They have comprehensive data on asset condition and inventory available. They factor performance into decision-making and resource allocation, though data may not fully drive this process. They have some more sophisticated analysis methods and tools at their disposal.

Agencies with moderate maturity in performance-based preservation programming should:

- **Conduct basic needs/investment analyses on major assets.** Undertaking formal analyses can help support need-based funding allocation. Agencies can better understand their preservation needs and be able to communicate them to stakeholders. Agencies can start with simple preservation performance measures such as an asset sustainability index.
- **Use benefit/cost and/or performance-cost measures to support preservation programming decisions.** Agencies can put preservation performance measures to work for them by linking decisions to invest (or disinvest) in preservation with the resulting impacts on benefits and performance. These analyses can vary from basic performance-cost relationships (*if the agency invests $X it can expect to see assets perform at level Y*) to sophisticated benefit/cost analyses which capture detailed user cost impacts, indirect costs, etc.
- **Establish some common metrics to better understand program tradeoffs.** Agencies can benefit from using data to support cross resource asset allocation. The simplest way to achieve this is to monetize the impacts of investment using benefit/cost or performance-cost estimates. Agencies can then review programming decisions across asset types and ensure they are getting the best possible performance for their investment and are limiting life-cycle costs for assets.
- **Incorporate least life-cycle cost into preservation decisions.** Agencies can assess the least life-cycle cost options preservation of major assets and follow

the guidance to minimize costs. Agencies can share the analyses driving these decisions to make the case for proactive investment in preservation and maintenance rather than allowing infrastructure to deteriorate.

- **Communicate using economic terms.** Agencies can make the case for preservation by linking investment to economic health and development and support for local businesses and jobs.

Agencies with Significant Maturity in Performance-Based Preservation Programming

This tier covers agencies with significant experience in performance management and asset management. They have advanced data, capacities, and resources available to support data-driven decision-making and funding allocation. Agencies in this tier are likely actively pursuing strategies to make the case for preservation. They have probably encountered difficulty in communicating the message to stakeholders and the public and are searching for better ways to frame the message and tell the story of the value of preservation.

Agencies with significant maturity in performance-based preservation programming should:

- **Support all performance-based preservation programming decisions with detailed data and analysis.** A fully mature agency has the resources to implement and maintain a clearly understood mechanism for preservation decision-making. Each decision can be data-driven and defensible. This can lead to a responsive, transparent, forward-looking program. Achieving this difficult goal requires use of multiple performance measures and measure types.
- **Design a preservation program to reach policy goals, fulfill needs, support target achievement, minimize risk, achieve least life-cycle cost, and communicate the value of preservation.** Decisions can provide value in one or many of the key applications for preservation programming. Agencies can review their activities in preservation programming to ensure they are providing value in as many areas as possible. Some agencies may find the framework for performance-based preservation programming in this Report helpful. They can review the processes linked to preservation programming and identify strengths and weaknesses.
- **Supplement the story of preservation with additional measures such as avoided cost, customer satisfaction surveys, targeted benefit/cost analyses, and economic development impacts.** Agencies need to choose performance measures which support their priorities. There is no single set of measures that can be recommended for every agency given the diverse challenges each agency faces. It is clear, however, that there are many opportunities for sophisticated measures to support performance-based preservation programming. Agencies can research the more difficult measures and use them to supplement the story of preservation.

The framework for performance-based preservation programming identifies several necessary processes. The research in this Report covers the measures which can support and shape these processes. Some areas, such as major asset condition measures, have a substantial body of research behind them. Other areas would benefit from additional research:

- The use of the avoided cost measure and its communication with the decision-makers and the public has not been explored extensively in the literature. The use of avoided cost appears to be largely limited to "making the case" for preservation. This is valuable, but it would be beneficial to see a program where avoided cost is driving decision-making and is a clearly communicated element of major program decisions.
- Benefit/cost is largely applied for project selection and there are limited examples of a preservation-specific application. Greater research can be explored on the use of benefit/cost analysis specific to preservation programming.
- Target-setting specifically for asset preservation can be further explored, particularly within the context of MAP-21 requirements and as a means of cross-asset trade-off analysis.
- A next phase of this research could present the framework to agencies, and garner agency responses to the framework for performance-based preservation programming to learn whether the framework fully captured their processes and needs related to preservation. Agencies may be able to add valuable insight about which measures are effective in serving the different processes.
- A more refined maturity model and self-assessment tool for agencies, linked to the recommended steps for improvement for each element, can be a means of practically implementing this research.

1.0 Introduction

Over the past 10 years a tremendous amount of research and best practice summaries have focused on performance measures, data requirements, analytic tools and approaches for integrating measures into a performance management process that supports performance-based decision-making at both the state and metropolitan region levels. The recent enactment of the Moving Ahead for Progress in the 21st Century (MAP-21) legislation reinforces the commitment to create a more performance-based Federal program though many states and metropolitan planning organizations (MPO) already have taken significant steps to move in this direction.

However, despite all of the previous work focused on performance measures and performance management, there continues to be a challenge in making the case for timely and cost-effective preservation activities encompassing both reactive and preventive maintenance as well as capital investments. Because these activities, and particularly preventive maintenance actions, often should occur when a facility seems to be in a "state of good repair" to nonprofessionals, the challenge of demonstrating and communicating the value of the right sequence of actions over a facility's life cycle can be difficult. In times of significantly constrained resources, delaying preservation activities is often attractive in the short term in order to fund other programs (e.g., safety, mobility, etc.) even though the long-term costs and consequences of such a strategy can be significant.

There currently is no "golden measure" that is likely to resolve all of the difficulties in properly evaluating and communicating preservation needs. While this research project looks at available measures, it also seeks to address an important gap in the measurement of preservation activities: **a framework for evaluating preservation policies and their impacts, tied to a strategy for communicating the results effectively to senior management, elected officials and the general public**. This research focuses on defining such a framework, and then reviewing preservation measures best practices within the context of whether they successfully address all the needs of performance-based preservation programming.

Three key definitions support understanding of this document. Firstly, the National Cooperative Highway Research Program (NCHRP) Report 551: *Performance Measures and Targets for Transportation Asset Management* defines preservation as follows:

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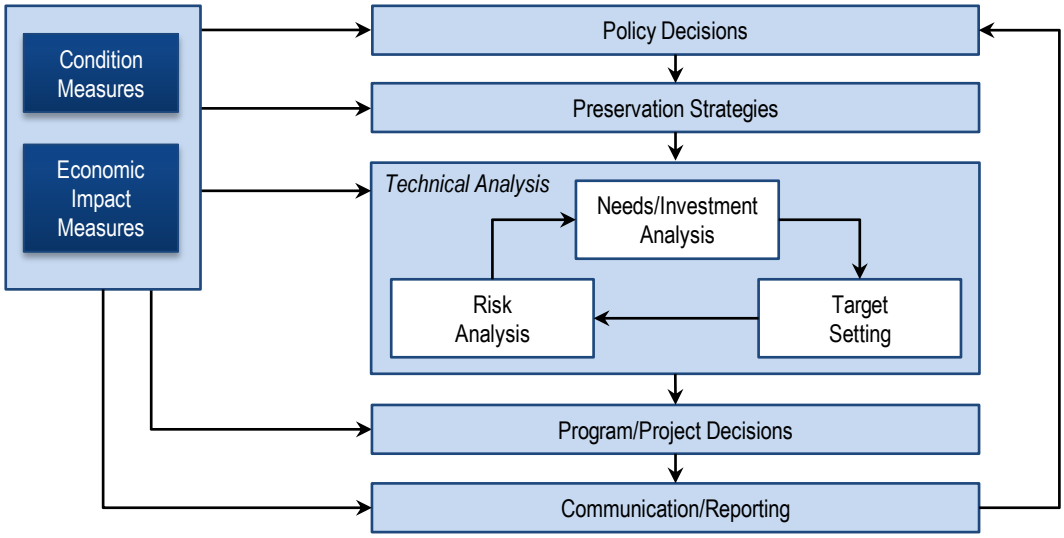
2.0 Framework for Performance-Based Preservation Programming

There are several critical interconnected elements that make up effective performance-based preservation programming. The framework developed to showcase all of these elements begins with the high-level policy decisions that shape the actions of agencies and ends with the determination and communication of results. As demonstrated in Figure 2.1, condition and economic impact measures provide guidance in these decisions and every decision along the way to successful preservation.

Figure 2.1 Framework for Performance-Based Preservation Programming



One way to think through the framework is to look at a single element, and imagine a performance-based preservation program in which this element was missing. For example, if there were no condition measures, there would be no way of identifying where work was needed. If there was no target setting, each decision would be made in isolation, with no consideration of the overall health of the system.

Each of the elements is summarized briefly below, beginning with the measures on the left-hand side of the framework, and then continuing down the center of the framework, following the typical path a preservation decision-maker would follow.

Condition Measures

Any consideration of transportation infrastructure preservation actions requires some understanding of the infrastructure's current condition. Whether formalized or not, decision-makers have standards for the system and need mechanisms to determine where these standards are being met and where they fall short. Condition measures can include directly collected data such as the International Roughness Index (IRI) and bridge condition ratings or derived measures such as customer satisfaction surveys.

Economic Impact Measures

Decision-making about transportation infrastructure preservation actions requires some understanding of the impacts of actions. Economic impact measures are needed to direct actions in valuable directions. These measures tie in the costs of preservation in various ways. Measures can include least lifecycle cost estimations, user and agency costs, avoided costs, replacement costs, and metrics to address the long-term performance of highway assets based on expected expenditure levels, such as the asset sustainability index. Economic measures build on a foundation of condition measures and essentially translate condition measures into impacts that are broader and more understandable to decision-makers and the public.

For purposes of this framework, economic impact measures are not limited to impact on the economy, but include measures of the impact of expenditure on performance and benefit provided to users.

Policy Decisions

All preservation activities are first and foremost shaped by the high-level policy decisions and values of an agency. These include broad decisions about what assets to preserve and what transportation users and uses to prioritize. For example, an agency may determine support for goods movement is a priority and will take action to develop and preserve a roadway network that can support heavy truck travel. Agencies may also face policy rules that require geographic distribution of preservation expenditures.

Preservation Strategies

A set of strategies is needed to identify available preservation actions. This can be thought of as a "menu" for preservation projects, and might include activities such as crack sealing, surface sealing, bridge washing, concrete sealing, as well as more capital-intensive strategies such as pavement resurfacing, rehabilitation and bridge element replacement. An agency looking at its options in preservation strategies would also consider its capacity to deliver these actions, either through their own resources or through contracting mechanisms. The focus of least life-cycle cost analysis is identifying the sequence and timing of preservation strategies that will meet objectives for the minimum cost.

Needs/Investment Analysis

Once a set of available preservation strategies is identified, a comprehensive preservation program requires analysis of system needs. Agencies look at the impact of preservation and maintenance investment on performance. They use deterioration models and estimation mechanisms to identify the impacts of taking action to preserve their assets or of channeling their limited funds to other options, such as new capacity projects. In considering needs, agencies also look at the future demands on infrastructure and required future performance. These analyses require effective preservation measures.

Target Setting

Closely linked with a needs analysis, agencies set condition and performance targets to ensure they are using available resources in the most effective manner in responding to the needs of their customers and achieving broad agency goals and commitments. This process is often informal (even taking actions to avoid negative consequences such as complaints from drivers is target setting) but is more frequently being employed as part of comprehensive asset management. System condition targets prevent project decisions from being made entirely in isolation. Targets rely on preservation measures to identify the objective performance and to indicate where this state is achieved or lacking. Target setting often represents an effective way to evaluate the implications of different cross-asset allocation strategies.

Risk Analysis

Risk analysis is a component of asset management decisions with increasing emphasis from Federal legislation such as MAP-21. Agencies need to assess potential risks and how their actions can mitigate these risks. Risks affecting preservation activities can range from the agency level (funding shortfalls, increasing construction cost inputs, declining political capital) to the program level (loss of preservation funding in favor of capacity projects, natural events with broad impacts on infrastructure health) to the asset or project level (accelerated deterioration due to natural events, security). Risk analysis relies on preservation measures to quantify the potential impacts of an event and the effect on performance. Risk analysis supports needs assessment and target setting.

Program/Project Decisions

Following the analysis portion of the framework, an agency must then make program and project-level decisions. The larger decision is how to allocate funding between program areas, which is part of a larger long-range planning process consisting of high level goals/objectives; performance measures; target setting; resource allocation; and monitoring performance. This performance based process is assumed to occur in the "policy decisions" box above. The asset preservation contributions to that long-range planning process occur through the subsequent boxes in the diagram. At the same time, those "policy decisions"

trickle down to the rest of the boxes and provide the framework of priorities and resources within which the more detailed asset preservation decisions must occur.

Within program areas, such as bridge and pavement preservation and maintenance programs, agencies then decide a specific program of projects, taking advantage of available resources to address the system needs, reach targets, and mitigate risks.

Communication/Reporting

Once the decisions are made and projects are implemented, agencies review the results. This serves several purposes. Agencies need to communicate the effectiveness of preservation activities, making the case for continued investment in preservation. Agencies can report results to other stakeholders, fulfilling requirements. Agencies can feed results back into decision-making. This might include making changes to policy-level decisions, adjusting preservation strategies, or revising analyses to reflect the latest real-world outcomes. The value of preservation measures is partially determined by how effectively they can be used to communicate preservation needs or progress towards preservation or condition targets.

In the Best Practices Review and Summary Section, several of these key elements are explored in greater detail, including:

- Condition-based measures for preservation;
- Economic impact measures;
- Need/investment analysis and measures;
- Target setting and measures;
- Risk analysis and measures; and
- Communication/reporting of measures.

3.0 Best Practices Review and Summary

This review covers existing and proposed preservation measures and the best practices for application of measures in performance-based preservation programming. The section is divided into subsections which follow key elements of the framework for performance-based preservation programming, introduced and described in Section 2.0.

The literature review for this study examined a broad base of research. Reviewed documents are noted in Section 5: Bibliography. This review was not an exhaustive search of the literature, but was targeted on existing studies that had summarized state of the practice in preservation measures and their application.

From these resources, some best practices were identified to serve as models for application of preservation measures in various capacities such as target setting and risk analysis. Where existing best practice research was not available, researchers looked for any available examples of preservation measure applications.

3.1 CONDITION-BASED MEASURES FOR PRESERVATION

How Condition Measures Are Applied to Support Preservation Decision-Making

Condition measures support effective decision-making about preservation, needs assessment, target setting, risk analysis, and communication of results. Understanding the current condition of an asset informs any consideration of transportation preservation actions. Decision-makers have formal or informal standards for the system and need processes to evaluate where standards are and are not met. Condition measures can include directly collected data, such as the IRI and bridge condition ratings, or derived measures such as remaining service life or customer satisfaction surveys.

Table 3.1 summarizes a few types of condition measures.

Condition measures have varying levels of maturity and effectiveness. Collecting condition data always involves a tradeoff. Agencies can do detailed and costly assessments of their assets, but the data collection burden is significant. With collection of simple asset condition measures, agencies can have a high-level understanding of asset condition, but lack detailed

understanding of what treatments may be required, when they will be required, and at what cost.

Based on a review of maintenance quality assurance programs, the NCHRP Report *Best Practices in Performance Measurement for Highway Maintenance and Preservation* concluded that condition measures frequently can be categorized as pass/fail, level of service, or a hybrid of the two. The Report highlighted the importance of data consistency and confidence in data for them to be effective drivers of decision-making.

Table 3.1 Summary of Condition-Based Measures

Measure Type	Example	Outcome/Usefulness of Measures
Direct Condition Measures	• IRI for pavements • Sufficiency rating for bridges • NBI condition ratings	Provides understanding of system condition and performance, provides baseline for additional data-driven analysis
Remaining Service Life (RSL)	• RSL for pavements, reported in years until replacement is needed • RSL for bridges, usually a function of age and condition, reported in years until replacement is needed	Makes link to asset performance, provides understanding of future investment needs
Customer-Driven and User Perspective	• Customer survey and/or outreach results	Can be tied to outputs (such as miles of pavement repaved) to quantify cause and effect, improves accountability and targeted investment towards elements the customers find important

One effective model for understanding various asset condition measures and their level of maturity comes from research by the American Association of State Highway and Transportation Officials (AASHTO) and the FHWA.

As documented in NCHRP Project 20-24 (37)G and FHWA's pilot study – Improving FHWA's Ability to Assess Highway Infrastructure Health, condition measures can be organized into tiers based on their level of maturity. The tiers are defined as:

- Tier 1 measures are considered complete or nearly complete and ready for use at the national level. They meet the criteria of having:
  - General consensus on the measure's definition,
  - A common or centralized approach to data collection in place, and
  - Established availability of consistent data.
- Tier 2 measures meet one or two of Tier 1's criteria, but require further work before deployment.

- Tier 3 measures are generally still in the proposal stage and require further work before deployment.

Table 3.2 summarizes these pavement and bridge condition measures by tier.

Table 3.2 Pavement and Bridge Condition Measures

Condition Measure	Tier 1 – Ready for Deployment	Tier 2 – Additional Development Required	Tier 3 – Proposal Stage
Pavement Condition	International Roughness Index (IRI)	Functional Adequacy Based on Highway Performance Monitoring System (HPMS) Distress Data	Structural Condition Based on Tier 2 Plus Deflection Data; and RSL
Bridge Condition	Structural Deficiency (SD)	Structural Adequacy Based on National Bridge Inventory (NBI) Ratings	Detailed element-level inspection data

Source: NCHRP Project 20-24 (37)G and Improving FHWA's Ability to Assess Highway Infrastructure Health.

Condition Measures for Pavements

International Roughness Index (IRI)

IRI is widely recognized as an indicator of road smoothness and is defined as the property of a roadway's longitudinal profile. The scale starts at zero for a road with no roughness and increase proportionally with increase in road roughness. IRI is typically measured by inches per mile or meter per kilometer.

The IRI is a Tier 1 condition measure as it is widely utilized. State agencies are required to report IRI to the Highway Performance Monitoring System (HPMS) for all National Highway System (NHS) roadways. Pavement data collection protocols and analysis for IRI are somewhat consistent, although there is variability between the State DOTs. To achieve nationwide consistency and standardization in measuring and reporting IRI data, FHWA requires state agencies to follow HPMS Field Manual guidelines.

State agencies typically collect and store IRI data in their Pavement Management System (PMS) databases for decision-making on project priority, funding, and program development. A proposed measure (from the NCHRP 20-24(37)G Technical Guidance Report) is the percent of lane-miles on the NHS classified as "good," "fair," and "poor" as determined by thresholds for the IRI. The measure is first calculated by determining the IRI value for all roads on the NHS. Using thresholds as defined by FHWA, agencies identify the lane-miles classified as "good" (IRI<95), "fair" (IRI between 95 and 170), and "poor" (IRI>170), and divide the total lane-miles to get the percent of pavement within each category.

The biggest disadvantage of using IRI as a condition measure is that it does not fully represent the pavement condition. For instance, IRI indicates very little about the pavement structure's ability to withstand traffic loadings.

Pavement Condition Index (PCI)

The PCI is an indicator of the pavement's structural integrity and surface operational condition. PCI is a numerical rating of the pavement condition that ranges from 0 to 100 with 0 being the worst possible condition and 100 being the best possible condition. The distress information obtained as part of the PCI condition survey provides insight into the causes of distress and whether it is related to load or climate. The use of PCI for airfields, roads, and parking lots has received wide acceptance and has been formally adopted as standard procedure by many Federal, state, and local agencies nationwide. It is considered a Tier 2 measure rather than a Tier 1 as it is not universally collected by agencies.

The PCI method has many advantages. The PCI method has been standardized; the American Society for Testing and Materials (ASTM) standards D6433 and D5340 outline the procedure for roadways and airfields, respectively. Table 3.3 presents these standards' thresholds. The PCI method also provides a comprehensive approach for distress measurement and condition evaluation with a comprehensive list of distress types and their definitions of severity and extent levels. Table 3.3 provides a list of PCI method distress types for both asphalt concrete (AC) and Portland Cement Concrete (PCC) pavements.

Table 3.3 PCI Thresholds

Category	PCI Threshold
Good	>85
Satisfactory	71-85
Fair	56-70
Poor	41-55
Very Poor	26-40
Serious	11-25
Failed	<11

Source: Improving FHWA's Ability to Assess Highway Infrastructure Health.

The disadvantage of the PCI is that it is data-intensive and requires collection of 19 distresses on AC pavements and another 19 distresses on PCC pavements (see Table 3.4). It is difficult for agencies to collect these data on high-speed corridors with a high accuracy without interrupting traffic flow. Current "automated" multifunction network data collection vehicles require significant manual interpretation of the pavement images to generate a PCI.

Table 3.4 List of Distresses in the PCI Method

AC Pavements	PCC Pavements
Alligator Cracking	Blowup/Buckling
Bleeding	Corner Break
Block Cracking	Divided Slab
Corrugation	Durability Crack
Depression	Faulting
Edge Cracking	Joint Seal Damage
Joint Reflection Cracking	Lane/shoulder
Lane Shoulder Drop Off	Linear Cracking
Longitudinal and Transverse Cracking	Patching Large
Patching and Utility Cut Patching	Patching Small
Polished Aggregate	Polished Aggregate
Pot Holes	Popouts
Railroad Crossing	Pumping
Rutting	Punchout
Shoving	Railroad Crossing
Slippage Cracking	Scaling
Swell	Shrinkage Cracks
Weathering/Raveling	Spalling (Joint)
	Spalling (Corner)

Source: NCHRP 20-24(37)G Technical Guidance Report.

PCI's other disadvantage is that it does not necessarily correlate with roughness. It may be necessary to combine the PCI and IRI conditions to capture the information each provides about the pavement condition.

There are also several standardization issues with applying the PCI. For instance, state agencies vary on the distress types collected for different pavement types. The NCHRP 20-24(37)G Technical Guidance Report found that most states collect only specific distress types, whereas fewer states include an extended set of distress types. The most prominent distress types among states include load-related and nonload-related cracking, rutting, faulting, punchouts, patching, raveling, and joint spalling.

Combination of Pavement Roughness and Selected Distresses

A combined condition measure of HPMS data would reflect a more complete picture of pavement condition than a standard pavement condition measure such as IRI or PCI could indicate. States have adopted various composite condition indices to aggregate various distresses in defining the pavement condition. This allows states to get a more detailed understanding of the nature of the preservation need and its cause, and therefore to better target maintenance and repair strategies. This type of measure is considered a Tier 2 measure. As Table 3.5 shows, states use different approaches in aggregating various distresses,

in computing weighted distress indices, and in treating distress and rideability/ roughness indices together for determining the overall pavement condition.

