NCHRP 20-24(37)E

Measuring Performance Among State DOTs, Sharing Best Practices

Comparative Analysis of Bridge Condition

Final Report

for

National Cooperative Highway Research Program

by

Spy Pond Partners, LLC

with

Arora and Associates

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ADT	Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ABC	Accelerated Bridge Construction
BME	Bridge Management Elements
BMS	Bridge Management System
BNAM	Bridge Needs Assessment Model
CoRe	Commonly Recognized
DOT	Department of Transportation
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
FO	Functionally Obsolete
GAO	Government Accountability Office
HBP	Highway Bridge Program
HBRR	Highway Bridge Rehabilitation and Replacement
LTBP	Long Term Bridge Performance
NBE	National Bridge Elements
NBI	National Bridge Inventory
NCHRP	National Cooperative Highway Research Program
NHS	National Highway System
QA	Quality Assurance
QC	Quality Control
SCOPM	Standing Committee on Performance Management
SCOQ	Standing Committee on Quality
SD	Structurally Deficient
SEI	Structural Engineering Institute
SR	Sufficiency Rating
STIP	State Transportation Improvement Program

Executive Summary

Comparative Performance Measurement for Bridge Condition

Today's transportation agencies need to find ways to improve service and demonstrate tangible results for their customers while operating under increasingly tight resource constraints. Within an agency, performance measurement provides a valuable tool for strengthening external accountability and achieving alignment and focus around desired end results.

Comparative performance measurement allows agencies to examine their individual performance within a larger context. It motivates organizations to pursue improvements by showing them what their peers have been able to achieve. It facilitates improvement by identifying specific practices of agencies that have achieved good results. Establishing comparable measures can take considerable effort, but pays off when participating organizations learn from practices employed by their peers to improve their own performance. Comparative performance measurement initiatives also have the important effect of shining a spotlight on current approaches to how performance is being measured and how results are being used. Participating agencies have an opportunity to examine the consistency and accuracy of their measurement practices, learn about differences in measurement across agencies, and work towards a greater degree of commonality.

This report presents results of the fourth in a series of comparative performance measurement efforts sponsored by the American Association of State Highway and Transportation Officials (AASHTO). The purpose of these efforts is to identify states that have achieved exemplary performance, find out what practices have contributed to their success, and document these practices for the benefit of other states. This effort focuses on bridge condition.

Contribution of This Study

This study was based on an analysis of bridge condition data from the National Bridge Inventory (NBI.) Based on the available data, it identifies states that have achieved a high level of performance relative to other states, with respect to recently reported (2009) bridge condition or with respect to improvements in bridge condition since 1999. It presents bridge management, maintenance, design and construction practices that the representatives of these states feel have contributed to these performance results. While these practices are already fairly well recognized among those in the highway bridge community, linking them to performance results serves to underscore their importance. Given the critical importance of bridges and the high costs of bridge construction and preservation, this study adds an important dimension of state department of transportation (DOT) performance to the comparative performance measurement series. Highlighting these results in the context of comparative performance information provides a compelling basis for executives to quickly identify where they stand, see the potential for further improvement, and scan the key types of practices that can be explored for achieving that improvement.

Analysis of Bridge Data

NBI data for 34 states was analyzed to calculate eight bridge condition performance measures and produce rankings of states based on these measures. Performance measures included in this study were:

Structurally Deficient Bridges - Deck Area (2009 NBI) - Percent of total state bridge deck area on bridges designated as Structurally Deficient. A bridge is considered Structurally Deficient if its NBI Deck, Superstructure, Substructure and/or Culvert rating is 4 or less (poor or worse condition) or its NBI Structural Condition or Waterway Adequacy is rated 2 or less.

Bridges with Sufficiency Rating ≤50 - Deck Area (2009 NBI) - Percent of total state bridge deck area represented by bridges with a Sufficiency Rating of 50 or below. Sufficiency Rating is derived from NBI indicators of structural adequacy and safety, serviceability and functional obsolescence, and essentiality for public use. Bridges with a Sufficiency Rating of 50 or below are eligible for federal bridge replacement funds.

Posted Bridges - Deck Area (2009 NBI) - Percent of total bridge deck area represented by bridges that are posted, closed, or recommended for posting (based on NBI Item 41).

Bridges in Good Condition - Deck Area (2009 NBI) - Percent of total bridge deck area represented by bridges with NBI Deck, Superstructure and Substructure ratings all of 7 or higher.

Structurally Deficient Bridges - Deck Area (Change from 1999 to 2009 NBI) – Change in the percentage of state bridge deck area on Structurally Deficient bridges between 1999 and 2009. Note that this is the absolute percentage point change – thus, a state moving from 10 percent of its deck area on Structurally Deficient bridges in 1999 to 5 percent in 2009 would have a value of 5 percent for this measure.

Bridges with Sufficiency Rating ≤50 - Deck Area (Change from 1999 to 2009) – Change in the percentage of state bridge deck area on bridges with Sufficiency Rating ≤50 between 1999 and 2009.

Posted Bridges - Deck Area (Change from 1999 to 2009) - Change in the percentage of state bridge deck area on posted bridges between 1999 and 2009.

Bridges in Good Condition - Deck Area (Change from 1999 to 2009) - Change in the percentage of state bridge deck area on bridges in good condition (as defined above) between 1999 and 2009.

A summary of results for each performance measure is as follows:

- **Structurally Deficient Bridges** (2009 NBI percent of state bridge deck area on Structurally Deficient bridges) - the range across participating states was from 1 to 20 percent, with a mean of 7 percent and a median of 6 percent. Northeastern states tended to have more deck area on Structurally Deficient bridges – they are clustered in the 10 to 20 percent range.

- **Bridges with Low Sufficiency Ratings** (2009 NBI percent of state bridge deck area on bridges with Sufficiency Rating of 50 or below) - the range for all bridges was from 0 to 17 percent, with both a mean and median of 4 percent. Results for Interstate bridges showed better conditions – as would be expected, with a range from 0 to 9 percent.
- **Posted Bridges** (2009 NBI percent of state bridge deck area on posted bridges) - the range for all bridges was from 0 to 18 percent, though the distribution was highly skewed towards the low end of this range, with a mean value of 2 percent and a median value of less than 1 percent. Only two of the 34 participating states had more than 5 percent of deck area on posted bridges. Results for Interstate bridges showed 33 states with 2 percent or less posted deck area and the remaining state with a very high 31 percent posted deck area.
- **Bridges in Good Condition** (2009 NBI percent of state bridge deck area on bridges with NBI Deck, Superstructure and Substructure ratings of 7 or higher) - the range was from 3 to 83 percent, with a mean of 40 percent and a median of 38 percent.
- **Change in Structurally Deficient Bridges** (Change from NBI 1999 to 2009 in percent of state bridge deck area on Structurally Deficient bridges) – this ranged from a 15 percent decrease to a 9 percent increase. Twenty-two of the 34 states improved or stayed the same over this time period with respect to this measure.
- **Change in Bridges with Low Sufficiency Ratings** (Change from NBI 1999 to 2009 in percent of state bridge deck area on bridges with Sufficiency Rating of 50 or below) – this ranged from a 12 percent decrease to a 4 percent increase. Twenty-seven of the 34 states improved or stayed the same with respect to this measure.
- **Change in Posted Bridges** (Change from NBI 1999 to 2009 in percent of state bridge deck area on posted bridges) – the range for all bridges was from a 5 percent decrease to a 4 percent increase. Twenty-seven of the 34 states improved or stayed the same with respect to deck area on posted bridges.
- **Change in Good Condition Bridges** (Change from NBI 1999 to 2009 in percent of state bridge deck area on bridges with NBI Deck, Superstructure and Substructure ratings of 7 or higher) - this ranged from a 21 percent increase to a 42 percent decrease. Fourteen of the 34 states improved or stayed the same with respect to this measure.

Identification of High Performing States

Based on rankings of states derived from the selected performance measures, there was a large pool of candidate states that could be justified for selection, depending on the measure used. Therefore the research team developed the following approach to selecting top performing states for interviews:

- Include one state from each census region (Northeast, South, Midwest and West).
- Include states showing good 2009 performance as well as states showing improvements from 1999 to 2009.

- Select states primarily based on measures related to Sufficiency Rating, Structurally Deficient bridges and bridges in good condition, given the highly clustered nature of values for measures based on posted bridges.

Based on these criteria, the following four states were selected to represent the four regions:

- State 24 - Kansas (Midwest region) - selected for its strong 2009 performance across multiple measures.
- State 26 - Utah (West region) – selected for its performance improvements between 1999 and 2009, as well as its relatively strong performance in 2009. Utah ranked second with respect to deck area on bridges in good condition.
- State 15 - New York (Northeast region) – selected for its improvements between 1999 and 2009 with respect to Structurally Deficient bridges, bridges with low Sufficiency Rating and bridges in good condition – particularly on the National Highway System (NHS).
- State 23 - Georgia (South region) – selected for its strong 2009 performance across multiple measures. Georgia ranked third with respect to both bridges in good condition and Structurally Deficient bridges.

A representative of each of these states was interviewed to identify practices that may have contributed to strong performance.

Practices Contributing to Strong Bridge Performance

While each state has unique circumstances and needs and there is no one-size-fits-all approach for improving bridge conditions, several themes emerged from interviews with the four selected states: make the case for bridge investment in order to secure and properly target resources, invest in bridge preservation, and construct maintainable bridges. Ten specific practices employed by these states were identified within these three categories.

Theme 1: Make the Case for Bridge Investment

Practice #1: Establish and use performance measures within the agency for benchmarking bridge conditions and communicating agency targets.

Practice #2: Determine funding requirements to meet alternative performance targets the agency may want to consider. Revisit targets periodically to facilitate high-level decision making affecting resource allocation and bring these decisions into alignment with reality.

Practice #3: Document the agency's approach to prioritizing major rehabilitation and replacement projects to ensure that funds are targeted to where they are most needed and improve accountability.

Theme 2: Emphasize Bridge Preservation

Practice #4: Inspect bridges at the element level to provide an understanding of appropriate preservation actions required to address the underlying issues contributing to bridge deterioration.

Practice #5: Track bridge-level work recommendations as part of bridge inspections, and establish an approach to tracking, reviewing and prioritizing bridge work recommendations. Using these processes helps to identify low cost actions to help preserve bridge conditions and forestall more aggressive and expensive actions. Encourage communication between district/area and central office staff on the conditions and needs of the bridge inventory.

Practice #6: Establish programs for common types of preservation actions including bridge washing, joint repairs, deck overlays, painting and concrete repairs. Identify common preservation actions, establish guidance concerning when to perform actions and provide for flexibility in the use of preservation funds to respond to changing conditions.

Theme 3: Construct Maintainable Bridges

Practice #7: Discourage use of high maintenance design details – reduce life cycle costs by identifying and eliminating design details with potentially high maintenance costs such as bridge joints and emphasizing lower cost, easy to maintain, good performing designs.

Practice #8: Encourage use of standard designs – institutionalize maintainable bridge designs to reduce the use of high-maintenance details and reduce the time and cost required for bridge design.

Practice #9: Take advantage of alternative contracting and delivery approaches such as design/build and accelerated bridge construction to encourage further standardization of more maintainable structures.

Practice #10: Enhance communication between bridge design and maintenance staff through quarterly or annual meetings – allow bridge maintenance staff with day-to-day experience inspecting and maintaining bridges to provide designers with their perspectives on designing for maintainability through review during design, development of standards, project scoping or other preconstruction activities.

Improving Future Bridge Comparative Performance Measurement

At the present time, the NBI provides the only consistent and complete national data set on bridge condition with coverage of all publicly owned bridges open to vehicular traffic over 20 feet in length. The data are widely used both within individual agencies and nationally to provide a high level picture of bridge condition and performance.

While there was agreement among study participants to use the NBI data as the basis for this study, some of the participants (in discussions with members of the research team) raised a number of concerns about limitations of the NBI condition ratings:

- NBI ratings are based on visual inspection methods, which are subjective and therefore variable across states and across individual inspections within a state – particularly where strong quality controls are not in place. Ratings for a given bridge can and do fluctuate from inspection to inspection without any actual change in condition.

- NBI ratings are intended to describe the overall or "average" condition of three major bridge components: deck, superstructure and substructure. The rating scale emphasizes severity,

rather than the extent of deterioration. It can be difficult for inspectors to decide what the "average" condition is when a bridge has mainly localized problems and multiple distress symptoms.

- NBI data is used for funding decisions and therefore may be subject to bias.

Many of the states participating in this effort, and all that were interviewed in depth, go beyond the inspections required by the NBI, and perform more detailed element-level inspections to determine not just the overall condition of a bridge, but also the underlying issues contributing to its condition.

Proposed changes to element-level bridge inspection standards developed by the AASHTO Technical Committee for Bridge Management, Evaluation and Rehabilitation (T-18) would improve and clarify the existing bridge elements and establish a standard set of National Bridge Elements that are designed to be consistent across agencies to facilitate the capture of bridge element condition at the national level. Implementation of these changes could provide an improved basis for national comparative bridge performance measurement. While these changes will take time to be fully implemented, it is likely that availability and consistency of element-level data will continue to improve, and use of element-level data will be a viable option for future comparative performance measurement efforts.

In this context, the following recommendations were developed to improve the state of the practice in comparative performance measurement for bridge condition:

Continue Use of Performance Measures Based on NBI Data in the Short Term. In the short term, continue use of performance measures derived from the NBI but work towards transitioning to performance measures based on the new National Bridge Elements.

Support Transition to Use of Element-Level Data for Performance Measurement. Support ongoing efforts to establish a standard, clearly defined set of National Bridge Elements and facilitate adoption and use of these elements. Support development of a common method for aggregating element-level data into a single index representing structural condition, and pilot its use for comparative performance measurement.

Base Bridge Performance Measures on Deck Area. Base performance measures on deck area rather than based on bridge counts. Measures based on deck area are better suited for comparative analysis given varying bridge size distributions across states. Measures based on deck area are also more reflective of the backlog of work implied by bridge conditions.

Use Good-Fair-Poor Categories for Performance Tracking and Reporting. Use bridges (weighted by deck area) in good, fair and poor condition as the primary cluster of measures for comparative performance analysis. This would provide a readily understandable and powerful way to summarize bridge condition information. Rather than emphasizing deficient bridges alone, it would allow agencies to track the distribution of bridges across condition ranges. Using the NBI ratings, poor bridges can be defined as bridges with deck, superstructure or substructure ratings ≤ 4, good bridges can be defined as bridges with deck, superstructure and substructure ratings ≥ 7, with all other bridges falling into the fair category. The good-fair-poor

reporting method can be modified in the future to be based on element-level condition ratings or a condition index derived from element-level ratings.

Include Structurally Deficient Bridges as a Supplemental Measure. Given the prevalence of its use at the national level and within individual states, it would be appropriate and useful to include measures based on Structurally Deficient bridges as one of a package of bridge measures used for comparative performance.

Track a Bridge Condition Measure Independent of Bridge Decks. Track a supplementary performance measure that captures the structural condition of a bridge independent of the deck condition – for example, bridges with NBI superstructure or substructure rating ≤4.

Track Changes in Bridge Condition in Addition to Current Condition. Track changes in network condition as a supplemental performance measure. This can be helpful for distinguishing states that have been able to improve conditions from those that have longstanding good conditions due to a younger population of bridges or relatively benign environmental conditions. Because most bridges are only inspected every two years, and changes in the network distribution of bridge condition are gradual, a ten-year time horizon for tracking changes in condition is appropriate.

Don't Use Posted Bridges as a Primary Comparative Performance Measure. While it remains important for individual states to track the number of posted bridges in their inventory, use of the number of posted bridges as a national performance measure is complicated by differing standards for rating and posting bridges. Thus, the number of posted bridges is not recommended as the basis for a primary measure for comparing performance across states.

Support Bridge Inspector Training and Quality Assurance. Continue to promote and support inspector training and quality assurance to maximize consistency of bridge condition ratings. Recently published guidelines for implementing Quality Control (QC) and Quality Assurance (QA) for bridge inspections provide useful material to support process improvements.

Improve Bridge Cost Data. Cost information is critical for providing a context for understanding performance. There is a need to improve availability and consistency of cost data reporting for bridge work. Currently states provide FHWA with direct costs of replacement and construction (per bridge and per unit deck area.) No information is provided on rehabilitation or maintenance. This gap makes it difficult to establish relationships between expenditures and resulting condition. Precise definitions of cost components are required to ensure consistency. Reporting also needs to incorporate non-federal sources of funding. AASHTO should consider establishment of a best practice guide to bridge cost tracking to improve the state of the practice.

1. Introduction

Study Background

Comparative performance measurement is a valuable tool for driving improved results. Showing organizations what their peers have been able to achieve provides motivation to pursue further opportunities for improvement. Most importantly, comparative performance measurement helps to identify specific practices employed by high-performing organizations that may be adopted by others. This provides valuable information that state department of transportation (DOT) executive and mid-management staff can use as they develop strategies and programs for accelerating the pace of performance improvement within their organizations.

However, establishing comparable measures across DOTs takes time and effort, and requires close collaboration across agencies to ensure that measures are meaningful, consistent, used appropriately, and reflect the collective buy-in of the participants. A successful comparative performance program does not involve a report card approach that emphasizes who is "best" and "worst". Instead, the focus is on identifying strategies that have worked well and are producing results. The performance comparisons are a means to this end, rather than an end unto themselves.

In 2004, the American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Quality (SCOQ) Performance Measures and Benchmarking Subcommittee initiated National Cooperative Highway Research Program (NCHRP) Project 20-24(37) – Measuring Performance Among State DOTs. This initiative aims to establish a handful of comparative performance measures in key strategic focus areas, such as project delivery, system condition, congestion, and safety; facilitate comparisons of these measures across a group of volunteer agencies; and use these comparisons as a way to identify and share best practices and lessons learned. The initial performance area selected was on-time, on-budget project delivery. The final report for this initial comparative performance measures effort, Project 20-24(37)A, presents data for 20 states, and provides a synthesis of 28 best practices from the nine top performing states (*1*). The second project in the series, 20-24(37)B, examined pavement smoothness as measured using the International Roughness Index (IRI) (*2*). This effort involved 32 states and identified specific practices that were employed by the agencies with the smoothest pavements. A third effort, Project 20-24(37)C, was recently completed and focused on traffic safety (*3*). This effort utilized data from the Fatality Analysis Reporting System (FARS) to identify states that had been successful in reducing their fatality rates between 2000 and 2007 and used a literature review and interviews with ten top performing states to identify practices that contributed to these results.

The current effort focuses on bridge condition, an area of critical concern to the transportation community. The United States currently has approximately 600,000 publicly owned bridges over 20 feet in length (*4*). The 2008 AASHTO Report entitled "Bridging the Gap" (*5*) points out that 50 percent of the nation's bridges, when measured in terms of deck area, are between 35 and 55 years of age – the age range during which structural repair needs are greatest. One in four is

classified as either Structurally Deficient or Functionally Obsolete. The report cites current challenges faced by transportation agencies due to escalating construction costs and shrinking budgets. Funding gaps are constraining agencies' ability to perform bridge maintenance, repair and replacement needed to maintain safety and mobility. In this context, identifying and sharing successful and transferable bridge management practices is vital to DOTs.

This study of comparative performance measurement for bridges provides a high-level snapshot view of bridge performance and selected network-level bridge management practices. It builds upon and is complemented by a number of more detailed initiatives related to bridge performance and management practices. Work to date under the Federal Highway Administration (FHWA) Long Term Bridge Performance (LTBP) program (*6*) provides background information on performance measures in use, and, through focus groups, has identified key issues impacting bridge performance. A Performance Primer that synthesizes research activities related to bridge performance is scheduled to be published in 2010. While the LTBP data collection activities are currently in a pilot stage, this program will yield a much-improved information base for identifying effective maintenance practices and quantifying their performance impacts.

The recent AASHTO/NCHRP Domestic Scan on Bridge Management Decision Making (NCHRP Project 07-05) provides a rich base of information on bridge management practices in place in 24 states (*7*). The earlier (2008) American Society of Civil Engineers (ASCE) Structurally Engineering Institute (SEI) Workshop on Enhancing Bridge Performance (*8*) covered bridge management and performance measurement as well as design and detailing practices for specific bridge types. Together these references provide a wealth of information on practices impacting bridge performance. This information was incorporated into the design of interview tools for use in NCHRP 20-24(37)E. See Appendix A for more information on the literature reviewed for this report.

Research Objectives

The objective of this project is to use the techniques developed in NCHRP Projects 20-24(37)A, B and C to develop comparative statistics on bridge condition; to prepare, analyze and evaluate the performance data; and to identify and document successful practices employed by the top performing agencies. The results of this study complement those of related efforts discussed above, providing state DOT executives with a view of network-level bridge performance improvement opportunities that can lead directly to action. The study is also intended to recommend steps that can, over time, achieve a greater degree of consistency and comparability in bridge performance measures across states.

Report Organization

Section 2 presents an overview of how this study was conducted.

Section 3 presents the bridge performance measures used for this study, and summarizes the analysis results and the methodology that was used for identifying top performing states.

Section 4 summarizes results of the interviews with the top performing states.

Section 5 presents recommendations for improving comparability and consistency of bridge condition performance measures.

Appendices to this report present additional background information and detailed analysis results.

Appendix A presents a literature review covering current bridge performance measures in use, national bridge performance trends, and bridge management practices.

Appendix B includes results from an initial participant questionnaire.

Appendix C contains supplemental details on the data compilation and analysis.

Appendix D contains the interview guide used to identify practices of top performing states.

2. Study Overview

This study followed the approach that has been used in the prior comparative performance measurement efforts. It involved four major activities:

- Select comparative performance measures in consultation with participating states.
- Compile performance data, rank states based on the data, and identify the top performing state based on the rankings.
- Identify and summarize practices of the top performing states that may have contributed to their successful performance.
- Recommend steps that can be taken to improve availability of consistent comparative measures of bridge condition.

The key activities and decisions made in the course of the research are highlighted below. Specific definitions of the performance measures used and the analysis results are provided in later sections and in the appendices.

Selecting Performance Measures in Consultation with Participating States

The AASHTO Standing Committee on Performance Management (SCOPM) enlisted participation of 34 states as shown in Figure 1.

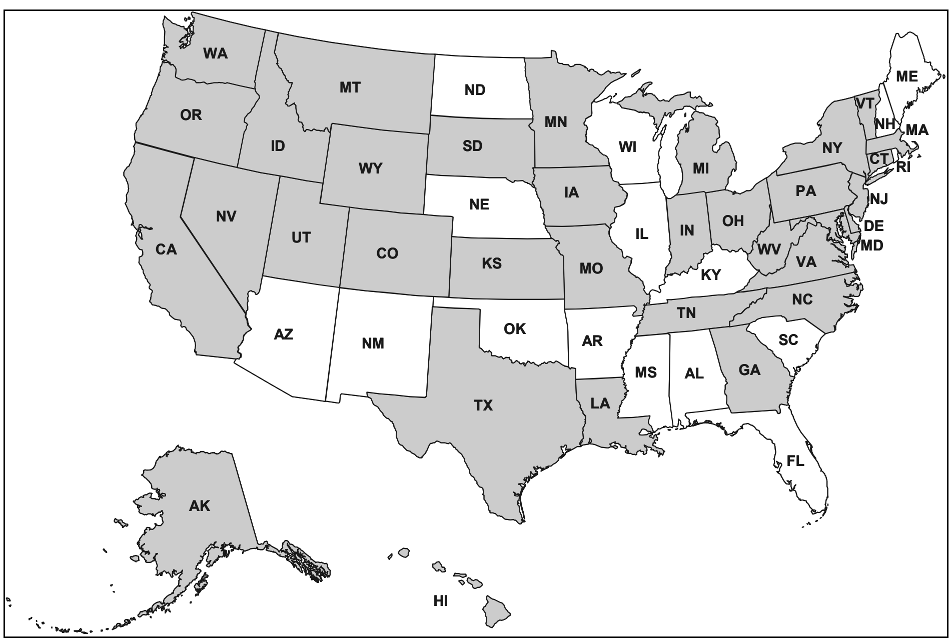

Figure 1. Participating States

Once participating states were on board, a set of candidate performance measures were compiled based on current National Bridge Inspection (NBI) standards and a review of existing literature on performance measures in use by states. (See Appendix A.)

Each participating state completed a questionnaire that ascertained what bridge condition measures they were using and what data they could make available. The questionnaire also asked for participant comments about the suitability of available measures. A conference call was held to review questionnaire results and discuss the recommended set of performance measures to be used. (See Appendix B for results from the questionnaire.)

Based on the questionnaire results and the conference call, the research team recommended that (1) NBI data be utilized for the study, (2) multiple measures of bridge performance be used, and (3) the scope of bridges to be included should be limited to facilitate comparisons across states. These decisions were reviewed with the project panel.

While there was agreement among study participants to use the NBI data as the basis for this study, several participants felt that the existing commonly used measures based on the NBI had limitations that detracted from their value for comparative performance measurement. There was support among several states for using performance measures based on finer grained element-level inspection data rather than the NBI data. However, based on a review of the questionnaire results, consistent element-level data was not available from enough of the participants to make element-level data a viable option for this project.

The decision to use multiple measures (rather than a single measure) was based on the lack of consensus among participants around a single best measure of performance. Participants pointed out how different measures emphasize different aspects of bridge performance (e.g. functional versus structural issues; deck deterioration versus more fundamental structural issues.) Therefore, an approach of using multiple measures for ranking states was adopted. Inclusion of multiple measures for ranking is useful in that it illustrates how performance is a multi-faceted concept and relative performance can vary based on choice of a measure – even within the seemingly narrowly defined area of bridge condition.

The third key decision made in this project was to restrict the scope of bridges to be included in order to maximize comparability of results across states. Based on the recommendations of participating states, the scope was limited to state-owned highway bridges only. In addition, certain non-standard bridge design types were excluded from the analysis.

An analysis was conducted based on a preliminary set of performance measures and reviewed by the project panel. This analysis included examination of correlations across measures. Preliminary results were also presented and discussed with members of the Transportation Research Board (TRB) Bridge Preservation Joint Subcommittee and the Bridge Management Committee at the 2010 TRB Annual Meeting. Based on feedback received from those groups, the research team established a set of final measures for the project.

Calculating Measures and Rankings

Measure Calculations

The final set of measures were based on four “core” indicators of bridge condition: (1) NBI Sufficiency Rating, (2) NBI Structurally Deficient Status, (3) NBI Posting Status and (4) an overall “Good” condition classification assigned to bridges with NBI Deck, Superstructure and Substructure Ratings greater or equal to 7 (on a 0 to 9 scale). Both current condition (based on 2009 NBI data) and changes in condition between the 1999 and 2009 NBI data sets were analyzed, for a total of eight performance measures. All measures were weighted by bridge deck area, but based on the condition of the entire bridge - not just the deck. More detail on the measure definitions and the results are provided in Section 3 of this report.

The eight measures were calculated separately for (1) all roads, (2) Interstate System roads, and (3) NHS roads. Then, 24 sets of rankings were calculated – one for each of the eight measures and the three road networks.

Peer Groupings

The research team explored establishment of peer groups to provide a way for individual states to compare their performance within a more limited set of states with similar characteristics impacting performance. Five different sets of peer groups were formulated based on geographic region, traffic levels, bridge age distribution, level of bridge replacement activity, and unit replacement costs. Peer groups based on geographic region showed the most pronounced differences in condition - specifically, when comparing northeastern states to other states. Results of the peer group analysis are summarized in Appendix C.

Identifying Top Performers

A series of charts were prepared that show relative performance of the participating states for each of the performance measures and networks. The highest ranked states in each region were identified for each of the 24 sets of rankings, and four states (one per region) were identified as top performers to be interviewed. The selections were finalized following review by the project panel. Section 3 of this report summarizes the state rankings and the approach used to select states for interviews. Detailed performance results are provided in Section 3 and Appendix C.

State Interviews and Identification of Practices

Telephone interviews were conducted with representatives of the four states identified as top performers. An interview guide was developed to be used to ensure that a standard set of factors were covered in the discussion for each state – this guide is included in Appendix D. The overall objective of these interviews was to identify bridge management, design and construction practices that contributed to achievement of good bridge condition or improvements in bridge condition over the past ten years. State use of bridge performance information was one of several topics explored in the interviews. It should be noted that the interview findings represent the opinions of the individuals interviewed about practices that

contributed to good performance. This study was not scoped to provide a quantitative assessment of causal relationships between practices and performance results.

Development of Recommendations for Improving Future Bridge Comparative Performance Measurement

The final step in the study was to provide recommendations to improve future bridge comparative performance measurement. A set of recommendations was developed based on the NBI data analysis and input from participating states. It did not involve a detailed investigation of potential new bridge performance measures.