Table 3.5 Pavement Condition Indices Used by State Agencies

Index	States
No index	Maryland, Alaska, Alabama, Arkansas, Connecticut
Pavement Condition Rating (PCR)	California, Georgia, Idaho, Mississippi, North Carolina, Ohio, Maine
Pavement Distress Index (PDI)	Arizona, Wisconsin
Pavement Condition Index (PCI)	Iowa, New York, Vermont, Hawaii
Pavement Structural Condition (PSC)	Washington State
Pavement Serviceability Rating (PSR)	Wyoming
PMS Category Rating	Nevada
Condition Index	Kentucky
Distress Index (DI)	Michigan
Distress Score (DS)	Texas
Overall Index	Oregon
Overall Condition Index (OCI)	Utah
Overall Pavement Index (OPI)	Colorado, Montana, Pennsylvania
Condition Rating Survey (CRS)	Illinois
Surface Distress Index (SDI)	New Jersey
Surface Condition Index (SCI)	South Dakota
Pavement Quality Index	Minnesota, Tennessee, South Carolina
Critical Condition Index	Virginia
Surface Rating (SR) and Dominant Distress Measure	New York State
Remaining Service Life	Colorado, Michigan, Oregon
Cracking Index, Rutting Index	Florida
Nebraska Serviceability Index (NSI)	Nebraska
Separate Cracking Index	Idaho
PACES Rating	Georgia

Source: NCHRP 20-24(37)G Technical Guidance Report.

The pilot study – Improving FHWA's Ability to Assess Highway Infrastructure Health – developed a prototype functional condition index (FCI), which combined HPMS performance data to represent a pavement's functional condition. For asphalt surfaced pavements, this index is calculated as a function of IRI, rut depth, percent cracking and crack length. For jointed plain concrete pavement (JPCP), the FCI is a function of IRI, faulting and percent cracking. For continuously reinforced concrete pavement (CRCP), the FCI is a function of IRI and faulting.

The FCI's advantage is that it considers more than one aspect of pavement condition. Establishing condition based on roughness, rutting and cracking for asphalt pavements will provide a fairly comprehensive review of a pavement's functional condition. Similarly, incorporating roughness, faulting and cracking for concrete pavements also covers most aspects of the pavement functional condition.

Structural Condition Based on Tier 2 Plus Deflection Data

To provide a comprehensive condition assessment, the pilot study – Improving FHWA's Ability to Assess Highway Infrastructure Health, Better Road – proposed a measure that combined pavement roughness, selected distresses, and RWD-based structural capacity. This measure is a Tier 3 measure, requiring significant work to be widely accepted and collected. The pilot study collected pavement structural capacity information along a three-state (South Dakota, Minnesota, and Wisconsin) pilot study corridor using FHWA's Rolling Wheel Deflectometer (RWD). The RWD as shown in Figure 3.1 is a continuous deflection devise that evaluates pavement structural pavement condition at highway speeds. The study used established condition thresholds based on normalized deflection (D_0 - maximum pavement deflection under the applied load), as shown in Table 3.6.

Figure 3.1 Rolling Wheel Deflectometer Used for Structural evaluation

Source: Improving FHWA's Ability to Assess Highway Infrastructure Health.

Table 3.6 Deflection Thresholds

Category	D_0 Threshold
Good	≤ 6
Fair	$6 < D_0 \leq 10$
Poor	> 10

Source: Improving FHWA's Ability to Assess Highway Infrastructure Health.

This type of analysis would provide the most complete picture of the pavement condition with an indication of whether intervention is required for a functional issue or for a structural issue. The pilot study combined the previously discussed FCI with D_0 conditions. In this approach, the minimum condition assessed using both the FCI and D_0 would be identified as the condition for each segment. For example, if the condition based on the FCI is good and the condition based on D_0 is fair, then the combined condition is fair.

A disadvantage to the use of the RWD is that no industry standards have yet been developed for equipment calibration, data collection, data analysis, and pavement condition evaluation. In addition, current RWD analysis methods require pavement layer thickness data, which is difficult to obtain with a high level of confidence.

Pavement Remaining Service Life

Pavement remaining service life (RSL) is a valuable measure as it provides understanding of future investment needs for pavements. It is a tier 3 measure as it requires analysis based on condition data and there is limited agreement on the calculation methodology across transportation agencies.

FHWA's Pavement Health Track (PHT) is an analysis tool for computing pavement RSL with the potential to serve as a one comprehensive pavement condition measure. The PHT tool utilizes simplified versions of the FHWA models for the Highway Economic Requirements System (HERS) and the National Pavement Cost Models. Data requirements for the PHT tool are based largely on the HPMS 2010+ data collection format. State DOT PMS or other sources of data can also be imported into the PHT tool. A limitation of the PHT tool is that the RSL analysis is only available for bituminous pavements, JPCP, AC overlay over existing AC pavement, and AC overlay over existing jointed concrete pavements. CRCP and CRCP with overlay pavement sections are not considered.

The PHT tool calculates the predicted distresses' values (IRI, rutting, fatigue cracking, transverse cracking and faulting) at the end of the overall service life. Each pavement distress type's RSL is calculated as the number or years (or Equivalent Single Axle Loads – ESAL) until the terminal values listed in Table 3.7 are reached for applicable pavement sections (e.g., faulting for rigid pavements). The PHT tool also provides the overall RSL for a particular pavement section. Users can determine whether the overall RSL is computed as the minimum or the weighted average of individual RSL values for each distress type. The FHWA's pilot study – Improving FHWA's Ability to Assess Highway Infrastructure Health – used the RSL thresholds shown in Table 3.8 to determine good, fair, and poor conditions.

Table 3.7 RSL Terminal Distress Values

Surface Type	Distress Type	Terminal Value
Rigid Pavement	IRI	170 inch/mile
	Cracking-Transverse	10%
	Faulting	0.15 inch
Flexible Pavement	IRI	170 inch/mile
	Cracking-Fatigue	20%
	Cracking-Transverse	640 feet/mile
	Rutting	0.4 inch
Composite Pavement	IRI	170 inch/mile
	Cracking Reflection	100 feet/mile

Source: Improving FHWA's Ability to Assess Highway Infrastructure Health.

Table 3.8 RSL Thresholds

Category	RSL Threshold, years
Good	> 10
Fair	1 < RSL ≤ 10
Poor	≤ 1

Source: Improving FHWA's Ability to Assess Highway Infrastructure Health.

Condition Measures for Bridges

Deck Area of Structurally Deficient Bridges

This measure is defined as the sum of a state's bridges' deck area flagged as Structurally Deficient (SD) in the National Bridge Inventory (NBI) divided by the deck area of all of a state's NHS bridges, expressed as a percent. It is a Tier 1 measure, broadly used and understood. State DOTs and Federal Agencies that own bridges are required to submit NBI data to the FHWA for highway bridges, including culverts, on public roads that are greater than 20 feet in length. A key component of NBI data is a series of condition ratings that range from zero (failed condition) to nine (excellent condition) or N (not applicable). FHWA determines SD status based on the NBI data submitted by state DOTs. A bridge is classified as SD if:

- The condition of its deck, superstructure, substructure, and/or culvert is rated four or less (on the zero to nine scale); or
- Its structural condition or waterway adequacy is rated two or less.

The challenge of flagging bridges as SD is that this is a binary option (whether a bridge is or is not SD), and does not present different threshold levels for bridge conditions. SD status cannot be converted to a good/fair/poor scale.

The calculation and reporting of this measure is straightforward because the data standards, collection procedures, quality control processes, and calculation methods are well established and have been used by state DOTs and the FHWA for several years. This measure is commonly used at a system level. FHWA encourages the use of this measure for NHS bridges.

Structural Adequacy of Bridges

The pilot study – Improving FHWA's Ability to Assess Highway Infrastructure Health – proposed a measure of a bridge's overall structural adequacy based on the minimum NBI rating of four bridge components – deck, superstructure, substructure, and culvert conditions. This minimum rating is compared to a set of thresholds developed in a comparative analysis study of bridge conditions conducted through NCHRP 20-24(37)E: 1) If minimum NBI rating is eight or nine, then the condition is good; 2) if minimum NBI rating is five or six, then the condition is fair; and 3) if minimum NBI rating is less than five, the condition is poor. This is a Tier 2 measure.

This measure could also be calculated by weighing all or portion of these ratings, based on each bridge component's relative importance to overall structural adequacy. By applying weights to the various bridge components, it would be possible to consider nonlinear deterioration rates. This approach would better reflect the overall structural adequacy of the nation's bridges than the Tier 1 measure, which based on SD status. The pilot study – Improving FHWA's Ability to Assess Highway Infrastructure Health – suggested four possible weighting schemes. They include use of the weights derived from NBIAS and the Sufficiency Rating formula, equal weights for deck, superstructure, and substructure, and a weighted average based on variable weights.

After the chosen weighting scheme is applied, agencies can use the same set of three condition thresholds as suggested by NCHRP 20-24(37)E to categorize bridges as good/fair/poor.

Detailed Element-Level Inspection Data and Health Indices

As the state of the practice advances, the bridge condition data could be transitioned from more aggregate NBI data to more detailed element-level inspection data. The NCHRP 20-24(37) G project proposed a more advanced version of the measure using AASHTO's Commonly Recognized (CORE) Element Inspect data and an updated version of the health index calculation currently used by AASHTOWare's Bridge Management System. The System converts element-level inspection data into a series of ratings of a bridge's major components – deck, superstructure, substructure, and culvert. These indices could replace the NBI condition ratings proposed as a basis for measure. These derived ratings could be combined into a structural adequacy index (or health

index) using the same weighting approach defined for the NBI-based measure, and bridges could be categorized as good, fair, and poor based on the same thresholds. AASHTOWare is in the process of updating the Bridge Management software.

Implementing an element-level measure is limited by the fact that not all states collect element-level data, and some that do, only collect the data for state owned bridges. In addition, the AASHTO Subcommittee on Bridges and Structure has recently updated the definitions of the AASHTO CORE bridge elements. It is anticipated that AASHTO will update AASHTOWare's Bridge Management System to reflect these definitions over several years.

Element ratings are often used to compile a health index. The bridge health index is a 0-100 ranking system for bridge maintenance. Different states use different methodologies to calculate a health index. Generally the network-average bridge condition is gauged by the percent of bridges with a health index of greater than 75 on a scale from 0 (poor) to 100 (excellent). Health index is often aggregated to provide a system level performance indicator. AASHTOWare's Bridge Management System includes a health index calculation.

In California, a bridge health index is calculated by calculating individual bridge total element values and current element values. It supports prioritization of maintenance, allocation of resources, and understanding of future deterioration. More details can be found in the report *AASHTO Commonly-Recognized Bridge Elements: Successful Applications and Lessons Learned*.

Detailed element-level inspection data are considered tier 3 measures as more work is required before it has the potential to be broadly adopted and understood.

Condition Measures for Other Assets

Assets aside from pavements and bridges generally have fewer broadly accepted and recognized condition measures. As pavements and bridges require a significant percentage of transportation resources, assessment of their condition has historically benefitted from more research and data collection investment.

In addition to the pavement and bridge conditions discussed in this section, states have agreed to a set of commonly recognized measures based on the National Workshop on Commonly Recognized Measures for Maintenance sponsored by AASHTO and the FHWA in June 2000. Table 3.9 summarizes these measures by maintenance element.

The adopted commonly recognized measures exist side-by-side with other performance measures that many states have already developed and generally use for maintenance management and asset management. The common measures are useful for customer-driven benchmarking, customer-driven asset management systems, performance-based contracting, and public reporting of

maintenance performance. Commonly recognized measures create efficiencies in data collection, measurement systems, and management systems.

Table 3.9 Commonly Recognized Measures Adopted by Consensus

Maintenance Element	Recommended Commonly Recognized Measure
Pavement Surfaces	• IRI • Rutting • Friction
Signs	• Retroreflectivity • Physical appearance: contrast, color fade, legibility, and sign post condition • Customer satisfaction
Pavement Markings	• Retroreflectivity • Physical appearance: contrast and presence • Customer satisfaction
Shoulders and Roadside	• Clear zone • Horizontal from edge (distance) • Vertical clearance (distance) • Vegetative obstruction • Vegetation height • Presence of noxious weeds • Litter count • Customer satisfaction • Edge variance: drop off and build up
Safety Features and Appurtenances	• Attenuators (functioning as intended) • Guardrails and guardrail end treatment (functioning as intended)
Drainage	• Culverts cross drains (percent blocked/damaged) • Open ditches (percent blocked/damaged) • Curb, gutters, and barrier wall (percent blocked/ damaged) • Catch basins and inlets (percent blocked) • Subsurface drainage (percent blocked)
Ice and Snow	• Road closures • Bare pavement indicator • Customer satisfaction surveys and focus groups

Source: NCHRP Report 511.

Customer-Driven and User Perception Measures

Customer-driven benchmarking involves assessing, adopting, and improving "best" practices that have been shown through measurement to lead to better products and services to customers. Customer-driven benchmarking is often an important part of maintenance quality assurance programs.

In customer-driven benchmarking, the measures focus on the results important to customers. The NCHRP Report 511 breaks these measures into four types:

- **Outcomes are the results of performing maintenance activities that are important to customers.** Examples of outcomes are smooth roads, edge markings that are easy to see in poor weather, and traffic signals that are reliable and work continuously.
- **Outputs are measures of accomplishment or production.** Examples are linear feet of ditches cleaned, the number of bags of litter collected, and acres of grass mowed.
- **Resources.** Resources consist of labor, equipment, materials, and financial costs.
- **Hardship factors.** These are factors outside an agency's control making it more difficult to satisfy customer desires and needs. Examples of hardship factors are weather, terrain, and population density.

Customer-driven benchmarking combines all four measures to give agencies a broad perspective on how well they are achieving outcomes that matter to customers in a manner that uses the fewest possible resources while taking into account the level of production and uncontrollable factors.

Outcomes

Three important outcomes can be measured: 1) customer satisfaction, 2) condition of asset and other attributes, and 3) value received by the customer.

An important measurement tool for assessing customer satisfaction is statistically valid measures of customer satisfaction obtained from administering a survey using random sampling. Examples include:

- The National Quality Initiative (NQI) in Transportation, developed and administered by the U.S. DOT in 1996 and 2000, assessed customer satisfaction and preferences regarding the nation's highway system. Because the NQI survey provides a national baseline of data, many states have incorporated questions from the NQI survey into their own customer satisfaction surveys. This inclusion allows states to compare the results obtained from their own surveys with those obtained nationally.
- More refined surveys and questions tailored to an agency's maintenance products and services than the NQI survey. For instance, the California DOT (Caltrans) has a question to assess customer satisfaction regarding how the state does in responding to maintenance problems associated with

mudslides, floods, and earthquakes. The Caltrans survey also included a series of related questions intended to assess customer preferences regarding response time for time-sensitive maintenance activities such as sign repair, traffic delays due to maintenance, and pothole repairs.

Condition measures are discussed in this chapter's previous sections, and are important because 1) the roads' physical attributes directly affect the road users' experience; 2) responsible road stewardship through proper and timely maintenance preserves highway and street investments, and avoids wasting money that could be used for more productive purpose; and 3) condition relate to results from maintenance service.

Many DOTs link customer expectations to performance targets through some form of maintenance customer survey. According to the NCHRP's recent study *Best Practices in Performance Measurement for Highway Maintenance and Preservation*, many agencies reported that these surveys have been suspended or are being done less frequently due to funding constraints.

Missouri DOT (MoDOT) is active in customer surveying. MoDOT has established a number of strategies for obtaining customer input to help ensure that the agency is focusing on what the public expects. MoDOT uses road rallies, customer surveys, and report cards to monitor the degree to which the public accepts the agency's performance. MoDOT spends approximately $200,000 each year on its public phone survey and a survey of the media and other partners, such as public officials and organizations.

Kansas DOT (KDOT) is one of the agencies that suspended customer surveys due to budget constraints. However, it had conducted surveys for approximately 10 years prior to ending the program. KDOT's customer survey results indicated that local and national events easily influenced the public's perception of conditions. For example, the Kansas media promoted a particular snowstorm as an extreme event, although the KDOT considered it no more than an average storm. However, because of the media attention to the storm, the public was very satisfied regarding the KDOT's success at clearing the roads so quickly.

Value perceived by the customers can be grouped into three types: 1) avoided user costs such as travel time, vehicle operating costs, and accident costs; 2) avoidable life-cycle costs if the roads were maintained with the right treatment at the right time; and 3) avoided external costs such as pollution or property value changes.

<u>Output</u>

Output measures are used to record maintenance production – for example, the miles of pavement resurfaced per day or the number of feet of guardrail repaired. Even though output measures are not focused on the customer, agencies have reasons to include them:

- Output measures provide a means to access the scale of activity of a benchmarking unit and therefore provide a more informed basis for comparing performance. For instance, one benchmarking unit may resurface only 10 miles of pavement per year, whereas another may resurface 100 miles.
- Surrogates for outcome measures. Reliable, repeatable, accurate, and reasonable-cost outcome measures may not be available in some instances. An output variable can act as a proxy for an outcome variable.
- Linkage to outcomes. Some analysts find that the most logical way to establish a measure of certain types of outcomes is to establish a functional relationship between outputs and various types of outcomes.

Many states publish an annual summary of maintenance treatments. For example, Oregon DOT's annual pavement condition report documents the lane mileage of full-depth roadway reconstruction, pavement resurfacing, and seal coat in the current year. The annual pavement condition report also lists the highway segments where paving or chip seal resurfacing treatments were conducted in recent years.

Resources

Resources composed of labor, equipment, material, and financial cost:

- An overall measure of the labor used to produce a maintenance product or service. Labor is measure in terms of person hours of labor. Labor hours can also be broken down by levels of training, education, and experience of different personnel.
- Equipment quantity consists of the number of hours each type of equipment is used or some metered measurement of usage. Equipment can be categorized by type, condition, frequency of breakdown, and operator requirements.
- Material usage can be measured by the physical quantity of each material type used to deliver a maintenance service. Examples of material use are the number of signs and posts, linear feet of guardrail, tons of pothole material, and gallons of crack sealant.
- Total costs of using the labor, equipment, and material to deliver a product or service. Sometimes, however, it is better to employ measures of the raw labor, equipment, and material inputs instead because there can be local and regional differences in labor, equipment, and materials' cost. If possible, the agency should differentiate between fixed and variable costs by activity, product, and service.

Minnesota DOT uses resources measures. The DOT's annual winter maintenance report tracks the amount of materials, labor and services for winter-related maintenance. Materials include the tonnage of salt used, the average

weighted cost of salt, and the gallons of salt brine used. Minnesota DOT also tracks the number of regular and overtime labor hours related to winter maintenance. The report compares these material and labor costs to winter weather conditions over the last decade to illustrate their relationship.

Hardship

These are factors outside the agency's influence, including:

- Weather conditions present at the time maintenance work is performed. To be more specific, standard daily work reporting should be augmented with weather data – at a minimum, the type and quantity of precipitation that occurred during the day and the high, low, and mean temperature.
- Geographic information – Mountainous and hilly areas are likely to affect maintenance outputs and outcomes differently than flat areas. Information on terrain is readily available from both government and private-sector data sets. Most state DOTs have access to a geographic information system (GIS) that has terrain information.
- Certain roadway attributes affect the productivity and outcomes of maintenance work – for example, the presence of shoulders makes it easier for crews to park their vehicles and work on roadside safety features such as guardrails and signs.

State DOTs record seasonal weather conditions that affect maintenance costs, materials, and system performance. For instance, Wisconsin DOT publishes an annual winter maintenance report that compares the current year's winter weather condition and maintenance needs with historical averages. This winter maintenance report records statewide snowfall, number of winter storms, and a winter severity index (this index is calculated from the number of snow events, the number of freezing rain events, total snow amount, total storm duration, and total number of weather-related incidents).

Conclusions for Condition Measures

General Observations

- Condition measures create the foundation for data-driven decision-making.
- Comprehensive, up-to-date, accurate condition data for major assets is needed for subsequent analysis, including needs assessment, risk assessment, target setting, and making data-driven programming decisions.

Direct Condition Measures

- Direct condition measures such as IRI and NBI structural deficiency ratings are widely used as a foundation for asset management, performance management, and preservation programming.

- Condition measures have varying levels of maturity. Some are broadly understood and available. Other have minimal agreement among agencies, making data collection and processing a challenge.

Remaining Service Life

- Moving from direct condition measures to RSL measures can add much greater understanding of preservation needs and risks. RSL measures are not universally understood or applied, however, making this area a challenge for many agencies.

Customer-Driven and User Perception Measures

- Customer-driven and user perception measures can be tied to outputs (such as miles of pavement repaved) to quantify cause and effect.
- Customer-driven and user perception measures improve accountability and target investment towards elements the customers find important.

3.2 ECONOMIC IMPACT MEASURES

How Economic Impact Measures Are Applied to Support Preservation Decision-Making

Decision-making about transportation infrastructure preservation actions (i.e., activities to keep the transportation system in a state of good repair) requires some understanding of the impacts of those actions. Economic impact measures build on the foundation of condition measures that are widely used by transportation agencies. Economic impact measures translate condition measures, enabling agencies to focus on the impact of their policy choices. For example, the impact (benefit or disbenefit) of not rehabilitating a bridge at the economically optimal time would be monetized to determine the economic loss to the agency and to the public.

It is important to note that the majority of economic impact measures that are tied to preservation decisions require condition measures as a foundation. Condition measures provide an understanding of the value of an asset before and after a decision, such as the option of investing in preservation or not investing in preservation.

Overall economic impact measures are the product of technical analyses that can serve multiple purposes, such as monetizing needs, helping to communicate the consequences of current trends and the long-term consequences of investment decisions, and illustrating the impact of a do-nothing scenario. As such, economic impact measures serve as a key element of performance-based preservation programming and can help to make the case for infrastructure investment. In addition they can help transportation agencies identify and adopt strategies aimed at making the most use of limited preservation programming dollars. These types

of measures provide a sense of the financial order-of-magnitude that is not found in measures that only report infrastructure condition.

With respect to how transportation is broadly perceived by decision-makers and the public, economic impact measures can often tell the story of preservation needs better than condition measures alone. By way of example, the public understands that house repairs are necessary over time. Similarly, aging assets like pavements and bridges eventually will need replacement. This is where economic impact metrics come into play as they can help to further illuminate public understandings of asset preservation needs and issues. It should be noted however, that there is limited consensus over what the most effective economic impact measures are and certain measures, such as avoided cost (described in a later section), are not broadly understood.

Economic impact measures can include metrics on the economic benefits that are created, least lifecycle cost estimations, user and agency costs, avoided costs, replacement costs, and metrics to address the long-term performance of highway assets based on expected expenditure levels, and other analytical methods. It is possible to use these measures to illustrate the consequences of different levels of investment to better understand tradeoffs among competing programs and alternatives within a program. For example, highway programs consist of a menu of projects and services, each with their own set of needs. With limited resources to fund all these needs, many times tradeoffs are necessary. This section provides a host of examples about the application of economic impact measures from existing literature on the topic as summarized in Table 3.10.

Table 3.10 Summary of Economic Impact Measures

Measure Type	Example	Outcome/Usefulness of Measures
Life-Cycle Cost	• Remaining service life • Life-cycle cost analysis • Life expectancy analysis	Determine the most cost-effective strategy (e.g., replacement, maintenance/preservation activities) among alternatives
Avoided Cost	• Relationship between asset level of service, required maintenance work, and cost consequences of delayed maintenance • Cost of poor pavement condition in terms of vehicle operating costs and costs to restore pavement to good condition	Describes the implications for implementing projects or programs, quantify the impacts of deviating from a least life-cycle cost approach
Sustainability Index	• Asset sustainability index, a high-level composite assessment of asset condition for pavement, bridge, and maintenance	Provides an indicator of the gap or surplus between need and investment, helps indicate the degree to which investment is adequate or inadequate

Measure Type	Example	Outcome/Usefulness of Measures
Benefit/Cost/ Performance-Cost	• Utility function as a measure of benefit • Budget scenarios and effects on infrastructure condition • Benefit cost to assess asset investment options	Supports choosing between alternatives, testing feasibility of options, comparing programming scenarios
Economic Development Impact	• Employment is widely used and understood • Personal income • Property values	Illustrates the experience by users as well as transportation's contribution to the general economy

Life-Cycle Cost Measures

Life-cycle costs measures address all of the costs – agency and user – that are incurred during the service life of an asset. With respect to agency costs related to preservation, costs that are measured typically include the full schedule of expenses related to maintenance and rehabilitation activities. Overall, life-cycle cost analysis (LCCA) is a method of comparing alternatives in which costs are dispersed over time. LCCA allows all costs for a given alternative to be consolidated into a single present value. The resulting present value can then be compared to that of other alternatives on an apples-to-apples basis.

The goal of LCCA for state DOTs is to minimize the costs of managing the transportation network. For example, is it better financially to: 1) spend *more* money now and *decrease* future maintenance costs; or 2) to spend *less* money now and *increase* future maintenance costs? LCCA is designed to help answer this type of question.

Life-cycle costs are a fundamental measure for performance-based preservation. They rely on accurate current condition data, deterioration modeling, and cost estimation. While life-cycle costs are not always simple or easy to calculate, it is important to note that most other economic impact measures are some derivation of life-cycle cost. Life-cycle costs provide a foundation to guide decision-making.

As described in FHWA's *Life-Cycle Cost Analysis Primer*, LCCA is a subset of benefit/cost analysis. With respect to preservation, the LCCA approach enables the total cost comparison of competing preservation alternatives. LCCA typically occurs once an agency has already decided to undertake a project or improvement and is seeking to determine the most cost-effective means to accomplish the project's objectives. LCCA is applied only to compare project implementation alternatives that would yield the same level of service and benefits to the project user. The difference between LCCA and benefit/cost analysis is shown in Table 3.11.

Table 3.11 Comparison of Analysis Elements: Life-Cycle Cost Analysis versus Benefit/Cost Analysis

Project Element	LCCA	BCA
Agency construction, rehabilitation, and maintenance expenditures	Yes	Yes
User costs during construction, rehabilitation, or maintenance	Yes	Yes
User costs during normal operations	Yes	Yes
User benefits resulting from project	No	Yes
Externalities resulting from project	No	Yes

Source: FHWA, *Life-Cycle Cost Analysis Primer*, Washington, D.C., 2002.

LCCA is intended for use when benefits of alternatives are equal, but costs are different. Comparisons among alternatives that have differing benefits are better analyzed using a benefit/cost analysis. For example, LCCA is well-suited to selecting pavement types in late stages of roadway design, where overall project benefits from all alternatives are equal and the lowest-cost option is sought. Different pavement types and maintenance strategies can have different impacts on costs, but have little impact on user experience except for construction delays, which can be included in LCCA.

FHWA's LCCA Primer also describes the LCCA methodology. Some asset improvements will have service lives that exceed the analysis period. In other words, at the end of the analysis period, an alternative may still have value if it is not at the end of its service life. Determining the remaining service life (RSL) is a part of the process of estimating agency costs. A RSL value exists when there is a residual value of an improvement because its service life extends beyond the analysis period.

NCHRP Report 713 (Volumes 1 and 2) *Estimating Life Expectancies of Highway Assets* describes how life expectancy estimates are important for evaluating, ranking, valuing, and budgeting asset replacement and life-extending maintenance/preservation activities. Life expectancy estimation is built on the products of the research and data collection processes of an agency; and in turn, life expectancy analysis contributes directly to preservation policy formation, project development, and preservation needs assessment, largely through use as a performance measure for quantifying the effects of agency decisions. Less directly, the expectations of an agency's designated asset lifespans affect the design of certain information systems and their analyses, as well as the assumptions that are made in financial decisions such as debt terms, depreciation, amortization, and cash flow. Further, through its use in preservation policy and planning, asset life expectancy indirectly affects the processes of budgeting, network planning, corridor development, design, and maintenance planning. Agencies increasingly seek to adopt design and construction methods that minimize future maintenance requirements or that facilitate coordination of preservation activities across asset categories in a corridor or region.

Agencies are well versed in the contributing role that life expectancy analysis can have when used as a part of a larger transportation asset management plan. Assumptions about asset lifespan are built into various design and maintenance tools and procedures. Predictions of asset life extension form a part of the justification for various maintenance, repair, and rehabilitation projects, programs, budgets, and policies.

Avoided Cost Measures

Avoided costs can be a way to understand the performance and service lives of transportation infrastructure assets in ways that go beyond physical condition and describe the implications for the general public (not just motorists). Avoided cost is often framed is an expression of "the consequence of inaction."

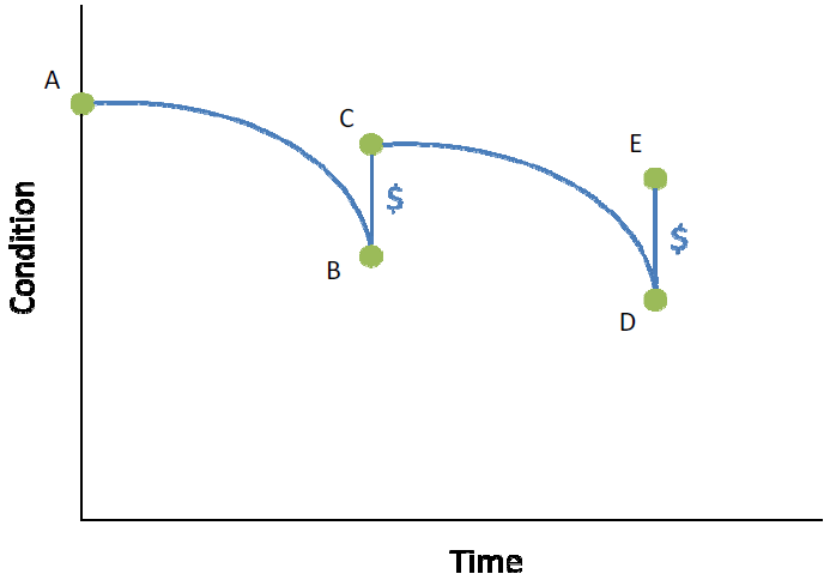
Avoided costs can be viewed as an extension of the thinking which began with LCCA. If an agency knows the best possible preservation programming to minimize life-cycle costs, avoided costs can communicate the costs of deviating from that programming.

The concept of avoided cost is revealed in several indirect different ways in the literature. NCHRP Report 14-20 *Quantifying the Consequences of Delayed Maintenance* provides a process to help agencies articulate the impact of different maintenance strategies for bridges and pavements, which can be a useful tool to help communicate the consequences of policy decisions. AASHTO's *Rough Roads Ahead Report* uses a different approach to articulate the consequence of not addressing preservation needs, mainly through descriptive text, which helps to paint a picture of avoided cost.

NCHRP Report 14-20 provides a conceptual framework for assessing the relationship between asset level of service, required maintenance work, and costs from which the concept of avoided cost emerges. Figure 3.2 shows one scenario where maintenance is performed:

- An asset has a specified starting condition (illustrated by point A in the Figure 3.2).
- Over time, the asset deteriorates and the condition decreases. Eventually it reaches a predefined condition threshold at which work is recommended (point B).
- The recommended work is performed, a cost is incurred, and the condition improves (point C).
- The asset again begins to deteriorate until additional work is recommended (point D).
- Again, the recommended work is performed, a cost is incurred, and the condition improves (point E).
- This cycle is repeated over the life of the asset.

Figure 3.2 Conceptual Modeling Framework
Scenario 1

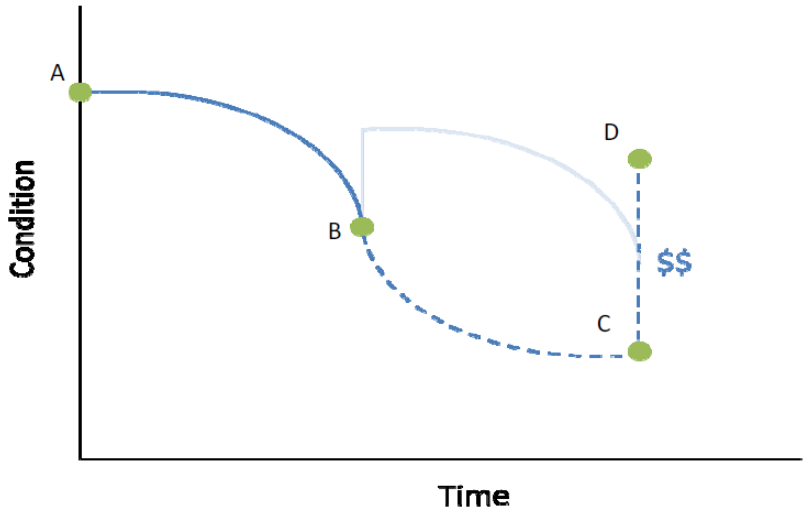


Source: Transportation Research Board, *Consequences of Delayed Maintenance*, (NCHRP Report 14-20), Washington, D.C., 2012.

An alternative scenario shows the framework where maintenance is delayed as shown in Figure 3.3.

- An asset has the same starting condition as the previous scenario (point A).
- It again reaches a predefined condition threshold at which work is recommended (point B).
- In this scenario however, the recommended work is not performed, and the asset continues to decrease until a point at which more expensive work is recommended (point C).
- The more expensive work is performed, a higher cost is incurred by the agency (higher relative to the cost incurred if work had been performed at point B), and the condition improves (point D).

Figure 3.3 Conceptual Modeling Framework
Scenario 2

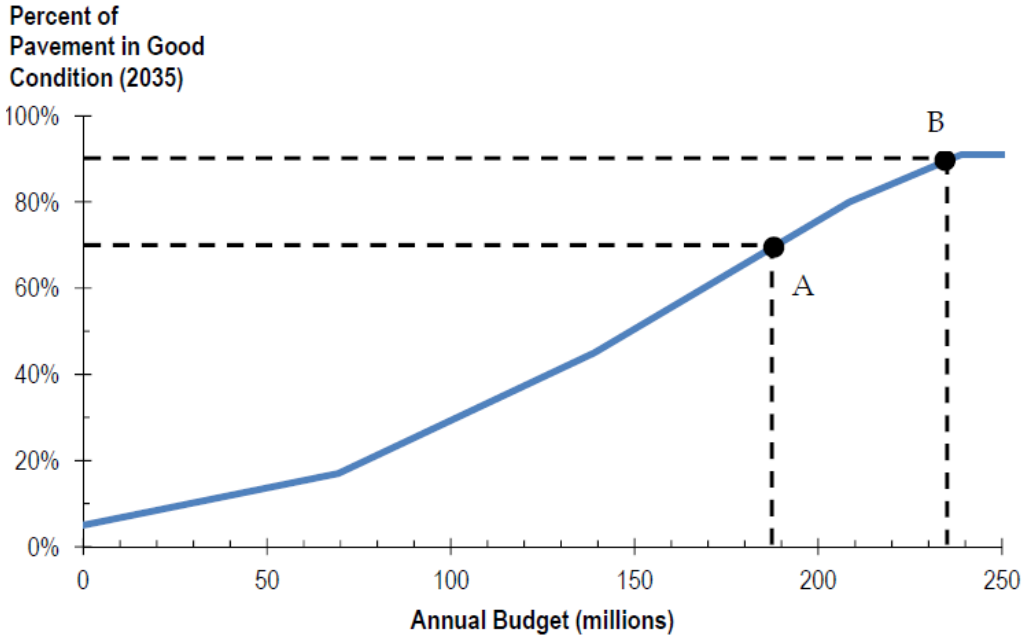


Source: Transportation Research Board, *Consequences of Delayed Maintenance*, (NCHRP Report 14-20), Washington, D.C., 2012.

NCHRP Report 14-20 provides several ways to quantity the consequence of delayed maintenance. One approach to demonstrating the relationship between cost and level of service is described by the researchers as follows: Consider a case in which point A represents the current level of service (70 percent pavement in good condition in 2035). Figure 3.4 shows that maintaining this condition through 2035 would cost about $188 million annually. If an agency wanted to improve the level of service to 90 percent condition level (point B), it would cost about $235 million annually; an increase of $47 million per year.

The Report describes how that these types of curves also enable agencies to quantify the consequences of delayed maintenance with respect to the change in level of service. For example, if point B in Figure 3.4 indicates current funding levels ($235 million per year), any reduction in funding would predicate a reduction in level of service. Therefore, it is possible to estimate the consequences of delayed maintenance by finding a lower budget level on the graph and the resulting level of service. For example, if the current budget allocates $235 million per year to pavement maintenance (point B) and the budget is reduced to $188 million per year (point A), then the level of service is expected to decrease from 90 percent (point B) to 70 percent (point A).

Figure 3.4 Quantifying the Cost of Achieving Improved Conditions



Source: Transportation Research Board, *Consequences of Delayed Maintenance*, (NCHRP Report 14-20), Washington, D.C., 2012.

The approach described in Figure 3.4 address changes in level of service and user costs due to delayed maintenance. An alternative approach identified in NCHRP Report 14-20 also estimates the impact on agency costs and is described by the researchers as follows: similar to the first alternative, a user specifies a budget level, and a management system is used to determine which work should be done with these funds, and the impact of this work on level of service. However, now, agency costs are now handled as an output as it reflects a baseline scenario. In this scenario, a preferred maintenance policy is defined and followed. In this context, the term "preferred maintenance policy" refers to a set of condition thresholds at which work should be performed. The scenario now reflects a delayed maintenance scenario.

In the delayed maintenance scenario described in in NCHRP Report 14-20, work recommended by the preferred maintenance policy is delayed until after the delay period ends. As the delay period lengthens, the cost incurred at the end of it eventually will exceed the cumulative costs incurred in the baseline scenario. The difference in the net present value (NPV) of these two cost streams represents the change in agency costs due to delayed maintenance. In the new approach, changes in agency costs are considered along with changes in network condition and changes in user costs. For example, at the end of the delay period, the difference in network conditions between baseline scenario and the delayed maintenance scenario reflects another consequence of delayed maintenance.

AASHTO's *Rough Roads Ahead Report* paints a picture of the concept of avoided cost, albeit in a different way from NCHRP Report 14-20. The AASHTO report

makes the case indirectly through its assessment of highway maintenance needs and costs. Researchers note that the public pays for poor pavement conditions twice – first through additional vehicle operating costs (i.e., driving on rough roads accelerates vehicle depreciation, reduces fuel efficiency, and damages tires and suspension), and then in higher costs to restore pavement to good condition. Report researchers estimate that for the average driver, rough roads add $335 annually to typical vehicle operating costs. In urban areas with high concentrations of rough roads, extra vehicle operating costs are as high as $746. Generally, larger vehicles have a greater increase in operating costs due to rough roads. The underlying argument of the AASHTO report is that these costs could be avoided if investments are made to keep a road in good repair, rather than paying more at a later point in time to address greater deterioration.

To illustrate this argument the Report describes the lifecycle stages of roadways from initial design to disintegration and failure. The Report notes that actions taken at each stage can affect the long-term durability of the road as well as maintenance and preservation costs. Higher quality investments earlier in the life of the road will save money over the long run because maintaining a road in good condition is less expensive than repairing or rebuilding one in poor condition. Figure 3.5 describes how reconstructing a road that has reached Stage 5 costs significantly more than preserving a road at Stage 3.

Figure 3.5 Life Cycle of a Road

Life Cycle of a Road

1 **Design**—This stage deals with dimensions, type of materials, thickness of base and top surfaces, and the drainage system. Investments made at the design stage affect the long-term durability of the pavement surface. If, however, sufficient funding is not available to upgrade the design, the road starts out and stays mediocre.

2 **Construction**—A high-quality construction process produces a longer-lasting pavement surface.

3 **Initial Deterioration**—During the first few years of use, the road surface starts to experience some initial deterioration caused by traffic volume, rain, snow, solar radiation, and temperature changes. At this stage, the road appears in good condition, providing a smooth ride. Preservation strategies during Stage 3 will sustain the smooth ride, preserve the foundation, extend the life, and reduce the need for costly reconstruction later on.

4 **Visible Deterioration**—At Stage 4, visible signs of distress such as potholes and cracking occur. Repairs made at this stage using overlays and milling to eliminate ruts will restore a smooth ride and extend the life of the road.

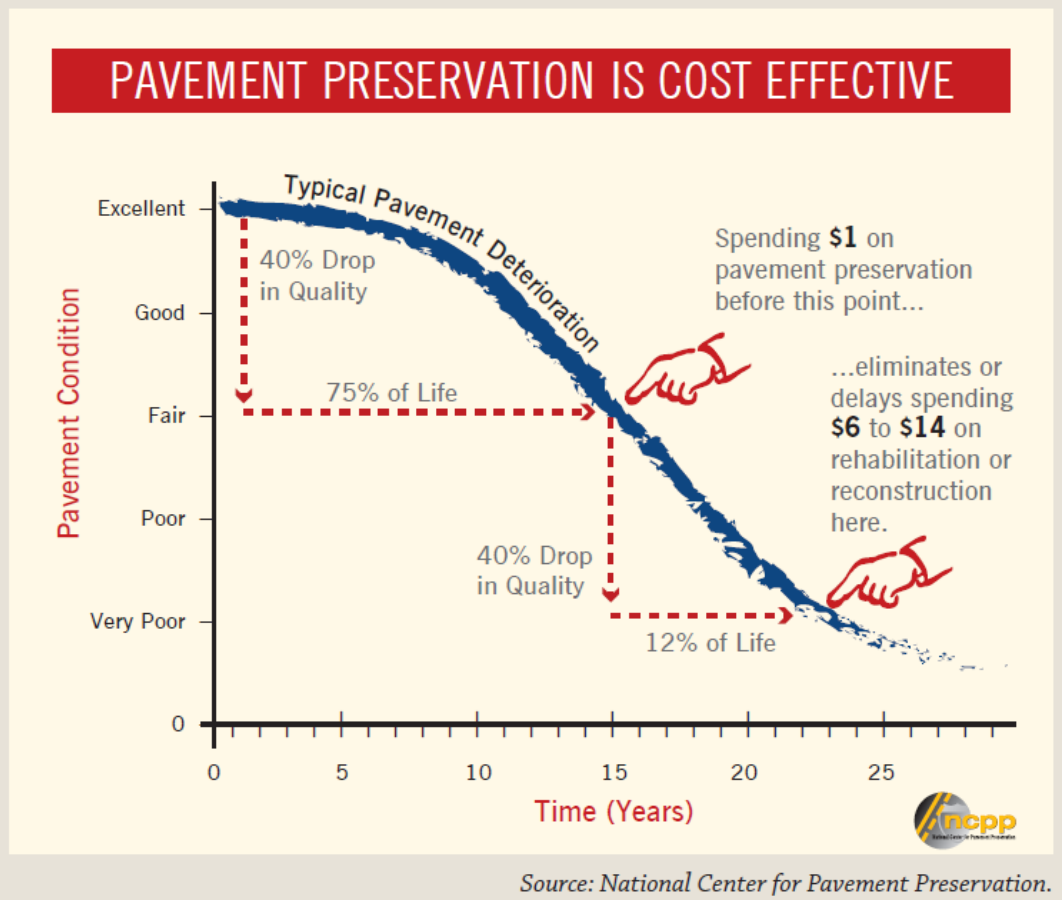
5 **Disintegration and Failure**—Roads not maintained at Stage 3 and repaired at Stage 4, eventually will fail and need costly reconstruction. Once a road's foundation disintegrates, surface repairs have an increasingly short life.

Source: AASHTO, *Rough Roads Ahead*, (ISBN 978-1-56051-443-5), Washington, D.C., 2009.

The AASHTO report employs the following catch phrase, which essentially makes the case for avoided costs: Pay Me Now or Pay Me Lots More Later. This concept is illustrated in Figure 3.6. The report argues for pavement preservation to extend the service life of roads before they need major rehabilitation or

replacement. The report suggests that good roads cost less and that maintaining a road in good condition is easier and less expensive than repairing one in poor condition.

Figure 3.6 Pavement Preservation is Cost Effective



Source: AASHTO, *Rough Roads Ahead*, (ISBN 978-1-56051-443-5), Washington, D.C., 2009.

In summary, avoided costs can provide a measure of the impacts of deviating from the least life-cycle cost approach to preservation. However, avoided costs are often difficult to quantify and communicate.