3. Comparative Performance Analysis

Introduction

This section presents a snapshot view of relative performance across states with respect to bridge condition. Several points should be kept in mind when reviewing the results of this analysis. First, there are multiple factors impacting bridge performance results – many of which are beyond the control of DOTs – for example, weather conditions, traffic levels and the age and composition of the bridge network. Second, different states face very different sets of challenges and therefore place legitimately different levels of emphasis on bridges versus other transportation investments, and on the types of bridge investments that are made. Finally, achieving improvements to network average bridge condition is a multi-year process – it takes time for impacts of policies and programs to become apparent.

Performance Measure Definitions

As described in Section 2 of this report, bridge performance measures for comparative analysis across states were calculated using data from the 1999 and 2009 NBI files. Note that because most bridges are inspected biennially, the 2009 NBI includes a mixture of inspection data from 2007, 2008 and early 2009.

Descriptions of the NBI items used for calculation of measures are provided below:

Structurally Deficient Status - A bridge is considered Structurally Deficient if its NBI Deck, Superstructure, Substructure and/or Culvert rating is 4 or less (poor or worse condition) or its NBI Structural Condition or Waterway Adequacy is rated 2 or less. The fact that a bridge is Structurally Deficient does not imply that the bridge is unsafe, just that deficiencies have been identified that require maintenance, rehabilitation or replacement to address. Structurally Deficient status is used as one criteria for establishing eligibility of a bridge for federal bridge funding. Note that bridges that have been replaced or reconstructed within the last ten years are not classified as Deficient and not eligible for HBBR funds, even if the above conditions are met *(9)*.

Sufficiency Rating - Sufficiency Rating is a measure of a bridge's sufficiency to remain in service, and is based on NBI indicators of structural adequacy and safety, serviceability and functional obsolescence, and essentiality for public use. Sufficiency Rating is calculated as a percentage in which 100 percent represents an entirely sufficient bridge and zero percent represents an entirely insufficient or deficient bridge. A bridge's Sufficiency Rating affects its eligibility for federal funding for maintenance, rehabilitation, or replacement activities. For bridges to qualify for federal bridge funds, they must have a rating of 50 or below (and be classified as either Structurally Deficient or Functionally Obsolete). To qualify for federal rehabilitation funding, a bridge must have a rating of 80 or below (and be classified as either Structurally Deficient or Functionally Obsolete).

Deck, Superstructure and Substructure Ratings (NBI Items 58, 59 and 60) – Single number from 0-9 that represent the overall condition of the bridge deck, superstructure, and substructure relative to the initial as-built state. Generally a rating of 4 or less represents poor condition; a rating of 7 or higher represents good condition.

Posting Status (NBI Item 41) – Performance measures for posted bridges were based on bridges that were posted, closed or recommended for posting based on NBI Item 41. A posted bridge is restricted to carrying loads less than the legal load limit.

Table 1 provides definitions for the eight performance measures used in this study that were based on the NBI items described above. The first column of this table provides a descriptive shorthand term for the key characteristic of each measure; the second column provides a more precise name for the measure. The third column describes how the measure is derived. The final column summarizes the rationale for including the measure in this study.

Table 1. Bridge Performance Measure Definitions

Measure Characteristic	Measure Name	Measure Definition	Why Included?
Structurally Deficient Bridges	Percent of state bridge deck area on Structurally Deficient bridges (2009 NBI)	Sum of deck area on Structurally Deficient bridges in the state divided by the total deck area of all bridges in the state, as reported in the 2009 NBI	Most commonly nationally used single measure of physical bridge condition.
Bridges with Low Sufficiency Rating	Percent of state bridge deck area on bridges with Sufficiency Rating ≤ 50 (2009 NBI)	Sum of deck area on bridges in the state with Sufficiency Rating ≤50 divided by the total deck area of all bridges in the state, as reported in the 2009 NBI	Most commonly nationally used measure that incorporates both condition and functional issues
Bridges in Good Condition	Percent of state bridge deck area on bridges rated in good condition (2009 NBI)	Sum of deck area on bridges in the state with NBI Deck, Superstructure and Substructure Ratings ≥7 divided by the total deck area of all bridges in the state, as reported in the 2009 NBI	Based on input from study participants – measure added to reflect importance of maintaining structures in good condition; balances other measures that focus on bridges in poor condition
Posted Bridges	Percent of state bridge deck area on posted bridges (2009 NBI)	Sum of deck area on bridges in the state that are posted, closed or recommended for posting divided by the total deck area of all bridges in the state, as reported in the 2009 NBI	Measure emphasizing the impact of bridge condition on passenger and freight mobility

Measure Characteristic	Measure Name	Measure Definition	Why Included?
Change in Structurally Deficient Bridges	Change in percent of state bridge deck area on Structurally Deficient bridges (from 1999 NBI to 2009 NBI)	Percent of deck area on Structurally Deficient bridges as reported in the 1999 NBI minus the percent of deck area on Structurally Deficient bridges as reported in the 2009 NBI	It is instructive to identify practices of states that have been able to achieve substantial improvements in bridge condition over time. – irrespective of the current level of condition.
Change in Bridges with Low Sufficiency Rating	Change in percent of state bridge deck Area on Bridges with Sufficiency Rating ≤ 50 (from 1999 NBI to 2009 NBI)	Percent of deck area on bridges with Sufficiency Rating ≤ 50 as reported in the 1999 NBI minus the percent of deck area on bridges with Sufficiency Rating ≤ 50 as reported in the 2009 NBI	
Change in Good Condition Bridges	Change in percent of state bridge deck area on bridges rated in good condition (from 1999 NBI to 2009 NBI)	Percent of deck area on bridges rated in good condition based on deck, superstructure and substructure ratings as reported in the 1999 NBI minus the percent of rated in good condition based on deck, superstructure and substructure ratings as reported in the 2009 NBI	
Change in Posted Bridges	Change in percent of state bridge deck area on posted bridges (from 1999 NBI to 2009 NBI)	Percent of deck area on bridges in the state that are posted, closed or recommended for posting as reported in the 1999 NBI minus the percent of deck area on bridges that are posted, closed or recommended for posting as reported in the 2009 NBI	

Note that last four measures were based on the change in absolute percentage points - a state moving from 10 percent of deck area on Structurally Deficient bridges in 1999 to 5 percent in 2009 would have a value of 5 percent for the change in percent of Structurally Deficient bridges from NBI 1999 to 2009.

Preliminary analysis for this project also calculated separate performance measures based on bridges with deck ratings ≤4, and bridges with superstructure or substructure ratings ≤4. Because Structurally Deficient status is established based on deck, superstructure and substructure ratings, these measures were excluded from the final analysis conducted for the

purpose of identifying the top performing states. However, they were included in the peer group analysis. Appendix C includes an analysis of correlations across different bridge performance measures that was used to narrow down the set of candidate measures to the eight measures listed in Table 1.

Scope for Performance Measure Calculations

Bridges Included in the Analysis

Based on input from participating states, the analysis was performed based on a subset of NBI bridges in order to enhance comparability of results across states. Specifically, the following NBI bridges were included in this analysis:

- Bridges carrying highway traffic (NBI Item 5A = '1' and NBI Item 42A = 1,4,5,6,7 or 8)
- State-maintained bridges only (NBI Item 21 <> '1')
- "Standard" bridge design types (NBI Item 43B = 1,2,3,4,5,6,7, or 20) – excludes culverts, suspension, segmental box girder, orthotropic, truss, arch, stayed girder, movable, tunnel, and channel beam design types
- NBI records with deck width and length > 0, and deck ratings, sufficiency ratings and posting status not NULL

These inclusion criteria resulted in an analysis set of 154,540 bridges.

Separate Calculations by Highway Network

As noted in Section 2, measures were calculated for all state-maintained bridges in each state and then for two subnetworks: Interstate bridges only, and NHS bridges only. Looking at results for these restricted subnetworks can be helpful for comparing performance results across states. Identification of Interstate bridges was based on NBI Item 26 – Functional Classification; identification of NHS bridges was based on NBI Item 104 – Highway System of the Inventory Route.

State Peer Groups

Many states find it helpful to compare their performance with a limited group of peer states – that are geographically close or that share certain characteristics that may impact performance. As participants in this study pointed out in their responses to the initial questionnaire (see Appendix B), a state's network-level bridge performance is a function of multiple factors – many of which are outside of the control of a DOT. These include the size and composition of the bridge network, the distribution of bridge age, traffic loadings, and weather conditions. Respondents also noted the significance of the overall level of investment devoted to bridges, and the relative emphasis on preservation versus capacity expansion and functional improvements.

Because this study was concerned with enabling "apples to apples" comparisons across states, five different sets of peer groups were developed, each based on a different variable that would be expected to correlate with state-level bridge performance:

- Geographic location – based on US Census regions. Figure 2 shows the regional boundaries.
- Bridge age – based on the share of bridge deck area on bridges that are at least 40 years old as reported in the 2009 NBI. Forty years was selected as the cutoff value based on a review of bridge age versus condition.
- Traffic – based on Annual Daily Traffic (ADT) per lane as reported in the 2009 NBI.
- Unit replacement costs – total bridge replacement costs divided by the square footage of deck area on the replacement structures. (See Appendix C for explanation of the sources and derivation of this item.)
- Five year replacements – the square footage of deck area on structures replaced over the past five years divided by the total deck area. (See Appendix C for explanation of data sources.) This peer grouping was developed to enable comparisons across states that have been replacing relatively sizable portions of their bridge network from those that have replaced relatively few bridges.

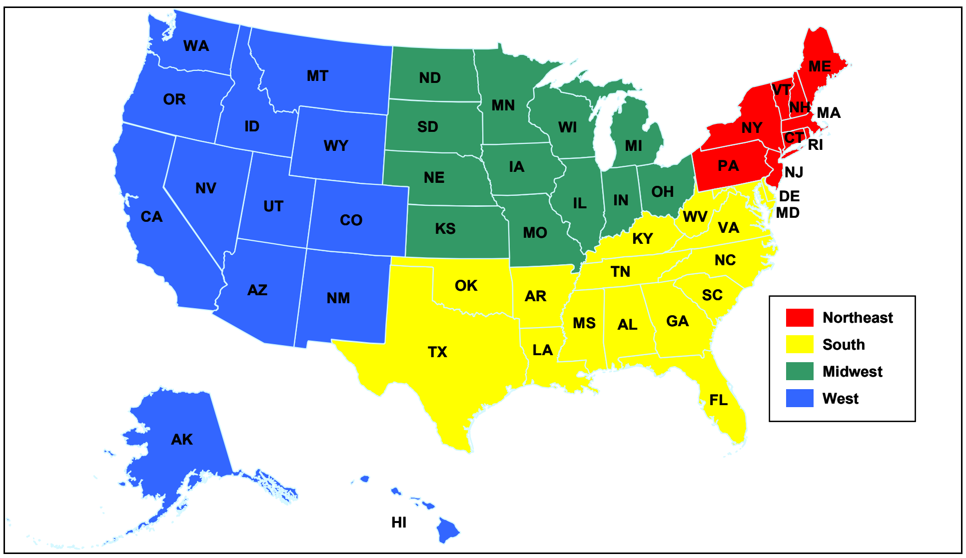

Figure 2. Census Regions used for Geographic Peer Groups

Values of selected performance measures were examined within each set of peer groups to identify obvious patterns of variation across groups. All of the sets but the one based on traffic showed variations in average condition across peer groups:

- For the geographic location peer group, the average bridge condition was worse for the northeast states than for states in other regions.
- For the peer group based on bridge age, states with a relatively low proportion of older bridges (<20 % based on deck area) had better average condition than other states, as would be expected.

- Variations within the regional and age-based peer groups were most pronounced for performance measures based only on superstructure and substructure condition, which is presumably related to populations of older bridges that have had deck replacements.
- For the peer group based on unit replacement costs, states with lower unit replacement costs had better average condition. This result presumably reflects the ability of these states to stretch available funds across a greater portion of the network than states with either inherently higher construction costs or those that undertook a more costly mix of projects.
- The peer group based on the percent of the network replaced showed better average condition for states replacing over 10 percent of their bridge deck area. Variation for this peer group was most significant in the performance measure based on bridges in good condition.

The peer group based on regions was factored in to the selection of top performing states, as described in the next section.

Further details on the peer group definitions and analysis are provided in Appendix C. This information can be used by participating states to compare performance results for their state with other states based on different criteria.

Cross State Comparison Results

Key observations based on review of the values for each measure across the participating states are summarized below:

- **Structurally Deficient Bridges** (2009 NBI percent of state bridge deck area on Structurally Deficient bridges) - the range across participating states was from 1 to 20 percent, with a mean of 7 percent and a median of 6 percent. Results for the subsets of Interstate and NHS bridges were similar. Northeastern states tended to have more deck area on Structurally Deficient bridges – they are clustered in the 10 to 20 percent range.
- **Bridges with Low Sufficiency Ratings** (2009 NBI percent of state bridge deck area on bridges with Sufficiency Rating of 50 or below) - the range for all bridges was from 0 to 17 percent, with both a mean and median of 4 percent. Results for NHS bridges were similar; results for Interstate bridges showed better conditions – as would be expected, with a range from 0 to 9 percent.
- **Posted Bridges** (2009 NBI percent of state bridge deck area on posted bridges) - the range for all bridges was from 0 to 18 percent, though the distribution was highly skewed towards the low end of this range, with a mean value of 2 percent and a median value of less than 1 percent. Only two of the 34 participating states had more than 5 percent of deck area on posted bridges. Results for NHS bridges were similar; results for Interstate bridges showed 33 states with 2 percent or less posted deck area and the remaining state with a very high 31 percent posted deck area.
- **Bridges in Good Condition** (2009 NBI percent of state bridge deck area on bridges with NBI Deck, Superstructure and Substructure ratings of 7 or higher) - the range for all

bridges was from 3 to 83 percent, with a mean of 40 percent and a median of 38 percent. Results were similar for Intestate and NHS bridges.

- **Change in Structurally Deficient Bridges** (Change from NBI 1999 to 2009 in percent of state bridge deck area on Structurally Deficient bridges) - the range for all bridges was from a 15 percent decrease to a 9 percent increase. Twenty-two of the 34 states improved or stayed the same over this time period with respect to deck area on Structurally Deficient bridges.
- **Change in Bridges with Low Sufficiency Ratings** (Change from NBI 1999 to 2009 in percent of state bridge deck area on bridges with Sufficiency Rating of 50 or below) - the range for all bridges was from a 12 percent decrease to a 4 percent increase. Twenty-seven of the 34 states improved or stayed the same with respect to this measure.
- **Change in Posted Bridges** (Change from NBI 1999 to 2009 in percent of state bridge deck area on posted bridges) - the range for all bridges was from a 5 percent decrease to a 4 percent increase. Twenty-seven of the 34 states improved or stayed the same with respect to deck area on posted bridges.
- **Change in Good Condition Bridges** (Change from NBI 1999 to 2009 in percent of state bridge deck area on bridges with NBI Deck, Superstructure and Substructure ratings of 7 or higher) - the range for all bridges was from a 21 percent increase to a 42 percent decrease. Fourteen of the 34 states improved or stayed the same with respect to deck area on bridges in good condition.

Figures 3 through 10 on the following pages contain bar charts showing performance measure values for each of the 34 states participating in this project. These figures show results for all state owned highway bridges. Separate results for Interstate and NHS bridges are provided in Appendix C.

Each bar on the charts represents a performance measure value for an individual state. States are displayed in order of decreasing performance from left to right. States are color coded by census region. (See Figure 2 for region definitions.)

One of the ground rules of this and prior comparative performance studies was that the studies do not publish state-specific results other than for the top performing states. Therefore, state ID's rather than names are shown on the horizontal axis.

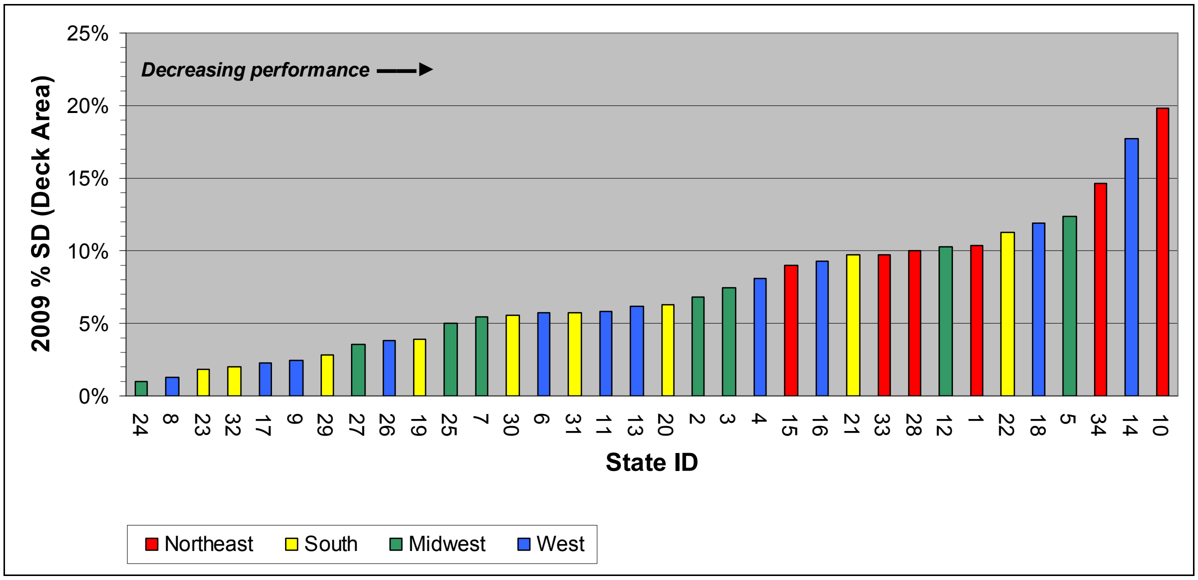

Figure 3. Percent of State Bridge Deck Area on Structurally Deficient Bridges, 2009 NBI

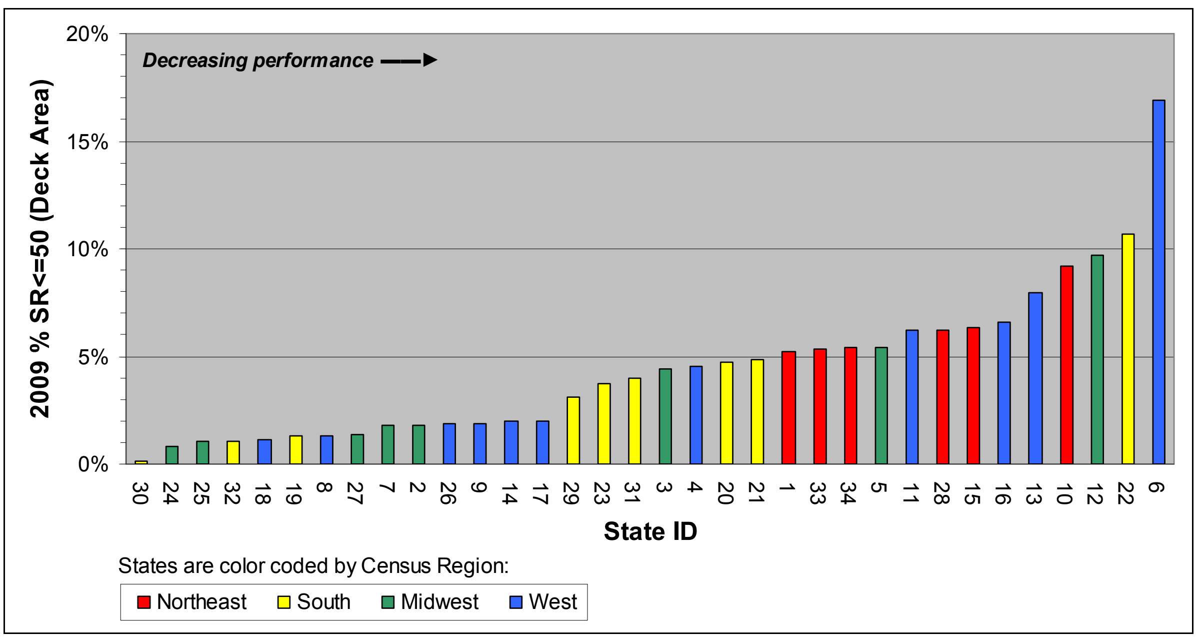

Figure 4. Percent of State Bridge Deck Area on Bridges with Sufficiency Rating ≤50, 2009 NBI

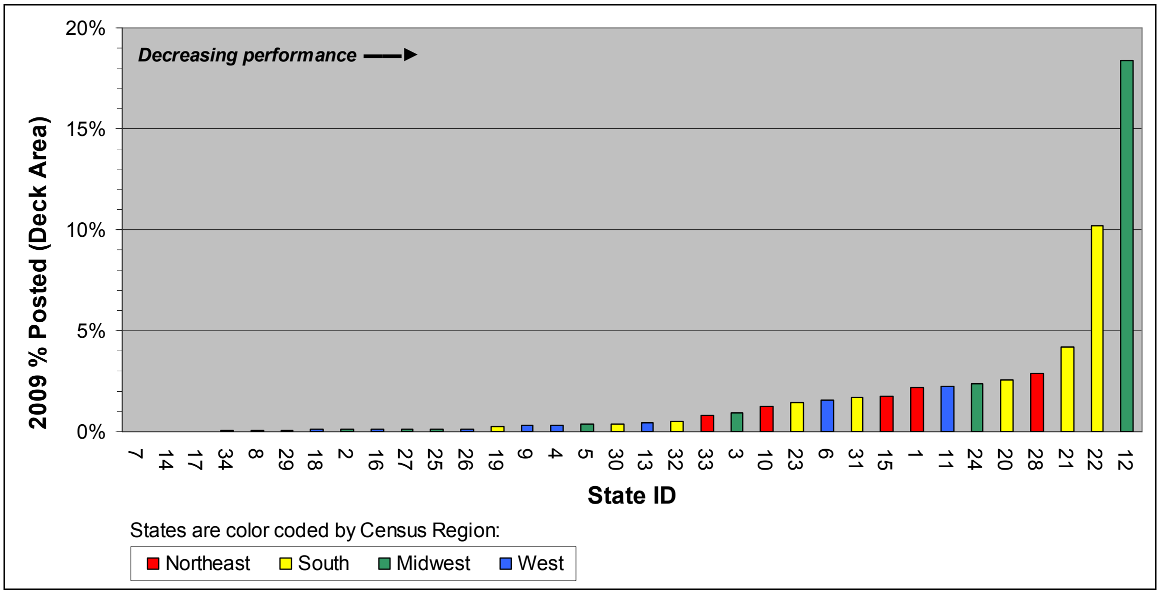

Figure 5. Percent of State Bridge Deck Area on Posted Bridges, 2009 NBI

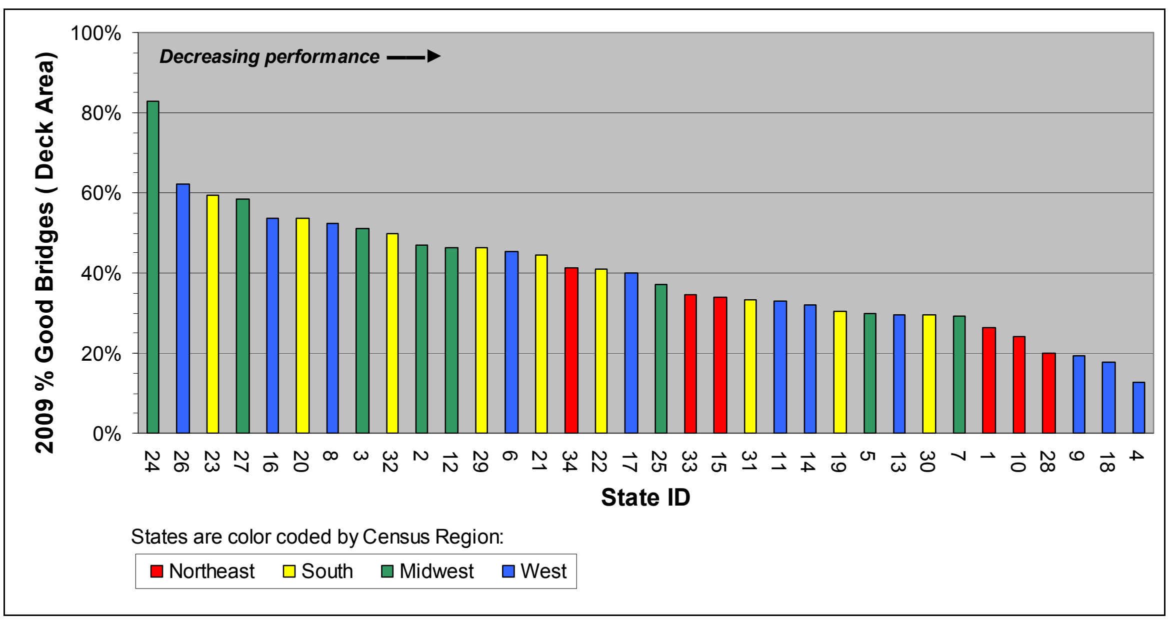

Figure 6. Percent of State Bridge Deck Area on Bridges in Good Condition, 2009 NBI

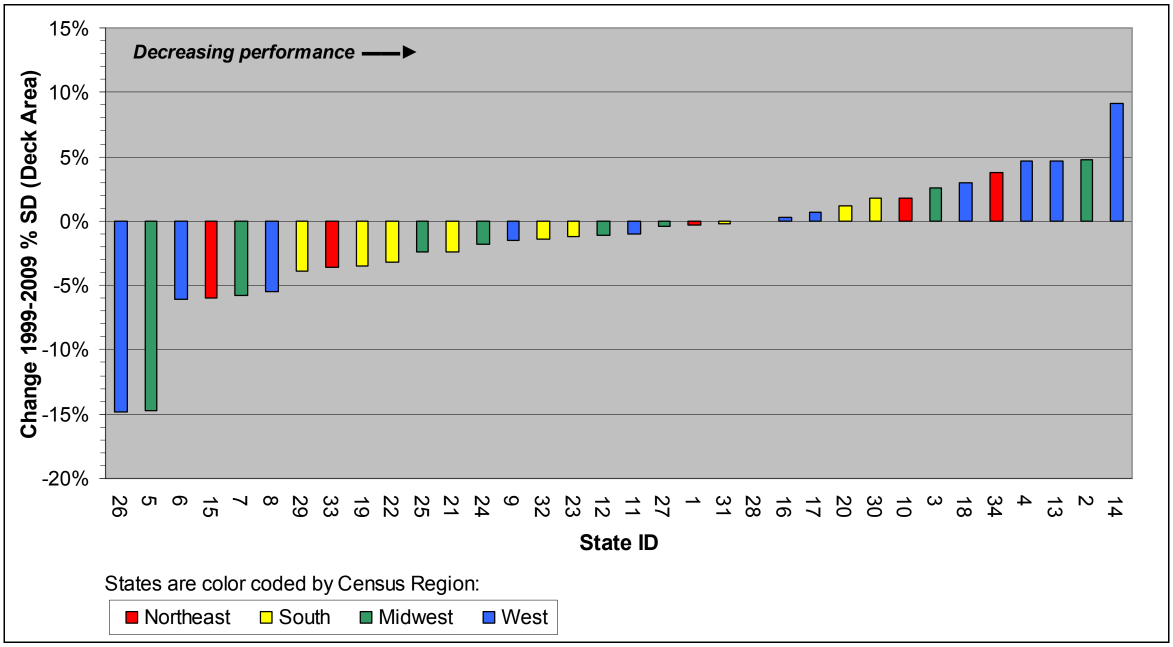

Figure 7. Change in Percent of State Bridge Deck Area on Structurally Deficient Bridges, 1999 to 2009 NBI