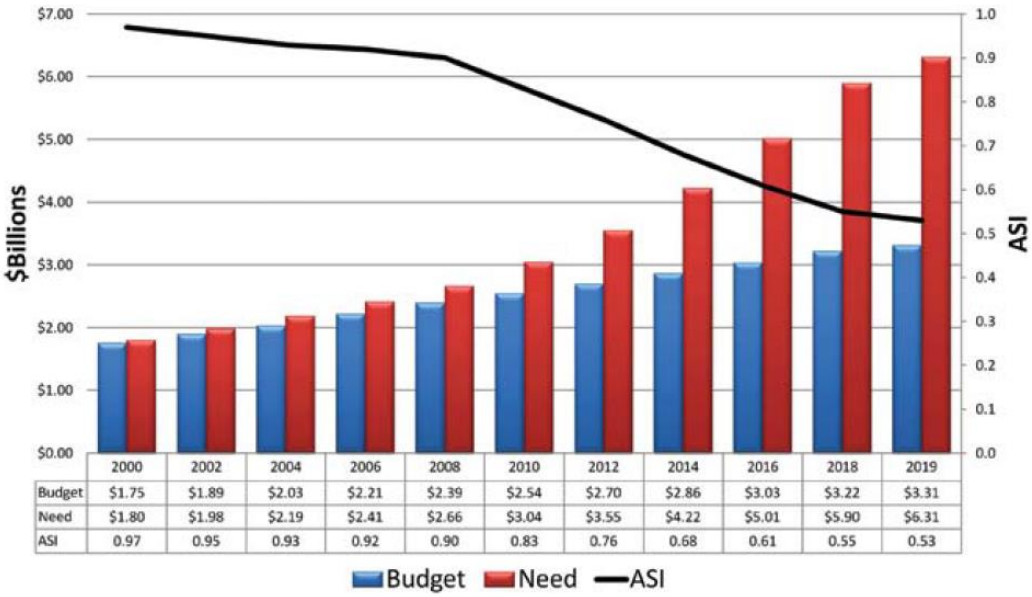
Sustainability Index Measure

FHWA's *Asset Sustainability Index Report* proposes a new measure for assessing the long-term performance transportation assets. The measure captures the difference between the needed level of investment and the actual. This is one simplified way for agencies to apply the ideas behind avoided cost without getting bogged down in difficult analysis and hard to explain concepts.

The Asset Sustainability Index (ASI) is comprised of three ratios for pavement, bridges, and maintenance. Each of these ratios are derived by dividing the amount budgeted for pavement, bridges or maintenance over time by the

amount needed to achieve a specific pavement, bridge, or maintenance condition. These ratios provide an indicator of the gap or surplus between need and investment and can help to indicate the degree to which investment is adequate or inadequate. Together, the ASI represents a composite metric computed by dividing the amount budgeted on infrastructure maintenance and preservation over time by the amount needed to achieve a specific infrastructure condition target (see Figure 3.7). An ASI of 1.0 is considered optimum because expenditures match need; lower than 1 reflects a gap, while higher than 1.0 represents excess spending. In the Figure 3.7 example, the ASI demonstrates that investment is only 53 percent of need in 2019, down from 97 percent in 2000.

Figure 3.7 Simplified Asset Sustainability Index



	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2019
Budget	$1.75	$1.89	$2.03	$2.21	$2.39	$2.54	$2.70	$2.86	$3.03	$3.22	$3.31
Need	$1.80	$1.98	$2.19	$2.41	$2.66	$3.04	$3.55	$4.22	$5.01	$5.90	$6.31
ASI	0.97	0.95	0.93	0.92	0.90	0.83	0.76	0.68	0.61	0.55	0.53

Source: FHWA, *Asset Sustainability Index: A Proposed Measure for Long-Term Performance*, (FHWA-HEP-12-046), Washington, D.C., 2012.

As described in the FHWA Report, individually the ratios and the composite ASI can help to depict the amount of additional spending needed to achieve a specific condition target. The ASI is proposed as a forward-looking measure and is in limited use in the U.S., though the FHWA Report does identify international precedent in practices found in Great Britain and Australia. In these countries State and local governments are required to report on the long-term financial sustainability of their infrastructure. FHWA envisions that the ASI would serve as a planning and long-term programming metric and is proposed to be used in a time series to measure trends. The time series is deemed to be important because of the long-term nature of infrastructure management and performance. Although the amount budgeted for a program and the amount spent for it may vary year to year, researchers have assumed that over time a strong correlation exists.

As shown in the Table 3.12, the ASI represents the weighted average of the three ratios (pavement, bridge, or maintenance) combined. Because the ASI is a composite derived from a series of components, each of the individual ratios can be examined separately to illustrate the tradeoffs that have been made and the consequences of them. In other words, because the ASI is an aggregate measure, it also allows for the disaggregation of its components. Table 3.13 shows how each of the ratios can be broken out by program and budget categories.

Table 3.12 Calculation of a Sustainability Index

	Budgeted Investment	Needed Investment	Calculations	Sustainability Ratio	Sustainability Index
Pavement	$415	$500	$415/$500	0.83	
Bridge	$225	$250	$225/$250	0.90	
Maintenance	$214	$225	$214/$225	0.95	
Total	**$854**	**$975**	**$854/$975**		**0.88**

Note: Dollars in Millions.

Source: FHWA, *Asset Sustainability Index: A Proposed Measure for Long-Term Performance*, (FHWA-HEP-12-046), Washington, D.C., 2012.

Table 3.13 Sustainability Ratios over Time by Asset Class or Activity

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

Source: FHWA, *Asset Sustainability Index: A Proposed Measure for Long-Term Performance*, (FHWA-HEP-12-046), Washington, D.C., 2012.

As part of this FHWA research effort, data used in asset management programs at select DOTs was determined to be suitable for producing the ASI as a long-term indicator. In other words, the DOT examples indicate that it is possible to pull metrics from existing asset management systems used in the U.S. for use in an ASI. It should be noted however that each state uses different definitions and

categories of assets and expenditures so they do not readily compare from state to state.

Benefit/Cost/Performance-Cost Measures

Benefit/cost ratios measure and compare the social benefits and costs of transportation projects or programs. They are valued for their holistic approach. Benefit/cost analysis is most frequently used in project selection and justification. As it requires a very specific action to be defined, the measure can be helpful for project-level decisions, but sometimes is more challenging to use on a larger scale.

A white paper developed for the National Surface Transportation Policy and Revenue Study Commission provides a high-level description of benefit/cost analysis. As described in Briefing Paper 4K-05 *Benefit/Cost Analysis in Public-Sector Infrastructure Investment Decisions*, benefit/cost is an economic analysis tool for measuring and comparing the social benefits and costs of transportation projects or programs. The analysis is based on a multiyear period that typically incorporates much or all of the operational lifespan of the project being evaluated. The analyst quantifies the costs (e.g., the resources expended to build, maintain, and operate the project) and the direct benefits of the operational project (e.g., travel time savings of system users) and, to the extent possible, puts them into dollar terms. Only costs and benefits of the project that are incremental to a "no action" base case are quantified. The analyst then converts these dollar amounts, whether realized initially or 30 years in the future, into "present value" amounts using a discount rate. The discount rate measures the annual opportunity cost of money, which is equivalent in concept to an interest rate that would have been earned on the invested funds had they not been expended on the project. Discounting causes dollars realized in the future to have lower present value than current dollars. Once the analyst has calculated the present values of a project's lifecycle benefits and costs relative to the "no action" base case, the two sums can be compared using a variety of measures to see if the present value of the benefits exceeds the present value of the costs. Projects with positive net benefits are generally worth pursuing from an economic standpoint, although political, social, budgetary, and other factors may cause decision-makers to reject a project even if it has positive net benefits.

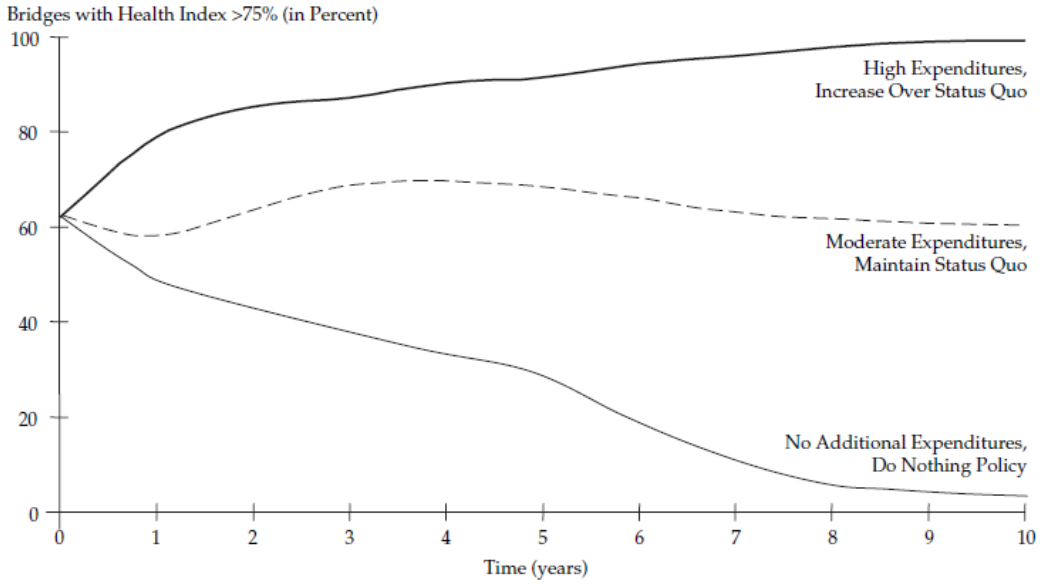
A subset of benefit/cost ratios that are often employed in preservation decision-making is the performance-cost measure. This measure links the amount of investment with the asset's performance. It often relates the performance to a condition target.

Many DOTs have existing management systems that can provide information on performance-cost relationships. NCHRP Report 551 notes that a general method for establishing long-term performance targets includes identifying the point at which additional investments begin to have a declining degree of impact on improvements in performance – in other words, where the slope of the investment-performance curve begins to decline.

NCHRP Report 551 describes an example of performance-cost analysis. Figure 3.8 illustrates three scenarios that have been analyzed for an example network of 500 bridges using the AASHTOWare Pontis® 4.0 bridge management system. Each scenario tests a particular budget level to preserve the bridge network through a 10-year analysis period. The network-average bridge condition is gauged by the percent of bridges with health index (HI) greater than 75 on a scale from 0 (poor) to 100 (excellent). The budget levels correspond to the following projected annual expenditures, which result in a markedly different result at the end of the 10-year analysis period and together define a range of options in funding bridge preservation:

- A relatively high annual expenditure;
- A moderate annual expenditure; and
- No annual expenditure, representing a "do-nothing" policy.

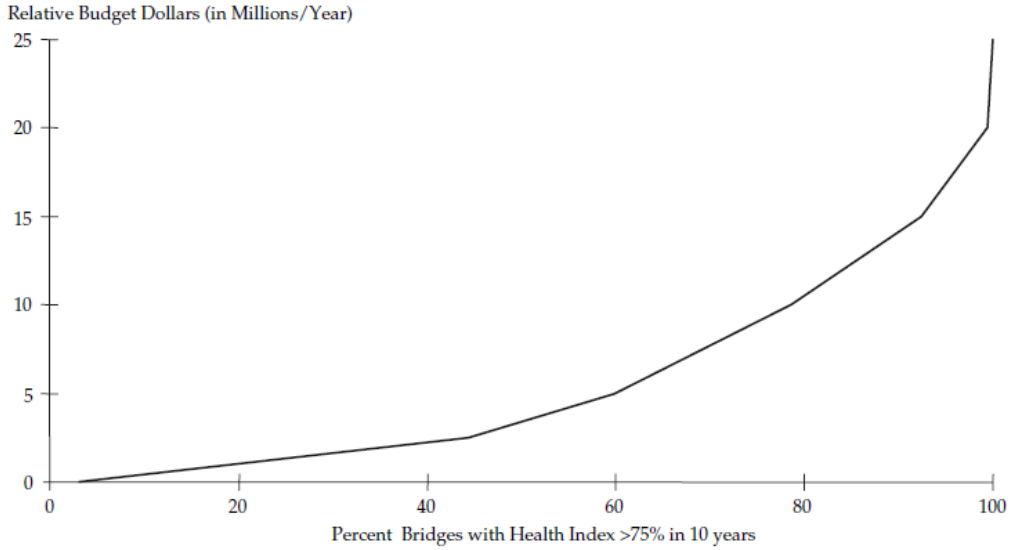
Figure 3.8 Example of Budget Scenarios and Effects on Infrastructure Condition



Source: Transportation Research Board, *Performance Measures and Targets for Transportation Asset Management*, (NCHRP Report 551), Washington, D.C., 2006.

Figure 3.8 plots the condition level at the end of 10 years versus the corresponding annual budget or expenditure level. The result is the relationship between condition level and needed expenditure. Figure 3.9 captures the tradeoff between constant expenditure level and resulting long-term condition. Researches note that this relationship can be used directly as a guide to identify the expenditure level to meet a specified target condition level, and that it can also can be used to explore long-term trends in network condition for different possible funding scenarios.

Figure 3.9 Resulting Relationship between Infrastructure Condition and Needed Expenditure



Source: Transportation Research Board, *Performance Measures and Targets for Transportation Asset Management*, (NCHRP Report 551), Washington, D.C., 2006.

This kind of analysis supports program-level preservation decisions and cross-asset resource allocation. NCHRP Report 551 notes that a core principle of asset management is that a range of potential solutions are considered to address transportation needs and that it is important to focus on a transportation result that could be met by more than one mode. In doing so, there are often tradeoffs across modal options.

The Report also illustrates how asset management can be used to assess different scenarios and competing investment needs. The Report notes, however, that many agencies either 1) are not yet at a stage of analytic capability or organizational readiness where they are able to perform systematic project and program tradeoffs or 2) choose not to perform these tradeoffs even if they have the prerequisites in place.

NCHRP Synthesis 424 *Engineering Economic Analysis Practices for Highway Investment* includes a case study of Caltrans. Caltrans has a bridge programming and permitting process that uses a utility function to characterize the health of bridge assets as a measure of benefit. Caltrans analyzes bridge project priorities for bridges not addressed by its bridge management system (BMS) using a multistep inspection, evaluation, and peer review process, conducted in the context of environmental permitting requirements for bridges that are near coastal zones, in environmentally sensitive areas, or are of historic importance. Caltrans computes the value of utility through a "benefit/cost analysis" to calculate the benefits of addressing bridge needs and prioritize preservation projects.

Benefit/cost analysis is used by transportation agencies to assess asset investment options for a variety of purposes. Results from the analysis can be used to help an agency choose between alternatives, to test the feasibility of a preferred alternative, to compare programming scenarios, and others. For example, FHWA's the *Economic Analysis Primer*, describes useful applications of benefit/cost analysis to help determine:

- Whether or not a project should be undertaken at all (i.e., whether the project's life-cycle benefits will exceed its costs).
- When a project should be undertaken. Benefit/cost analysis may reveal that the project does not pass economic muster now, but would be worth pursuing 10 years from now due to projected regional traffic growth. If so, it would be prudent to take steps now to preserve the future project's right-of-way.
- Which among many competing alternatives and projects should be funded given a limited budget. Benefit/cost analysis can be used to select from among design alternatives that yield different benefits (e.g., reconstruct a roadway with additional lanes versus no additional lanes); unrelated highway projects (a widened road versus an interchange on another road); and unrelated transportation projects in different transportation modes.

However, noted across the literature on benefit/cost analysis is that transportation agencies do not routinely apply benefit/cost analysis to determine project benefits in monetary terms, even for large projects.

Historically, cost analysis as it relates to asset life is a subject that has been strongly supported by the FHWA. FHWA notes that with respect to benefit/cost analysis, project benefits and costs should be evaluated relative to the life cycle of the highway assets in question. FHWA continues, noting that highway assets are expected to provide some measured benefit and perform above some minimum performance level during that period of time. The analysis includes costs incurred by agencies applying preservation, maintenance, and rehabilitation activities to maintain the asset. The product of a benefit/cost analysis includes a present value comparison of a project's life-cycle costs compared to the benefits derived from those costs.

Measures of Economic Development Impacts

Economic development is a broad field; but in general refers to the impacts on the level of economic activity in an area. Economic development impact measures attempt to quantify transportation's impact beyond simply helping people move from point A to point B. For preservation decisions, economic impact measures often seek to answer some form of the question: *What would be the impact if we allowed this roadway/bridge/roadway network fall into disrepair?*

Economic development impact measures are closely linked to the previous measures discussed. The primary difference is that the output of the measure is

tied to economic activity. There are a host of measures that capture transportation's broad range of impacts, such as personal income, tourism, property values. One popular impact measure used by many agencies is employment (jobs).

NCHRP Report 551 *Performance Measures for Asset Management* describes different types of asset management measures and a framework for using performance measures for asset management. As shown in Table 3.14, NCHRP Report 551 denotes those related to economic impacts, which can include direct (typically related to the cost of transportation experienced by users and shippers) or indirect impacts (transportation's contribution to the general economy). Researches also note that proxy measures are often used to gauge economic development impacts, such as traffic at border crossings, manufacturers/ shippers/employers who have relocated for transportation purposes, volume of freight originating or terminating in region, number or percent of employers that cite difficulty in accessing the needed labor supply because of transportation, and measures of truck travel per unit of regional economic activity.

Table 3.14 Economic Development Performance Measures

Measure Type	Examples
Economic Costs and Benefits	• Number of jobs within X minutes of population centers • Transportation-related impacts: jobs created, percent of state or regional gross product • Economic costs of pollution
Direct User Costs	• Average cost per trip • Average cost per ton-mile
Transportation Infrastructure Support for Freight Movement	• Road mileage converted to all-weather surfacing • Road mileage upgraded to support truck traffic
Support Improved Service to Existing Urbanized Areas	• Extent to which projects fall within census urbanized area
Support of Brownfield or Infill Sites	• Serves one or more Brownfield or infill sites (expressed as Yes/No on project basis; percent or qualitative measure on system basis)
Customer Perceptions	• Percent of business that cite problems with transportation as a major factor in relocation, productivity, or expansion

Source: Transportation Research Board, *Performance Measures and Targets for Transportation Asset Management*, (NCHRP Report 551), Washington, D.C., 2006.

NCHRP Synthesis 290 *Procedures for Assessing Economic Development Impacts from Transportation Investments* notes that the meaning of economic development impacts remains multifaceted, because there are many different ways to view and measure economic development impacts. In the context of transportation, economic development impacts are most frequently measured in terms of changes in business output (sales), income generated (value added or wages) and associated employment (jobs) within some given study area. Economic

development impact measures are not a substitute for evaluating transportation system user benefits; rather, it is used to provide insight into nonuser impacts.

The Strategic Highway Research Program (SHRP) 2 Report S2-C03-RR-1 *Interactions Between Transportation Capacity, Economic Systems, and Land Use* supports findings from NCHRP Synthesis 290. The Report notes that most types of economic development impact analysis focus on measuring economic activity expansion by looking at measures of jobs, income, GDP (value added), and business sales. The Report also notes that public groups sometimes broaden the scope of analysis to encompass a wider range of societal goals for economic development, including economic standards (e.g., unemployment rate, average wage, standard of living, and job skill level) and business factors (productivity and competitiveness). These analyses may also incorporate broader measures of quality of life (e.g., safety/security, air quality, and carbon footprint). As noted in the SHRP 2 Report, most agencies focus on jobs because they are most easily understood by the public and do not require potentially confusing inflation adjustments.

Conclusions for Economic Impact Measures

Effective performance measures are a key component necessary for advancing asset management business processes at transportation agencies. Economic impact measures require forecasting tools (e.g., financial, performance) that enable transportation agencies to be proactive and to actively intervene in the management of their assets to make smart and reasonable choices about investment and performance. Agencies do this through the application of an effective framework to drive decision-making. Analytic techniques and tools, quality data, and clear communication methods and messaging are all foundational parts of the process. In contrast, a less mature process is characterized by reactive decision-making in which decisions serve as reactions to conditions and problems which have already taken place.

There are several takeaways from the limited literature on economic impact measures and the concept of avoided cost in theory and in practice, described briefly as follows:

<u>General Observations</u>

- While many transportation agencies use performance measures to monitor transportation system performance, the practice of applying monetary values to the full range of impacts is still new for many agencies. As such, the area of economic impact is still evolving and there are not many cases that point to a mature process for measuring economic impact.
- The practice of performance management is evolutionary – today's measures generally reflect the tools and data currently available and speak to the challenges that agencies face today. As such, measures are not static, but can change over time.

- Measures of economic impact are most readily applied to pavements and bridges, as these assets tend to have the most mature management systems with data to support them.
- More research and agency documentation is needed to better understand alternative ways (beyond asset condition) that agencies are analyzing the impacts of asset performance and between alternative preservation policy choices.
- Predictive models and methods for relating investment levels to future performance are available, though taking advantage of these opportunities is not widespread across transportation agencies.

Life-Cycle Cost

- Life-cycle costs measures address all of the costs – agency and user – that are incurred during the service life of an asset.
- With respect to agency costs related to preservation, costs that are measured typically include the full schedule of expenses related to maintenance and rehabilitation activities.
- Agencies are well versed with LCCA, making it a good starting place to pivot from and develop economic impact measures.

Avoided Cost

- The concept of avoided cost is not broadly understood, nor is it being used widely by transportation agencies to communicate preservation needs, alternatives, and benefits.
- Avoided costs can be viewed as an extension of the thinking which began with LCCA. If an agency knows the best possible preservation programming to minimize life-cycle costs, avoided costs can communicate the costs of deviating from that programming.

Asset Sustainability Index

- The asset sustainability index captures the difference between the needed level of investment and the actual.
- It is one simplified way for agencies to apply the ideas behind avoided cost without getting bogged down in difficult analysis and hard to explain concepts.

Benefit/Cost/Performance-Cost

- Benefit/cost ratios measure and compare the social benefits and costs of transportation projects or programs.
- Benefit/cost analysis is most frequently used in project selection and justification.

- Performance-cost links long-range predicted performance with maintenance costs.
- Maturity levels in benefit/cost and performance-cost measurement vary significantly.

Economic Development Impact Measures

- Economic development impact measures attempt to quantify transportation's impact beyond simply helping people move from point A to point B.
- There are a host of measures that capture transportation's broad range of impacts, such as personal income, tourism, property values. One popular impact measure used by many agencies is employment (jobs).
- There is no standardization of economic development impact measures.

3.3 NEEDS/INVESTMENT ANALYSIS

In order to effectively program for preservation, a comprehensive preservation program requires analysis of long-term system investment need. Needs analysis includes estimating what system needs will cost and forecasting what revenues will be available to address them. Another aspect of a needs assessment is to identify the outcomes that would result if transportation system improvements were implemented to address the needs. It includes looking not only at the current condition of the system, but at future performance to meet specified goals and under different scenarios. In this context, agencies look at the impact of preservation and maintenance investment on performance. They use deterioration models and estimation mechanisms to identify the impacts of taking action to preserve their assets or of channeling their limited funds to other options, such as new capacity projects. In considering needs, agencies also look at the future demands on infrastructure and required future performance.

This section covers several of the tools that support need/investment analysis with a focus on what preservation measures can support this important step in the framework for performance-based preservation programming.

Models of Needs/Investment Analysis

There are different frameworks to support performance-based preservation programming that incorporate condition and preservation performance measures. Following is a brief overview of a range of frameworks in place that are being employed to support performance-based preservation programming.

NCHRP Synthesis 426 *Performance-Based Highway Maintenance and Operations Management* looked at current practices in performance-based management as applied to highway maintenance and operations. Thirty-one (76 percent) of state DOTs reported using a performance-based approach for managing maintenance and operations. Ten reported not using a performance-based approach.

Table 3.15 shows the degree to which the respondents organized and developed a performance-based process on a programmatic basis to address a range of business procedures and management decisions. Research findings suggest that all of the various approaches developed by state DOTs to date tend to share a common set of practices, perceptions, or characteristics at an overall level. These are summarized below:

- Address a wide range of highway features (e.g., road surfaces, bridges, pavement markings, drainage features, road signs, guardrails, and roadside and median vegetation.
- Maintenance and operations are delivered under the auspices of the state DOT using its own employee work forces, contractors, volunteers, or prison labor.
- Performance measures and level of service (LOS) thresholds currently tend to be defined on a uniform statewide basis.
- Inspections to determine field conditions that support the performance-based approach are conducted in various ways with no particular method predominating.
- Setting performance-based targets is accomplished as a matter of professional judgment considering several factors.
- State DOTs tend to look to several management tasks in common to be supported by performance-based methods (e.g., tracking of condition, performance, and quality; maintenance and operations prioritization; budget development and justification; development of needs-based management estimates; resource allocation among field offices; and an understanding of the relationship between LOS and cost).
- Solicit feedback from customers.
- Apply performance-based measures to contracts, often using the same LOS or performance measures as those applied to in-house forces doing comparable work.
- Agencies view communication of performance-based information as important, whether it concerns information prior to a decision or the consequences that may result following a decision.

Table 3.15 Categories of Performance-Based Use Defined in the Synthesis Survey

Category	Description	Agency Response
1. Primary Condition and Performance Data Tracking	M&O-related condition or performance measures provide data to track performance trends, identify critical needs, and support tasks such as budget requests, but otherwise are not used in day-to-day management.	5
2. Strategic or Generalized Program Performance Measures	Our agency uses several generalized or strategic performance measures (capturing facility condition, congestion, crash data, etc.) to assess multiple highway investment programs: maintenance and operations as well as capital preservation, mobility, safety, and so forth.	3
3. Performance-Based Process Just Beginning	This agency has just begun investigating performance-based concepts, and is formulating its approach to M&O-related performance measures or levels of service.	3
4. Performance-Based Performance Measures	Performance measures have been defined for maintenance and operations specifically, and are used in M&O management tasks such as planning, budgeting, prioritization, regional allocations of funding, and accountability for results.	6
5. Preliminary Maintenance and Operations (M&O) Levels of Service	The agency has defined M&O levels of service (including any underlying performance measures) for some or all activities/assets but these are preliminary and likely to be revised in the near future.	6
6. Mature M&O Levels of Service	The agency has a mature program of M&O levels of service (including any underlying performance measures) that is well integrated in management procedures, assessments, decisions, and systems, and is used in reporting and communication.	8
7. Not Well Described Here	The performance-based, LOS, or performance-based practices used by this agency are not well described by any of the above statements.	0

Source: Transportation Research Board, *Performance-Based Highway Maintenance and Operations Management*, (NCHRP Report 426), Washington, D.C., 2012.

NCHRP Synthesis 426 findings also reveal barriers to more widespread use of performance-based maintenance and operations management:

- The agency was evolving in its management approach, but no decisions had been made yet.
- The agency does not have the resources to support a performance-based approach.
- The agency's current management systems do not support a performance-based approach.
- The state government has not yet adopted a performance-based philosophy.
- One other respondent noted that his or her agency was satisfied with their current management approach and did not see a need to consider moving to performance-based methods.

Another framework is found in FHWA's Bridge Preservation Guide, which presents a framework for a systematic approach to a preventive maintenance program as part of a strategic, systematic, and balanced approach to managing bridge preservation and replacement needs. FHWA's Guide recognizes that focusing only on replacing deficient bridges while ignoring preservation needs will be inefficient and cost-prohibitive in the long term. Adopting a "worst-first" approach to managing bridge assets may also yield ineffective results that allows bridges in good condition to deteriorate into the deficient category which generally is associated with higher costs and other challenges. For example, FHWA's Guide notes that preservation activities often cost much less than major reconstruction or replacement activities. Delaying or forgoing warranted preservation treatments will result in worsening condition and can escalate the feasible treatment or activity from preservation to replacement. The latter will result in extensive work and higher cost. A viable alternative is timely and effective bridge preservation of sound bridges to assure their structural integrity and extend their useful life before they require replacement.

The FHWA Guide presents a framework known as the Systematic Preventive Maintenance (SPM), which is a planned strategy of cost-effective treatments to existing bridges that are intended to maintain or preserve the structural integrity and functionality of elements and/or components, and retard future deterioration, thus maintaining or extending the useful life of the bridge (see Figure 3.10). The FHWA Guide also notes that a SPM program can also be defined as a documented methodology regularly applied to repeatedly achieve a desired outcome or goal. An SPM program may be applied to bridges at the network, highway system, areawide, or regionwide basis.

Figure 3.10 Systematic Preventive Maintenance (SPM) Program

Source: FHWA, *Bridge Preservation Guide*, (FHWA-HIF-11042), Washington, D.C., 2011.

As shown in Figure 3.10, a SPM program has at a minimum the following six attributes:

- **Goals and Objectives –** Clearly defined goals and objectives for the SPM program.
- **Inventory and Condition Assessment –** Availability of tools and resources to conduct bridge inspections and evaluation.
- **Needs Assessment –** Documented needs assessment process that outlines how preventative maintenance (PM) needs are identified, prioritized, and programmed.
- **Cost Effective PM Activities –** Ability to demonstrate that the proposed PM activities are a cost-effective means of extending the life of a bridge.
- **Accomplishing the Work –** Availability of tools and resources to accomplish the PM work.
- **Reporting and Evaluation –** Ability to track, evaluate, and report on the planned and accomplished PM work on an annual and/or as-needed basis.

TRR 2361 *Prioritizing Infrastructure Maintenance and Rehabilitation Activities under Various Budgetary Scenarios* evaluates two approaches to infrastructure maintenance and rehabilitation that are often employed by transportation agencies: worst-first and benefit/cost. Researchers note that there is little research on the effectiveness of the worst-first approach under different budgetary scenarios. As such, this research is focused on the benefits and shortcomings of the worst-first approach to infrastructure maintenance and rehabilitation in relation to a benefit/cost approach based on analysis of highway pavement in Texas.

Results suggest that when maintenance and rehabilitation budgets are split, the disadvantages of the worst-first approach relative to the benefit/cost diminish. Separating the maintenance and rehabilitation budgets seem to be an effective measure to guard against the drawbacks of the worst-first approach. This is because separate budgets force prioritization approaches to select a balanced mix of maintenance and rehabilitation, and consequently produces similar network condition and backlog. When budgets for maintenance and rehabilitation are applied, the benefit/cost approach performs better in terms of network condition and backlog.

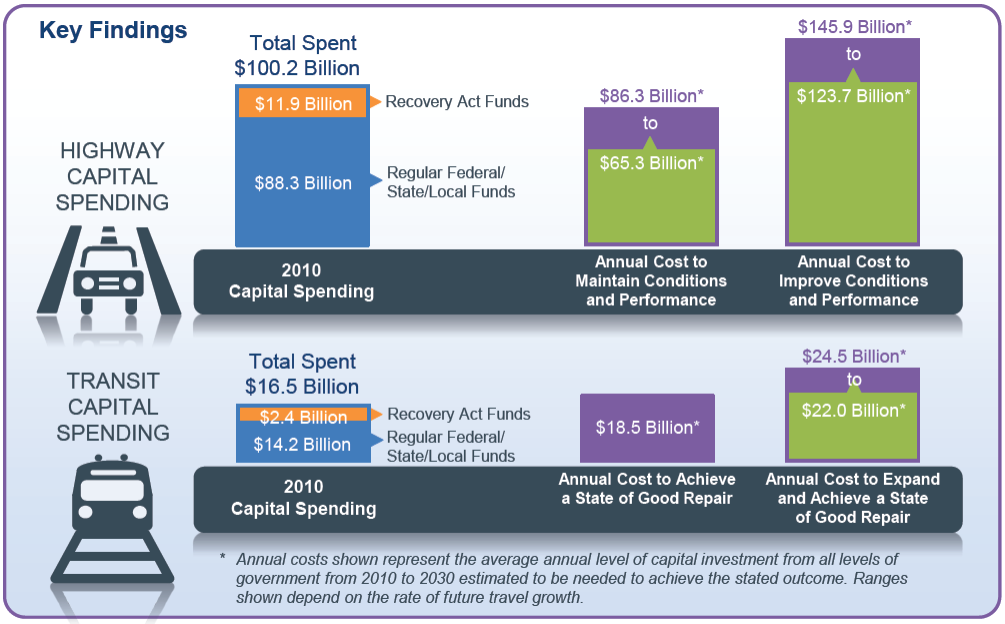
These frameworks reveal that there are different ways in which agencies can apply condition and economic impact measures to inform the preservation programming process.

Asset Deterioration Modeling

Deterioration modeling is widely used by transportation agencies as part of the process to analyze preservation needs from both a condition and a cost standpoint. In fact, many asset management systems for pavements and bridges have analytic capabilities to apply detailed deterioration models to forecast future asset condition. NCHRP Report 713 (Volume 1) notes that a range of deterioration models can used to forecast decline in condition in the absence of corrective action by the agency. More general than life expectancy models, they forecast not only the end-of-life, but all other possible condition levels as well.

Overall deterioration models help to inform decision-makers of the maintenance activities required and at what points in time those should occur to reach or maintain a certain LOS for different performance measures. Other tools that are used extensively in the analysis of preservation needs are the HERS Highway Economic Requirements System (as well as the State Version) and the National Bridge Investment Analysis System (NBIAS). (Neither the HERS or NBIAS model allow for multimodal analysis.) These tools have consistently been used to conduct the investment/needs analysis of highways, bridges, and transit for the Conditions and Performance reports to Congress, including the most recent 2013 report (see Figure 3.11).

Figure 3.11 Key Findings: 2013 Conditions and Performance Report



Source: FHWA, *2013 Status of the Nation's Highways, Bridges, and Transit: Conditions and Performance*, Washington, D.C.

HERS-ST is often used by DOTs to conduct needs assessments and/or as part of performance-based planning processes. According to the FHWA HERS-ST is an engineering/economic analysis (EEA) tool that uses engineering standards to identify highway deficiencies, and then applies economic criteria to select the most cost-effective mix of improvements for systemwide implementation. HERS-ST is designed to evaluate the implications of alternative programs and policies on the conditions, performance, and user cost levels associated with highway systems. The model will provide cost estimates for achieving economically optimal program structures, as well as predict system condition and user cost levels resulting from a given level of investment.

Similarly, the NBIAS model can be used to conduct needs assessments and/or as part of performance-based planning processes. According to the FHWA, NBIAS performs a system-level analysis of anticipated bridge investment needs and outcomes. Data is used to calculate performance trends, financial needs for maintaining specified performance levels, and the outcomes of various funding scenarios.

Asset deterioration models require accurate condition measures to assist in performance-based preservation programming. For example, the HERS model uses information on pavements, geometry, traffic volumes, vehicle mix, and other characteristics from the Highway Performance Monitoring System (HPMS) sample dataset. NBIAS uses structural deficiency or condition ratings for bridges. Together these tools translate condition measures into system needs, enabling scenario analysis which links investment packages to performance.

Economic Impact Modeling

In general, various economic analyses can be conducted to support and inform needs/investment analyses. As such they serve as a component of an integrated preservation planning and programming process where the results of needs/ investment analyses help inform project and program decisions. Economic impact models generally support performance-based preservation programming by providing measures as their output. These measures can then be considered as part of decision-making. Transportation decision-makers can identify where investments that preserve the transportation system have broad economic impacts.

NCHRP Synthesis 424 *Engineering Economic Analysis Practices for Highway Investment* describes a range of EEA methods to support transportation decisions. EEA include, but are not limited to, LCCA, benefit/cost analysis (BCA), present-worth analysis, measures of cost-effectiveness, and cost avoidance as a concept of benefit. These may be applied at one or more stages of a project life cycle, such as planning, project scope development, programming (including ranking, project selection, and budgeting), resource allocation, best-value procurement, project design and development [including value engineering (VE) at the preliminary engineering or concept development stage], construction (e.g., analysis of options for accelerated project delivery), and operation and maintenance. These often are used around the selection of a preferred alternative among projects or assessments of levels of service. Overall EEA provides a way of comparing the economic gains expected from an investment with the cost of that investment; providing an objective understanding of value to be expected for cost incurred.

The report describes the value of performing economic analyses as two broad classes of benefit:

- The first is the direct or tangible benefit of having obtained an economic result that shows the value or merit of a highway investment. This value may be in benefits received by road users or costs avoided by them and by the agency. There is generally a link between economic performance (benefits versus costs) and engineering or technical performance of the highway facility. Monetized benefits help in understanding tradeoffs among competing alternatives. The process of preparing an economic analysis also imposes a discipline to account for all costs and all benefits in as comprehensive and accurate a way as possible.
- The second is the indirect or intangible benefit of encouraging a better decision process within the organization. This benefit and its implications are discussed at length in Section 4.0, but generally relate to an incentive to identify all realistic alternatives for solution, to maintain focus on the purpose of the proposed investment and avoid "scope creep," to avoid biases toward familiar or traditional options (such as particular paving materials), and to support these objectives through clear agency guidance and communication, backed by the availability of analytic tools and effective data collection and processing.

With respect to economic impact analysis (EIA), explicitly, the report notes that EIA provides an analysis of the direct effects that a project or service has on the economy of a defined area, measured by resulting changes in business output, jobs, income, or tax revenue. According to the FHWA, EIA captures how the direct benefits and costs of a highway project (such as travel time saving) affect the local, regional, or national economy. It attempts to measure the consequences that a highway project or action will have on considerations such as local or regional employment patterns, wage levels, business activity, tourism, housing, and even migration patterns. In other words, economic impact analyses are a method for providing insights into the overall economy, where benefit/cost analysis measures the efficiency of spending from the viewpoint of benefits and costs to society.

As shown in the National Surface Transportation Policy and Revenue Study Commission Briefing Paper 4K-06 *Economic Impact Analysis in Public-Sector Infrastructure Investment Decisions* Table 3.16 describes typical types of impacts addressed in an EIA.

Table 3.16 Economic Impacts Measured Using EIA

Economic Impacts	Measure
Standard Measures	
Regional Output	Value of all business sales of goods and services, including intermediate products.
Gross regional product (GRP) or value added output	Value of goods and services produced in the region that are not purchased for further processing or resale in the region. This is the most useful measure for representing real changes in economic activity.
Wages or personal income	The dollar value of wages represents a portion of the value of output measures.
Employment	Number of jobs.
Related Indicators	
Productivity measures	Measures such as the ratio of output to cost of some input showing efficiency.
Capital investment	Money spent on improvements for land, construction of buildings, purchases of equipment, etc.
Property value appreciation	Increases in appraisal values or rents for property
Miscellaneous other measures	Numerous other measures include tourism dollars, unemployment rates, changes in business composition, etc.

Source: National Surface Transportation Policy and Revenue Study Commission Briefing Paper 4K-06.

Life-Cycle Cost Analysis

LCCA, introduced earlier, allows all costs over the life of an asset or project to be consolidated into a single present value. Costs that are measured typically include the full schedule of expenses related to maintenance and rehabilitation activities.

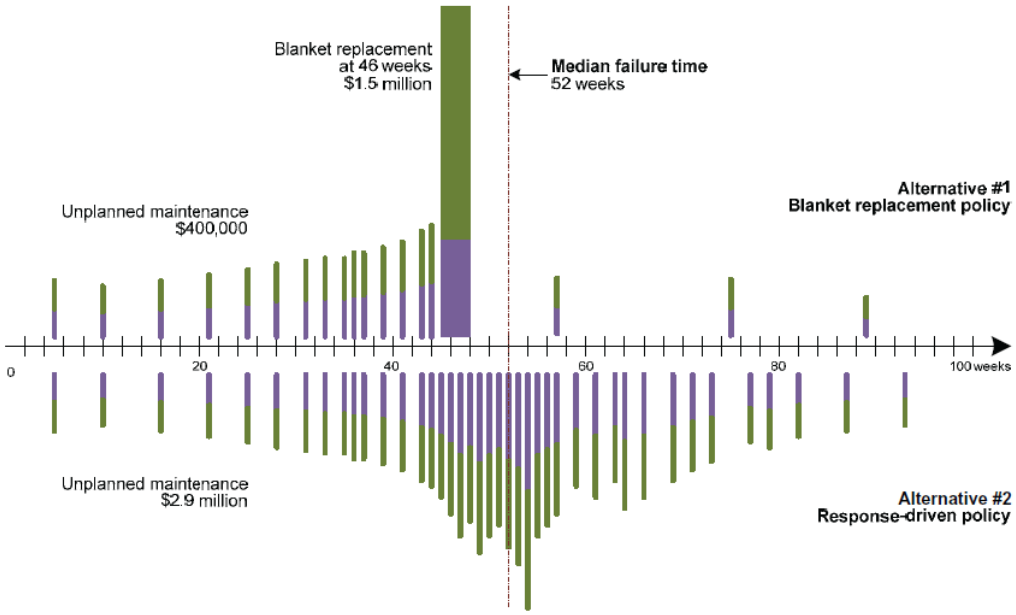
NCHRP Report 713 (Volume 2) *Estimating Life Expectancies of Highway Assets* describes how life expectancy estimates are estimates into asset management functions, with applications in evaluating, ranking, valuing, and budgeting asset replacement and life-extending maintenance/preservation activities. LCCA allows for the economic-based evaluation of competing alternatives over an analysis period, in consideration of monetized benefits and costs. LCCA can examine alternative preservation strategies for existing transportation assets. For example, LCCA can be used to compare alternative preservation activities, justify routine preventive maintenance, identify the optimal replacement interval, compare design alternatives, compare life extension alternatives, price design and preservation activities, synchronize replacements, and assess the value of life expectancy information. In the asset management task of preservation treatment or strategy (policy) identification, the optimal treatment or strategy does one of the following:

- Minimizes the lifecycle costs over the asset lifecycle at a specified level of benefits;
- Maximizes the lifecycle benefits under given cost constraints; or
- Maximizes some function of the lifecycle benefits and costs under benefit and/or cost constraints.

LCCA is used widely by transportation agencies given legislative requirements, including Governmental Accounting Standards Board (GASB) 34, to use of lifecycle costing in highway design, engineering, and management. With respect to budgeting, NCHRP Report 713 (Volume 2) notes although many agencies still practice "worst-first" activity planning, long-term life expectancy forecasts can be used to minimize the lifecycle costs of assets and identify needs prior to any potential shortage of funds. If replacement is the most viable option for an asset within the planning horizon, then the replacement cost directly adds to the budget needs.

As noted in NCHRP Report 713 (Volume 1), lifecycle cost models are key ingredients in asset management systems. Figure 3.12 shows an example of lifecycle cost analysis, for replacement of traffic signal lamps.

Figure 3.12 Example of Cost Streams for Traffic Signal Lamp Replacement



Source: Transportation Research Board, *Estimating Life Expectancies of Highway Assets, Volume 1: Guidebook*, (NCHRP Report 713), Washington, D.C., 2012.

Conclusions for Needs/Investment Analysis

Overall, transportation agencies have building blocks in place through existing asset management systems and tools to support various asset management applications. While imperfect, these systems and tools typically include the use of preservation measures and, with additional work, can also be incorporated into various techniques to support the calculation of economic impact. Clearly every agency has its own needs so asset management applications may differ from one to another. Moreover, there is no "right approach." The process of conducting a needs/investment analyses itself is an important exercise for an agency to conduct as part of a larger asset management planning and programming framework.

As described in this section, there exists a range of techniques to accomplish effective needs/investment analysis. Some of these processes require condition measures as inputs, while others can be used to generate measures. Some of these techniques can be readily applied to capacity-related projects (as opposed to maintenance projects), and represent a more mature state of practice. Overall quality data are key to conducting quality analyses. Agencies that focus on regularly collecting, analyzing, and expanding their data programs are well positioned to apply these data in meaningful ways to support preservation programming. Moreover, ensuring quality data are available as well as adding data characteristics to existing datasets helps to strengthen the accuracy and confidence of outputs. In addition, it allows agencies to creatively utilize their

datasets in new ways, to analyze different aspects of preservation and maintenance investment on performance, and to effectively develop targets.

3.4 TARGET SETTING

Target setting is another key element in performance-based preservation programming. Whether officially adopted or not, transportation agencies use targets to drive investment and understand investment tradeoffs. Target setting activities can range from merely minimizing customer or political complaints up to sophisticated condition-based targets which vary by asset type.

Formal target setting has recently seen greatly increased emphasis. In 2012, MAP-21 established a performance and outcome-based program with the objective for states to invest resources that collectively support national transportation goals. Specifically, the legislation's national goal for infrastructure condition is to maintain the highway infrastructure asset system in a state of good repair. To support this goal, states and their MPOs were required to coordinate and set target thresholds:

- Each state must maintain minimum thresholds for Interstate pavement condition; and
- No more than 10 percent of total NHS bridge deck area may be on structurally deficient bridges.

MAP-21 also requires that states integrate these goals in the state asset management plans under the National Highway Performance Program (NHPP). This legislation requires that states and MPOs be accountable for target setting to meet bridge and pavement condition thresholds. If a state fails to meet the thresholds over a statutorily designated time period, MAP-21 requires the state to reserve a specified portion of its NHPP funding for Interstate pavement and NHS bridge projects.

The Role of Target Setting in Preservation Decisions

Closely linked with a needs analysis, agencies set condition and performance targets to ensure they are using available resources in the most effective manner in responding to the customers' needs and achieving broad agency goals and commitments. This process is often informal (even taking actions to avoid negative consequences such as complaints from drivers is target setting) but is more frequently being employed as part of comprehensive asset management. System condition targets prevent project decisions from being made entirely in isolation. Targets rely on preservation measures to identify the objective state-of-good-repair or performance and to indicate where this state is achieved or lacking. Target setting often represents an effective way to evaluate the implications of different cross-asset allocation strategies.