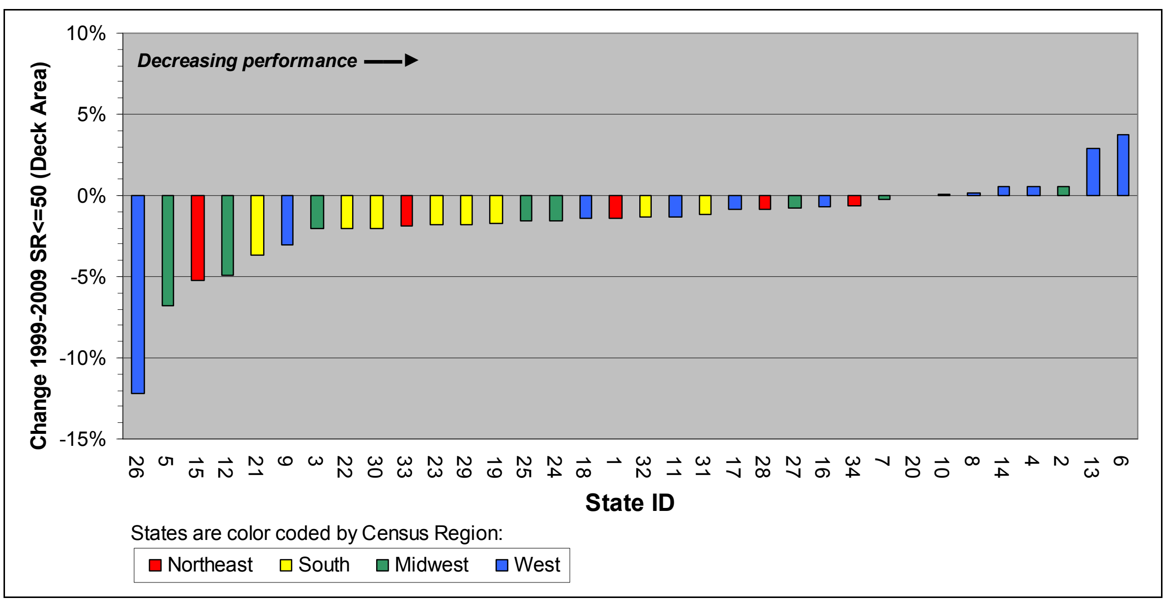

Figure 8. Change in Percent of State Bridge Deck Area on Bridges with Sufficiency Rating ≤ 50, 1999 to 2009 NBI

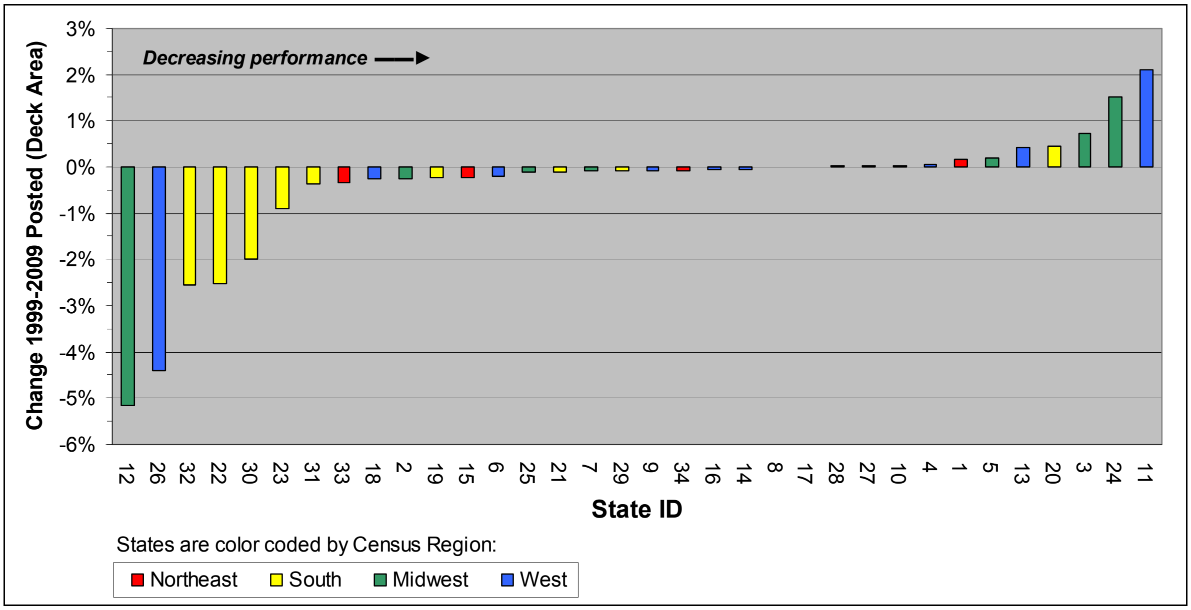

Figure 9. Change in Percent of State Bridge Deck Area on Posted Bridges, 1999 to 2009 NBI

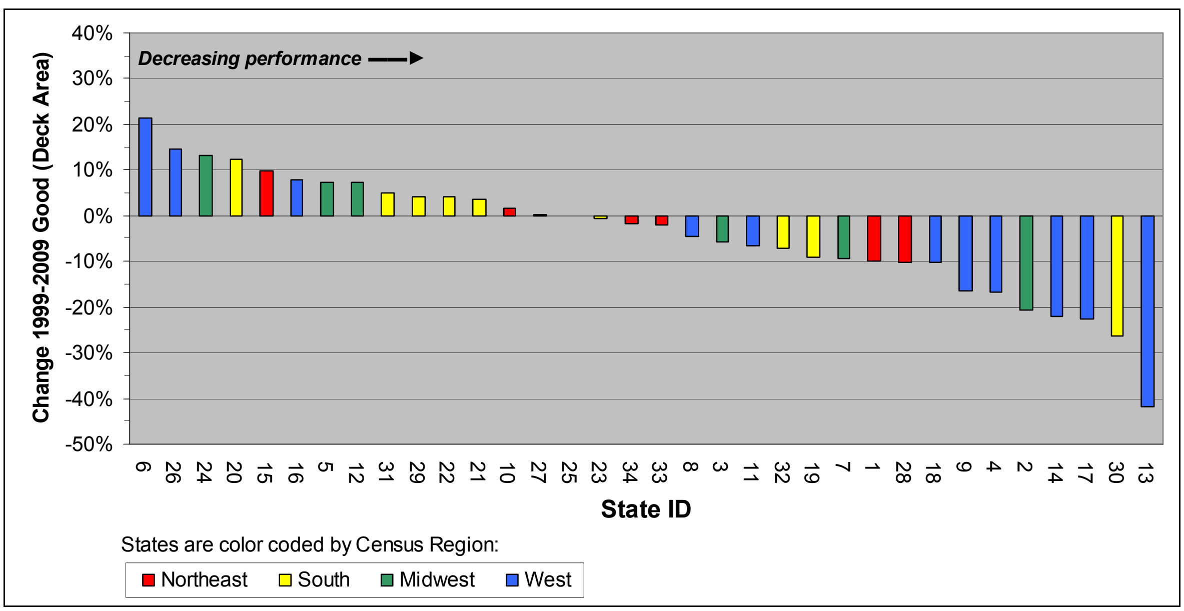

Figure 10. Change in Percent of State Bridge Deck Area on Bridges in Good Condition, 1999 to 2009

Tables 2 and 3 provide a condensed view of the comparative performance information. They show how each participating state ranked with respect to each of the eight performance measures. Table 2 presents results for bridges on all roads; table 3 presents results for bridges on the NHS only. (Ranks for Interstate bridges were similar to those for NHS bridges.) A rank of 1 represents the highest (best) performance. In both tables, the top five ranked states for each measure are shaded. Multiple states show the same rank where performance measure

values were identical. It should be noted that where performance measure values are clustered within a narrow range, differences in ranks are not meaningful. For example, For 2009, 21 of the 34 participating states show a very low (<1) percentage of deck area on posted bridges – thus the ranks at the low end of the scale were not useful for distinguishing performance across states.

Table 2. State Ranks for the Eight Selected Performance Measures (All Roads)

State Number	2009				Change 1999-2009			
	Posted	SD	SR ≤50	Good	Posted	SD	SR ≤50	Good
Region: Northeast								
1	27	28	22	29	28	20	17	25
10	22	34	31	30	26	27	28	13
15	26	22	28	20	12	4	3	5
28	31	26	27	31	24	22	22	26
33	20	25	23	19	8	8	10	18
34	4	32	24	15	19	30	25	17
Region: South								
19	13	10	6	24	11	9	13	23
20	30	18	20	6	31	25	27	4
21	32	24	21	14	15	12	5	12
22	33	29	33	16	4	10	8	11
23	23	3	16	3	6	16	11	16
29	6	7	15	12	17	7	12	10
30	17	13	1	27	5	26	9	33
31	25	15	17	21	7	21	20	9
32	19	4	4	9	3	15	18	22
Region: Midwest								
2	8	19	10	10	10	33	32	30
3	21	20	18	8	32	28	7	20
5	16	31	25	25	29	2	2	7
7	1	12	9	28	16	5	26	24
12	34	27	32	11	1	17	4	8
24	29	1	2	1	33	13	15	3
25	11	11	3	18	14	11	14	15
27	10	8	8	4	25	19	23	14
Region: West								
4	15	21	19	34	27	31	31	29
6	24	14	34	13	13	3	34	1
8	5	2	7	7	22	6	29	19
9	14	6	12	32	18	14	6	28
11	28	16	26	22	34	18	19	21
13	18	17	30	26	30	32	33	34
14	1	33	13	23	21	34	30	31
16	9	23	29	5	20	23	24	6

State Number	2009				Change 1999-2009			
	Posted	SD	SR ≤50	Good	Posted	SD	SR ≤50	Good
17	3	5	14	17	23	24	21	32
18	7	30	5	33	9	29	16	27
26	12	9	11	2	2	1	1	2

Table 3. State Ranks for the Eight Selected Performance Measures (National Highway System)

State Number	2009				Change 1999-2009			
	Posted	SD	SR ≤50	Good	Posted	SD	SR ≤50	Good
Region: Northeast								
1	32	29	26	28	27	12	9	24
10	13	32	31	29	20	27	15	11
15	20	23	28	25	4	1	1	2
28	27	26	24	32	24	22	19	26
33	24	24	23	17	5	9	10	16
34	1	30	22	13	12	29	30	17
Region: South								
19	1	9	5	27	12	10	11	27
20	28	14	18	6	30	28	32	4
21	30	27	17	18	26	17	4	15
22	29	22	32	14	32	7	31	12
23	22	5	15	3	7	14	16	14
29	1	3	8	10	12	8	18	10
30	NA	NA	NA	NA	NA	NA	NA	NA
31	11	10	11	21	18	20	23	7
32	18	6	3	7	3	16	17	20
Region: Midwest								
2	1	20	14	11	6	32	28	31
3	26	21	21	8	31	26	6	19
5	19	31	25	22	25	3	3	6
7	1	8	7	20	12	4	12	21
12	33	15	20	9	2	21	7	9
24	25	1	4	1	29	13	20	5
25	14	13	6	19	8	11	13	13
27	12	11	12	5	19	23	24	18
Region: West								
4	16	19	19	33	22	30	27	28
6	23	17	33	16	21	5	21	1
8	1	2	2	12	12	6	22	22
9	1	7	10	30	11	15	5	29
11	31	16	27	24	33	19	25	23
13	21	18	29	26	28	31	33	33
14	1	33	16	23	9	33	29	30

State Number	2009				Change 1999-2009			
	Posted	SD	SR ≤50	Good	Posted	SD	SR ≤50	Good
16	17	25	30	4	23	18	14	8
17	1	4	9	15	12	24	26	17
18	1	28	1	31	10	25	8	25
26	15	12	13	2	1	2	2	3

It can be seen from Figures 3 through 10 and Tables 2 and 3 that states ranked highly based on one performance measure are not necessarily the same as those ranked highly based on another measure. For example:

- State 18 ranks in the bottom five with respect to Structurally Deficient bridges and bridges in good condition, but is ranked in the top five with respect to bridges with low Sufficiency Rating and posted bridges.
- State 24 ranks in the top two with respect to Structurally Deficient bridges, bridges in good condition, and bridges with low Sufficiency Rating, but is ranked 29 out of 34 with respect to posted bridges.
- State 5 ranks second with respect to changes from 1999 to 2009 in Structurally Deficient bridges and bridges with low Sufficiency Ratings, but is ranked 30 out of 34 with respect to 2009 Structurally Deficient bridges.

Identification of Top Performing States

Notably, the results showed that nearly all of the states (29 of the 34) could be classified as "top performers" based on at least one measure/network combination. The research team developed the following approach to selecting a set of top performing states for interviews:

- Include one state from each census region (Northeast, South, Midwest and West);
- Include states showing good 2009 performance as well as states showing improvements from 1999-2009; and
- Select states primarily based on measures related to Sufficiency Rating, Structurally Deficient bridges and bridges in good condition, given the highly clustered nature of values for measures based on posted bridges.

The comparative performance results were examined to see which states consistently stood out across multiple measures.

With respect to *current* (2009) performance for all state-maintained bridges, State 24 showed the highest percentage of deck area on bridges in good condition, by a significant margin – over 80%. State 24 also had the lowest percentage of deck area on Structurally Deficient bridges and the second lowest percentage of deck area on bridges with low Sufficiency Rating.

With respect to *changes* between 1999 and 2009 in performance for all state-maintained bridges, States 5 and 26 stood out with the largest improvements for deck area on Structurally Deficient bridges and deck area on bridges with low Sufficiency Rating. States 12 and 26 stood out with

the largest improvements with respect to deck area on posted bridges. State 6 had the largest improvement in the percent of deck area on bridges in good condition.

For NHS bridges only, State 24 was ranked highest for measures based on Structurally Deficient bridges and bridges in good condition. States 8, 18, and 32 ranked higher than State 24 with respect to bridges with low Sufficiency Rating, though absolute differences in this performance measure across these three states were minimal (all had less than 0.5 percent of deck area on bridges with low Sufficiency Rating.) States 26 and 15 showed the largest improvements with respect to Structurally Deficient Bridges and bridges with low Sufficiency Rating. States 26 and 12 showed the largest improvements with respect to posted bridges. States 6, 15 and 26 showed the largest improvements for bridges in good condition.

Based on this analysis, the following four states were selected to represent the four regions:

- State 24 - Kansas (Midwest region) - selected for its strong 2009 performance across multiple measures.
- State 26 - Utah (West region) – selected for its performance improvements between 1999 and 2009, as well as its relatively strong performance in 2009. Utah ranked second with respect to deck area on bridges in good condition.
- State 15 - New York (Northeast region) – selected for its improvements between 1999 and 2009 with respect to Structurally Deficient bridges, bridges with low Sufficiency Rating and bridges in good condition – particularly on the NHS.
- State 23 - Georgia (South region) – selected for its strong 2009 performance across multiple measures. Georgia ranked third with respect to both bridges in good condition and Structurally Deficient bridges.

In addition to these four, the research team selected two additional states that were of interest based on the performance results:

- State 14 – tied for first place with respect to posted bridges, but ranked next to last with respect to SD bridges.
- State 12 - ranked last with respect to posted bridges, but highest with respect to the reduction in posted bridges.

These states were contacted and asked to provide insight into their performance results.

State 14: As a matter of policy, this state seeks to have no posted bridges on the state highway system. This is a result of concerns about mobility and public perception. If a bridge on the state system is likely to become posted, they attempt to fix it immediately. This state posts bridges at the legal limit for strength. However they model a design permit truck with an axle load of 52,000 lbs, quite a bit higher than the legal limit. Thus, if a bridge is at the point that it needs to be posted, to them this means the bridge is pretty far gone. The representative of this state cautioned that comparisons based on posted bridges needs to recognize the fact that different states use different criteria for posting, and different methods for load rating.

Regarding the high number of Structurally Deficient bridges, since around 1993 this state has been using FHWA's NBI Translator to calculate condition ratings from element-level data, and thus to calculate Structurally Deficient status. They have found that the NBI Translator overstates the impact of smart flags (e.g., the deck cracking smart flag), and thus tends to over-report the number of Structurally Deficient bridges. To put things in perspective, this state saw their number of Structurally Deficient bridges increase approximately 35% over a two-year period when they began using the NBI Translator. Approximately 94% of their Structurally Deficient bridges are classified as such due to deck conditions, so much of the issue with the increase was a result of decks being marked down in condition. After the initial increase they observed no further change in Structurally Deficient values. They feel the change was a result of the Translator rather than a result of deterioration, and have contacted FHWA regarding the behavior of the Translator. The representative further noted that his state does not use Structurally Deficient status as the basis for decisions about what bridges to work on, or what work to perform, because they do not consider this a reliable measure.

State 12: The representative of State 12 noted that improvements in the number of posted bridges have been the result of projects in the State Transportation Improvement Program (STIP) and a two-phase program to improve 802 of the state's lowest-rated bridges. Re-decking projects have helped because they can often convert a bridge from non-composite to composite when the deck is replaced. This action often removes the load posting.

4. State Interview Findings

State Interview Summaries

Representatives of the four selected states with notable performance results (as determined using the methods described in Section 3) were interviewed in order to gain an understanding of practices that may have been related to achievement of the observed results. A standard interview guide was used (see Appendix D), covering organizational responsibilities for bridges, resource allocation processes, performance measures in use, design and construction practices, and maintenance practices. The representatives of each state were asked for their opinion about which practices have had the greatest influences on their state's bridge performance results.

Prior to the interviews, each state received a copy of the interview guide. Interviews were conducted with the agency bridge engineer. Following the interview, a draft summary was prepared utilizing notes from the interview. The draft summary was transmitted to the primary state contact for review. Comments received were incorporated into the final versions of the summaries. A synthesis of common themes across the four states was prepared.

Summaries of interviews with the four states are presented below.

Kansas Department of Transportation (KDOT)

Kansas was selected for its strong performance based on 2009 NBI data, with respect to Structurally Deficient bridges, and bridges in good condition. Kansas also ranked highly with respect to changes between 1999 and 2009 in good condition.

At KDOT responsibility for bridge management is shared among three different bureaus. Maintenance personnel at district, area and subarea offices within the Bureau of Operations have day-to-day responsibility for managing the bridges in their respective areas, and perform routine maintenance on their bridges. The Bridge Office within the Bureau of Design performs all bridge inspections, coordinates bridge preservation work and houses the bridge management activities. The Bureau of Planning and Development leads the development of KDOT's capital program, including bridge rehabilitation and replacement projects included in the capital plan. KDOT staff felt that housing their bridge management activities within the Design organization has allowed for rapid reaction to problems identified by the bridge management system.

Kansas collects element-level bridge condition data using the standard AASHTO Commonly Recognized (CoRe) elements with some modified definitions (generally to provide comments for additional clarity) and some state-specific elements. Kansas began to phase in the element-level inspection approach in 1993. They also continue to separately collect the standard NBI condition ratings. Kansas computes a Bridge Health Index (BHI) from the element-level ratings. They have established the following categories for describing bridge condition: Very Good (BHI over 95), Good (BHI between 85 and 95) Fair (BHI between 70 and 85) and

Deteriorated (BHI ≤ 70.) They use the health index, together with individual element ratings and NBI ratings as inputs to the project development and prioritization process.

Bridge preservation activities performed by KDOT are largely guided by the bridge inspection process. Bridge inspectors make recommendations for each bridge based on engineering judgment. These recommendations are reviewed at area meetings. Staff at the district and area levels determine what work they are able to perform (typically light maintenance activities that do not require heavy equipment or additional contracts) and create a set-aside list for other work that is needed but cannot be performed at the district or area level. The State Bridge Office has budgets for five bridge preservation programs for bridge and culvert preservation work beyond that performed by district/area staff: bridge repair, painting, culvert replacement, priority re-decking, and priority culvert work (typically converting culverts into bridges). Budgets are established for each of these programs annually, but in practice the Bridge Management Engineer can shift funds between programs as needed. Currently, bridge preservation funding is largely being used for guardrail replacement, expansion joint repairs, substructure repairs, and deck overlays.

KDOT's capital plan establishes the overall budget for bridges, and details major projects, including bridge replacements and other bridge projects with an individual project estimated budget of $20 million or more. For establishing the budget, the Bridge Office determines funding requirements needed over a 10-year period to maintain four different levels of performance. These levels (and the approximate annual funding for the level identified in the most recent analysis) are defined as follows:

- Desirable ($125M/yr)
- Responsible ($100M/yr)
- Essential ($75M/yr)
- Deferment ($50M/yr)

Each of these investment levels corresponds to a target for percentage of bridges in good, fair and deteriorated condition. KDOT has established a priority optimization formula for helping to prioritize bridge work in the capital plan. Currently capital funding for bridges is based largely upon funds available from the federal Highway Bridge Rehabilitation and Replacement (HBRR) funds. However, over the last ten years KDOT used additional state money, approved through a set of highway funding bills, to perform additional bridge work. The two most recent bills were for budgets of $7B and $10B, respectively.

KDOT has taken a number of steps to reduce the initial costs of bridge design and construction, as well as the long-term cost of bridge maintenance. KDOT has provided standard designs to consultants, termed "cookbook plans", to help control costs, improve quality and encourage use of inspectable and repairable bridge designs. Many of the structures built using such standards are haunched slabs, post-tensioned slabs, or prestressed concrete. KDOT also has discouraged use of design details that tend to be expensive to maintain, such as open-faced diaphragms, and has encouraged structure designs that minimize the number of expansion joints.

Facilitating communication between bridge inspectors, maintenance engineers and designers is an important aspect of KDOT's bridge management approach. Inspectors participate in meetings with senior squad leaders to discuss design details, ultimately leading to improved designs for new bridges. District maintenance engineers meet approximately four times a year, and bridge management staff participates in those meetings as needed. Also, bridge management staff participates in bi-annual operations meetings and annual district construction meetings.

From KDOT's perspective, the major contributing factors that have resulted in improved bridge performance include:

- A strong inspection process, which results in maintenance recommendations for each bridge;
- Commitment to preservation activities such as repairing joints, decks and other bridge components;
- Institution of performance measures for tracking bridge condition, which in turn has helped make the case for increased funding;
- Use of standard designs to reduce costs of construction and long-term maintenance; and
- Close coordination among bridge managers, designers and district and area-level staff on bridge needs.

Georgia Department of Transportation (GDOT)

Georgia was selected for its strong performance based on 2009 NBI data, ranking third with respect to both Structurally Deficient bridges and bridges in good condition.

At GDOT bridge management responsibilities are shared among: district offices, which are responsible for routine maintenance; the Division of Planning, which has responsibility for developing capital plans; and the Division of Engineering. In the Division of Engineering, bridge management activities are led by the Bridge Maintenance Unit within the Office of Bridge Design. This unit is responsible for inspecting and rating bridges, contracting for bridge preservation work outside of the scope of what GDOT district staff can perform, and prioritizing capital projects for bridges.

The budget for bridge preservation, as well as for bridge replacement and other capital projects, is established annually as part of the capital plan development process. Overall funding for bridges is largely determined by the federal HBRR funds.

GDOT began collecting element-level bridge condition data in 1993. Element-level data are collected for structures on state routes only. NBI ratings are collected separately. Individual steel element ratings; the NBI Sufficiency Rating; and NBI Deck, Superstructure and Substructure ratings are used as input to the project identification and prioritization process. GDOT uses measures derived from NBI data (e.g., Sufficiency Rating and Structurally Deficient/Functionally Obsolete status) to summarize bridge conditions, but bridge staff has found that the existing measures are problematic, and tend to rely on bridge-level assessments of needs for program planning and budgeting. GDOT has established a bridge prioritization

formula as a general guide for prioritizing bridges for rehabilitation or replacement. The formula includes adjustments for a variety of structural and functional factors, such as traffic, detour distance, posting status, condition ratings, and clearances.

Bridge maintenance and preservation work is driven by bridge inspector recommendations. The Bridge Maintenance Unit enters recommendations for routine maintenance actions for district staff to perform in the Highway Maintenance Management System but the work is decided upon and performed at the district level. For specialized repairs, such as replacing broken joints, the Bridge Maintenance Unit prepares repair plans through a set of three task order contracts that are administered by the districts. GDOT staff feel that reliance on district expertise contributes to successful management. However, currently district resources are tightly constrained, so that maintenance work performed by district staff is largely limited to maintaining signage and lines of sight.

An emphasis area for GDOT in the bridge area has been to use standard design approaches that minimize construction and long-term maintenance costs. Georgia DOT has developed a Bridge and Structures Policy Manual that details department policies and recommends standard approaches to bridge designs. As a result of this emphasis, since the 1970's Georgia DOT has constructed primarily prestressed and reinforced concrete bridges that to date have required relatively little maintenance. Further, beginning in the 1980's Georgia DOT began using simple-span prestressed beams where possible, making spans continuous over bents to minimize the use of expansion joints. This in turn has resulted in much lower costs from joint maintenance relative to costs incurred from older designs.

Besides the use of low-cost/low-maintenance bridge designs, an important factor that has helped GDOT in its bridge performance is that in the 2000's GDOT implemented a series of significant capital programs. Through the Governor's Transportation Choices Initiative (GTCI) initiated in 2001 and the successor program Fast Forward initiated in 2004, GDOT used a combination of state funds and bonds to significantly increase its transportation spending. Though many of the highway improvements were intended to increase capacity, they nonetheless resulted in rehabilitation or replacement of a large number of bridges. Thus, GDOT effectively accelerated work on many of its bridges through these programs, significantly contributing to the overall condition of the network.

New York State Department of Transportation (NYSDOT)

New York was selected for its improvements in bridge condition between 1999 and 2009, ranking in the top five with respect to changes in Structurally Deficient bridges, bridges with low Sufficiency Rating and bridges in good condition.

At NYSDOT, staff in each region has primary responsibility for day-to-day management of NYSDOT bridges, as well as for developing their regional bridge program. The Policy and Planning Division is responsible for developing the annual capital plan, which establishes the overall distribution of funds by asset type and region. The Structures Division maintains bridge inspection and inventory data, assists the Policy and Planning Division in analyzing bridge conditions and investment needs, manages major rehabilitation and replacement projects, and provides support to the regions.

Each of NYSDOT's 11 regions is staffed with a bridge maintenance engineer, structures engineer and bridge management engineer. Approximately 550 of NYSDOT's 4,300 maintenance staff are associated with bridge maintenance. Though in winter months these staff focus on snow and ice control, at other times of the year they are tasked with performing bridge maintenance work. NYSDOT attributes having "many eyes" on their bridges at least in part to the successes they are experiencing in bridge serviceability.

NYSDOT reports that their staff's stability is also an attribute. Bridge staff tends to stay within maintenance, inspection or design within the state which provides high quality personnel to select for positions.

Other suggested reasons for good performance given by NYSDOT staff include:

- Efforts to make bridge components more inspectable since the early 1980's
- Scheduled maintenance activities (deck washing, sealing, lubing, etc.)
- Performing element level inspections
- The general increase in investment in bridge maintenance over time

NYSDOT has a well-established approach to bridge management, largely instituted in the late 1980's. The primary measure of bridge condition is NYSDOT's condition rating, a seven-point scale measuring bridge condition similar to the NBI condition ratings, with 1 representing the worst possible condition, and 7 representing the best condition. New York rates bridges based on 47 elements (which are not based on the AASHTO CoRe elements). Twenty five of the elements are rated on a span by span basis. The overall condition rating for a bridge is a weighted average of the condition ratings for 13 bridge components. NYSDOT has developed matrices defining appropriate treatments by condition rating, and has developed deterioration curves that predict how condition rating varies over time with and without recommended bridge maintenance activities. Bridge Management System (BMS) logic matrices are based on Component Condition Indices which aggregate inspection ratings for various bridge components. The Bridge Needs Assessment Model (BNAM), incorporates this information to predict bridge conditions and investment needs over time, and is used to support goal development and high-level resource allocation decisions. BNAM is one of several NYSDOT developed tools that are available to assist and provide data points for bridge management decisions.

Each region has a structures management team established to evaluate each of the region's bridges and plan maintenance work on an annual basis. Regional structures management teams focus their programming recommendations on local needs considering the Statewide Five Year Capital Plan. Resources to assist maintenance planning include the document "Fundamentals of Bridge Maintenance and Inspection", which provides guidance on recommended maintenance techniques and frequencies, a bimonthly newsletter on bridge maintenance issues, and periodic statewide meetings of bridge maintenance staff. Although to a large degree, maintenance staff are forced to work in a reactive mode, NYSDOT attempts to maintain a standard of having bridge maintenance crews spend at least 25% of their time on cyclical maintenance activities, such as bridge washing, crack sealing and bearing lubrication. The most common bridge maintenance activity is joint repair. NYSDOT has established a

"vertical down" maintenance program to help address joints, and problems caused under the bridge deck by leaky joints. (The "vertical down" term refers to the fact that if a problem with a joint is ignored, this in turn creates additional problems on the structural components underneath the joint.)

Since the 1980's NYSDOT has tended to emphasize repairing or rehabilitating existing bridges as an alternative to bridge replacement. For example, for Fiscal Year 2007-2008, of approximately $592M spent by NYSDOT on its bridges, there were approximately 50 bridges replaced at a cost of approximately $159M. Other capital projects (rehabilitation, minor bridge work and removal) were performed on 246 bridges at a cost of approximately $291M, and preventive maintenance activities were performed on over 5,800 bridges at a cost of approximately $142M. NYSDOT has established a "5 to 7 Program" (referring to condition ratings from 5 to 7) for performing needed work on bridges that are in generally good condition to prevent theses bridges from slipping into a deficient condition. Further, NYSDOT has requested FHWA provide it flexibility for using federal bridge funds for preventive maintenance activities. From NYSDOT's perspective, the agency's focus on bridge preservation as the most cost-effective approach to maintaining the condition of the bridge network, coupled with the overall level of investment, is the major contributing factor to improvements observed in its bridge conditions over time.