Performance targets require consideration of a mix of influencing factors:

- Financial Resources
- Technical Resources.
- Political/Legislative Influence
- Customer Service Focus
- Performance-Based Preservation History/Evolution in State of the Practice
- Commitment to Regular Communication and Reporting
- Span of Control/Agency Jurisdiction
- Timeframe
- Organizational Structure
- Stakeholder Expectations
- Internal Support/Culture

NCHRP Report 666, expanding upon a process first outlined in NCHRP Report 551, describes seven steps for establishing performance targets by considering all of these factors.

Step 1: Establish Performance Management Framework.

Establish the Framework that links organizational goals to resources and results. Performance measures and their attendant targets are the link connecting goals to specific investments.

Step 2: Evaluate the Factors Influencing Target-Setting.

Ask the right questions about the factors internal and external to the agency that affect target-setting and the approaches that can be used.

Step 3: Select the Appropriate Approaches for Target-Setting.

Based on the factors in Step 2, select an approach or approaches for setting targets. These include five basic approaches (Table 3.17).

Table 3.17 Managing Risk of Target-Setting Approaches

Target-Setting Approach	Advantage	Risk	Approach to Balancing Advantages with Risks
Edict	• Less time- and money-intensive. • Unequivocal and well-understood.	• Lack of defensibility and inclusion.	• Use hybrid approach.
Expert Opinion	• Insures broad understanding and acceptance within and outside agency.	• May founder in effort to be inclusive.	• Appoint internal champion to lead effort to identify the "critical few" measures and targets.
Customer Feedback	• Insures more transparent process.	• May be confusing to discuss technical measures with public.	• Describe measures and targets in the simplest terms possible.
Benchmarking	• Provides a peer group comparison.	• Can be misused for comparative rankings.	• Continue to refine comparative analysis techniques.
Modeling	• Defensibility. • Better understanding of future performance.	• More time- and money-intensive. • Models change over time.	• Continue to refine modeling techniques. • Use hybrid approach.

Source: NCHRP Report 666.

- **Edict –** In this approach the target is set by management or elected leaders. The underlying principle of this approach is that success in hitting the target is entirely a function of motivation and execution, and that planning is a relatively minor part of reaching the target. The advantage of the Edict approach is that the target is unequivocal and well-understood throughout the organization. The challenge is that the approach is not inclusive or consultative.
- **Expert Opinion –** This approach leverages the technical, practical, and local knowledge of members of the agency and stakeholders within the agency's jurisdiction. Not only does this help to ensure that targets will reflect local and stakeholder priorities, but also that they will better reflect "on the ground" reality. Such a process is usually informed by internal staff analysis, but ultimately approved by an agency's executive management and stakeholder committees.
- **Customer Feedback –** Under this approach, direct feedback on system performance and objectives for transportation investment are gathered from the transportation system user through a variety of survey and outreach methods. This feedback is then used by transportation agency staff to

develop specific measures and targets that are closely aligned with the needs of the traveling public (the "customer").

- **Benchmarking –** Benchmarking as a target-setting approach provides a transportation agency with the means to establish targets in a relatively quick and efficient manner that can be realistically achieved. Under this approach, criteria should be set for peer group selection and analysis, such as similar investment approaches, jurisdiction, and span of control, and agency size. Once the peer group is set, practitioners should review each agency's performance measures and targets, and the degree to which those targets are being achieved. The comparison among agencies will help guide the final determination of targets within selected performance measure categories.

- **Modeling –** Top-down modeling determines the strategies or funding needed to achieve the target; Bottom-Up Modeling determines what level of performance is possible, and then uses that to calculate the expected target. For preservation target-setting, targets can be set (where feasible) based on economic efficiency considerations, including minimizing life-cycle costs and maximizing the benefit obtained for a given level of investment.

  Example approaches for setting infrastructure condition goals include:

  - Establish a threshold for "poor" pavement based on a level of roughness that is noticeable to road users (particularly trucks) and is associated with a marked increase in road user costs (due to vehicle wear and tear, increased fuel consumption, or reduced speed). Set a long-term goal of having minimal travel on poor roads (e.g., less than five percent).

  - Use capabilities of pavement and bridge management systems to determine a long-term optimal network condition distribution, which minimizes life-cycle costs. Use this distribution to set goals for either average condition or percent of infrastructure (e.g., number of bridges, deck area, and miles) above a given threshold condition level.

  - Base goals on maintaining a steady-state condition distribution to avoid future peaks in preservation or replacement costs that would be difficult to address given a relatively constant level of funding. These goals would be expressed in terms of the percent of the network in different ranges of condition level (or remaining life categories).

  Ideally all performance targets, particularly those that apply to a relatively short time horizon (e.g., fewer than 5-7 years), should be placed within the context of future funding availability. Projections of future funding can be made based on past trends and available information about future appropriation levels. Historical breakdowns of funding allocation and use to program areas and cost components can provide useful input to future projections. In many instances, a scenario approach can be used, in which targets are set based on continuation of current funding levels, 10-20 percent lower, and 10-20 percent higher.

The capability to predict performance and relate performance to cost is required to formulate realistic targets based on anticipated funding availability. Many pavement and bridge management systems include this capability as a standard feature. Other tools, such as the FHWA Highway Economic Requirements System – State Version (HERS-ST), can predict a broader set of preservation, safety, and congestion-related performance measures for different resource allocation scenarios. Some agencies have developed in-house tools or informal spreadsheet-based or "back-of-the-envelope" calculation methods to provide this capability as well.

Based on the influencing factors, as well as practical limitations in data and tools, agencies need to identify which measures to include for each type of target-setting approach, or whether to include them for a target at all, by considering:

- Some qualitative measures are not amenable to quantitative target setting.
- Some measures do not have sufficient base or trend data to allow for reasonable targets, or do not have available tools or methods for predicting values.
- Where targets for multiple measures are being considered for a given policy objective (e.g., pavement preservation), technical analysis should be conducted to see if one of the measures acts as a "controlling target."

Ultimately, the ideal approach for setting any target is likely a hybrid of the various approaches stated above.

Step 4: Establish Methods for Achieving Targets.

Within the context of the Performance Management Framework, identify methods that orient the agency and its resources towards achieving the targets set in Step 3.

Step 5: Track Progress Towards Targets.

Track progress specifically against targets.

Step 6: Adjust Targets Over Time.

Based on financial and political realities (e.g., dramatic rise in gasoline prices or passage of a new transportation finance package), ease, or difficulty of achieving targets, and increasing experience in performance-based allocation of resources for asset preservation, continuously reevaluate and adjust targets.

Table 3.18 shows examples of preservation performance targets from several agencies.

Table 3.18 Examples of State DOT Performance Targets

Measure	Description	State	Target
International Roughness Index (IRI)	Index based on vehicle response to roughness (lower = smoother)	Federal	93% ≤170
		Louisiana	<15% >170
		Nevada	I – 70% <80 II – 65% <80 III – 60% <80 IV – 40% <80 V – 10% <80
		Pennsylvania	94
Pavement Condition Survey	0–10 scale for pavement segments based on ride smoothness, pavement cracking, and rutting	Florida	80% >6 for all 3 criteria
NBI Appraisal Ratings	0–9 scale based on deck, substructure, and superstructure condition	Ohio	≥85% of deck area ≥5
		Delaware	75% ≥6 <10% ≤4
		Washington	95% Good or Fai

Source: NCHRP Report 551.

Cross-Asset Resource Allocation

Cross-asset resource allocation is a framework to optimally distribute the budget across multiple assets such as pavements, bridges, culverts, guardrails, and signals, and to promote the quality of service of the entire facility. Cross-asset resource allocation is complicated by the heterogeneity of assets with different goals and objectives, and their relative merit to the overall system. In addition, an allocation framework can also consider impacts on environment, land use, greenhouse gas emissions, recycling practices, and material consumption, for instance, have to be included into the overall decision framework.

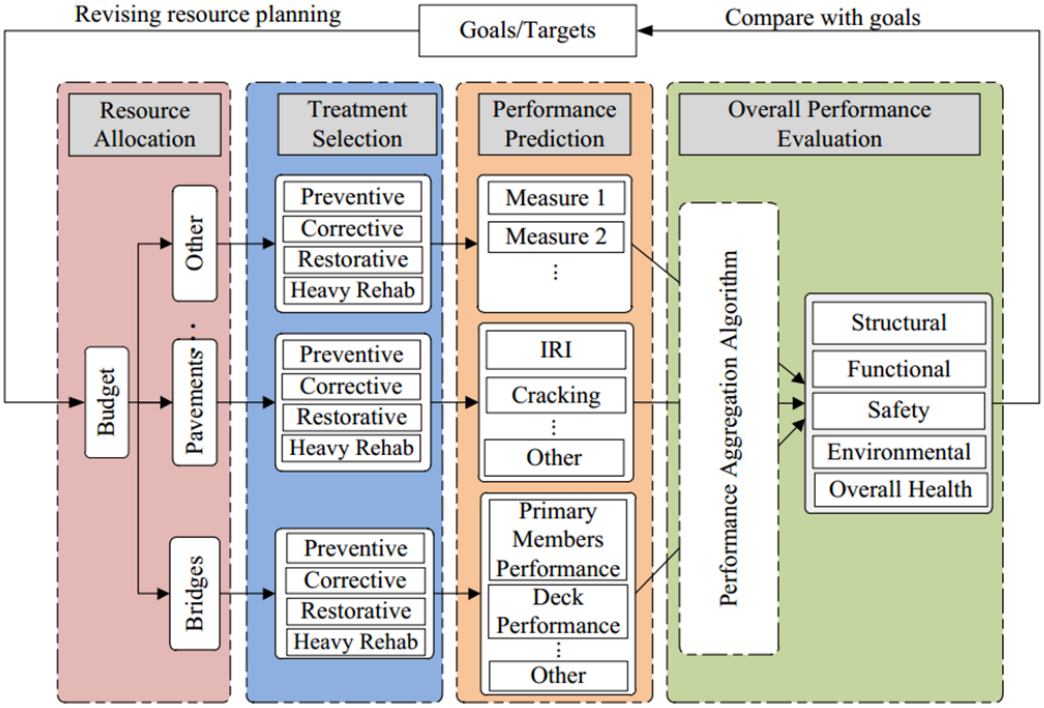
Performance measures that reflect the physical condition of assets tend to be unique to each specific asset class and are therefore difficult to use for cross-asset class comparisons. However, if physical condition measures are translated into measures of user benefits/costs and agency "avoided cost," these higher-level measures could be the basis of some cross-asset class comparisons.

Dehghanisanij et al. proposed a sustainable cross- asset management framework in TRR 2361 *Cross-Asset Resource Allocation Framework for Achieving Performance Sustainability*. It consists of four steps:

- **Resource allocation.** The process begins with an initial allocation scenario based on expert opinions, goals and objectives, and agency constraints. In this framework, the results and outcomes of each resource allocation scenario are compared with the agency's goals and objectives, and are used to update the scenario until the optimal resource allocation is reached.
- **Treatment selection.** Once the agency selects a resource allocation scenario, the resources are distributed across its assets. The agency then selects best maintenance treatments based on the available budget. The treatments are classified under the main categories of preventive, corrective, restorative, and heavy rehabilitation.
- **Performance prediction.** After the agency selects treatments, the next step is to predict performance improvements from maintenance applications. Functional performance represents an evaluation of the asset serviceability and superficial conditions (i.e.; roughness, surface friction, etc.) and structural performance identifies asset distresses and structural deficiencies. These two performance types can be combined with other performance features such a safety or environmental evaluation to develop a combined performance.
- **Overall Performance Evaluation.** The predicted performance measures for each assets are aggregated into combined measures that explain the entire corridor or facility's performance by:
  - Converting quality measures to performance indicators (on a scale of 0 to 10). Performance indicators for each bridge element are calculated based on the total quantity of element type.
  - Converting performance indicators to asset health indicators. The asset health indicators is a weighted average of performance indicators across different quality measures of an asset.
  - Aggregating the asset health indicators into corridor health indicators. The corridor health indicator is a weighted average of asset health indicators across the corridor's assets.
  - Aggregating corridor health indicators into the overall corridor health rating. Weights are applied to each corridor health indicator indicating its importance to overall corridor health rating.

Figure 3.13 shows the four steps of the cross-asset resource allocation framework.

Figure 3.13 Cross-Asset Resource Allocation Framework



Source: Dehghanisanij et al., 2013. *Cross-Asset Resource Allocation Framework for Achieving Performance Sustainability*, Transportation Research Record 2361.

Functional, structural, and environmental performance measures

Dehghanisanij et al.'s proposed framework assessed each maintenance treatments by three sets of performance measures:

- Functional gain (scale of 0 to 10) after preventive maintenance by analyzing data on gains in associated performance measures after the maintenance activity. Preventive maintenance effectiveness from real pavement sections. Transportation agencies can use common indices such as IRI and Rutting, or their own performance measures, since deterioration trends and maintenance effectiveness significantly change depending on traffic levels, climate conditions, and current pavement structure.
- Structural evaluation was conducted by analyzing the improvements on the asset's structure. Several commonly used indices for evaluating the structural capacity of pavements and bridges were analyzed and used to derive an effectiveness value (0 to 10 scale).
- Environmental impacts are usually measured through the computation of the greenhouse gases (GHG) emitted in the atmosphere during the whole process over the life cycle of a product; this is also known as carbon footprint. A carbon footprint is a measure of the impact a specific activity has on GHG emissions. It is composed of six GHGs. To simplify the calculations, emissions from the six gases are combined together into the equivalent carbon dioxide.

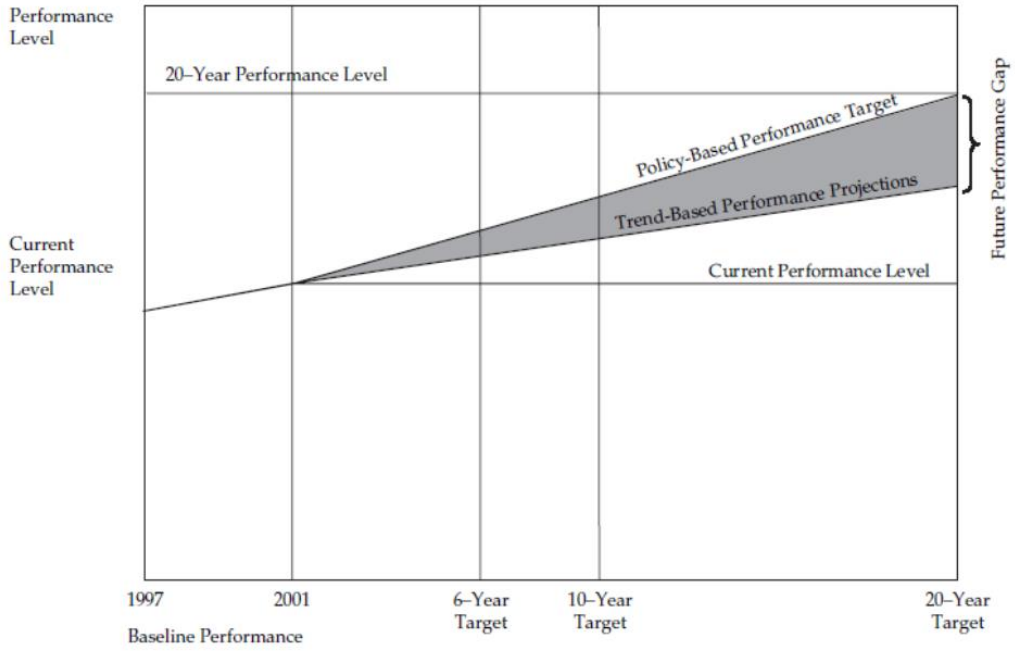
Minnesota Example

States have various practices in target setting. For instance, in the past Minnesota DOT has developed targets in a short-, medium-, and long-range context. Short-term targets are more financially constrained, while longer-term targets have more latitude. Minnesota DOT defined three performance measures categories and treats them differently in target setting:

- **Mature –** baseline data exist, and targets have been set;
- **Emerging –** data are available, but targets are not yet established; and
- **Developmental –** neither data nor targets now exist.

Minnesota DOT only set targets after a baseline data trend was established. For mature measures, the agency compared current performance level with trend-based performance projections and policy-based performance target, as shown in Figure 3.14. This allowed Minnesota DOT to highlight the future performance gap, and allows the agency to compare actual level with targets to ensure that the targets were achievable.

Figure 3.14 Minnesota DOT's Performance Target Levels



Source: NCHRP Report 551.

Following the target-setting steps from NCHRP Report 666, MnDOT has continued to evolve in their target-setting practices, regularly evaluate targets, and refine those targets. As their capabilities have become more robust, MnDOT has modified its target-setting approaches.

For pavement preservation, MnDOT's primary performance measure for planning purposes is percent good, fair, or poor based on the ride quality index (RQI). Policy performance targets have been set previously as 70 percent good for all principal arterial Interstates, with a minimum of 2 percent poor. Based on the trends and projected annual funding, the funding shortfall is estimated.

As part of the 2013 Minnesota GO State Highway Investment Plan, MnDOT began incorporating risk into the target-setting process for the remaining roadway network. This approach examines several different funding scenarios in each program area (such as pavement preservation), and projected outcomes for each measure. A minimum level of acceptable risk (the minimum "target") is set, so that all funding for pavement will be at or above this level. Conversely, the maximum is reached when no more remaining funding is available, as these funds are reserved for reaching the minimum levels of risk for all other performance measures. Several intermediate scenarios are evaluated as well, with resulting projected targets between the minimum and maximum.

This evaluation of different performance outcomes with different funding levels (and therefore different possible targets) not only incorporates risk, but also evaluates the tradeoffs of achieving different levels of performance in different goal areas, as well as across different assets.

Conclusions for Target Setting

Formal target setting remains relatively immature as an area, and few best practices have emerged that are directly applicable to preservation. Agencies have successfully used various kinds of measures.

The importance of target setting, however, does fuel the need for better condition data. MAP-21 and the subsequent rulemakings started to establish formal target setting requirements. Data are needed to establish a baseline, establish achievable targets, and monitor results.

In the important area of cross-asset resource allocation, agencies need to be able to translate condition to performance and find a method for comparing performance impacts on users.

3.5 RISK ANALYSIS

The Role of Risk Analysis in Preservation Decisions

Risk analysis helps agencies assess potential risks and understand how their actions can mitigate these risks. Risks affecting preservation activities can range from the agency level (funding shortfalls, increasing construction cost inputs, declining political capital) to the program level (loss of preservation funding in favor of capacity projects, natural events with broad impacts on infrastructure health) to the asset or project level (accelerated deterioration due to natural events, security). Risk analysis uses preservation measures to quantify an

event's potential impacts and its effect on performance. Risk analysis supports needs assessment and target setting.

To begin analyzing risks, agencies must first identify its key assets and possible risks to these assets. Some of the major assets will be readily identifiable, such as the components of the Interstate Highway System, other may be less apparent. The FHWA's Risk-Based Transportation Asset Management Report identified two major types of risks:

- Risks due to gradual failure or gradual degradation of asset performance. These can be caused by a lack of sound preservation practices, inadequate asset inventories, a lack of management systems or weak asset management policies to ensure sound long-term performance for the lowest possible lifecycle costs.
- Risk to a network or corridor can also be considered from a perspective of sustaining it in fully functioning and good condition at the lowest possible life-cycle cost to preserve its long-term value.

The risk identification process develops an asset risk inventory or "risk register" documenting the following information:

- Date and phase of project development when risk was identified.
- Name of risk and whether it poses a threat or present an opportunity.
- Detailed description of risk event – the description should provide information that is specific, measurable, attributable, relevant, and time bound.
- Risk trigger – each identified risk must include trigger(s) that signal imminent threat or opportunity.
- Risk type – these risks could be possible threats such as increasing traffic loadings, or climatic, seismic, geologic threats. They could also include organization risks (weak internal management systems) or financial risks (such as increasing costs, decreasing revenues, and resulting budget constraints).
- Potential responses to identified risk – can the identified threat be avoided, transferred, mitigated, or is it to be accepted?

Case Studies in Risk Analysis

Various state DOTs have conducted risk analysis to estimate the cost of maintaining assets at certain measure thresholds. This section describes examples from Michigan DOT and Florida DOT.

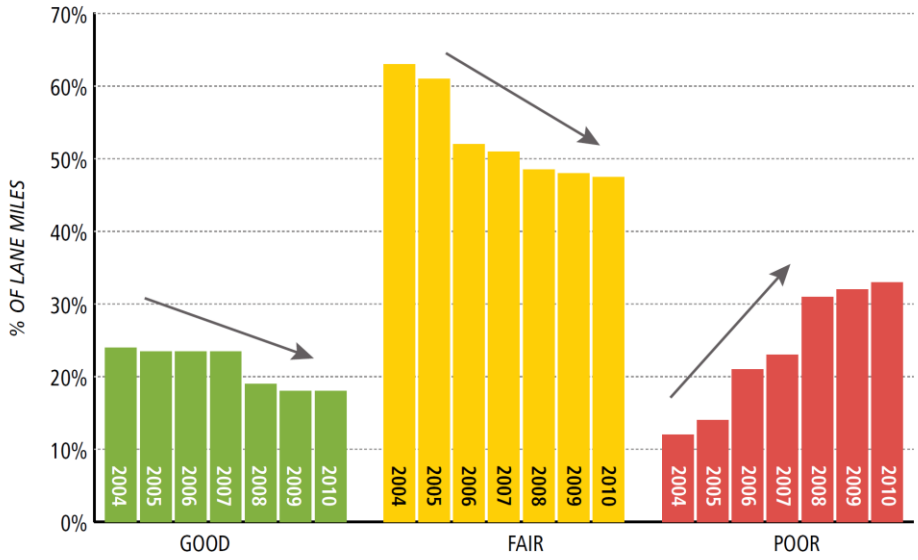
<u>TAMC – Pavement Condition Measure</u>

The Michigan Transportation Asset Management Council (TAMC), a legislated council with representatives from agencies responsible for managing or funding

roads, conducted a series of analyses looking at pavement condition from 2004 to 2010. In these analyses, TAMC identified that:

- The trend of roadways in poor pavement conditions have increased over the year as shown in Figure 3.15; urgent action is necessary, as returning poor roads to good condition costs four to five times more than maintaining a road in fair condition.
- As a result of declining condition, the percent of lanes needing structural improvements during this time period doubled to 34.8 percent.
- During the time period, the Michigan's Transportation Fund's (MTF) total gross revenue dedicated to roads and bridges have declined by 200 million dollars.

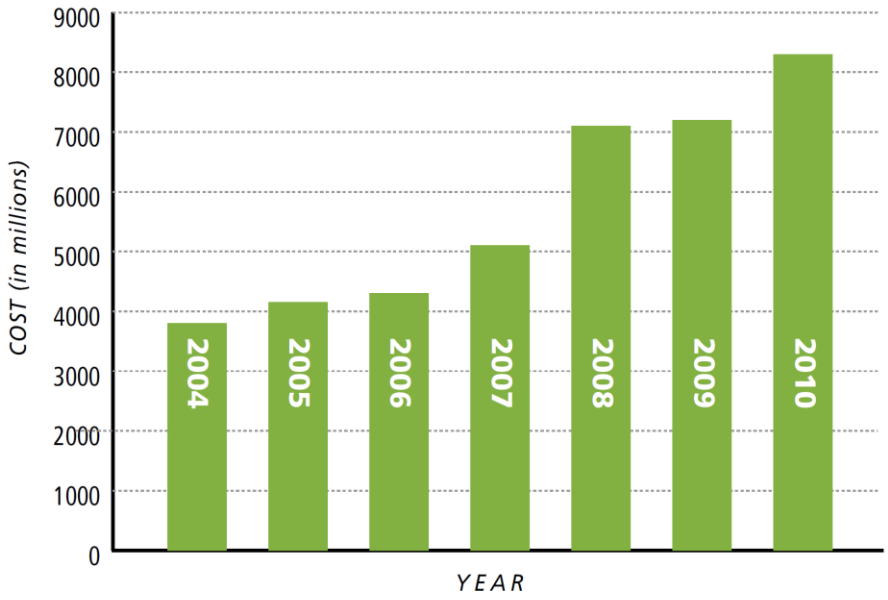
Figure 3.15 2004 to 2010 Pavement Condition



Source: FHWA's Risk-Based Transportation Asset Management: Managing Risks to Networks, Corridors, and Critical Structures – Report 4.

TAMC used these three pieces of risk analysis information to warn of the impending financial and economic risk that needs to be averted. TAMC's analysis also showed that the cost of returning all lane miles to good condition almost doubled from 2004 to 2010 (see Figure 3.16) and highlight the risk of loss in value of the road assets without immediate injection of fund.

Figure 3.16 2004 to 2010 Pavement Condition



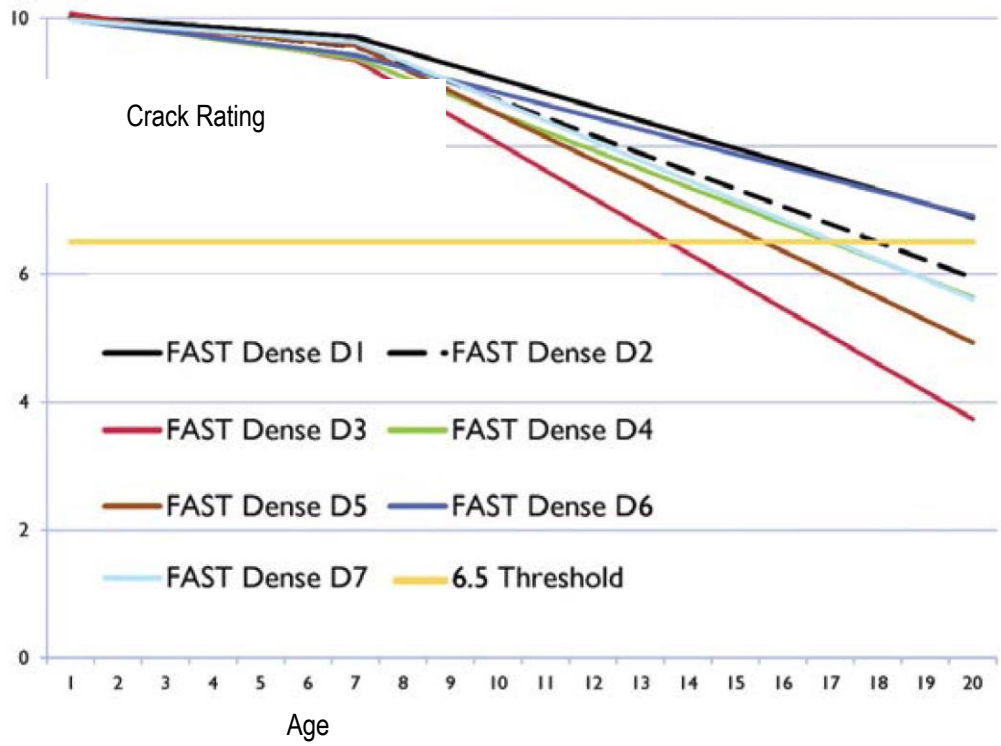
Source: FHWA's Risk-Based Transportation Asset Management: Managing Risks to Networks, Corridors, and Critical Structures – Report 4.

Florida DOT – District- and System-Level Pavement Performance

The Florida DOT uses an in-house management system called "Florida's analysis system for targets" to track pavement conditions. The DOT used over 35 years of historical pavement condition data to study the impact and relationship of several variables, including truck volume, average daily traffic, geographic location, asphalt thickness, and surface type to performance. This analysis helped the agency determine the variables that had the greatest correlation to pavement performance – the geographic district where the roadway was located, and the surface type (open versus dense) – were the most reliable factors in predicting future pavement performance. By knowing each district's performance characteristics, Florida DOT can apply an expected performance curve to each individual roadway.

Figure 3.17 shows the pavement deterioration curves by district for cracks on dense graded surfaces. Similar deteriorations curves are generated for open-grade surfaces as well for other factors such as smoothness and rutting. The predicted risk to the pavements based on the analysis enables the DOT to make financial decisions and to accurately allocate funds based on expected future needs.

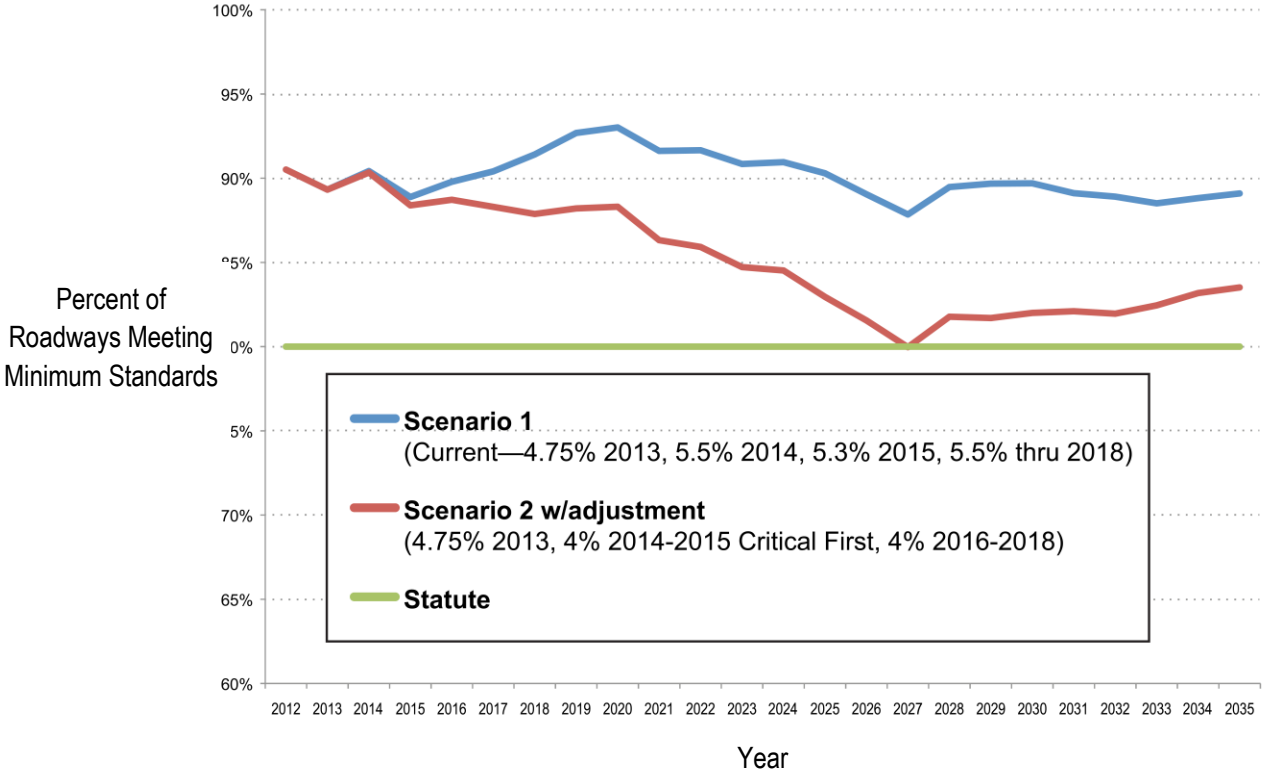
Figure 3.17 Plot of Predicted Crack Rating versus Age by District



Source: FHWA's Risk-Bas Risks to Networks, Corridors, and Critical Structures – Report 4.

Florida DOT's analysis of historical data enables the agency to make funding decisions about pavement preservation activities five years into the future. Figure 3.18 shows how predicted future pavement performance is used to make funding decisions. The green line shows the DOT's statutory requirement – to keep a minimum of 80 percent of the state's pavements meeting the Department's minimum standards. In May of 2012, over 90 percent of the state's pavements met Florida DOT's minimum standards. The current policy (as of May 2012), shown in blue, was to resurface 5.5 percent of the state's highways annually. That policy was predicted to result in performance that would exceed 93 percent by 2020 and remain at a level below 95 percent through 2035. The analysis indicated to the upper management that the DOT was over-preserving the system and the effort on resurfacing be lowered. This resulted in a decision to resurface 4 percent of the system annually through 2018, with a return to 5.5 percent in 2019 (revised policy, shown in red). The Agency is currently pursuing this revised policy that is projected to bring the system performance back below 85 percent by 2023.

Figure 3.18 Forecasted Scenarios of Pavement Performance



Source: FHWA's Risk-Based Transportation Asset Management: Managing Risks to Networks, Corridors, and Critical Structures – Report 4.

Conclusions for Risk Analysis

The identification of risks can support the argument for preservation as a priority by highlighting future problems and making the case for preventative actions. Risk identification requires comprehensive asset condition data and some projection of deterioration. Selecting mitigation strategies requires data on the performance-cost relationship and scenario planning which includes tradeoffs.

The best practices in risk mitigation do not rely on complicated measures. They use basic asset condition measures and conduct sophisticated analyses to tie condition to current and future performance based on various intervention levels.

3.6 COMMUNICATION/REPORTING

Once the preservation programming decisions are made and projects are implemented, agencies review the results. This serves several purposes. Agencies need to communicate the effectiveness of preservation activities, making the case for continued investment in preservation. Agencies can report results to other stakeholders, fulfilling requirements. Agencies can feed results

back into decision-making. This might include making changes to policy-level decisions, adjusting preservation strategies, or revising analyses to reflect the latest real-world outcomes. The value of preservation measures is partially determined by how effectively they can be used to communicate preservation needs or progress towards preservation or condition targets.

Communication and Reporting of Preservation Decisions

Many agencies distribute information about their programs through a web site printed materials, and increasingly through social media. While these vehicles are key tools to communicate with customers and stakeholders, it remains difficult to understand and track the influence of public opinion on maintenance programs.

As described in NCHRP Report 330 *Public Benefits of Highway System Preservation and Maintenance*, there exists a lack of appreciation of the benefits of infrastructure maintenance on behalf of the public, which may be linked with inadequate commitment to preventive maintenance and preservation. Findings from published literature, a study survey, and anecdotal evidence about public views on highway maintenance activities and agencies' efforts to publicize the benefits of those activities are summarized in NCHRP Report 330 as follows:

- Public perceptions of maintenance and its benefits – Surveys show that a majority of the general public holds favorable views of highway conditions generally and of the operations of their highway agencies. There is evidence that public perceptions are linked to specific characteristics of pavement or other road-way conditions, but that such evidence is limited. Officials of many agencies believe that elected officials as well as the general public have favorable views of agency maintenance activities.
- Influence of public opinion – The idea that customer opinion should influence agency management decisions is widely espoused. Many agencies have used surveys or other market research techniques to assess public opinions of their highways and maintenance operations. The influence of such information on agency decisions about maintenance budgets and program management is not well documented.
- Efforts to communicate with the public and market maintenance – Some agencies routinely hold briefings or make other efforts to inform legislators or the general public about maintenance issues. Some agencies routinely report maintenance program productivity or other performance measures to the general public, although most agencies calculate such measures only for their internal management.

One component of effective communication is understanding the audience, giving consideration about who will view information and tailoring material suitable for consumption by that audience. Agencies are finding more ways to applying visual and interactive techniques and tools in their communication of preservation needs. For example, preservation needs might be presented to an

audience of transportation professionals differently than to the general public. There are many ways to do this, for example through online dashboards, interactive and customizable tools, report cards or scorecards, quarterly or annual reports with descriptive analysis, and others. Overall it is important to understand that different audiences call for different levels of detail of information, as described in Table 3.19.

Table 3.19 Tips for Presenting Audience-Friendly Data

Tip	Example/Explanation
Avoid terms not frequently used outside of the transportation planning/policy community.	Headways, VMT, Deferred maintenance
Avoid terms with multiple meanings.	Shipping (can refer to the movement of goods by ship OR the movement of goods between two parties)
Avoid science and math concepts that can be misunderstood. If these terms or concepts must be used, be sure to explain them in an easy-to-understand way.	Average Daily Traffic, Proportions
Focus on the main message instead of detailed scientific arguments or outcomes.	When making decisions, many people use heuristics (shortcuts) rather than the rational decision-making model used by most scientists.
Explain how the data may impact audiences.	Demonstrating impact can help audiences understand why the data are relevant to them.
Present data in a distinctive way that helps you gain the attention of your audiences.	For a majority of people in the United States, transportation issues are of moderate-to-low interest. Presenting relevant and interesting information can reduce the likelihood that people will filter it out due to lack of interest.

Source: FHWA Performance Reporting, Part 1, 2013.

The use of appropriately tailored visualization techniques can help to effectively communicate results and to translate complex issues to both technical and nontechnical audiences. Many industries, such as the financial and healthcare sectors, have advanced the use of data visualization to tell a story and communicate in more engaging ways with their audiences. Traditionally transportation has lagged in this area, though there is evidence that more agencies are beginning to embrace these techniques.

AASHTO's *Rough Roads Ahead Report* provides a good example of communicating preservation needs, with visual aids to underscore the argument. The *Rough Roads Ahead Report* provides a strong narrative about avoiding costs if investments are made to keep a road in good repair, rather than paying more at a later point in time to address greater deterioration. The Report communicates preservation needs using the following messages in support of the argument, which is summarized as *pay me now or pay me lots more later:*

- Rough Roads Lead To Higher Costs;
- Challenges Facing America's Highways;
- Highway Maintenance Needs Exceed Available Funds; and
- Strategies For Saving America's Highways.

Another resource, NCHRP Report 742 *Communicating the Value of Preservation: A Playbook*, provides guidance for state DOTs and other transportation agencies to improve the ability to communicate effectively with stakeholders and enhance public understandings of the role and importance of maintenance and asset-preservation in sustaining highway system performance and the consequences of deferring maintenance and preservation efforts. NCHRP Report 742 describes the following four building blocks for effectively communicating preservation:

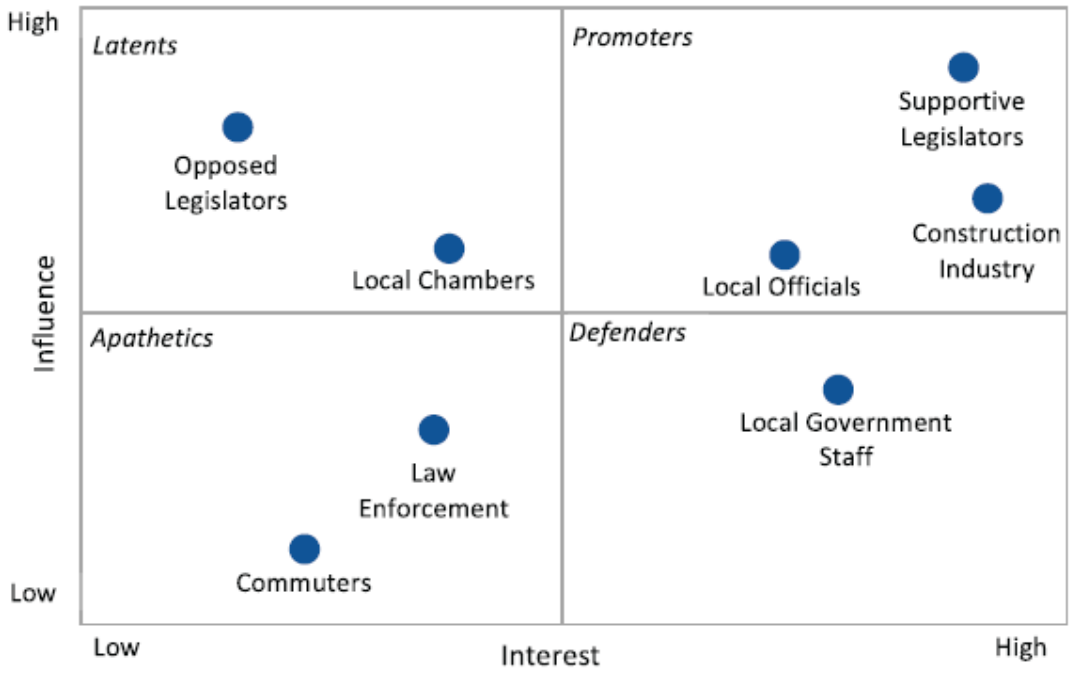
- **Audience Identification –** Identify audiences so you can find out what motivates them, what words resonate with them, who their trusted sources of information are, and which communication methods are most effective.
- **Message Design –** Translate technical data about preservation into concise and compelling messages that not only deliver facts, but also appeal to the emotions and interests of your most important audience segments and work in multiple delivery channels.
- **Message Delivery –** How a message is delivered should be continuous and will have the most impact when you use all three major avenues – traditional, one-on-one, and new Internet media opportunities – to effectively communicate messages to your most important audience segments.
- **Market Research –** Utilizing research – particularly primary research that connects your DOT directly to what stakeholders are thinking, feeling, and saying – is the mortar that holds the building blocks of good communication together.

With respect to audience identification, NCHRP Report 742 describes an interest/influence matrix technique for mapping audience segments as shown in Figure 3.19. The interest/influence matrix maps audience segments according to their level of interest in preservation and their ability to influence outcomes. As described in the Report, it helps focus on moving audience segments into the top right corner of the matrix and keeping them there – these are the medium- or high-interest/high-influence audience elements and they include:

- Stakeholders who are already supportive but need buttressing with resources and information and
- Stakeholders with enough common interests to become part of a support coalition.

This group becomes the basis from which to develop an ongoing coalition of support for maintenance and preservation.

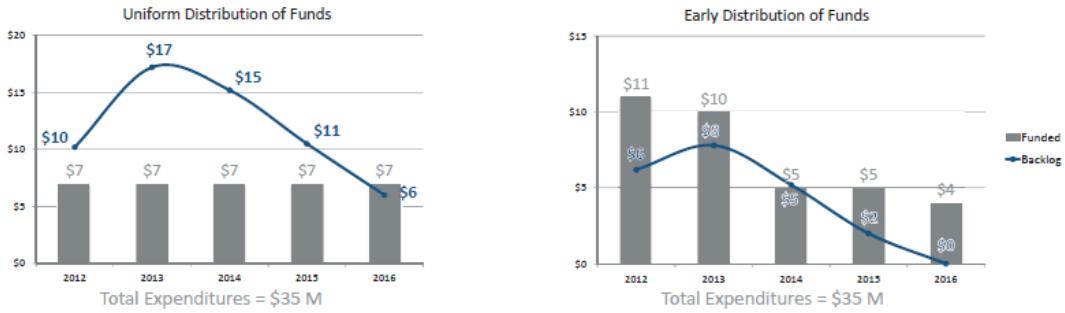
Figure 3.19 Hypothetical Audience Interest/Influence Matrix



Source: Transportation Research Board, *Communicating the Value of Preservation: A Playbook* (NCHRP Report 742), Washington, D.C., 2012.

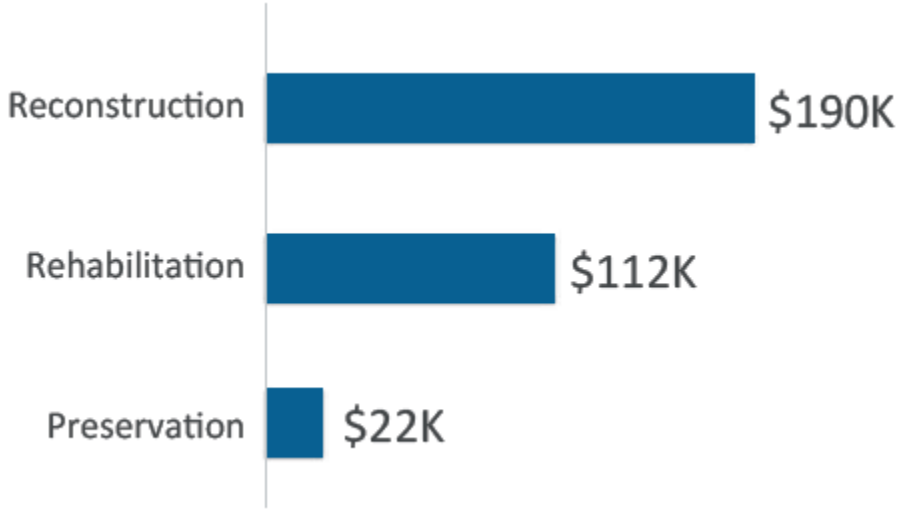
NCHRP Report 742 also notes that with respect to messaging, the analytic methods used in asset management are often complicated and can be difficult to translate into a simple message, but when it is done effectively it can make a compelling case for system preservation. As noted in the Report, the Penny Paved campaign offers an effective illustration of the impact of funding distribution to the backlog of preservation needs (see Figure 3.20). In addition, messaging can be developed to explain preventative maintenance and its life-cycle cost benefits, such as how it is cheaper to preserve a road than to rebuild it and how spending the right amount now saves money in the long run. Another example from the Penny Paved campaign demonstrating how preventative maintenance is a more cost-effective option is cited in the Report, and is shown in Figure 3.21.

Figure 3.20 Impact of Funding Distribution on Preservation Backlog



Source: Transportation Research Board, *Communicating the Value of Preservation: A Playbook* (NCHRP Report 742), Washington, D.C., 2012.