Utah Department of Transportation (UDOT)

Utah was selected for its improvements in bridge condition between 1999 and 2009, ranking in the top three with respect to all four measures. Utah also ranked second with respect to bridges in good condition for the 2009 NBI.

In UDOT responsibilities for bridge management and maintenance are shared among district offices, the Structures Division, and the Asset Management Division. Districts are responsible for day-to-day management and routine maintenance activities (e.g., cleaning, sweeping and minor maintenance on bridge joints). The Structures Division manages the bridge inspection program, develops UDOT's bridge preservation strategy, and prioritizes and manages the bridge capital program. The Asset Management Division establishes overall asset investment levels, and determines how to distribute available funds across assets.

UDOT began collecting element-level bridge condition data in 2003, and uses the standard AASHTO CoRe elements. UDOT also separately collects NBI condition ratings, and uses the NBI Translator to verify (not calculate) the bridge ratings.

UDOT generally uses Federal HBRR Replacement funds for major bridge capital projects (rehabilitation and replacement, excluding capacity expansion projects), and uses state funds for additional bridge preservation work. For programming bridge rehabilitation and replacement work, UDOT maintains a list of Structurally Deficient bridges, and allocates capital funds to bridges on this list. UDOT classifies each bridge on the list based on its vulnerability on a high/medium/low scale. Within each of these categories, a score is computed considering functional issues, traffic, economic development impacts and other issues. UDOT has established a good/fair/poor measure for high-level reporting of bridge conditions. Structurally Deficient bridges are considered "poor"; bridges with deck, super and

substructure ratings of 7 or greater are considered "good"; and all other bridges are considered "fair".

Bridge preservation is prioritized and funded separately from the rehabilitation and replacement program using state funds. An overall budget is established for pavement and bridge preservation, and the Asset Management Division determines how to allocate these funds across asset types. The Structures Division determines how to allocate available funds for bridge preservation. Typical activities include deck patching/sealing, replacing or removing joints, concrete repair, painting, and other activities short of major rehabilitation.

When replacing bridges, either as a result of deteriorated condition or as part of a capacity expansion project, UDOT has focused on using innovative contracting and construction techniques to speed construction and reduce costs. UDOT has been at the forefront in the use of techniques such as, design/build, Construction Manager/General Contractor (CM/GC) contracting and Accelerated Bridge Construction (ABC) to reduce the time required to contract, design and construct a facility from years to months, and in some cases weeks. UDOT's experience in this area has been well-documented in other recent NCHRP reports. UDOT reports that use of such innovative techniques has been extremely successful in accelerating construction schedules and enhancing the agency's credibility with the public - particularly recently with the rapid delivery of projects funded by the American Reinvestment and Recovery Act. While acceleration of bridge schedules does not directly impact network-level bridge condition, Utah reports that use of innovative contracting and construction has also reduced overall construction costs (allowing available resources to go further), and most importantly, has encouraged use of standardized designs that are expected to be more maintainable over time.

UDOT has recently replaced a large number of bridges as part of capacity expansion projects funded outside the bridge program. The agency currently has approximately $4B of work under contract, a significant portion of which is for structures work. In addition to this work, in 2002 UDOT completed the $1.6B I-15 project in Salt Lake City. This project alone, performed from 1998 to 2002, resulted in replacement of 144 bridges, or 7.8% of the state inventory. The fact that UDOT has relied on innovative contracting and construction techniques has likely helped enable the rapid replacement of so much of the state inventory in a more cost effective manner than using typically contracting and construction techniques.

Synthesis of Practices

Each of the four states interviewed operates in a distinct environment with a different set of needs, opportunities and constraints. Each state has taken a different path to achievement of its performance results. The following provides a synthesis of themes identified in interviews with the four states. Within each theme, specific practices noted by one or more of the four states are highlighted. This provides a convenient checklist of potentially useful practices for consideration by states seeking to make further progress towards improved network-level bridge condition.

Note that while it is valuable and useful to identify the practices of these states that may have contributed to their strong performance, it is important to keep in mind that this type of macro-scale analysis including only a handful of states has limitations. More specific studies that examine specific bridge components and the design, construction and maintenance practices are required for identification of causal relationships between practices and performance results.

Theme 1: Make the Case for Bridge Investment

Three of the four states interviewed – Kansas, Utah, and Georgia – reported that they have been able to secure funding for bridges beyond those available from the federal HBRR program. The ability to do this depends on making a clear and compelling case for investment. This begins with a foundation of credible and objective inspection data, which is used to report on the performance of the agency's bridges using an agreed-upon set of performance measures. Establishment of performance targets with estimates of the level of investment required to achieve these targets provides the basis for resource allocation decisions. An established, data driven method for project prioritization is also an important program element for enhancing credibility and transparency, ensuring that available funds are targeted to where they are most needed, and streamlining the decision-making process.

Specific practices include:

- Establish performance measures for benchmarking bridge conditions and communicating agency targets.
- Determine funding requirements to meet alternative target levels of performance.
- Document the agency's approach to prioritizing major rehabilitation and replacement projects.

Theme 2: Emphasize Bridge Preservation

For agencies with significant numbers of aging structures, it simply is not feasible to build one's way out of the problem of deteriorating bridge conditions. Thus, it is critical to emphasize effective bridge preservation approaches that can be applied to existing structures to arrest deterioration to the extent possible. Bridge preservation starts with having a comprehensive bridge inspection program. All states are required to inspect according to FHWA standards. Most states, and all that were interviewed in depth, go beyond these standards, and perform more detailed element-level inspections to determine not just the overall condition of a bridge, but develop an understanding of the underlying issues contributing to its condition.

A practice noted by several of the agencies interviewed was to include identification of specific work recommendations as part of the bridge inspection process, and to establish an approach to tracking, reviewing and prioritizing bridge inspector work recommendations. Agencies reported that establishing these processes can identify low cost actions to help preserve bridge conditions and forestall more aggressive and expensive actions. Also, it facilitates much-needed communication between district/area and central office staff on the conditions and needs of the bridge inventory.

Another essential element noted by several of the agencies interviewed was the establishment of specific programs for common preservation actions. The actions an agency may perform depend heavily on the characteristics of its bridge inventory and operating environment. Nonetheless, common preservation actions include bridge washing, joint repairs, deck overlays, painting and minor concrete repairs. Agencies interviewed used different approaches to establishing these programs, including establishing centrally-administered programs with specified annual budgets by type of action, and developing recommendations for district or regional staff to use concerning frequency of common actions. The key ingredients of the preservation programs reported by the agencies interviewed include identifying common preservation actions, establishing some form of guidance concerning when to perform actions, and providing for flexibility in the use of preservation funds to respond to changing conditions.

Specific practices include:

- Inspect bridges at the element level.
- Track bridge-level work recommendations.
- Establish programs for common types of preservation actions.

Theme 3: Construct Maintainable Bridges

Clearly, it is easiest to maintain bridges in good condition if one constructs bridges that are easy to inspect, and easy to maintain. Three of the states interviewed attribute their performance results, in part, to longstanding design and construction practices aimed at minimizing inspection and maintenance costs, allowing available resources to go further for maintaining bridge conditions over time.

A common theme in the interviews was that of reducing the life cycle cost of constructing and maintaining a bridge. Identifying and eliminating high cost design details, particularly bridge joints, is a key practice in this regard. Agencies interviewed discussed their emphasis on lower-cost, easy-to-maintain, and good performing designs as a contributing factor to improved bridge performance Institutionalizing recommended design practices into standard designs further reduces use of high-maintenance details, and reduces the time and cost required for bridge design.

To develop a better understanding of how to make bridges more inspectable and maintainable, agencies cited the importance of facilitating communication among designers, inspectors and maintainers, such as through quarterly or annual meetings between these groups. Bridge maintenance staff with day-to-day experience inspecting and maintaining bridges can provide a valuable perspective on how to design a bridge that they can easily inspect and cost-effectively maintain.

Alternative contracting and delivery approaches have the potential to further reduce initial, repair and reconstruction costs within the life cycle of the bridge. Where these approaches are effective, they can have a two-fold effect by helping an agency stretch its budget further to perform more work, and by encouraging further standardization of more maintainable structures.

Specific practices include:

- Discourage use of high maintenance design details.
- Encourage use of standard designs where possible.
- Take advantage of alternative contracting approaches to encourage standardization of more maintainable structures.
- Enhance communication between bridge design and maintenance staff through review during design, development of standards, project scoping or other preconstruction activities.

5. Improving Future Bridge Comparative Performance Measurement

This final section presents recommendations for steps that can be taken to improve the basis for bridge comparative performance measurement. These recommendations are based on a limited literature review, opinions expressed by participating states, and results of the analysis of NBI data conducted as part of this study.

Selecting Bridge Condition Measures for Comparative Performance

Limitations of Existing Measures based on the NBI

At the present time, the NBI provides the only consistent and complete national data set on bridge condition with coverage of all publicly owned bridges open to vehicular traffic over 20 feet in length. The data are widely used both within individual agencies and nationally to provide a high level picture of bridge condition and performance. The literature review presented in Appendix A provides information about use of NBI-related performance measures at the national and state levels.

While there was agreement among study participants to use the NBI data as the basis for this study, some of the participants (in discussions with members of the research team) raised a number of concerns about limitations of the NBI condition ratings:

- NBI ratings are based on visual inspection methods which are subjective and therefore variable across states and across individual inspections within a state – particularly where strong quality controls are not in place. Ratings for a given bridge can and do fluctuate from inspection to inspection without any actual change in condition.
- NBI ratings are intended to describe the overall or "average" condition of three major bridge components: deck, superstructure and substructure. The rating scale emphasizes severity, rather than the extent of deterioration. It can be difficult for inspectors to decide what the "average" condition is when a bridge has mainly localized problems and multiple distress symptoms.
- NBI data is used for funding decisions and therefore may be subject to bias.

One of the state bridge engineers participating in this project felt that the NBI deck rating provided a reasonable condition measure, but the NBI superstructure and substructure conditions were less useful for providing an understanding of a bridge's condition given the complexity and variability of these components across structures. He noted that the cost to bring a bridge up to standards would be a more informative measure – though acknowledged that it would be difficult to obtain consistent cost information across states.

Some study participants also expressed concern about the two main national bridge-level measures derived from NBI data that are used to determine federal funding eligibility -

Structurally Deficient bridges and Sufficiency Rating. Issues raised with respect to these two measures are summarized below.

Structurally Deficient Bridges. One concern about using the Structurally Deficient status as a comparative performance measure is that it doesn't distinguish between a bridge that has a deteriorated deck from one with more fundamental problems with the superstructure and/or substructure. Two states may have the same number of Structurally Deficient bridges, but one state's Structurally Deficient bridges may be related primarily to decks and the other's due to superstructure or substructure. Because deck issues are less costly to correct, the state that has mostly deck issues has issues that are more easily addressed than the one with superstructure or substructure issues. It can be argued, however, that while lower superstructure and substructure ratings are typically more indicative of serious structural concerns than low deck ratings, deck ratings do impact safety and are more visible to the public. Correction of poor deck condition can provide low hanging fruit for agencies to harvest.

A second concern expressed about use of Structurally Deficient status is that it is partially determined by a structural appraisal rating based on a comparison to current design standards. Thus, some bridges that do not meet modern design standards but are in very good condition may be classified as Structurally Deficient. However, in the subset of bridges considered in this research, 97 percent of the Structurally Deficient structures also had deck, superstructure or substructure rating ≤4, indicating that the structural appraisal rating was not a driving factor in assignment of Structurally Deficient status.

One final issue with use of Structurally Deficient status as a comparative performance measure relates to the FHWA NBI Translator. In order to eliminate the need for states that collect element-level condition data to have to perform independent ratings of deck, superstructure and substructure for their NBI reports, FHWA has provided the NBI Translator tool. This tool takes element level condition data (based on the AASHTO CoRe elements) as input and produces the NBI ratings. Four of the participating states in this study indicated in the questionnaire that they used the NBI Translator. One of these states reported that NBI ratings calculated by the FHWA Translator deviated substantially from those based on direct assessment. This state experienced a 35 percent increase in their count of Structurally Deficient bridges over a two-year period when they began using the NBI Translator. This experience raises concerns about comparability of NBI ratings and Structurally Deficient status between states that do use the Translator with states that do not. This issue will likely be resolved at some point in the future given the proposed changes to the CoRe elements (see below.)

Sufficiency Rating. The Sufficiency Rating based on NBI data emphasizes functional and geometric characteristics of bridges. NBI condition ratings are considered, but to a limited extent. Risk factors – for example seismic vulnerability are not included. A bridge in very good structural condition could have a low Sufficiency Rating due to a high detour length or a deficient railing. Therefore, while it is valuable to include a measure that considers the functionality, serviceability and safety of bridges (and not just physical condition alone), it is

important to keep in mind that performance measures based on Sufficiency Rating will not necessarily be impacted by exemplary preservation practices.

Potential for Future Use of Element-Level Data for Comparative Performance

Agencies that conduct element-level inspections utilizing the AASHTO CoRe elements can provide measures derived from these element-level ratings. Such measures include percentage of selected element quantities in high or low condition states, or a health index derived from the element-level data. Measures of condition derived from element-level data can more precisely describe the severity and extent of deterioration on a structure than the NBI ratings and are less subject to variation across inspectors *(10)*.

Forty four states license the Pontis bridge management software from AASHTO (*11*). This software supports element-level inspection data and can be used to report the Health Index. However, not all Pontis users employ the Health Index and many of those that do make use of it customize its calculation –for example, by utilizing state-specific failure costs.

The use of CoRe element data was explored for this study, but it was found that standard CoRe element data was only available from 19 of the 34 participating states, This was not felt to be a large enough representation to effectively perform the study. However, of the 15 states that could not provide CoRe element data:

- Only two were not collecting any element-level data.
- Five were collecting state-specific element-level data not compatible or only partially compatible with the AASHTO CoRe elements.
- Eight were at a relatively early stage in their collection of element-level data and therefore did not yet have either full network coverage, trend information, or were not yet comfortable making the data available.

Led by the AASHTO Technical Committee for Bridge Management, Evaluation and Rehabilitation (T-18), efforts are underway to modify the CoRe elements in order to further improve their usefulness for condition assessment and bridge management. These changes will address some of the recognized shortcomings in the current CoRe elements. They will primarily impact structural steel and deck/slab elements, separating out wearing surfaces and coatings, and modifying units of measure for deck/slab elements from "each" to square feet (or meters). In addition, the number of condition states for each element will be standardized to four, representing good, fair, poor and severe conditions. Expanded element smart flags will be incorporated. Element descriptions will also be enhanced to provide improved inspector guidance.

A draft AASHTO Bridge Element Inspection Manual incorporating these changes has been prepared to replace the existing AASHTO Guide to Commonly Recognized Structural Elements (*12*). This manual distinguishes a set of National Bridge Elements, a set of Bridge Management Elements, and a set of Agency Elements as follows:

- **National Bridge Elements (NBE)** represent primary structural components of bridges necessary to determine overall condition and safety of the primary load carrying members.

These elements represent a refinement of the NBI deck, superstructure, substructures and culvert condition ratings. The NBE also includes bridge rail and bearing elements. The NBE are designed to be consistent across agencies to facilitate the capture of bridge element condition at the national level.

- **Bridge Management Elements (BME)** define secondary components of bridges such as joints, wearing surfaces and protective coating systems that are typically managed by agencies utilizing Bridge Management Systems. The BME are defined in a general fashion to provide flexibility for modification by individual agencies.

The manual notes that agencies can define custom elements that are either independent from the NBEs and BMEs or sub-elements of NBEs or BMEs. In this way, the new Bridge Element Inspection Manual seeks to provide both the standardization needed to support national performance measurement and the flexibility needed to meet individual state needs.

The changes to the CoRe elements and the proposed set of national bridge elements are important steps towards improving the basis for national comparative bridge performance measurement. While these changes will take time to implement, it is likely that availability and consistency of element-level data will continue to improve, and use of element-level data will be a viable option for future comparative performance measurement efforts.

Recommendations

Given the discussion above, actions to improve the basis for comparative performance measurement for bridges should focus on supporting adoption and consistent interpretation of the National Bridge Elements. Since this will take time, recommendations below address short term use of NBI-based measures but support transition to longer-term use of measures based on the new National Bridge Elements.

Continue Use of Performance Measures Based on NBI Data in the Short Term. In the short term, continue the use of performance measures derived from the NBI but work towards transitioning to performance measures based on the new National Bridge Elements.

Support Transition to Use of Element-Level Data for Performance Measurement. Support ongoing efforts to establish a standard, clearly defined set of National Bridge Elements and facilitate adoption and use of these elements. Support development of a common method for aggregating element-level data into a single index representing structural condition, and pilot its use for comparative performance measurement.

Base Bridge Performance Measures on Deck Area. Base performance measures on deck area rather than based on bridge counts. Measures based on deck area are better suited for comparative analysis given varying bridge size distributions across states. Measures based on deck area are also more reflective of the backlog of work implied by bridge conditions.

Use Good-Fair-Poor Categories for Performance Tracking and Reporting. Use bridges (deck area) in good, fair and poor condition as the primary cluster of measures for comparative performance analysis. This would provide a readily understandable and powerful way to summarize bridge condition information. Rather than emphasizing deficient bridges alone, it

would allow agencies to track the distribution of bridges across condition ranges. Using the NBI ratings, poor bridges can be defined as bridges with deck, superstructure or substructure ratings ≤4, good bridges can be defined as bridges with deck, superstructure and substructure ratings >=7, with all other bridges falling into the fair classification. The good-fair-poor reporting method can be modified in the future to be based on element-level condition ratings or a health index derived from element-level ratings.

Include Structurally Deficient Bridges as a Supplemental Measure. Given the prevalence of its use at the national level and within individual states, it would be appropriate and useful to include measures based on Structurally Deficient bridges as a one of a package of bridge measures used for comparative performance.

Track a Measure Independent of Bridge Decks. Track a supplementary performance measure that captures the structural condition of a bridge independent of the deck condition – for example, bridges with NBI superstructure or substructure rating ≤4.

Track Changes in Bridge Condition in Addition to Current Condition. Track changes in network condition as a supplemental performance measure. This can be helpful for distinguishing states that have been able to improve conditions from those that have longstanding good conditions due to a younger population of bridges or relatively benign environmental conditions. Because most bridges are only inspected every two years, and changes in the network distribution of bridge condition are gradual, a ten-year time horizon for tracking changes in condition is appropriate.

Don't Use Posted Bridges as a Primary Comparative Performance Measure. While it remains important for individual states to track the number of posted bridges in their inventory, use of the number of posted bridges as a national performance measure is complicated by differing standards for rating and posting bridges. Thus, the number of posted bridges is not recommended as the basis for a primary measure for comparing performance across states.

Support Bridge Inspector Training and Quality Assurance. Continue to promote and support inspector training and quality assurance to maximize consistency of bridge condition ratings. Recently published guidelines for implementing Quality Control (QC) and Quality Assurance (QA) for bridge inspections provide useful material to support process improvements (*13*).

Improve Bridge Cost Data. Cost information is critical for providing a context for understanding performance. There is a need to improve availability and consistency of cost data reporting for bridge work. Currently states provide FHWA with direct costs of replacement and construction (per bridge and per unit of deck area). No information is provided on rehabilitation or maintenance. This gap makes it difficult to establish relationships between expenditures and resulting condition. Precise definitions of cost components are required to ensure consistency. Reporting also needs to incorporate non-federal sources of funding. AASHTO should consider establishment of a best practice guide to bridge cost tracking to improve the state of the practice.

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Appendix A – Literature Review

Introduction

A limited literature review was conducted to support this study, with coverage of three topic areas:

- Currently available bridge performance measures;
- Recent national studies related to comparative bridge performance; and
- Recent reviews of best practices in bridge management.

The first two topics provided background for developing candidate measures for use in the current study. The third topic was used to develop the interview guide used to identify practices of top performing states.

Available Bridge Performance Measures

National Bridge Inventory-Based Measures

An extensive set of national measures has been established for characterizing, monitoring and reporting bridge conditions. The FHWA National Bridge Inspection (NBI) Coding Guide (*1*) defines the basic data that each state must maintain for its bridges including inventory items, functional characteristics and deck, superstructure and substructure condition ratings. Also, this document details the calculation of a series of items calculated from bridge inventory and inspection data, including the appraisal ratings and Sufficiency Rating. Eligibility for HBRR funds is calculated based on NBI data. FHWA has developed supplemental guidance (*2*) defining funding eligibility. This guidance specifies how to determine whether a bridge is classified as being Structurally Deficient (SD) or Functionally Obsolete (FO).

Element Condition-Based Measures

Many, but not all, states collect more detailed condition data as part of the bridge inspection process. AASHTO's Guide for Commonly Recognized (CoRe) Structural Elements (*3*) defines a default set of structural elements for use in performing bridge inspections. States performing element inspections typically use a customized version of these definitions for their inspections. Some states, including California and Kansas, use a Health Index as a single measure of bridge condition. The Health Index is calculated as a weighted average of element conditions for a bridge. Calculation of this measure is defined in the Pontis Technical Manual (*4*).

Other Measures

Besides the measures described above derived from NBI and element-level condition data, practitioners and researchers have defined a number of additional bridge performance

measures. Appendix A of NCHRP Report 590 (*5*) provides a comprehensive review of various bridge performance measures, classifying them in the following categories:

- Remaining service life;
- Economic returns;
- Reliability;
- Risk of damage or failure;
- Geometric or functional adequacy;
- HBRR program eligibility;
- Life-cycle cost;
- Community impact;
- User cost of safety, time, and vehicle operation; and
- Traffic capacity.

Examples are available of measures in each category, but only those measures based on NBI or element-level data have been applied in multiple states.

State Practices

Several prior efforts have documented performance measures used by different states based on surveys or review of state DOT websites. For example, preliminary work for the Long Term Bridge Performance Program included a review of state performance measures in use (*6*). The Midwest Transportation Knowledge Network "DOT State Stats" web site (*7*) provides links to state DOT resources related to performance measurement, and also includes annual syntheses listing performance measures used in different states. Washington State DOT's Performance Measure Library web page (*8*) also provides a set of links to performance measure-related documents for each state. These resources were used to compile a list of bridge condition related measures in use for each state. Information on the WSDOT Performance Library web page and reference (*6*) were checked for states where the synthesis did not include any bridge-related performance measures. Using this approach, bridge measures were identified for all but nine states. Note that the table focuses on measures that are used to provide high level summaries of bridge condition for external accountability. These are not necessarily the same as measures used within agencies to identify and prioritize bridge work.

Table A-1. High Level Bridge Condition Measures by State

State	Bridge Performance Measures
Alabama	Total Structurally Deficient bridges Total Functionally Obsolete bridges Weighted average bridge condition rating Percentage of bridges with condition rating of 4.99 or worse
Alaska	Square footage of Structurally Deficient deck area

State	Bridge Performance Measures
Arizona	Bridge condition (sufficiency rating obtained from ADOT Bridge management system "BMS") and condition rating index using element condition state.
California	Number and percent of distressed bridges (bridges with identified rehabilitation needs) Network Bridge Health Index (BHI) Number Percent of state-owned bridges classified as Structurally Deficient or Functionally Obsolete
Colorado	Percent of bridge deck area in poor or fair condition Bridge condition by functional classification Bridge maintenance level of service grade
Connecticut	Percent of roadway bridges in good or better condition
Delaware	Percent of bridges rated Structurally Deficient
Florida	Percent of bridge structures on the state highway system having a condition rating of excellent or good Percent of bridge structures on the state highway system with posted weight restrictions
Georgia	Percentage of on-system bridges with a sufficiency rating less than or equal to 50
Hawaii	NA
Idaho	Percent of bridges in good structural condition
Illinois	NA
Indiana	NA
Iowa	Percent of Structure Inventory and Appraisal (SI&A) values for our bridge system that meets last year's values
Kansas	Bridge Health Index Percent of bridges in good condition
Kentucky	NA
Louisiana	Percentage of bridges classified as Structurally Deficient or Functionally Obsolete
Maine	Percent of bridges in good, fair and poor condition (poor = structurally deficient; good = deck, superstructure and substructure rating all greater than or equal to 7)
Maryland	Number of bridges and percent that are Structurally Deficient
Massachusetts	Total Structurally Deficient bridges Bridge Health Index in percent
Michigan	Percent of all freeway bridges in good or fair condition Percent of non freeway bridges on the trunkline system in good or fair condition Number of trunkline Structurally Deficient bridges
Minnesota	Percentage of highway bridges in good or satisfactory condition by state arterials square footage Percentage of highway bridges in poor condition by state arterials square footage

State	Bridge Performance Measures
Mississippi	NA
Missouri	Percent of bridges on major highways in good condition Percent of bridges on minor highways in good condition Number of deficient bridges on the state system (major and minor highways) Percent of major bridges in good condition
Montana	Number of deficient bridges on or off the state highway system Percent of state highway bridges in need of repair or replacement Percent of non state highway bridges in need of repair or replacement Number of Functionally Obsolete, Structurally Deficient and substandard bridges as measured by the National Bridge Inventory Condition Assessment
Nebraska	Percent of structurally sound and functionally adequate bridges
Nevada	Percent of department-owned bridges which are eligible for federal funding and are classified as Structurally Deficient or Functionally Obsolete Bridges in good/fair/poor condition (based on Sufficiency Rating
New Hampshire	Number of “red list” bridges (Structurally Deficient) Number of “near red list bridges (bridges with one or more structural elements having condition rating of “5”)
New Jersey	Square footage of deficient deck area Number of deficient bridges
New Mexico	NA
New York	Number of bridges in good, fair and poor condition based on condition rating (based on 13 different element ratings)
North Carolina	Percent of bridges in good condition Bridge Health index
North Dakota	NA
Ohio	Percent deck area with floor condition 1 or 2 Percent deck area with general appraisal ≥5 Percent deck area with wearing surface of 1 or 2 Percent deck area with paint condition ≥5
Oklahoma	Number of Structurally Deficient bridges Number of Functionally Obsolete bridges Number of load posted bridges
Oregon	Percent of state highway bridges that are not deficient
Pennsylvania	Number of Structurally Deficient bridges Percent of Structurally Deficient bridges
Rhode Island	Number of Rhode Island bridges listed as Structurally Deficient
South Carolina	Number of deficient bridges
South Dakota	NA

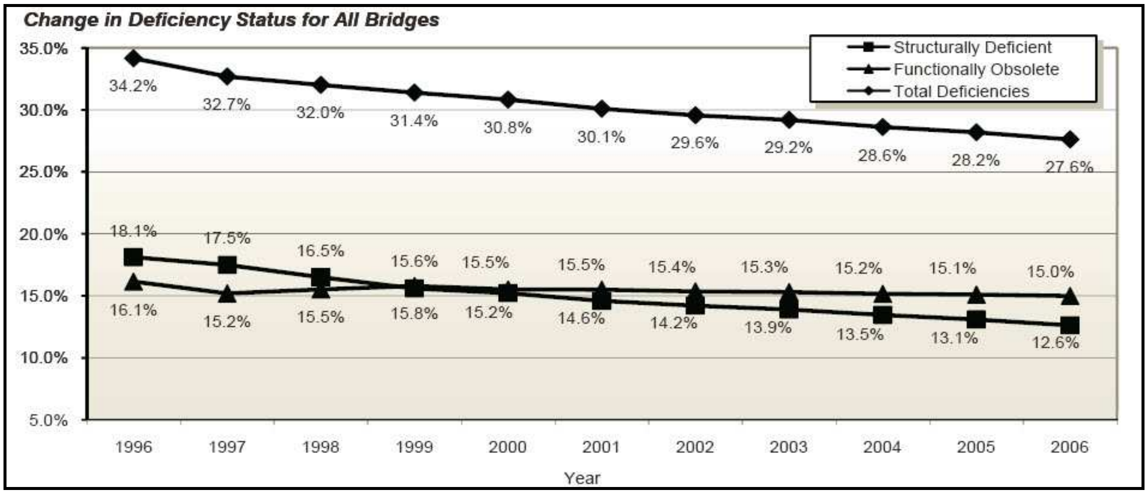
State	Bridge Performance Measures
Tennessee	Number of Structurally Deficient bridges Number of Functionally Obsolete bridges Number of posted bridges
Texas	Percent of bridges in good or better condition
Utah	Percent of bridges in poor condition
Vermont	Percent of Structurally Deficient bridges – Interstate, state and town highway system
Virginia	Percent of bridges that are Structurally Deficient (Red), Functionally Obsolete (Yellow), and not deficient (Green) Health Index Posted bridges
Washington	Percent of bridges in good, fair and poor structural condition Number of steel bridges due or past due for painting
West Virginia	NA
Wisconsin	NA
Wyoming	Condition of bridges on National Highway System Condition of bridges on non National Highway System

The most commonly used measures are based on Structurally Deficient status. Some states summarize bridge condition based on Functionally Obsolete status, Sufficiency Rating, and posted status. Many states classify bridges into good, fair and poor categories, based on NBI ratings for deck, superstructure and substructure or a state-specific condition index. Five states (California, Kansas, Massachusetts, North Carolina and Virginia) use a Health Index based on aggregation of element-level condition data.