Figure 3.21 Preservation Costs versus Reconstruction and Rehabilitation Costs



Source: Transportation Research Board, *Communicating the Value of Preservation: A Playbook* (NCHRP Report 742), Washington, D.C., 2012.

The Report suggests the following five steps to effective preservation messaging, noting that messaging should be built on a strong analytic foundation, but must also be succinct and resonate with the audience on an emotional level. In other words, for preservation messaging to improve, transportation agencies need to work on becoming better at translating technical data into compelling messages that not only deliver facts, but also appeal to the emotions and interests of the audience. The five steps are:

- Step 1: Survey Existing Messages;
- Step 2: Consider Your DOT's Environment;
- Step 3: Adapt Technical Data for Use in Messages;
- Step 4: Translate Data into Messaging by Factoring in Your Customers' Values; and
- Step 5: Seek Out Strategic Tie-ins to Other Messages.

Next the Report discusses executing the message through a variety of delivery options. As one would imagine, message delivery goes hand-in-hand with message creation so the two should be developed in coordination. The objective of message delivery is to use as many delivery options as practicable to create a surround sound campaign that ensures that the message is 1) heard 2) seen, and 3) remembered.

The Report describes market research – particularly primary research that connects DOTs directly to what stakeholders are thinking, feeling, and saying – as the mortar that holds the building blocks of good communication together. A wide variety of market research techniques that are applicable to the development of a comprehensive preservation and maintenance communication plan are noted in the Report

Visual and narrative examples focused around two hypothetical preservation campaigns are provided in NCHRP Report 742 that demonstrate different ways to communicate the value of preservation. Two examples of the communications materials are shown in Figures 3.22 and 3.23.

Figure 3.22 Presentation Example

1: I'm here today to talk about our preservation program.

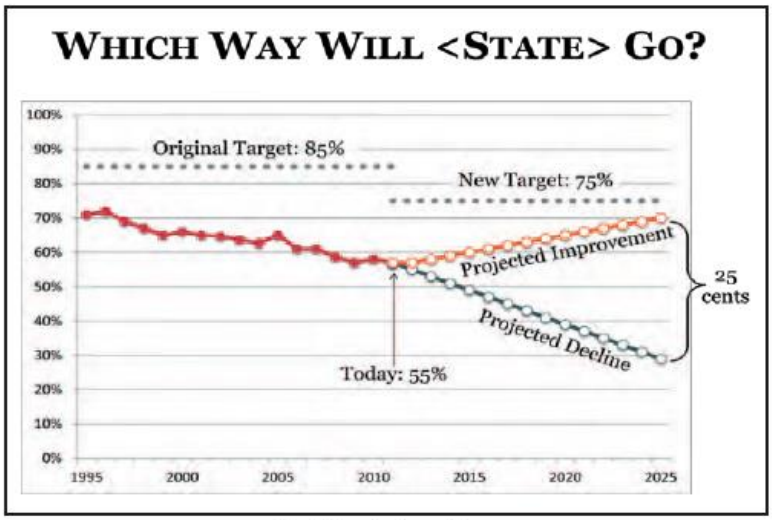
This picture is of course tongue in cheek, but it does capture the essence of the challenge we face.

Source: Transportation Research Board, *Communicating the Value of Preservation: A Playbook* (NCHRP Report 742), Washington, D.C., 2012.

Figure 3.23 Fact Sheets and Brochures Example

Rebuild Roads Now to Avoid Costly Increases Later

Start investing as little as 25 cents a day now to reclaim our roads, jump start our economy with immediate construction jobs and make <state> more competitive...OR let our highways and opportunities crumble and pay $4 per day later.



For More Information

To obtain more information about the Phoenix Project Task Force and its activities, please contact:

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Information is also available by visiting the Task Force's Web site and social networks:

http://phoenixproject.org
@PhoenixProject

Facebook.com/PhoenixProject
Linkedin.com/Phoenix Project

"As part of the Phoenix Project Task Force, I have been honored to serve with a group of concerned citizens, business owners, taxpayers, and elected officials to convene hearings across the state so we could hear – in people's own words – what they think of our highways and what, if anything they're willing to do about it."

Jane M. Doe
CEO and President, Company Name

Quotes from business leaders are used to support the data indicating drivers are highly dissatisfied and the business community supports increased investment in preservation.

Source: Transportation Research Board, *Communicating the Value of Preservation: A Playbook* (NCHRP Report 742), Washington, D.C., 2012.

Conclusions for Communication/Reporting

Successful communication and reporting is more about the message than the measure. As noted in NCHRP Report 742, agencies need to create an emotional connection with the audience. Technical condition measures are unlikely to accomplish this on their own. Agencies will benefit from incorporating tools such as avoided cost, customer satisfaction surveys, targeted benefit/cost analyses, and measures of economic development impact. Agencies which use these measures and craft a compelling story around them will have success in reaching an audience. This requires a high level of sophistication and effort. Agencies without the resources or expertise to tackle these measures will need to report succinctly and clearly using conventional condition measures if they wish to make the case for preservation.

4.0 Recommendations

Every transportation agency is different. Each faces unique challenges in measuring performance and preserving their transportation system. As noted earlier, there currently is no "golden measure" that is likely to resolve all of the difficulties in properly evaluating and communicating preservation needs, resulting in the need to employ multiple measures to capture different dimensions of performance and address all elements of the framework.

There are many lessons that can be learned from the research and agency best practices. This section includes an assessment of preservation measures and a roadmap which provides guidance on highest priorities for agencies to successfully apply performance-based preservation programming.

4.1 Assessment of Preservation Measures

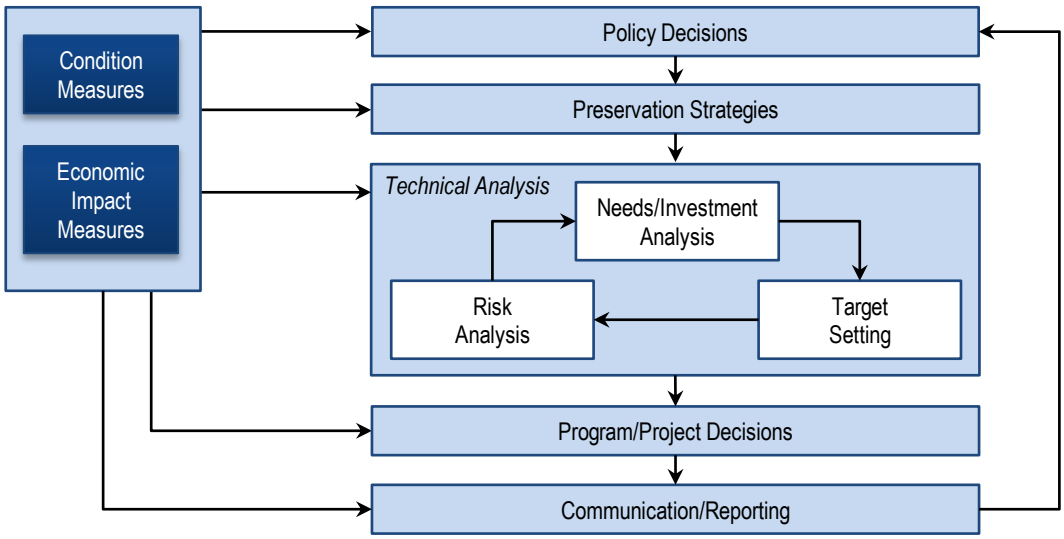
Table 4.1 provides a summary of the reviewed preservation measures. Each measure will satisfy different elements found in the framework for performance-based preservation programming (shown again in Figure 4.1). For example, simple condition measures can effectively support needs/investment analysis, target setting, and risk analysis. They are easy to communicate with the public. However, they do not always support the best programming decisions as they provide no insight into potential future performance.

Table 4.1 Summary of Reviewed Measures

Measure Type	Example	Outcome/Usefulness of Measures
Direct Condition Measures	• IRI for pavements • Sufficiency rating for bridges • NBI condition ratings	Provides understanding of system condition and performance, provides baseline for additional data-driven analysis
Remaining Service Life (RSL)	• RSL for pavements, reported in years until replacement is needed • RSL for bridges, usually a function of age and condition, reported in years until replacement is needed	Makes link to asset performance, provides understanding of future investment needs
Customer-Driven and User Perspective	• Customer survey and/or outreach results	Can be tied to outputs (such as miles of pavement repaved) to quantify cause and effect, improves accountability and targeted investment towards elements the customers find important

Measure Type	Example	Outcome/Usefulness of Measures
Life-Cycle Cost	• Remaining service life • Life-cycle cost analysis • Life expectancy analysis	Supports identifying the most cost-effective strategy (e.g., replacement, maintenance/preservation activities) among alternatives
Avoided Cost	• Relationship between asset level of service, required maintenance work, and cost consequences of delayed maintenance • Cost of poor pavement condition in terms of vehicle operating costs and costs to restore pavement to good condition	Describes the implications for implementing projects or programs, quantify the impacts of deviating from a least life-cycle cost approach
Sustainability Index	• Asset sustainability index, a high-level composite assessment of asset condition for pavement, bridge, and maintenance	Provides an indicator of the gap or surplus between need and investment, helps indicate the degree to which investment is adequate or inadequate
Benefit/Cost/ Performance-Cost	• Utility function as a measure of benefit • Budget scenarios and effects on infrastructure condition • Benefit cost to assess asset investment options	Supports choosing between alternatives, testing feasibility of options, comparing programming scenarios
Economic Development Impact	• Employment is widely used and understood • Personal income • Property values	Illustrates the experience by users as well as transportation's contribution to the general economy

Figure 4.1 Framework for Performance-Based Preservation Programming



Measures such as avoided cost and life-cycle cost can better support forward-looking preservation decisions, but require analysis resources and they are difficult to communicate. Some measures, such as economic development impacts, can tell a good story but are difficult to use as a base for comparing alternatives, being difficult to quantify for smaller-scale decisions.

Given that no one measure satisfies all of the agency needs, agencies can find value in coupling measure types. For example, combining simple condition measures with benefit/cost/performance-cost measures will give an agency good capacity in nearly all areas. Measures that performance well in needs/ investment analysis (such as remaining service life or an asset sustainability index) can be supplemented with measures that are useful in communicating the value of preservation (such as customer satisfaction or economic development impacts).

Roadmap for Use of Measures in Performance-Based Preservation Programming

This roadmap provides initial guidance on highest priorities for agencies to successfully apply performance-based preservation programming. Significant emphasis is placed on the development and application of preservation measures, the focus of this research.

Successful performance-based preservation programming is a challenge for all transportation agencies. There is no single model of demonstrated success that can be applied to all agencies. Agencies need to build on their existing strengths, resources, and opportunities. The path to success includes development of new areas and capabilities.

Recognizing this variation among agencies, the roadmap is broken into three tiers. Every transportation agency has a different level of maturity in data collection and analysis, asset management, performance management, target setting, and other activities which support performance-based preservation programming. The tiers are intended to provide guidance to those agencies with limited maturity, those with moderate maturity, and those with significant maturity in performance-based preservation programming.

The tiers are defined based on the various dimensions of "best practice" summarized in the previous section. This approaches recognizes that "best practice" is subjective and varies based on the role of an agency and its level of maturity within a variety of dimensions.

Determining an Agency's Tier

Each element for judging an agency's maturity in performance-based preservation programming can be classified within two categories:

- Performance and Asset Management Processes, including

- **Goals/Objectives –** An organization's goals and objectives define priorities and provide the foundation for performance-based planning and management decisions;
- **Performance Measures –** Performance measures establish a set of metrics to help organizations monitor progress toward achieving its goals and objectives;
- **Target Setting –** Establishing quantifiable targets for each performance measure allows an organization to gauge progress over time relative to a desired goal;
- **Resource Allocation –** An organization builds on the preceding steps by allocating resources such as time and money through budgeting processes to achieve specific performance targets; and
- **Performance Monitoring and Reporting –** Monitoring and reporting progress to decision-makers and other stakeholders allows organization to identify key factors influencing performance and necessary actions to improve results.

- Technology/Tools, including
  - **Data Collection/Availability –** This element assesses the availability and quality of data; and
  - **Analysis Tools/Capabilities –** This element reflects the capabilities of an agency to analyze data and translate it into information that can support performance-based preservation programming.[1]

The levels, from least to most mature, are as follows:

- **Tier 1 –Limited.** At this lowest level of maturity, activities for a given model element are nonexistent, limited, or somewhat "ad hoc."
- **Tier 2 – Moderate.** Activities at this level of maturity can be said to be "initiated" and "performed."
- **Tier 3 – Significant.** Activities at this level of maturity can be said to be "integrated" and "optimized"; activities and processes are continually monitored and improved.

More information on each tier is provided below, along with recommendations for next steps for each agency.

Agencies with *Limited* Maturity in Performance-Based Preservation Programming

This tier covers agencies that may be new to performance management and asset management. They have limited comprehensive data on asset condition and

[1] FHWA, *How to Improve Performance on Corridors of National Significance*, June 2013.

inventory available. They rely on historical funding allocations for maintenance and preservation and address maintenance needs on a "worst-first" basis. They lack significant tools, resources, or capacity to complete sophisticated data-driven decision-making.

Agencies with limited maturity in performance-based preservation programming should:

- **Strengthen asset inventory and condition data resources.** These data will drive all subsequent analysis and decision-making.
- **Compile and report condition measures for major assets.** With a comprehensive condition inventory of major assets such as pavement and bridges, agencies can compile system-level statistics. This can make the case for preservation and set a foundation for target setting.
- **Set targets based on system-level asset condition.** Target setting can link preservation and maintenance activities to future results and provide achievable goals to reach for. Agencies can formally adopt and publicize targets or chose to only internally and/or informally recognize targets. The important step is linking preservation activities to future asset conditions.
- **Track expenditures and results for communication with the public and decision-makers.** Once agencies have asset inventory and condition data, they can strengthen their understanding of how investment affects condition. Over time this will help agencies develop a cause-and-effect story of preservation.

Agencies with *Moderate* Maturity in Performance-Based Preservation Programming

This tier covers agencies with some experience in performance management and asset management. They have comprehensive data on asset condition and inventory available. They factor performance into decision-making and resource allocation, though data may not fully drive this process. They have some more sophisticated analysis methods and tools at their disposal.

Agencies with moderate maturity in performance-based preservation programming should:

- **Conduct basic needs/investment analyses on major assets.** Undertaking formal analyses can help support need-based funding allocation. Agencies can better understand their preservation needs and be able to communicate them to stakeholders. Agencies can start with simple preservation performance measures such as an asset sustainability index.
- **Use benefit/cost and/or performance-cost measures to support preservation programming decisions.** Agencies can put preservation performance measures to work for them by linking decisions to invest (or disinvest) in preservation with the resulting impacts on benefits and performance. These

analyses can vary from basic performance-cost relationships (*if the agency invests $X it can expect to see assets perform at level Y*) to sophisticated benefit/cost analyses which capture detailed user cost impacts, indirect costs, etc.

- **Establish some common metrics to better understand program tradeoffs.** Agencies can benefit from using data to support cross resource asset allocation. The simplest way to achieve this is to monetize the impacts of investment using benefit/cost or performance-cost estimates. Agencies can then review programming decisions across asset types and ensure they are getting the best possible performance for their investment and are limiting life-cycle costs for assets.
- **Incorporate least life-cycle cost into preservation decisions.** Agencies can assess the least life-cycle cost options preservation of major assets and follow the guidance to minimize costs. Agencies can share the analyses driving these decisions to make the case for proactive investment in preservation and maintenance rather than allowing infrastructure to deteriorate.
- **Communicate using economic terms.** Agencies can make the case for preservation by linking investment to economic health and development and support for local businesses and jobs.

Agencies with *Significant* Maturity in Performance-Based Preservation Programming

This tier covers agencies with significant experience in performance management and asset management. They have advanced data, capacities, and resources available to support data-driven decision-making and funding allocation. Agencies in this tier are likely actively pursuing strategies to make the case for preservation. They have probably encountered difficulty in communicating the message to stakeholders and the public and are searching for better ways to frame the message and tell the story of the value of preservation.

Agencies with significant maturity in performance-based preservation programming should:

- **Support all performance-based preservation programming decisions with detailed data and analysis.** A fully mature agency has the resources to implement and maintain a clearly understood mechanism for preservation decision-making. Each decision can be data-driven and defensible. This can lead to a responsive, transparent, forward-looking program. Achieving this difficult goal requires use of multiple performance measures and measure types.
- **Design a preservation program to reach policy goals, fulfill needs, support target achievement, minimize risk, achieve least life-cycle cost, and communicate the value of preservation.** Decisions can provide value in one or many of the key applications for preservation programming. Agencies can review their activities in preservation programming to ensure they are

providing value in as many areas as possible. Some agencies may find the framework for performance-based preservation programming in this Report helpful. They can review the processes linked to preservation programming and identify strengths and weaknesses.

- **Supplement the story of preservation with additional measures such as avoided cost, customer satisfaction surveys, targeted benefit/cost analyses, and economic development impacts.** Agencies need to choose performance measures which support their priorities. There is no single set of measures that can be recommended for every agency given the diverse challenges each agency faces. It is clear, however, that there are many opportunities for sophisticated measures to support performance-based preservation programming. Agencies can research the more difficult measures and use them to supplement the story of preservation.

4.2 AREAS FOR FURTHER RESEARCH

The framework for performance-based preservation programming identifies several necessary processes. The research in this Report covers the measures which can support and shape these processes. Some areas, such as major asset condition measures, have a substantial body of research behind them. Other areas would benefit from additional research:

- The use of the avoided cost measure and its communication with the decision-makers and the public has not been explored extensively in the literature. The use of avoided cost appears to be largely limited to "making the case" for preservation. This is valuable, but it would be beneficial to see a program where avoided cost is driving decision-making and is a clearly communicated element of major program decisions.
- Benefit/cost is largely applied for project selection and there are limited examples of a preservation-specific application. Greater research can be explored on the use of benefit/cost analysis specific to preservation programming.
- Target-setting specifically for asset preservation can be further explored, particularly within the context of MAP-21 requirements and as a means of cross-asset trade-off analysis.
- A next phase of this research could present the framework to agencies, and garner agency responses to the framework for performance-based preservation programming to learn whether the framework fully captured their processes and needs related to preservation. Agencies may be able to add valuable insight about which measures are effective in serving the different processes.

- A more refined maturity model and self-assessment tool for agencies, linked to the recommended steps for improvement for each element, can be a means of practically implementing this research.

5.0 Bibliography

American Association of State Highway and Transportation Officials. *Rough Roads Ahead, Fix Them Now or Pay for It Later*. Washington, D.C.: American Association of State Highway and Transportation Officials, 2009. Print.

Asset Sustainability Index: A Proposed Measure for Long-Term Performance. Rep. Washington, D.C.: U.S. Department of Transportation – Federal Highway Administration, 2012. Print.

Bridge Preservation Guide – Maintaining a State of Good Repair Using Cost Effective Investment Strategies. Rep. Washington, D.C.: U.S. Department of Transportation – Federal Highway Administration, 2011. Print.

Dehghanisanij et al. *Cross-Asset Resource Allocation Framework for Achieving Performance Sustainability*. Washington, D.C.: Transportation Research Record 2361, 2013. Print

Improving FHWA's Ability to Assess Highway Infrastructure Health Pilot Study Report. Rep. Washington, D.C.: U.S. Department of Transportation – Federal Highway Administration – Office of Asset Management, 2012. Print.

National Cooperative Highway Research Program. *Best Practices in Performance Measurement for Highway Maintenance and Preservation*. Project 20-68A, Scan 10-03. Washington, D.C.: Transportation Research Board, 2012. Print.

National Cooperative Highway Research Program. *Communicating the Value of Preservation: A Playbook*. Rep. No. 742. Washington, D.C.: Transportation Research Board, 2012. Print.

National Cooperative Highway Research Program. *Consequences of Delayed Maintenance – Recommended Process for Bridges and Pavements*. Rep. No. 14-20. Washington, D.C.: Transportation Research Board, 2012. Print.

National Cooperative Highway Research Program. *Engineering Economic Analysis for Highway Investment*. Rep. No. 424. Washington, D.C.: Transportation Research Board, 2012. Print.

National Cooperative Highway Research Program. *Estimating Life Expectancies of Highway Assets*. Rep. No. 713. Vol. 1. Washington, D.C.: Transportation Research Board, 2012. Print.

National Cooperative Highway Research Program. *Estimating Life Expectancies of Highway Assets*. Rep. No. 713. Vol. 2. Washington, D.C.: Transportation Research Board, 2012. Print.

National Cooperative Highway Research Program. *Guide for Customer-Driven Benchmarking of Maintenance Activities*. Rep. No. 511. Washington, D.C.: Transportation Research Board, 2004. Print.

National Cooperative Highway Research Program. *A Guidebook for Sustainability Performance Measurement for Transportation Agencies*. Rep. No. 708. Washington, D.C.: Transportation Research Board, 2011. Print.

National Cooperative Highway Research Program. *Guidebook on Risk Analysis Tools and Management Practices to Control Transportation Project Costs*. Rep. No. 658. Washington, D.C.: Transportation Research Board, 2010. Print.

National Cooperative Highway Research Program. *Managing Selected Transportation Assets: Signals, Lighting, Signs, Pavement Markings, Culverts, and Sidewalks*. Rep. No. 371. Washington, D.C.: Transportation Research Board, 2007. Print.

National Cooperative Highway Research Program. *Performance-Based Highway Maintenance and Operations Management*. Rep. No. 426. Washington, D.C.: Transportation Research Board, 2012. Print.

National Cooperative Highway Research Program. *Performance Measures and Targets for Transportation Asset Management*. Rep. No. 551. Washington, D.C.: Transportation Research Board, 2006. Print.

National Cooperative Highway Research Program. *Public Benefits of Highway System Preservation and Maintenance*. Rep. No. 330. Washington, D.C.: Transportation Research Board, 2004. Print.

National Cooperative Highway Research Program. *Technical Guidance for Deploying National-Level Performance Measurements*. Rep. No. 20-24(37)G. Vol. 1 – Measure Details. Washington, D.C.: Transportation Research Board, 2011. Print.

National Cooperative Highway Research Program. *Technical Guidance for Deploying National-Level Performance Measurements*. Rep. No. 20-24(37)G. Vol. 2 – Implementation. Washington, D.C.: Transportation Research Board, 2011. Print.

Thompson and Shepard. AASHTO Commonly-Recognized Bridge Elements: Successful Applications and Lessons Learned. Prepared for the National Workshop on Commonly Recognized Measures for Maintenance, 2000. Print.