States use a mixture of bridge counts and deck area to quantify bridges in various performance categories; and use both absolute numbers and percentages of the inventory. Several states separately report bridge condition for different networks – e.g. on and off the NHS; on and off the state highway system.

National Trends

A number of recent publications have examined national trends in bridge performance, particularly in the wake of the I-35W bridge collapse in Minneapolis. On a biennial basis FHWA and the Federal Transit Administration (FTA) prepare a report to Congress on the conditions and performance of highways, bridges and transit (the "C&P Report"). The most recent C&P Report was published in 2009 (*9*) and uses condition data from 2006. The report describes current conditions of highway bridges in the U.S. and documents the fact that bridge conditions have improved over time, with the percentage of bridges classified as SD dropping from 18.1% in 1996 to 12.6% in 2006. Over that same timeframe the percentage of bridges classified as either SD or FO dropped from 34.2% to 27.6%. In addition to documenting trends, the report projects investment needs for scenarios, concluding that without increased investment the backlog of bridge investment needs is likely to grow over time, from $98.9B in 2006 to $112.6B in 2026 (in 2006 dollars) if funding is held constant.



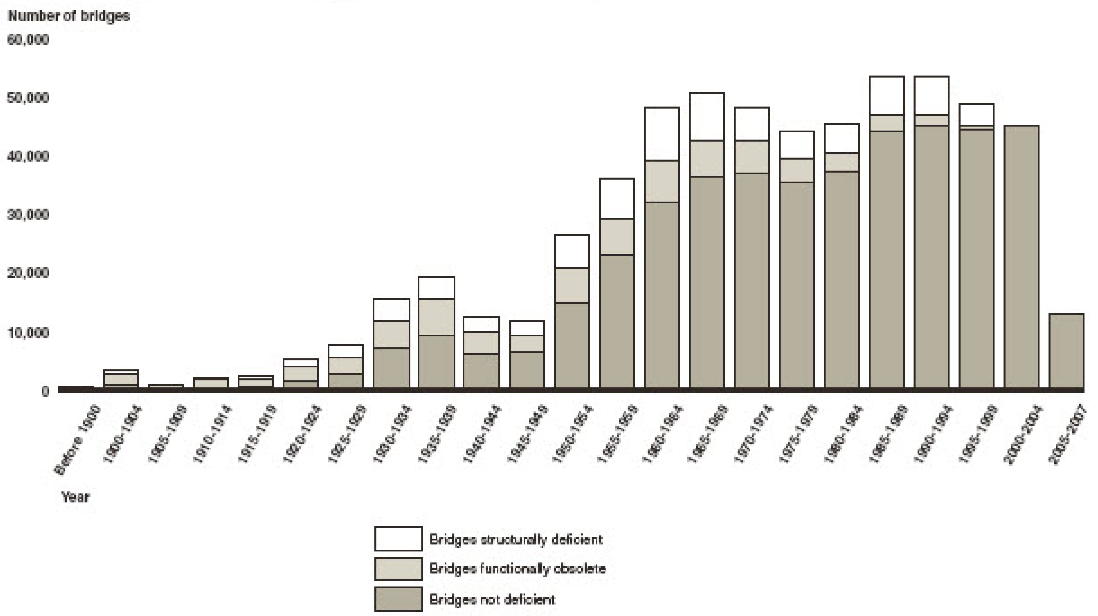
Source: FHWA and FTA, 2008 C&P Report, Exhibit 3-22, based on NBI data (9)

Figure A-1. Change in Deficiency Status 1996-2006

Recently AASHTO performed an analysis of U.S. bridge conditions (*10*). AASHTO's report uses NBI data to illustrate the distribution of bridges by age and current statistics for SD and FO bridges. Also, the report cites FHWA estimates concerning bridge investment needs.

The Government Accountability Office (GAO) performed another recent analysis of bridge conditions as part of an audit of the Highway Bridge Program (11). The GAO audit notes improvements in bridge conditions documented by FHWA and AASHTO. Further, the audit examines the relationship between bridge age and bridge deficiencies, concluding that it is likely that there will be an increased number of SD/FO bridges as the bridge population ages. The figure below, reproduced from the GAO audit, shows the distribution of bridges by deficiency status and age.

Figure 14: Bridge Deficiency Status, by Year Built or Reconstructed, 2007



Source: GAO analysis of FHWA data.

Note: Bridges are categorized by the year they were built or last reconstructed, whichever came later. Bridges fewer than 10 years old or fewer than 10 years since reconstruction are not allowed to be classified as structurally deficient or functionally obsolete, so no deficient bridge data appear for bridges after 1997.

Source: GAO, based on NBI data (11)

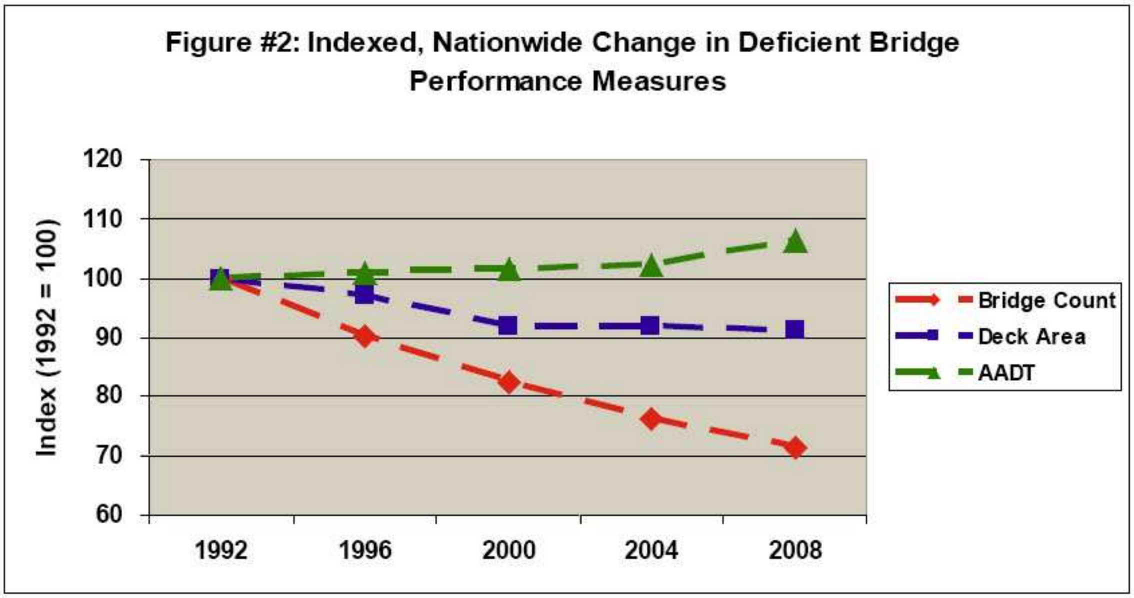
Figure A-2. Deficiency Status by Year Built or Reconstructed

GAO attempted to determine to what extent, if any, bridge performance was affected by the federal Highway Bridge Program (HBP). The audit concludes that it is difficult to determine the impact of the HBP on bridge conditions as a result of a variety of factors. With respect to the HBP the audit reports that:

- The program's statutory goals are not focused on a clearly identified federal interest;
- There is no clear tie between the program's funding and performance;
- The program lacks tools to determine the effectiveness of the federal investment; and
- Program sustainability remains a challenge.

Amey (*12*) performed another recent analysis of bridge conditions published in 2010. Like the other analyses described here, Amey's relies upon NBI data to examine conditions over time. Amey emphasizes that presenting results in terms of numbers of bridges can be misleading, given bridges are of varying size, and instead analyzes trends in SD/FO bridges in terms of deficient deck area. Amey concludes that though there has been a reduction in the deck area of deficient bridges over time, this reduction has been significantly more modest than the reduction in the number of deficient bridges. Further, ADT traveling on deficient bridges actually

increased over the analysis period (1992-2008). The figure below illustrates these trends. Also, Amey notes that bridges in metropolitan areas are generally in worse condition than bridges in rural areas, measured in terms of percent of deck area classified as Structurally Deficient or Functionally Obsolete.



Source: Amey, based on NBI data (12)

Figure A-3. Indexed Nationwide Change in Deficient Bridge Performance Measures

Best Practices in Bridge Management

There have been several recent reviews of best practices in bridge management. Some of these provide a general overview of the state of the practice, synthesizing information across agencies. Others detail practices in specific agencies. In the former category, NCHRP Report 632 (*13*) discusses the state of the practice in data and management systems for asset management, including bridges, with particular focus on the Interstate Highway System. The report concludes that the major sources of data for bridges include the NBI and element-level inspection data, typically collected using AASHTO's Pontis Bridge Management System. A variety of analytical tools have been developed to support resource allocation for bridges, with Pontis the most common of these.

NCHRP Synthesis 397 (*14*) provides significant additional detail on how agencies use their bridge management systems to support decision-making. This report summarizes the available bridge data and performance measures, as well as current bridge conditions. It provides a general description of the state of the practice in bridge management, presenting results from a survey of 24 U.S. and Canadian agencies, and providing additional detail on a set of five states based on a set of 15 in-depth interviews (the states are labeled with letters A to E and state names are not identified in the report). A major finding of the synthesis is that agencies typically do not use the advanced features of their bridge management systems to support decision-

making, instead typically using them as a data repository from which they query data to perform analyses external to any bridge management or other analysis system.

Recently the ASCE SEI hosted a workshop on bridge performance that examined current challenges and opportunities for improvements in this area (*15*). The workshop focused on: bridge design issues; performance measures; technologies that could be used to monitor bridge life and assess condition; and improving decision-making. Key themes that emerged from the workshop included: designing bridges to improve durability and enhance inspectability (e.g., through reducing the number of joints); need for improving quality assurance and quality control during construction; the need to address the subjective nature of visual inspection, supplementing visual inspection with Non-Destructive Evaluation (NDE) technologies; encouraging a circular design process that better integrates design, construction, inspection, maintenance and research; and improving inspector training and certification.

Three reports identified through the review provide cases studies of bridge management practices in specific agencies. In 2005 FHWA prepared a summary of how three states – California, Florida and South Dakota – use their bridge management systems (*16*). In 2007 a domestic scan was performed to review asset management practices in selected state and local agencies (*17*). The scan report describes bridge management practices in several of the agencies that participated in the scan, including the DOT of Florida, Michigan, Minnesota, and Ohio, Oregon and Utah. More recently, in 2009 a domestic scan was performed to review best practices in bridge decision-making. The scan tour report, currently in draft format, describes bridge management practices in 12 agencies, including nine state DOTs, two counties and one turnpike authority (*18*). The table below summarizes organizations described in these three scans, with comments on the most notable practices in each case.

Table A-2. Bridge Management and Decision Making Scan Results Summary

	Included in:			
Agency	**FHWA ('05)**	**AM Scan ('07)**	**Bridge Scan ('09)**	**Notable Practices/Key Themes**
California DOT	X		x	-Use of Structures Maintenance Automated Report Transmittal (SMART) for storing element-level inspection data and managing bridge inspector work recommendations -Well-defined processes for programming, developing work recommendations, tracking, training
Delaware DOT			x	-Process for prioritizing bridge inspector work recommendation and converting these into work orders

	Included in:			
Agency	**FHWA ('05)**	**AM Scan ('07)**	**Bridge Scan ('09)**	**Notable Practices/Key Themes**
El Dorado County DOT			x	-Tracking of scour and seismic vulnerabilities, in addition to NBI and element-level data
Florida DOT	X	x	x	-Implementation of Feasible Action Review Committees (FARC) at the district level to review bridge inspector work recommendations -Commitment to replace a bridge within 9 years of its being identified as deficient -Well-defined work order tracking process -Funding for maintenance is "taken off the top" during budgeting
Florida's Turnpike Enterprise			x	-Extensive use of contract forces for inspection and maintenance -Integrated approach with FDOT for processes such as inspection and work order tracking
Michigan DOT		x	x	-Comprehensive asset management approach emphasizing development of performance measures and goals within asset/investment category
Minnesota DOT		x		-Highly decentralized decision-making approach -Emphasis on preventive maintenance, including analysis of typical benefit/cost ratios for maintenance activities
New York State DOT			x	-Well-established processes for bridge maintenance -State-specific rating, deterioration models, needs analyses approaches -Decentralized (regional) structure
Ohio DOT		x	x	-Linking system performance to employee compensation

	Included in:			
Agency	**FHWA ('05)**	**AM Scan ('07)**	**Bridge Scan ('09)**	**Notable Practices/Key Themes**
Oregon DOT		x	x	-Well defined performance measures and goals -Use of an economic analysis on the impact of posting bridges to justify significant increase in bridge funds
Placer County Public Works			x	-Maintenance management approach defining categories of maintenance actions and protocols for each category
South Dakota DOT	X			-Use of the Pontis BMS to streamline the inspection process and help develop an initial bridge program
Utah DOT		x		-Emphasis on alternative contracting techniques incorporating asset management concepts (e.g., I-15 project) -Development of an approach for cross-asset allocation of system preservation funds
Virginia DOT			x	-Definition of activities and budget allocation for five bridge work categories: preventive, painting, restorative, rehabilitation, replacement -Recommended criteria/intervals by activity
Washington State DOT			x	-Maintenance Accountability Process including performance measures, targets and budgets for four types of bridge maintenance actions

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Appendix B – State Questionnaire Results

1. Most Important Factors Impacting Network-Level Bridge Performance

What do you think are the 3-5 most significant factors that explain variations in bridge condition across states, other than the overall level of investment. Do not include factors beyond the control of a state (e.g. weather, traffic levels, etc.)

COMMENTS:

Respondents noted the following factors:

- Size and composition of bridge inventory
- Age of bridge inventory
- Weather and location-related factors (including exposure to salt spray, us of salt and de-icing chemicals, freeze-thaw damage, tire chains)
- Traffic levels, percent trucks, truck weights, overweight truck policies
- Relative priority of bridge versus other investment, total dollars on bridges, level of bridge replacements
- Relative priorities for preservation and maintenance versus replacement, functional improvements, modernization and expansion
- Project selection methodology (i.e. sufficiency ratings, health index, poor NBI condition rating)
- DOT Leadership and staff experience and dedication
- Maintenance (including routine and preventive maintenance) practices and methods
- Guidelines for rehabilitation versus replacement
- Design and construction specifications and philosophies (concrete versus steel, use of coated reinforcement, overlaid versus bare decks, painted structures versus weathering steel, superstructure types, continuity, bearings, jointed versus jointless)
- Construction quality
- Environmental regulations
- Inspector training/skill level and consistency (some inspectors and some states rate harder than others)

2. Questions related to Availability of Element-Level Bridge Condition Data

What type of element-level condition data does your state collect?

Answer Options	Response Percent	Response Count
We use the standard AASHTO CoRe elements with no modifications	32.3%	10
We use the standard AASHTO CoRe elements with modified definitions	29.0%	9
We use state-specific elements that partially overlap with the AASHTO CoRe elements	22.6%	7
We use state-specific elements that are not compatible with the AASHTO CoRe elements	9.7%	3
We do not collect element level condition information	6.5%	2

COMMENTS:

- We use standard AASHTO plus approximately six additional elements (Precast Conc Culvert, High Performance Concrete Decks/Slabs, HP Conc Deck Overlays).
- We use CoRe with additional state defined elements.
- We use standard AASHTO CoRe elements with additional state-specific elements.
- We use the standard AASHTO CoRe elements with some modified definitions (generally we provide addition comments to clearly clarify our interpretation what is required). We also use some state-specific elements that are not found in the AASHTO CoRe elements.
- We use state-specific elements that partially overlap with the AASHTO CoRe elements and we use some state-specific elements that are not compatible with the AASHTO CoRe elements.
- We collect element data on State Route structures only. We have modified and added some elements. We do not use Pontis program. We use NBIS ratings collected on an Access database for our Bridge Information Management System (BIMS).

If your state collects AASHTO CoRe element data, what year did you start collecting it?

Answer Options	Response Percent	Response Count
2007	8.3%	2
2003	4.2%	1
1999 or earlier	87.5%	21

COMMENTS:

- TxDOT began collecting elemental data in 1996 but it was not implemented statewide until 1999/2000 timeframe.
- Note that the data collected in earlier years is not necessarily the same as in later years. The data collection process has evolved over the years.
- Only on state maintained bridges
- We staged the implementation, so all distircts will not have a complete inventory until May of 2010.
- Collection has taken place for 15 years but with many changes to the CoRe element descriptions so it is not a seamless data flow for the 15 years. The data over about 5 years old is not compatible with newer data.
- We began element level inspections with two Areas (approximately 400 bridges) in 1993.
- We started in 1993 and collect data on state routes only.
- NYSDOT has been collecting element-level data since 1987. The elements are similar to those in the CoRe elements - though we do not provide condition states.
- Our CoRe element data effort is not yet complete. We have not required CoRe element data collection for all inspections yet, due in part to additional costs to do CoRe inventory on 16,000 State bridges.

Do you use CoRe element data to generate your NBI deck, superstructure and substructure ratings?

Answer Options	Response Percent	Response Count
No	84.6%	22
Yes	15.4%	4

COMMENTS:

- Do element level inspections, use FHWA Translator, review results and change results if necessary.
- We use NBI translator to verify bridge rating.
- TxDOT does not agree with the methodology used in the translator
- We may in the future, but will collect it for now and compare that with the translator.
- We complete both element level and NBIS condition ratings on all inspections.
- Currently perform NBI and element level inspections on each structure

- Our inspectors rate the elements and do the NBI ratings, there is no automated generator used.
- We believe this critical part of bridge inspection needs the input of experienced bridge inspection team leaders and do not believe the Pontis Translator can perform that critical safety function. If we could disable the Translator in Pontis we would.

3. Questions related to Performance Measures in Use

Which of the following does your state use to develop or prioritize bridge maintenance, repair and replacement projects (select as many as apply):

Answer Options	Response Percent	Response Count
Recommendations from the Pontis BMS	22.6%	7
Recommendations from another BMS	32.3%	10
NBI Deck Rating	80.6%	25
NBI Superstructure Rating	83.9%	26
NBI Substructure Rating	83.9%	26
NBI Sufficiency Rating	64.5%	20
NBI Structural Evaluation Rating Code	35.5%	11
Posted Status	61.3%	19
Bridge Age	25.8%	8
Individual Deck Element Ratings	48.4%	15
Individual Steel Element Ratings	45.2%	14
Individual Prestressed Concrete Element Ratings	32.3%	10
Bridge Health Index	9.7%	3
Other Overall Bridge Condition Index	25.8%	8

COMMENTS:

- Pontis is used as a part of our Bridge Deficiency Formula. The formula assigns points based on condition, benefit-to-cost ratio, scour critical, load posting, functional class, truck traffic, detour length, historic, and fracture critical. Bridges are prioritized for work based on total points.
- Washington will be implementing a structural Bridge Condition Index (BCI) in 2010 based on element condition to prioritize major repair, rehabilitation, and replacements. Minor maintenance is prioritized based on need and available resources to complete the work.
- Although we have Pontis and have element level inspection data, we have not fully implemented Pontis for prioritization of our bridges.
- MoDOT prioritizes bridge maintenance work (e.g., preventative maintenance and repair) at the time of inspection based on the severity of need. Bridge rehabilitation and replacements are prioritized by bridge condition; but, funding of the project is ultimately decided by the regional planning organization.
- The overall condition of the bridge is assessed through the modified health index noted above. Sufficiency rating is only used to consider the funding source.

- The BMS recommendation is a hybrid of Pontis and in-house post processing.
- Our District offices prioritize the work initially and then Central office further refines the list.
- Structural Deficiency or Functional Obsolescence are the main criteria used to develop projects.
- We have a Bridge Priority Optimization Formula to identify potential bridge replacement projects. We then use the Pontis BMS system along with sound engineering judgment to select the actual order for each year's funding.
- We compare Bridge Health Index ratings to determine if our element level collection is on track.
- We also consider individual element ratings for other bridge components (deck, joints, etc.).
- We use a "Bridge Management System". We analyze NBI and Element level data, inspection remarks, and maintenance recommendations. The information is stored in Pontis, but although we have tried, we have not been successful yet with getting Pontis to help identify or prioritize projects.
- We use inspector work recommendations heavily too.
- We also look at scour and seismic vulnerability, and preventive maintenance
- We are heavily influenced by the inspection ratings/findings.
- Looking to incorporate Bridge Health Index in the near future
- PA collects maintenance needs from a list of specific items, along with their quantity and priority for repair during the NBIS inspections.

Does your state utilize an overall bridge condition index that can be used to classify bridges into categories (e.g. good/fair/poor)?

Answer Options	Response Percent	Response Count
No	46.7%	14
Yes - please describe what information is used to calculate this rating:	53.3%	16

COMMENTS:

- For historical reasons and reporting purposes, Washington uses only NBI Super and Substructure to record bridges as G/F/P since there is not a better accepted standard. This is not a good performance measure.
- We utilize NBI ratings for deck, superstructure and substructure as primary condition ratings to categorize the overall condition. Such that if one of these three rating are lower than the other two, the overall condition rating gets the same "low" rating.
- We have developed a system based only on the structural condition of the bridges. This considers the NBI ratings for the deck, superstructure and substructure, expansion device and

approach slab condition, inventory load rating factor, channel and channel protection, waterway adequacy, vulnerability to scour, lateral underclearance, vertical clearances, bridge roadway width and whether the bridge railing and approach railing meet current standards. We are in the process of modifying this such that the structural aspects are based on the core elements and evaluated condition state and the inventory rating of the bridge. This will result in a structure condition rating. We are adding a risk based component that considers the ADT, truck volume, facility type, detour length, vertical and lateral clearances, waterway adequacy, scour, and seismic vulnerability.

- A modified health index
- Good/Fair/Poor. We take the lowest of items 58, 59, and 60 (or 62 for culverts) and call it the Low Major Rating. Low Major Rating > 6 = Good, Low Major Rating =5 or 6 = Fair, Low Major Rating < 5 = Poor
- Good/Fair/Poor based on Bridge Health Index (BHI) - Very Good = BHI > 95, Good = 85 < BHI ≤ 95, Fair = 70 < BHI ≤ 85, Deteriorated = BHI ≤ 70 (We do not use the word ""Poor"" any more.)
- We currently use NBI ratings to classify structures in these categories.
- We range from Very Good to Very Poor. The NBI ratings for Deck/Super/Sub/Culvert are the primary inputs, but any bridge that is SD is rated as being "Poor" at best. In this way we also include NBI 67, structural condition.
- Sufficiency Rating
- We use the Bridge health Index and other methods.
- Good if deck/super/sub are all 6 or greater
- Recently we have been tracking the NBI deck, super, sub rating >= 6 as a performance measure.
- We calculate an overall weighted condition using the rated elements of the structure. A structure with a rating of less than 5 is considered "deficient". Those equal to or greater than 5 are non-deficient. Program areas within the agency break the rating down further – i.e. Bridge maintenance uses 0 to 4.4 as poor - 4.4 to 5.8 as fair and 5.8 to 7 as good.
- Sufficiency rating classifies project as rehabilitation or replacement.
- We do not have an overall condition index to classify bridges. Instead, we use a ranking system that considers the change in the NBI condition ratings as compared to a new bridge, ADT, Detour length, Functional Classification of the roadway, load carrying restrictions, deck geometry deficiencies, and the change in the Health Index over 15 years as predicted by PONTIS.
- Structural Deficiency indicator (crude for the purposes of asset management, but effective in agency and public perception)

Does your state maintain information on structural failures of bridge components?

Answer Options	Response Percent	Response Count
No	50.0%	15
Yes - Please describe	50.0%	15

COMMENTS:

- We maintain a list of critical findings reports.
- Keep notes in PONTIS
- Information is not available in a structured format or database, but an Excel file of general Bridge Collapse information exists.
- We keep a record of bridge failures due to either overload, flood, or deterioration. We do not keep a record of bridge element failures. This question should define the term failure. Response is assumed to mean failure as the structure is no longer functional and closed.
- MoDOT only maintains a list of total bridge failures due to structural failure from material, environmental, traffic causes. I believe NYSDOT compiles such information for the nation on an annual basis.
- Critical findings and work requests from the critical findings process
- Failure will have to be defined more clearly. We keep track of critical findings as required by the FHWA and maintain that list which would include bridge component failures that were critical to public safety.
- We have a comment field "Bridge Level Note" that can be occupied and then printed on every "Bridge Inspection Form". We also maintain and track a Critical Findings Log on each bridge with a significant problem that we determine meets are definition of a Critical Finding.
- We don't maintain this information in a database, but we maintain "institutional knowledge" of major component failures.
- We maintain maintenance files, these files do contain information on structural failures. However, there is no database. It is simply the memory of individuals to know what bridges were affected.
- Information contained within bridge inspection reports, as well as Critical Maintenance Reports.
- We would use the inspection rating for the element.
- We keep a history of inspection documents which has most of damage and closure incidents. Also, there are rehabilitation and maintenance projects which our office keeps the records of incidents which are repaired or replaced in house.

- Bridge Inspection notes and keeps records of Critical Structural Deficiencies. These include any structural deficiencies that create an extreme hazard or unsafe condition for the public.
- The definition of "Structural Failure" has not yet been determined by FHWA nor AASHTO. Is it limited to complete collapse, impending failures, suspicious cracks, closures for unexpected repairs, etc.?
- We report to our executive staff significant bridge problems or incidents that limit the use of the bridge, necessitate its closure, or require immediate repairs. This is primarily information for them to understand problems that may be unfolding and as a tracking device to ensure critical repairs/bridge restrictions are placed promptly.

4. Questions About Recommended Measures for this Study

Are there any types of bridges that you feel should be excluded from this analysis to improve comparability across states?

COMMENTS:

- If we are using deck area, probably not a big deal if there are a few major, complex bridges thrown in the mix. When we are looking at bridge numbers, we might want to throw out those (i.e. Golden Gate, Brooklyn, etc.)
- Exclude pedestrian structures.
- I feel that the types of bridges should be limited to those that make up the bulk (80% to 90%) of the nation's inventory. Unusual bridges or those that are not used in large numbers across the nation should be eliminated. It becomes too difficult and time consuming to try and capture all the unique bridge types that are not readily used for very little to no benefit except to skew the results.
- Structures that have FHWA Item 042A codes of 1, 4, 5 ,6 ,7 ,or 8. This would exclude Pedestrian, Railroad, Buildings, or other Non-Highway that may be problematic.
- Box bridges (i.e. standard large box culverts that are considered a bridge due to their size).
- Do not include culverts in the comparison.
- Structure sized culverts, cable stay and suspension bridges. Focus on the bread and butter bridges that compose a majority of the inventory.
- Signature bridges, mega projects, and bridges that are unique to a geographical region (i.e. timber cover bridges).
- Major or unusual structure types: suspension, segmental, truss, arch, etc.
- It would be nice to exclude culverts and large/complex structures but this may make the cost data more difficult to generate (manually excluding projects, etc.).

- Major bridge structures that are a unique design or are a signature structure that is not likely to be duplicated in the near future.
- Break them down to different categories: Culverts----Normal Bridges-----Big Bridges------etc.
- All structures that are NBI should be included (culverts, metal pipes etc.).
- Bridges that are unique to a state or region such as covered bridges. Bridges that are also at the other extreme where they are so big as to over shadow others in the same state and are treated as a separate entity outside of the main bridge program.
- Mega bridges or major historic bridges might skew the findings.
- Historic rehab projects on major bridges are very expensive and may skew the results if they are included.
- If all cost components are reported then you could find outliers and exclude them.
- Segmental, suspension, cable-stayed
- Use the Federal definition of 20' span - and highway structures only.
- Moveable and trusses
- Yes, large viaducts and or moveable bridges should be excluded.
- Cable stayed, truss, suspension
- Complex bridges (long span, curved girder, segmental etc.), movable bridges.

Please use the space below for any recommendations you have about which indicators of performance you feel should be included in this effort.

COMMENTS:

- Significantly modified elements would be the only known method to provide a reasonable structural or financial performance indicator.
- Use only NBI ratings when making comparisons of bridge condition.
- 1. Deck condition ratings - NBI or PONTIS, 2. Joint Condition, 3. Beam end conditions under joints, 4. ADTT. Truck traffic has an impact on all elements of a bridge.
- I think some are too worried about deck area, costs, etc. --- solve the real problem first. Getting everyone on the same page as to what is actually a condition state or condition is more important. Defining what is bad and recording the same rating whether in California-Kansas-New York is more important. Size doesn't really matter if you can't agree on the inspection method you use (Element Level vs. NBIS Condition Rating) and if you differ on the definition of each rating used. Until uniformity is realized throughout the entire bridge inspection community, good luck.

- Structurally Deficient is an easy performance indicator, but it alone is not sufficient. Numbers of restricted bridges would be good, bridges in "Good/Fair/Poor" could also be used.
- The only true national measure that you have is structurally deficient deck area. Identified needs by structure type, age or design type may be interesting.
- Recently we have been measuring the sq. ft. area of bridges that we define as in good condition. Through simple modeling we have linked bridge condition to spending.
- Performance should include all bridges and be limited to state-owned structures - categories for highway types are important.
- Bridge Health Index as determined from the CoRe element data.
- (1) SD Deck Area, (2) AASHTO CoRe element - For consistency of data nationwide, states must convert their non-CoRe element data to AASHTO data. This comment has also been made to FHWA as they consider a move to an element-level NBI. (3) Pontis Bridge Health Index

We would like to construct peer groupings based on the level of expenditures on bridges. Which of the following types of information would you be able to provide for this purpose for each year between 2004 and 2008 (please select all that apply):

Answer Options	Response Percent	Response Count
Total expenditures on bridge rehabilitation and replacement	100.0%	30
Total expenditures on bridge maintenance	46.7%	14
Federal bridge dollars expended	73.3%	22
Total agency construction budget	56.7%	17
Total agency maintenance and construction budget	33.3%	10
Number of bridges (and associated deck area) replaced	86.7%	26
Number of bridges (and associated deck area) rehabilitated	83.3%	25

COMMENTS:

- We have records for 2007 - 2009.
- It may be very difficult to obtain consistency in reporting level of expenditures across all the states.
- Information can be provided for state-maintained bridges only. However, this information will take a significant amount of time to compile.
- I am not sure, project cost data is not totally maintained by the bridge unit.
- I am not the "budget guy", but those values should be easy enough to obtain.

- The above may take some time, so I'm really not sure how much time we will be allotted in this study.
- All of this information will take some effort to collect. Some may not be retrievable back to 2004.
- We may not be able provide every dime spent on by each District on minor bridge maintenance.
- This data may not be totally accurate due to project duration. Most project run for more than one year.
- Total agency maintenance budget may be a bit difficult to obtain.
- We would like to balance the participation in this effort with our other work, so perhaps a years worth of data would be fine?
- Total expenditure numbers from our Annual Capital Program are fairly easily gotten, all the other information is not readily available.
- Our information on bridge maintenance expenditures is improving.

Appendix C – Supplemental Information

This appendix provides supplemental information on the data analysis conducted for this study. It includes:

- A brief description of the NBI data compilation methods;
- An analysis of correlation across performance measures that was used to determine the final set of measures to be used;
- Comparative performance analysis results for the Interstate and NHS networks; and
- Details on the peer grouping analysis, including peer group definitions and variations in performance across different peer groups.

Data Compilation

National Bridge Inventory (NBI) text data files for the 34 participating states for 1999 and 2009 were downloaded from the FHWA's web site (http://www.fhwa.dot.gov/BRIDGE/nbi/ascii.cfm.) The text files were downloaded into an MS Access database using the data specification matching the NBI table structure as documented in: http://www.fhwa.dot.gov/BRIDGE/nbi/format.cfm.

Analysis of Correlation Across Bridge Performance Measures

An analysis of correlation across measures was conducted in order to guide which combination of measures to utilize for the purposes of ranking. Results are shown in Table C-1 below.

Table C-1. Correlation Across Performance Measures

Correlation Coefficient by Measure												
Measure	**Posted**	**SD**	**SR≤50**	**Deck≤4**	**Good**	**Super/ Sub ≤4**	**Δ Posted**	**Δ SD**	**Δ SR≤50**	**Δ Deck≤4**	**Δ Good**	**Δ Super /Sub ≤4**
Posted	100%	18%	49%	10%	-6%	38%	1%	-13%	-32%	-4%	-39%	-4%
SD	18%	100%	59%	92%	43%	71%	8%	35%	3%	10%	2%	32%
SR≤50	49%	59%	100%	51%	12%	64%	15%	1%	6%	-1%	-31%	15%
Deck≤4	10%	92%	51%	100%	40%	52%	6%	22%	-6%	12%	0%	13%
Good	-6%	43%	12%	40%	100%	21%	12%	23%	10%	12%	57%	19%
Super/ Sub≤4	38%	71%	64%	52%	21%	100%	16%	18%	-2%	-16%	-19%	42%
Δ Posted	1%	8%	15%	6%	12%	16%	100%	29%	37%	28%	10%	35%

Measure	Posted	SD	SR≤50	Deck≤4	Good	Super/Sub ≤4	Δ Posted	Δ SD	Δ SR≤50	Δ Deck≤4	Δ Good	Δ Super/Sub ≤4
	Correlation Coefficient by Measure											
Δ SD	-13%	35%	1%	22%	23%	18%	29%	100%	50%	72%	57%	86%
Δ SR≤50	-32%	3%	6%	-6%	10%	-2%	37%	50%	100%	43%	30%	52%
Δ Deck≤4	-4%	10%	-1%	12%	12%	-16%	28%	72%	43%	100%	52%	44%
Δ Good	-39%	2%	-31%	0%	57%	-19%	10%	57%	30%	52%	100%	43%
Δ Super/Sub≤4	-4%	32%	15%	13%	19%	42%	35%	86%	52%	44%	43%	100%

Conclusions from this analysis are:

- Because bridges with low deck, superstructure or substructure ratings are assigned a Structurally Deficient (SD) status, the performance measures involving the deck, superstructure and substructure ratings are highly correlated with those based on SD status. SD is highly correlated with Deck Rating ≤ 4 (correlation coefficient >90%), and somewhat less correlated with Superstructure or Substructure Rating ≤ 4. Since decks typically have a service life much shorter than other components, deck condition is a significant controlling factor in designation of SD bridges.
- Change in SD is well correlated with change in Superstructure or Substructure Rating (correlation coefficient > 85%), and somewhat less correlated with change in Deck Rating ≤4.
- Sufficiency Rating (SR) is partially based on deck, superstructure and substructure ratings, so there is moderate correlation between bridges with SR ≤50 and bridges with deck, superstructure and substructure rating ≤4.
- Generally, SD, SR≤ 50, Deck ≤4 and Super/Sub ≤4 are better correlated with each other than with either Posted or Good.
- With the exception of Good, all of measures of overall value are at least somewhat positively correlated with each other. Further, all of the measures of changes are at least somewhat positively correlated with each other. However, measures of overall value are in many cases uncorrelated or negatively correlated with changes in value. This means that states seeing the greatest improvements in bridge condition since 1999 are not necessarily those with the best 2009 bridge conditions.
- Based on this analysis, it was decided that *either* SD *or* a measure based on deck, superstructure and/or substructure condition ≤4 should be used for the analysis - but not both. An additional analysis was conducted to assess whether ranking based on SD versus

based on a measure based only on deck, superstructure or substructure ratings ≤4 would be substantially different. This analysis showed that the results were not significantly different. Therefore, four key measures were selected for the ranking – Structurally Deficient bridges, Sufficiency Rating 50 or below, Bridges in good condition – based on NBI deck/superstructure/substructure ratings all ≥7, and Posted bridges

Comparative Performance Results – Interstate and NHS Bridges

The following 16 bar charts display results for the eight selected performance measures for bridges on Interstate and NHS subnetworks respectively. Results for the entire road network are shown in Section 3 of this report. As noted in Section 3, each bar on the charts represents a performance measure value for an individual state. Randomly assigned IDs are shown for each state for anonymity.

Note that when analyzing network subsets for Interstate and NHS bridges we excluded from the analysis states with less than 2,300 thousand square feet of deck area, which represents approximately 0.1% of the deck area of bridges in the 34 state sample. This cutoff value corresponds to approximately 200 bridges, on average. In analyzing the data, we found that where a state had less than 2,300 thousand square feet of deck area on a particular network, the results for that network subset could be significantly skewed by a small number of bridges, and in certain cases were inconsistent with the overall trends for the state.

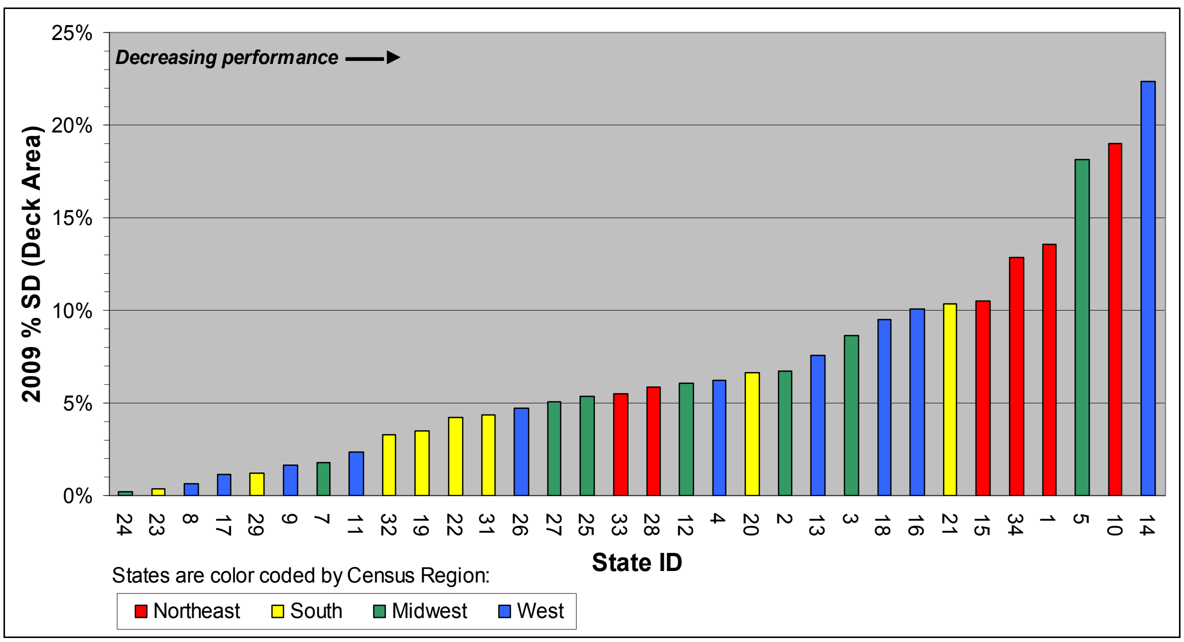

Figure C-1. Percent of State Bridge Deck Area on Structurally Deficient Bridges, 2009 NBI (Interstate)

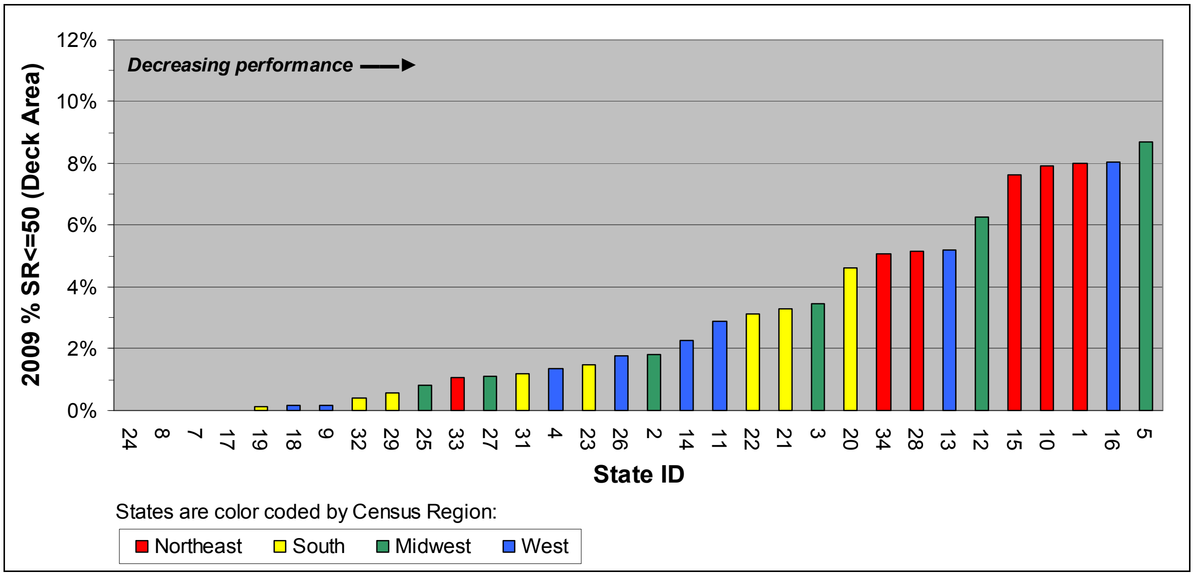

Figure C-2. Percent of State Bridge Deck Area on Bridges with Sufficiency Rating ≤ 50. 2009 NBI (Interstate)

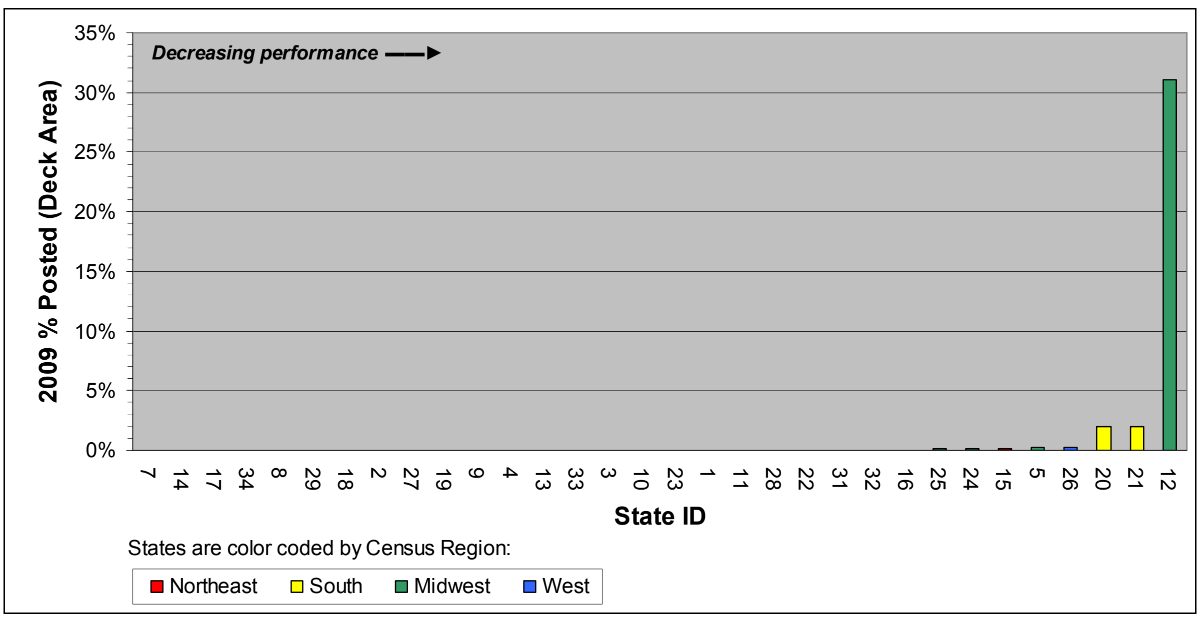

Figure C-3. Percent of State Bridge Deck Area on Posted Bridges, 2009 NBI (Interstate)

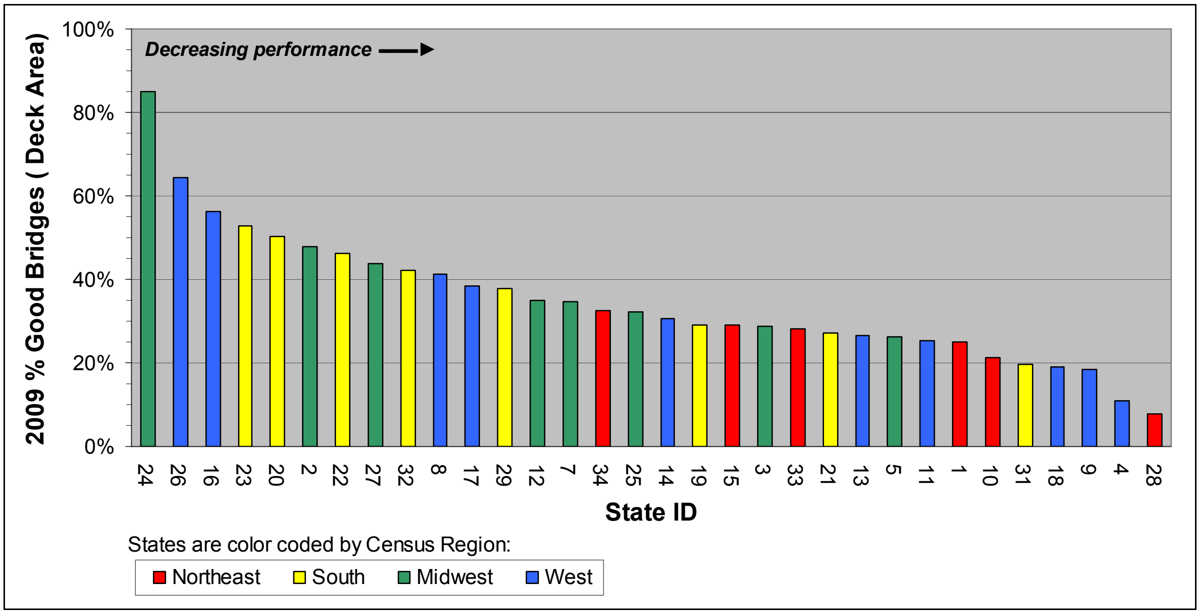

Figure C-4. Percent of State Bridge Deck Area on Bridges in Good Condition, 2009 NBI (Interstate)

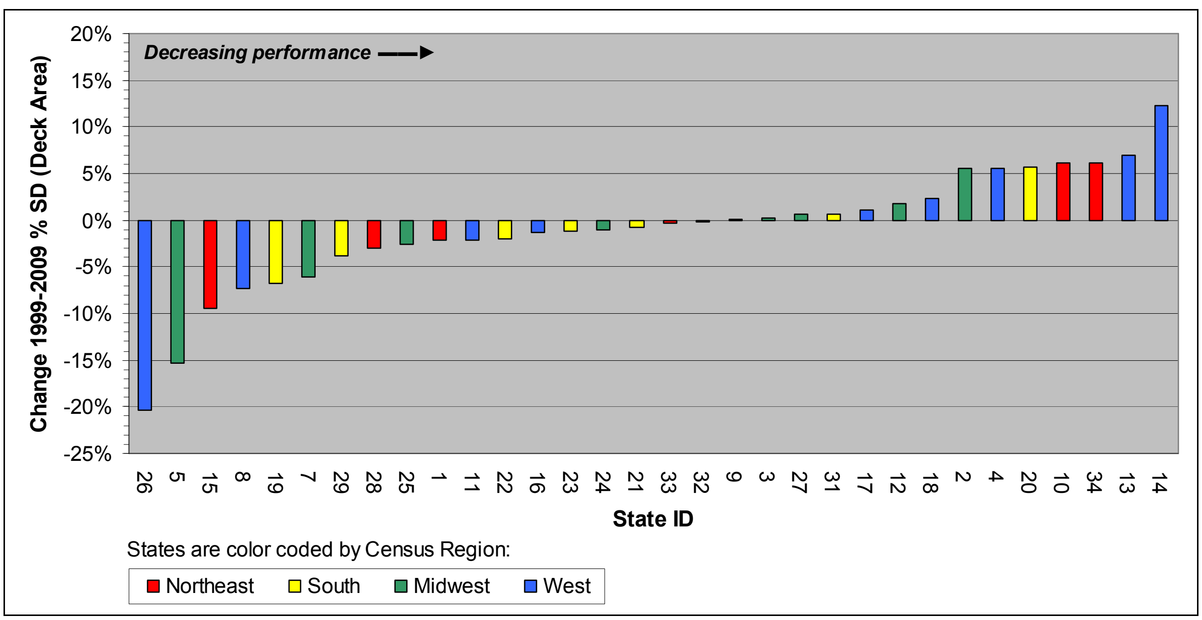

Figure C-5. Change in Percent of State Bridge Deck Area on Structurally Deficient Bridges, 1999 to 2009 NBI (Interstate)

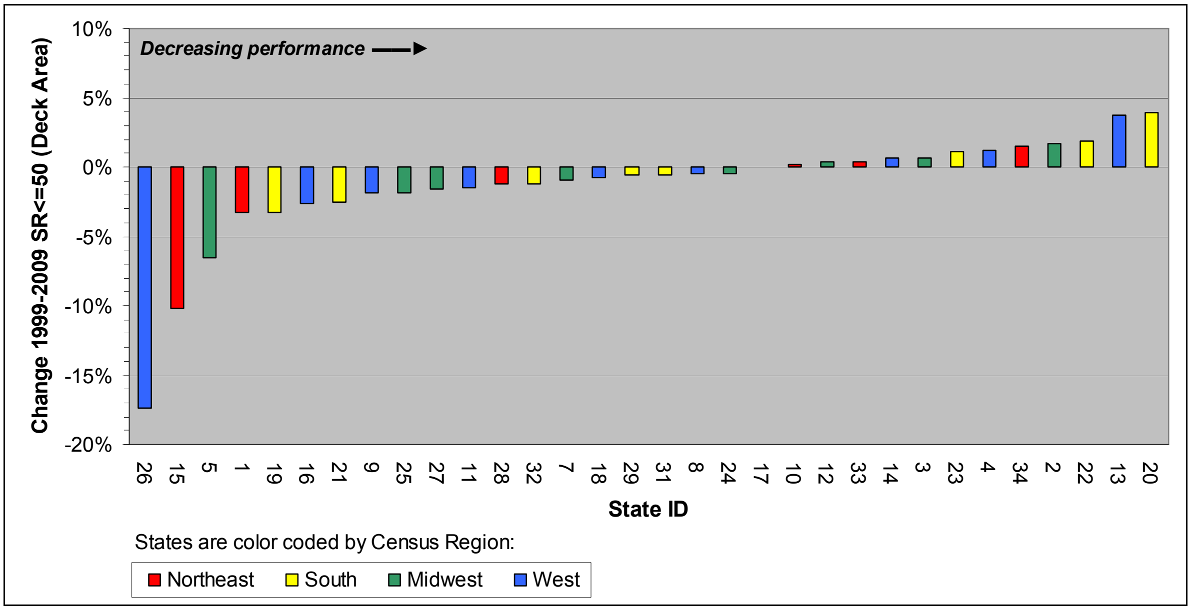

Figure C-6. Change in Percent of State Bridge Deck Area on Bridges with Sufficiency Rating ≤50, 1999 to 2009 NBI (Interstate)

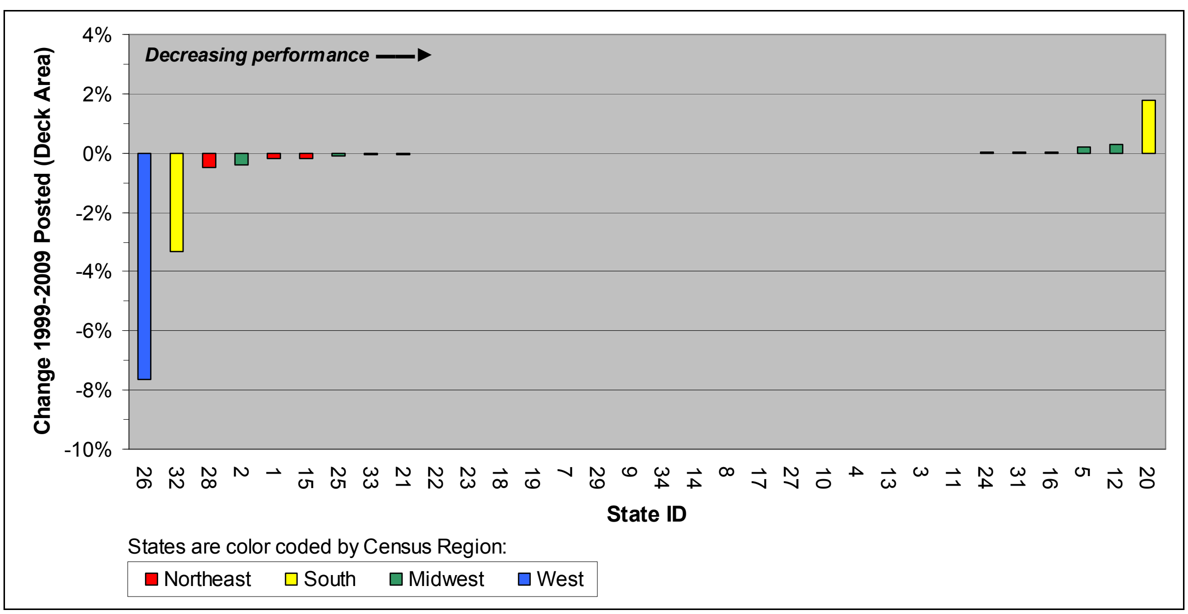

Figure C-7. Change in Percent of State Bridge Deck Area on Posted Bridges, 1999 to 2009 NBI (Interstate)

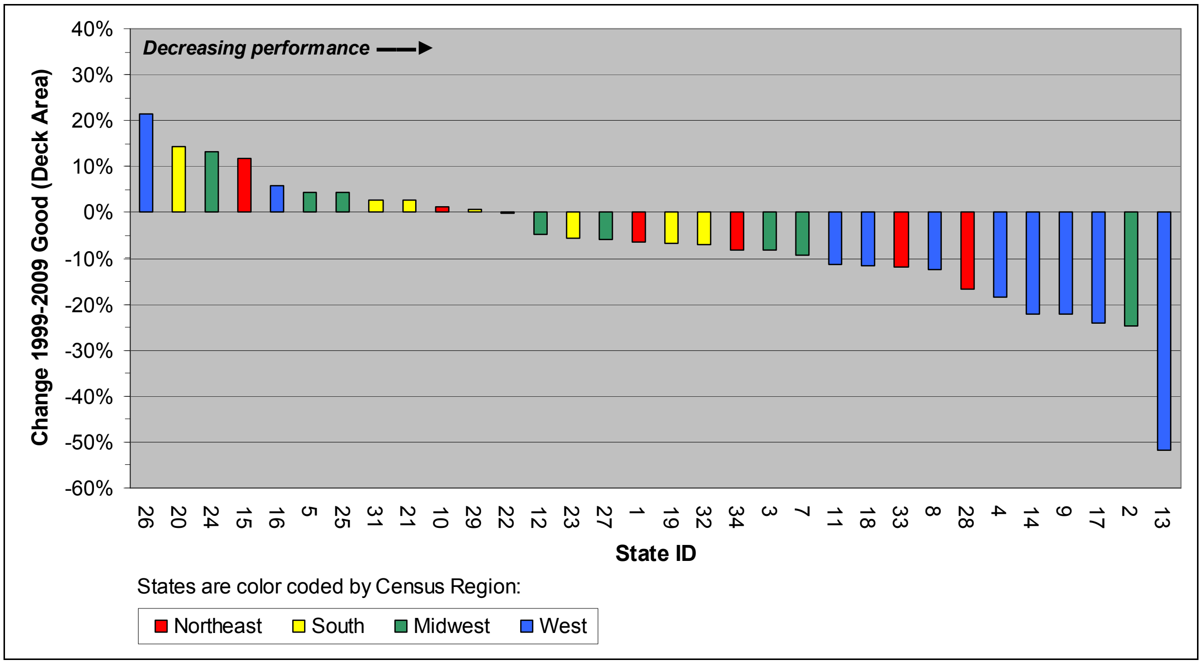

Figure C-8. Change in Percent of State Bridge Deck Area on Bridges in Good Condition, 1999 to 2009 NBI (Interstate)

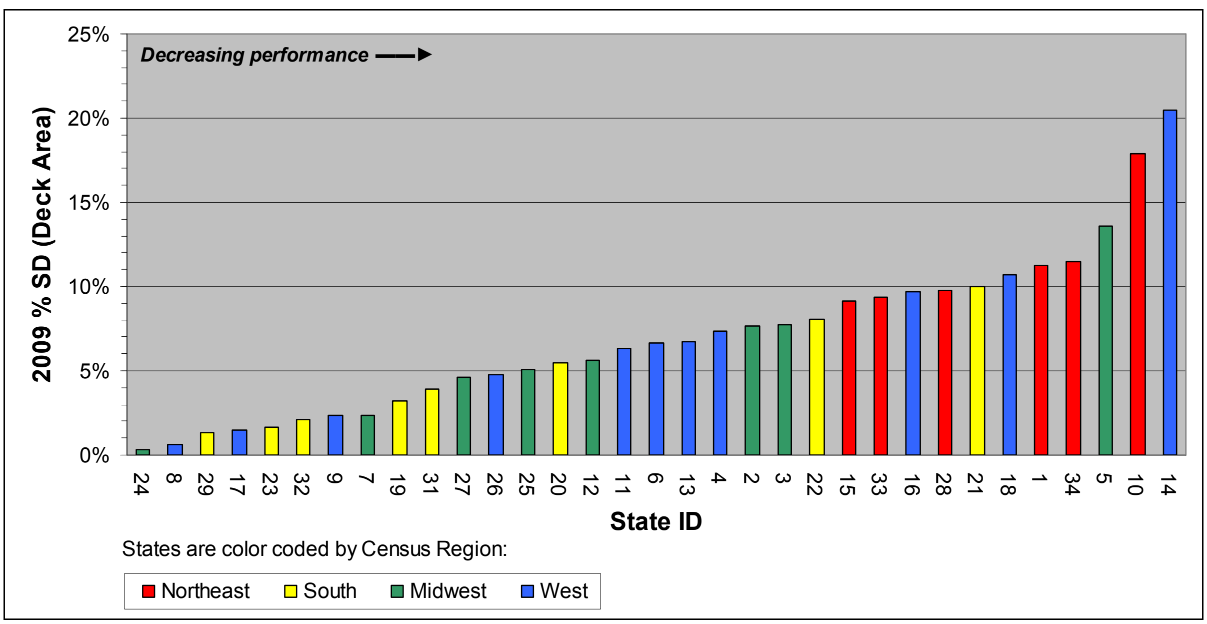

Figure C-9. Percent of State Bridge Deck Area on Structurally Deficient Bridges, 2009 NBI (NHS)

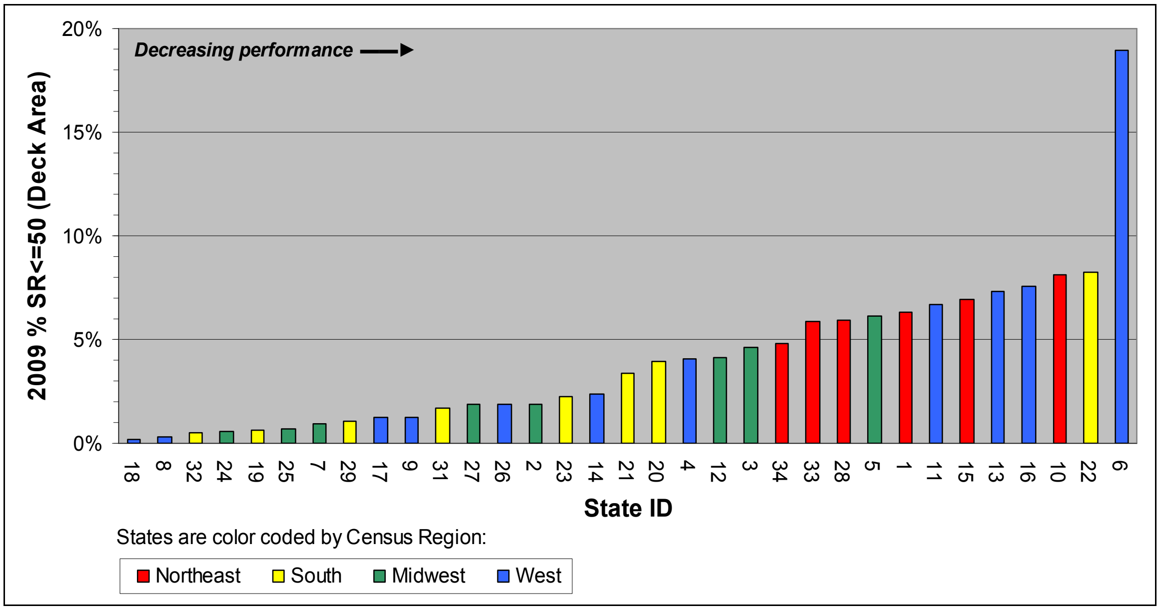

Figure C-10. Percent of State Bridge Deck Area on Bridges with Sufficiency Rating ≤ 50, 2009 NBI (NHS)

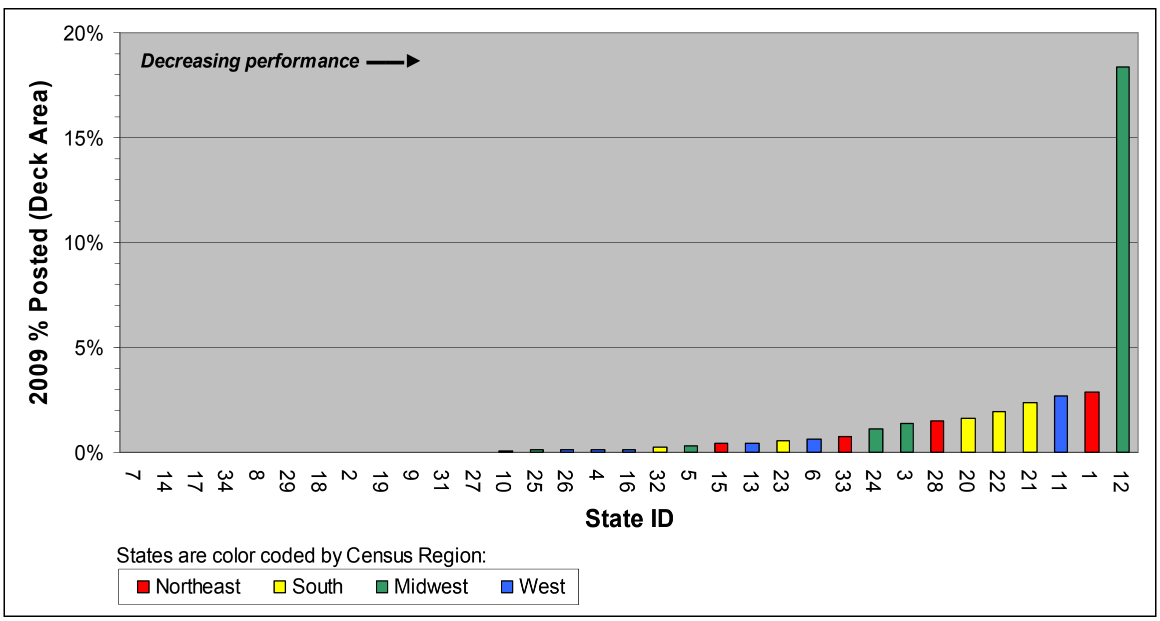

Figure C-11. Percent of State Bridge Deck Area on Posted Bridges, 2009 NBI (NHS)

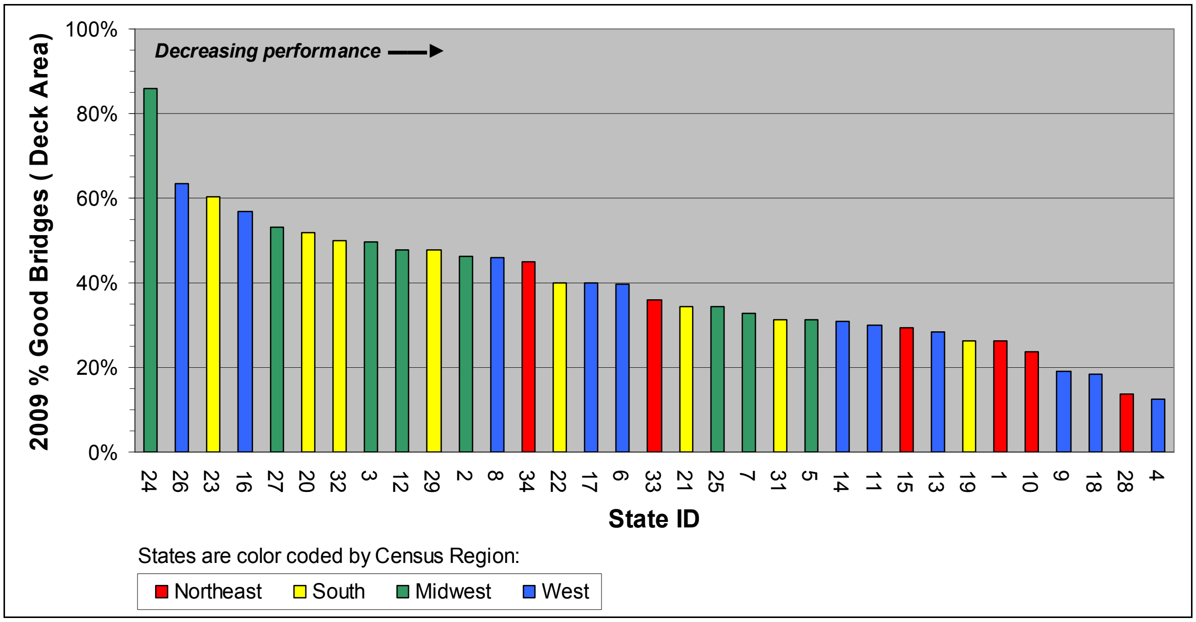

Figure C-12. Percent of State Bridge Deck Area on Bridges in Good Condition, 2009 NBI (NHS)

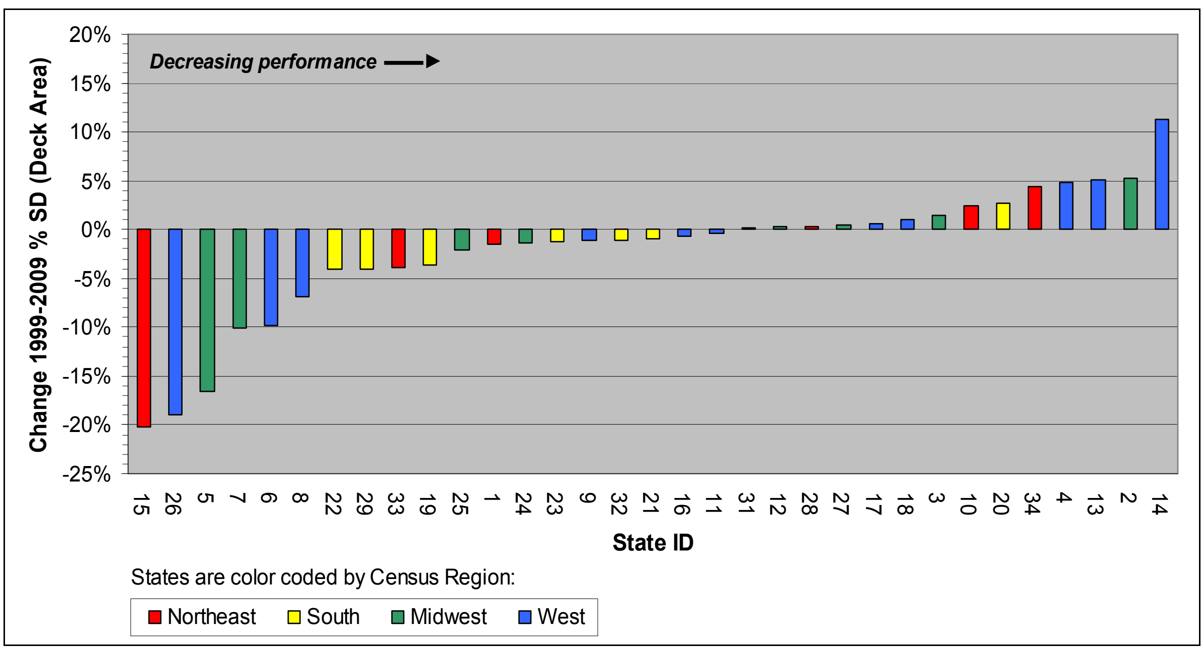

Figure C-13. Change in Percent of State Bridge Deck Area on Structurally Deficient Bridges, 1999 to 2009 NBI (NHS)

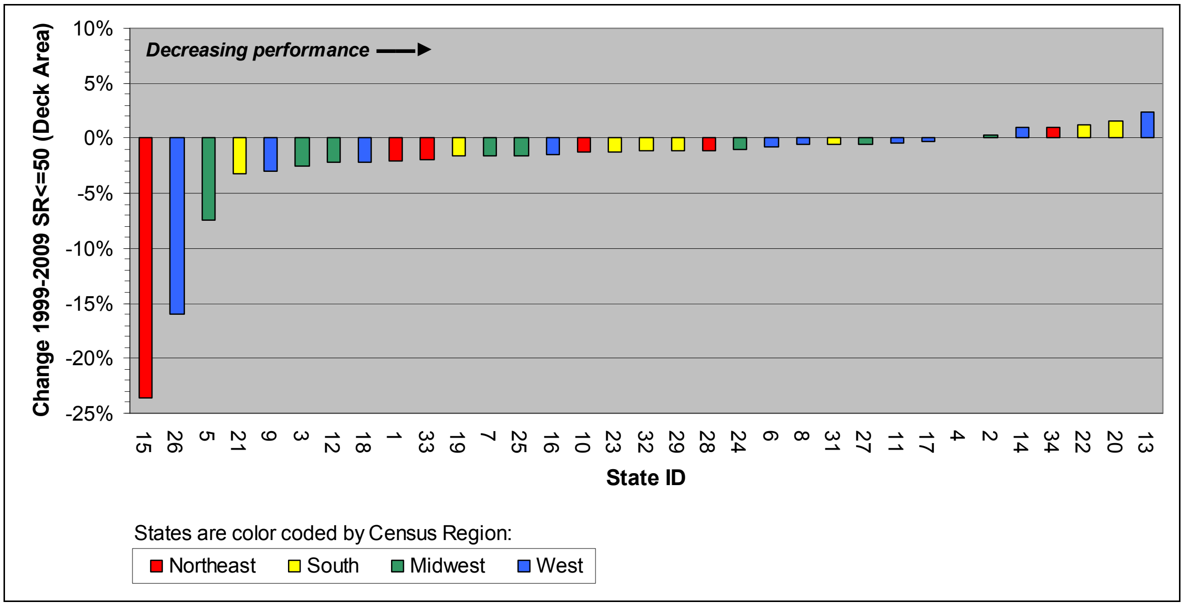

Figure C-14. Change in Percent of State Bridge Deck Area on Bridges with Sufficiency Rating ≤ 50, 1999 to 2009 NBI (NHS)

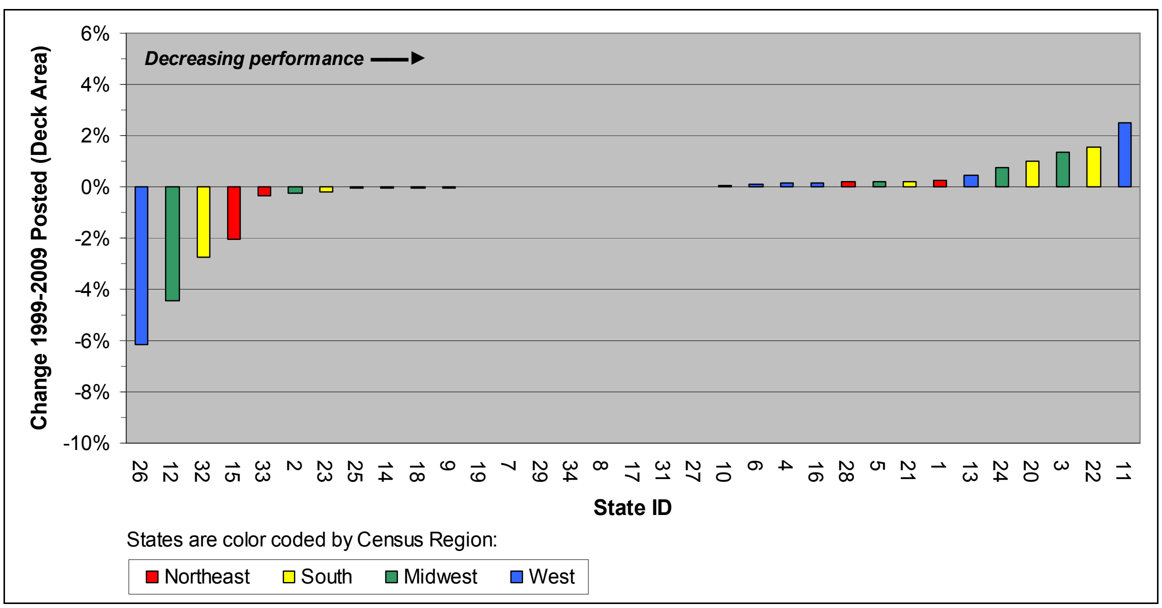

Figure C-15. Change in Percent of State Bridge Deck Area on Posted Bridges, 1999 to 2009 NBI (NHS)

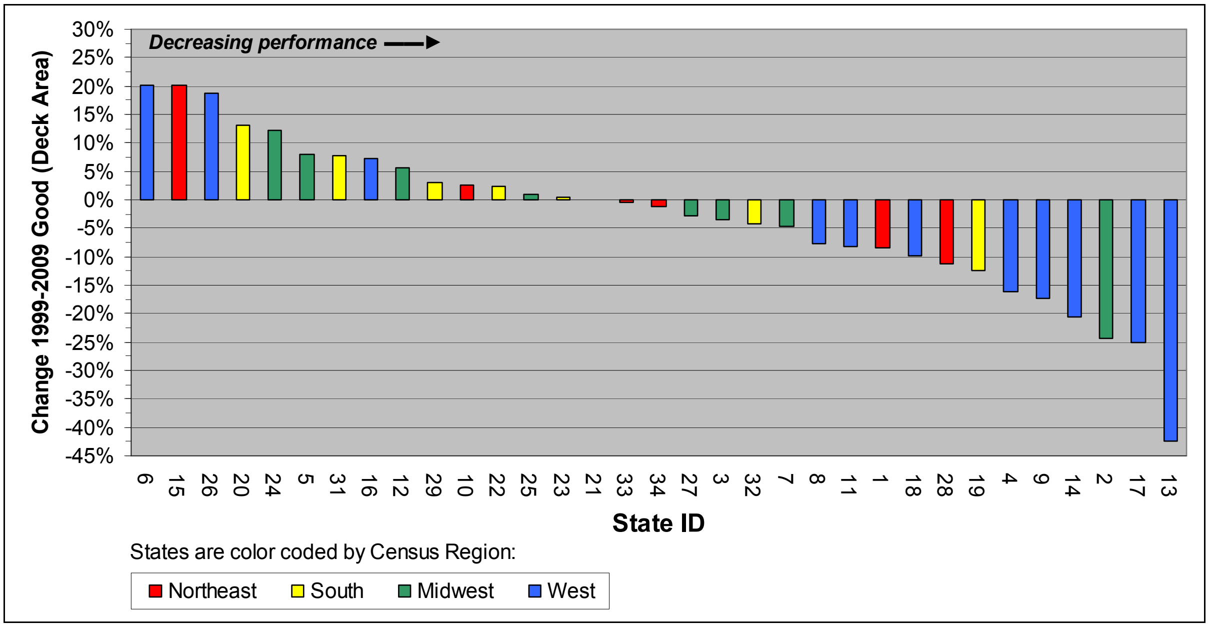

Figure C-16. Change in Percent of State Bridge Deck Area on Bridges in Good Condition, 1999 to 2009 NBI (NHS)

Peer Grouping Analysis

This section provides details on the peer grouping analysis that was presented at a summary level in Section 3.

Regional Peer Groups

A set of geographic peer groups was established using US Census regions. Figure C-17 below shows which states are assigned to the Northwest, South, Midwest and West regions respectively.

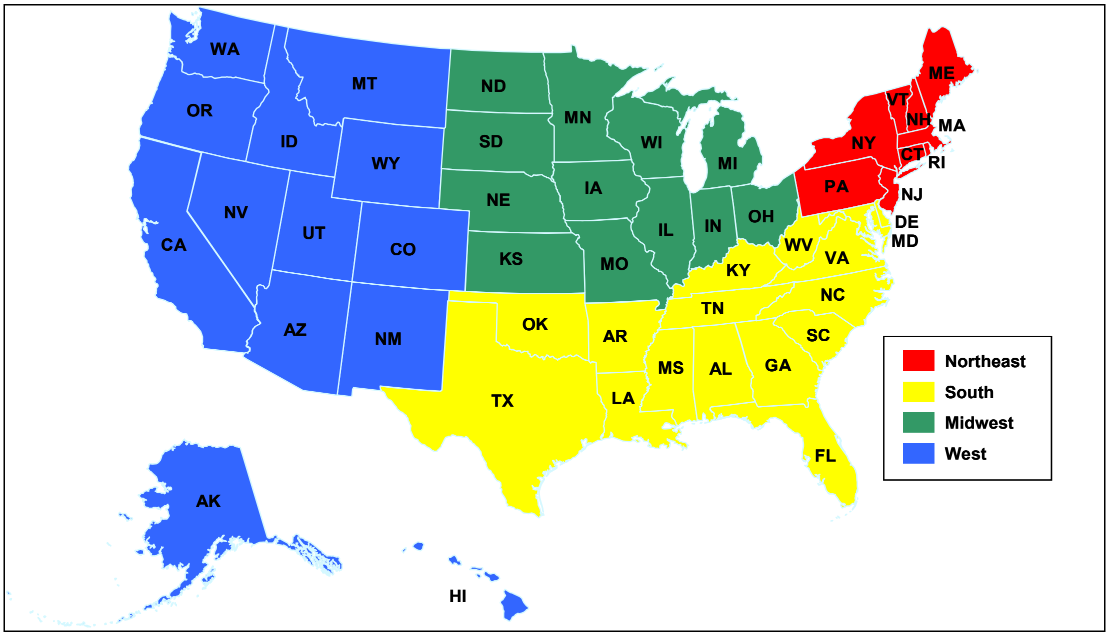

Figure C-17. Census Regions

Figure C-18 shows variations across regions in the percent of state bridge deck area on structurally deficient bridges.

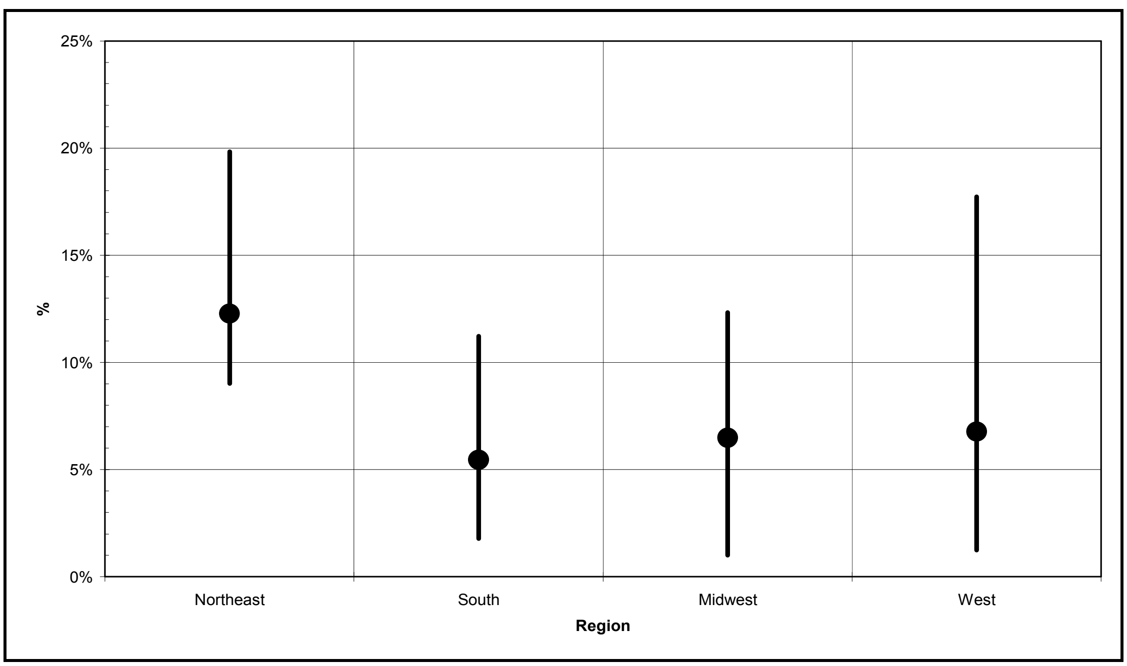

Figure C-18. 2009 NBI Percent of Deck Area NBI Structurally Deficient Bridges: Range and Mean Value by Region

Peer Groups Based on Bridge Age

Peer groups distinguishing states that have relatively higher and lower proportions of older bridges were constructed based on the percentage of bridges (weighted by deck area) with bridges over 40 years old. Bridge age was based on the 2009 values for NBI Items 27 (Year Built) and 106 (Year Reconstructed). Where Item 106 was populated, the age of the bridge in years in 2009 was estimated as the difference between 2009 and the value for Item 106. Where Item 106 was not populated, but Item 27 was populated, the age of the bridge was estimated as the difference between 2009 and the value for Item 27.

Peer group categories based on bridge age are as follows:

- Low (<20% of bridge deck area on bridges > 40 years old)
- Medium (20-30% of bridge deck area on bridges > 40 years old)
- High (>30% of bridge deck area on bridges > 40 years old)

The category definitions were based on examination of the data for natural break points and with a general goal of a relatively even distribution of states across the categories. Clustering of values in the 20-30% range resulted in assignment of 20 of the states to the "Medium" category, and seven each to the "High" and "Low" categories. Figure C-19 shows the assignment of states to peer groups based on bridge age. Only states that participated in this study were assigned to a peer group – non participating states are unshaded in the figure.

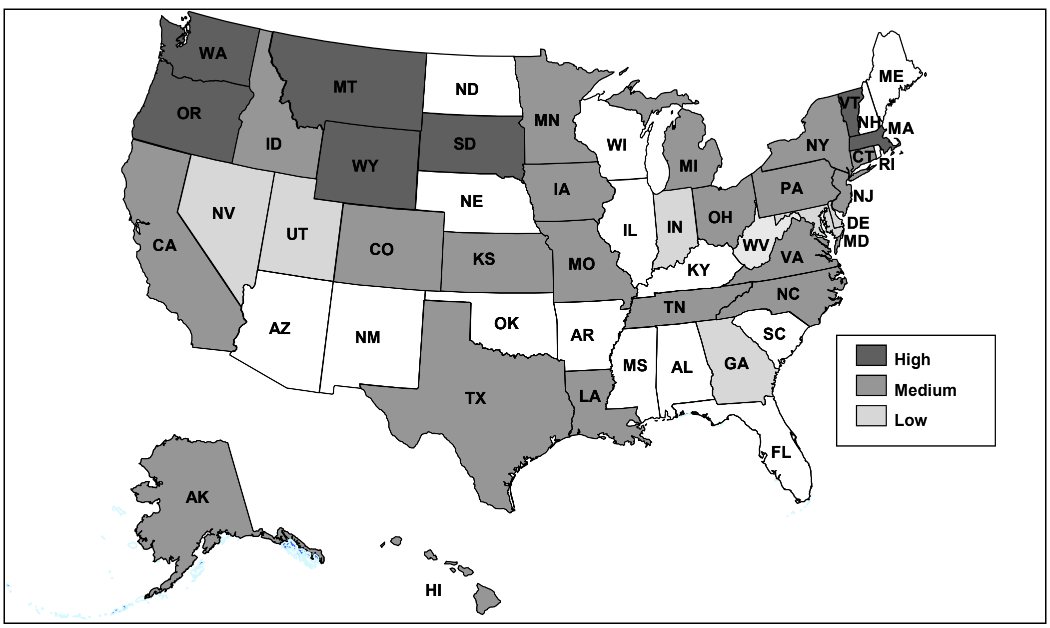

Figure C-19. Peer Groups – Bridge Age

Figure C-20 shows variations across the bridge age peer groups in the percent of state bridge deck area on structurally deficient bridges.

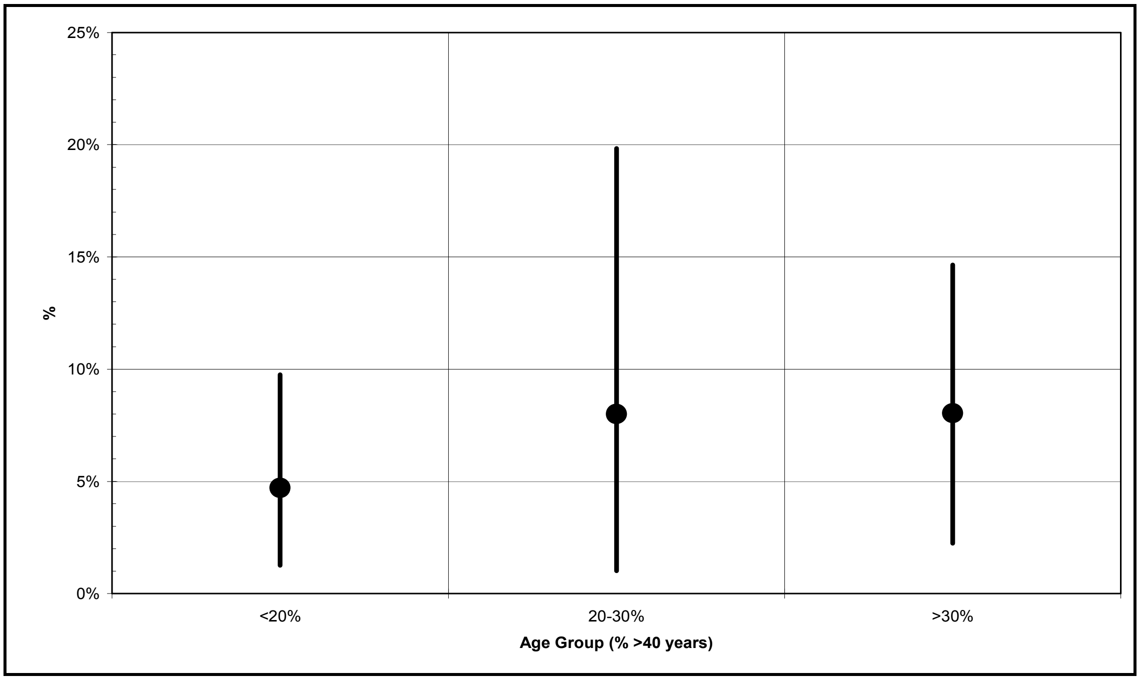

Figure C-20. 2009 NBI Percent of Deck Area on Structurally Deficient Bridges: Range and Mean Value by Age Peer Group

Peer Groups Based on Traffic

Peer groups were constructed to reflect differences in bridge traffic loadings across states – all else being equal, a state with lower average traffic on bridges would be expected to show better performance.

These peer groups were established based on the ratio of NBI Item 29 – Average Daily Traffic and NBI Item 28A – Number of Lanes on Structure.

Peer group categories based on ADT/Lane are as follows:

- Low (≤5,000 ADT per lane)
- Medium (>5,000 and ≤9,000 ADT per lane)
- High (>9,000 ADT per lane)

The category definitions were based on examination of the data for natural break points and with a general goal of a relatively even distribution of states across the categories. Ten states were assigned to the "Low" category; 13 to the "Medium" category and 11 to the "High" category.

Figure C-21 shows the assignment of participating states to peer groups based on ADT/Lane.

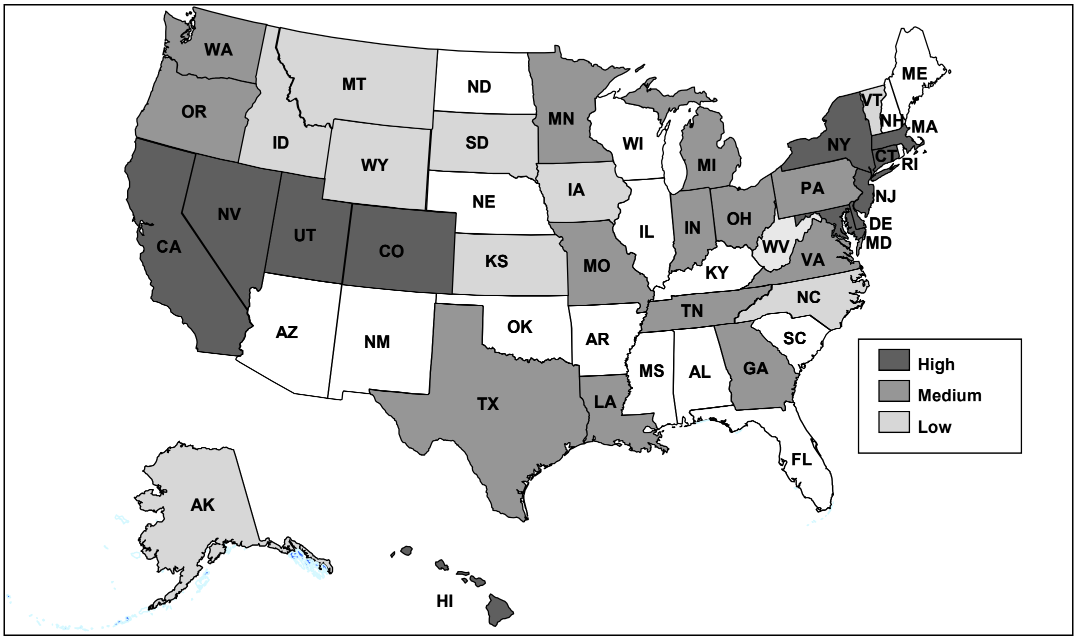

Figure C-21. Peer Groups – Traffic

Figure C-22 shows variations across traffic peer groups in the percent of state bridge deck area on structurally deficient bridges.

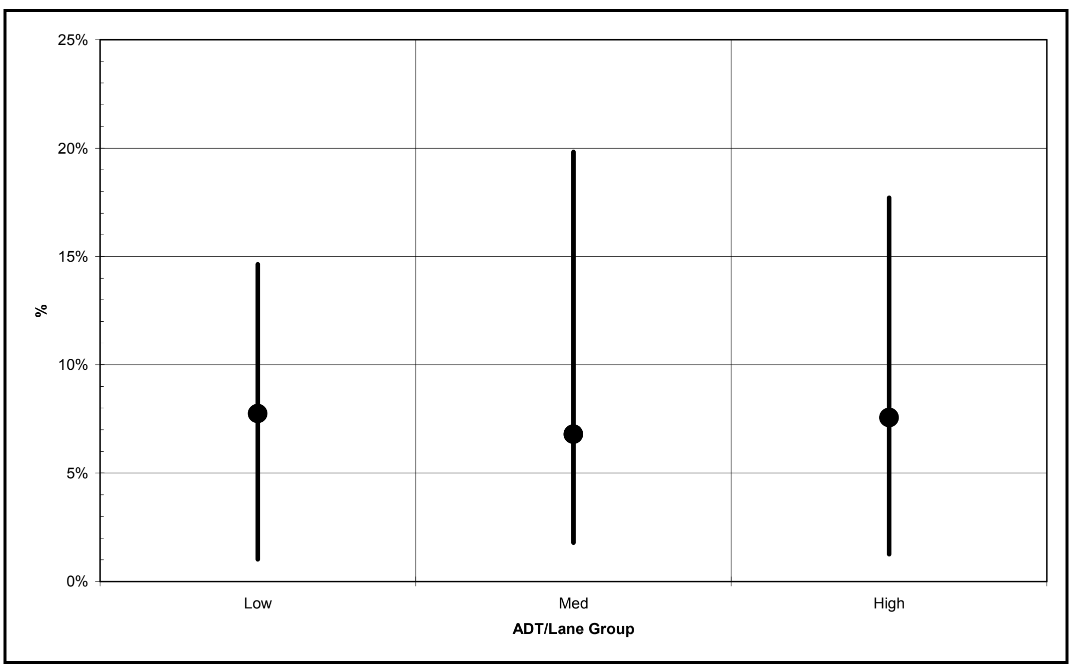

Figure C-22. 2009 NBI Percent of Deck Area on Structurally Deficient Bridges: Range and Mean Value by Traffic Peer Group

Peer Groups Based on Unit Bridge Replacement Costs

Peer groups based on unit costs of bridge replacement were established to reflect differences in bridge construction costs across states. With all else being equal, states with lower unit bridge replacement costs would be expected to have higher network-level performance because available dollars would not go as far.

For purposes of constructing peer groups based on costs, states were also asked to provide information on bridge rehabilitation and replacement costs for each year between 2004 and 2008, along with the number of bridges on which work was done and the square feet of deck area represented. States were asked to exclude large scope projects from these figures but note them separately. The data request specified that only construction phase costs be included (including construction management and environmental costs) – not design, right-of-way, or utilities. Twenty-two of the 34 states were able to provide complete data. Several states found this data request difficult to accomplish in an automated fashion – particularly where construction program project records did not include linkages to inventory data for specific bridges included.

Because cost data were not available from all of the states, supplemental data were compiled on unit replacement costs reported to FHWA. Note that the costs reported to FHWA are bridge costs only and not strictly comparable to the costs used for this study (which included some indirect costs). Also the costs are reported to FHWA separately for federal aid and non-federal aid projects. The values for 2008 were averaged to obtained a representative unit replacement cost for each state. Based on comparison of data provided by the 22 states with FHWA data for these states, a multiplier of 1.4 was established to inflate the bridge-only costs reported to FHWA for the 12 states that were not able to provide cost data. Then, peer groups were constructed with the objective of defining three groups with approximately equal numbers of states. To test the reasonableness of the 1.4 multiplier, an additional step was performed to determine whether states that provided data would have been placed in a different peer group, had the FHWA-reported cost been used for all states. This step showed than in 16 of the 17 cases in which data were available, the state would be placed in the same peer group with either approach, and that no other multiplier yielded better results than this. Thus, the multiplier and threshold values for each group were left unchanged.

Peer group categories based on unit replacement costs are as follows:

- Low (≤$140 per square foot of deck area)
- Medium ($140-$280 per square foot of deck area)
- High (>$280 per square foot of deck area)

The category definitions were based on examination of the data for natural break points and with a general goal of a relatively even distribution of states across the categories. Ten states were assigned to the "Low" category; 15 to the "Medium" category and 9 to the "High" category.

Figure C-23 shows the assignment of participating states to peer groups based on unit replacement cost.

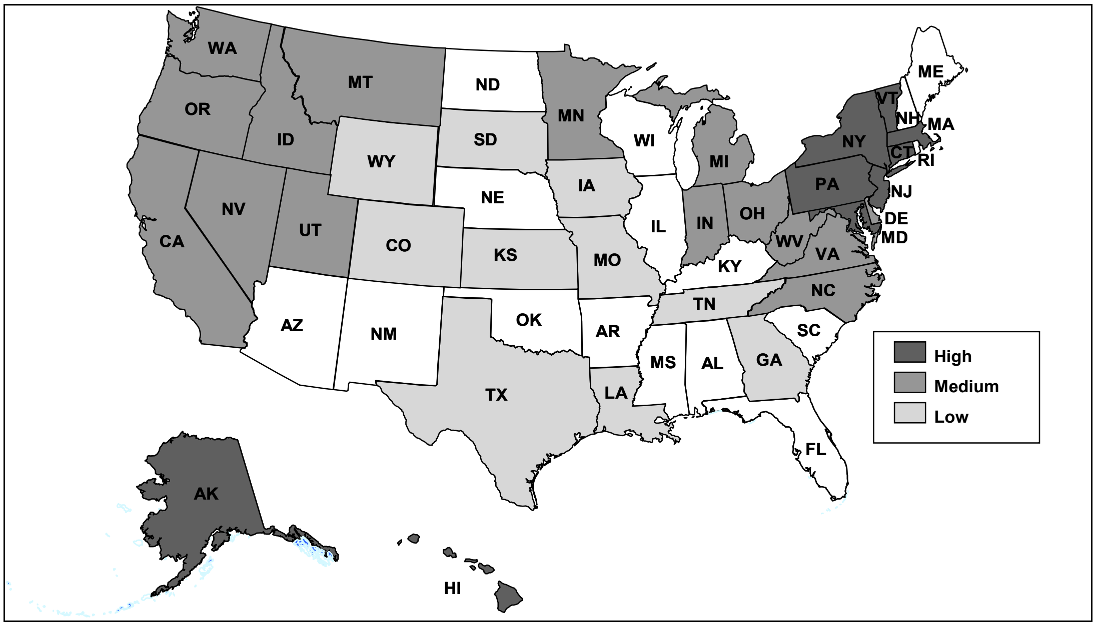

Figure C-23. Peer Groups – Unit Replacement Cost

Figure C-24 shows variations across the unit replacement cost peer groups in the percent of state bridge deck area on structurally deficient bridges.

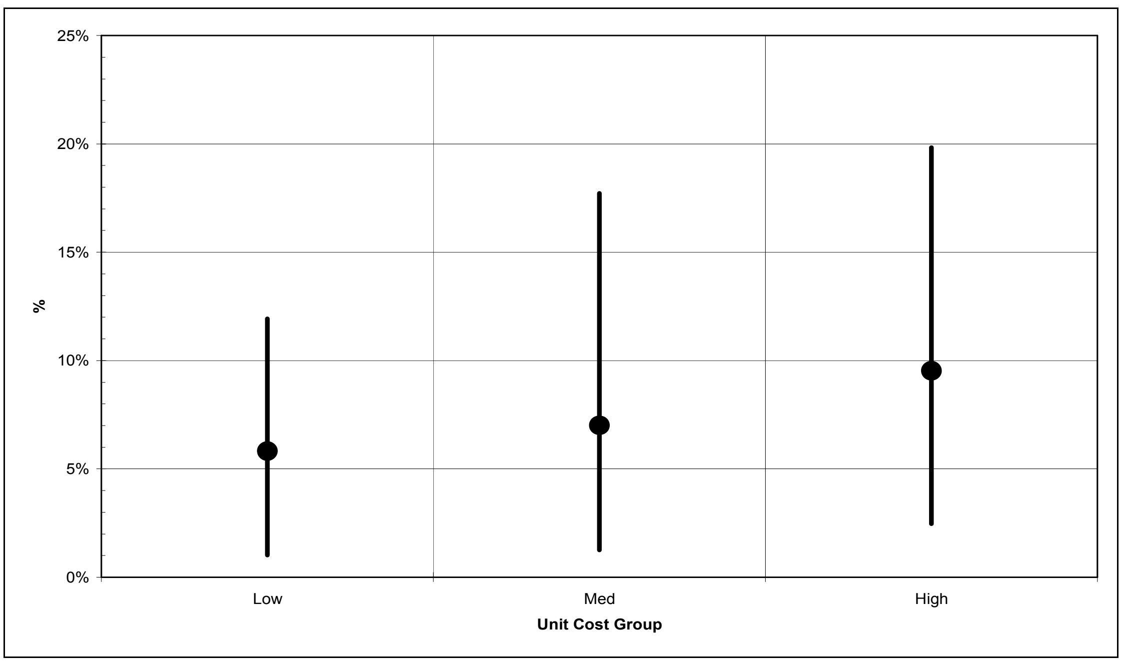

Figure C-24. 2009 NBI Percent of Deck Area on Structurally Deficient Bridges: Range and Mean Value by Unit Replacement Cost Peer Group

Peer Groups Based on Extent of Bridge Replacements Over Five Years

A final peer group was constructed to reflect the overall level of bridge replacement over the past five years. States replacing a higher portion of their inventory would be expected to show higher performance. Peer groups for the extent of the network replaced were based on a combination of data provided by the participating states on deck area of replacement bridges and NBI data. The 2009 NBI data were used to calculate the percentage of bridge deck area with an age of 5 years or less. If the state did not provide independent data on replacement deck area, the NBI data were used. If the state did provide independent data, the maximum of the values calculated from the state-reported data and the 2009 NBI file was used.

Peer group categories based on the ratio of the five year deck area of replacement bridges to total 2009 bridge deck area are as follows. Note that for this peer group, the category labeled "High" is expected to be positively correlated with performance and is listed first for consistency with the other peer groups.

- High (>10 % of 2009 deck area replaced over five years)
- Medium (5-10% of 2009 deck area replaced over five years)
- Low (≤5% of 2009 deck area replaced over five years)

As with the other peer groups, the category definitions were based on examination of the data for natural break points and with a general goal of a relatively even distribution of states across the categories. Eight states were assigned to the "Low" category; 15 to the "Medium" category and 11 to the "High" category.

Figure C-25 shows the assignment of participating states to peer groups based on unit replacement cost.

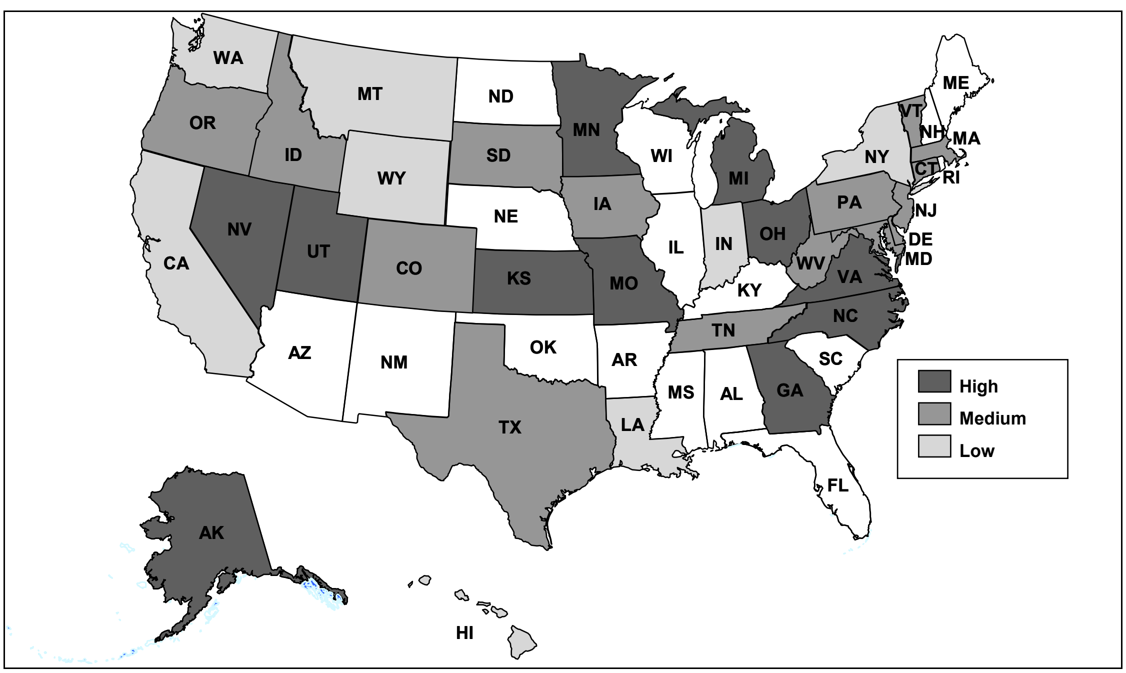

Figure C-25. Peer Groups – Five Year Replacements

Figure C-26 shows variations across the peer groups based on five year bridge replacements in the percent of state bridge deck area on structurally deficient bridges.

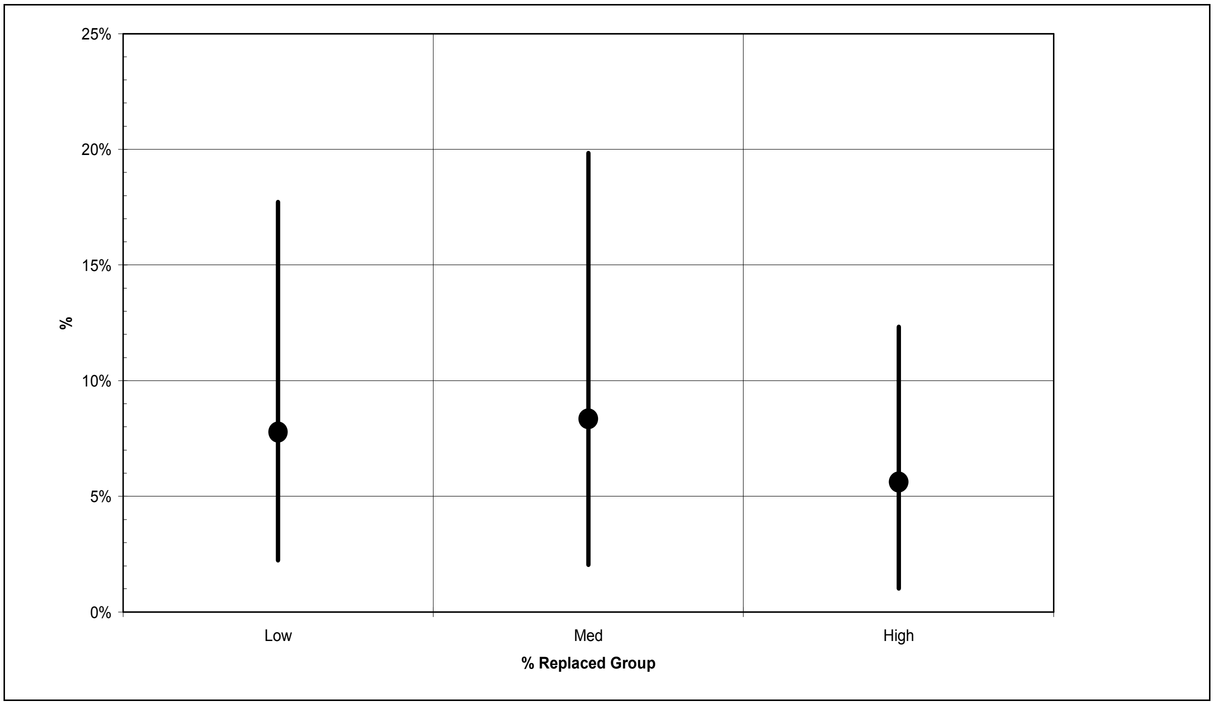

Figure C-26. 2009 NBI Percent of Deck Area on Structurally Deficient Bridges: Range and Mean Value by Five Year Replacements Peer Group

Summary of State Assignment to Peer Groupings

Table C-2 summarizes the assignment of participating states to the peer groups based on bridge age, traffic loadings, unit replacement costs, and replacement activity.

Table C-2. Summary of State Peer Group Assignments

State	Bridge Age	ADT/Lane	Unit Replacement Cost	Extent of Replacements
AK	Medium	Low	High	High
CA	Medium	High	Medium	Low
CO	Medium	High	Low	Medium
CT	Medium	High	High	Medium
DE	Low	High	Medium	Medium
GA	Low	Medium	Low	High
HI	Medium	High	High	Low
IA	Medium	Low	Low	Medium
ID	Medium	Low	Medium	Medium
IN	Low	Medium	Medium	Low

State	Bridge Age	ADT/Lane	Unit Replacement Cost	Extent of Replacements
KS	Medium	Low	Low	High
LA	Medium	Medium	Low	Low
MA	High	High	High	Medium
MD	Low	High	High	Medium
MI	Medium	Medium	Medium	High
MN	Medium	Medium	Medium	High
MO	Medium	Medium	Low	High
MT	High	Low	Medium	Low
NC	Medium	Low	Medium	High
NJ	Medium	High	High	Medium
NV	Low	High	Medium	High
NY	Medium	High	High	Low
OH	Medium	Medium	Medium	High
OR	High	Medium	Medium	Medium
PA	Medium	Medium	High	Medium
SD	High	Low	Low	Medium
TN	Medium	Medium	Low	Medium
TX	Medium	Medium	Low	Medium
UT	Low	High	Medium	High
VA	Medium	Medium	High	High
VT	High	Low	High	Medium
WA	High	Medium	Medium	Low
WV	Low	Low	Medium	Medium
WY	High	Low	Low	Low
AK	Medium	Low	High	High
CA	Medium	High	Medium	Low
CO	Medium	High	Low	Medium
CT	Medium	High	High	Medium
DE	Low	High	Medium	Medium

Appendix D – Interview Guide for Identification of Best Practices

Based on the data analyzed as part of this study, it appears that your agency's practices have resulted in good bridge performance relative to other peer states. Our research team is interested in obtaining more information about your state's practices that have contributed to these results. We would like to conduct a telephone interview to discuss the areas described below. The information you provide will be incorporated into the final report, which will provide a summary of state practices that are associated with successful performance results.

The research team will be contacting you shortly to schedule a telephone interview. If you have any published materials or web links that would help us prepare for the interview in advance, please let us know. If you have any questions, please don't hesitate to contact us. Thank you in advance for your participation in this study.

Name of interview participant(s):____

Agency:____

Position:____

1) **Organization.** Please describe the key state-level agency units involved in managing the bridge inventory within your state. Note that this study is specifically concerned with state-maintained bridges only.
2) **Resource Allocation.** Please summarize the process for making resource allocation decisions regarding state-maintained bridges. Specifically -

   a) What program/budget categories does your state use for bridge capital and maintenance expenditures - does your agency have separate budgets for new bridge construction, bridge preservation and bridge maintenance activities?
   b) How are the budgets for bridge replacement, rehabilitation and maintenance established (e.g. historical, use available federal funds, performance-based, etc.)?
   c) How are candidate bridge projects prioritized?
   d) How has the budget for bridge all projects varied over the past 10 years?
   e) To what extent have funding sources other than Federal BR funds been available and used over the past 10 years?
   f) How does your agency determine how much to invest in bridges versus other asset/investment areas?

3) **Performance Measures.** Please describe types of performance measures used at different organizational levels; targets established; and influence of performance measures on resource allocation, prioritization and practice.

   a) What measures of bridge performance does your agency track and report (e.g. percent good/fair/poor, health index, NBI sufficiency rating, etc.)?
   b) Does your agency set system wide or district-level goals for bridge performance?
   c) Does your agency have performance measures used to specifically track bridge maintenance program performance?
   d) Who is involved in the setting of bridge performance measures?
   e) How are performance measures used to support decision-making for bridges?

4) **Design and Construction.** Please detail relevant design and construction practices that you feel have contributed to your agency's success in achieving or sustaining good network bridge condition relative to other states.

   a) Has your agency developed design specifications to meet the maintenance or preservation needs of in-service bridges?
   b) Is bridge maintenance experience used to inform and improve design practice?
   c) If a new structure contains a complex or unusual structural detail, does the engineer provide maintenance guidance documentation (e.g. an owners manual) for your maintenance personnel to use?
   d) Has your agency developed or adopted serviceability requirements to be used in the design of new bridges?
   e) Are there particular design or construction practices that you have used to lower the cost of preserving, rehabilitating or replacing bridges? If so, have these practices enabled you to increase the amount of bridge work you perform?

5) **Bridge Maintenance.** Please describe your agency's approach to bridge maintenance. Note: in the items below "preservation" refers to all actions taken to improve the condition of an existing bridge short of replacement, "maintenance" refers to actions short of rehabilitation, and "preventive maintenance" refers to minor maintenance actions that can be undertaken on a periodic basis. However, these terms are often defined differently from this.

   a) How is "bridge maintenance" defined in your agency? How does this differ from "bridge preservation" and/or "preventive maintenance" in the context of bridges? Are bridge maintenance and preservation separate programs?
   b) To what extent have your bridge maintenance practices contributed to your agency's overall bridge performance results?
   c) Does your agency dedicate funding for bridge maintenance in its annual capital program?
   d) Has your agency developed a scheduled preventive maintenance plan for bridges?
   e) Are prescribed maintenance actions undertaken on a periodic basis? (i.e. spring deck washing, spot painting, bearing lubrication)

6) **Maintenance Delivery.** Please describe practices related to use of specialized crews for bridge maintenance, use of contractors, and training and certification programs.

   a) Are bridge management/preservation office staff personnel full time?
   b) Are bridge maintenance engineers/supervisors full time?
   c) Does you agency have special crews dedicated to bridge maintenance?
   d) Has your agency used any innovative contracting approaches to reduce the cost or improve the effectiveness of bridge maintenance.
   e) Does you agency have asset maintenance contracts (contracts for continuing maintenance) in place?
   f) Has your agency established training and certification programs for inspectors, maintenance staff and/or other staff that may have helped improve bridge conditions?

7) **Maintenance Techniques**. Please describe any notable maintenance techniques that may have contributed to your agency's successful performance results (e.g. use of specialized sealants).
   a) Do you have standard operating procedures (SOPs) for bridge maintenance activities?
   b) Do you have approved standard maintenance details and repair procedures for specific recurring activities?
   c) Do you have an approved materials and methods list for maintenance activities?
   d) Has your agency developed material specifications to meet the maintenance or preservation needs of in-service bridges?
   e) Has your agency developed contracting mechanism to meet the maintenance or preservation needs of in-service bridges?
   f) Other?

8) **Other practices**. Please describe any other practices in use in your agency that may have contributed to successful performance results. Possible examples include, bur are not limited to:
   a) Use of manuals, guides, special training, designated roles and/or special certification for bridge maintenance and/or inspection.
   b) Formalizing procedures for planning, prioritizing, performing and/or tracking bridge maintenance.
   c) Centralizing (or decentralizing) decision-making.
   d) Communicating bridge needs within the agency, to other stakeholders, and to the general public.
   e) Approaches for evaluating the effectiveness of bridge maintenance.
   f) Winter maintenance practices to minimize bridge deterioration.
   g) Policies related to truck size/weight enforcement.

9) Most Significant Practices. Considering everything we've talked about, which practices have had the greatest influences on bridge performance results achieved by your state?