

# JOINT TRANSPORTATION RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION  
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## Element Level Bridge Inspection: Benefits and Use of Data for Bridge Management



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## JOINT TRANSPORTATION RESEARCH PROGRAM

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<b>16. Abstract</b> <p>In 2012, Congress passed the Moving Ahead for Progress in the 21st Century Act (MAP-21) and committed to the development of a data-driven, risk based approach to asset management in the United States. This law requires the collection and submission of element level bridge inspection data for all National Highway System bridges, in addition to the National Bridge Inspection condition rating data. Ultimately, the data collected during element level bridge inspections should satisfy the requirements of the Federal Highway Administration and MAP-21 and be utilized by INDOT to evaluate bridge condition, predict deterioration, and guide decision making.</p> <p>The objective of this project is to develop recommendations for element level bridge inspection techniques, data collection, and inspector training based on a survey of INDOT peer agencies and a literature review of existing research and bridge inspection guidance. In order to collect consistent and reliable data, a rigorous inspector training program and detailed quality control procedures are necessary. INDOT must provide inspectors with the tools to be successful, including clearly defined expectations and instructions, comprehensive training and technical support, and effective inspection equipment. Similarly, robust quality control measures and periodic performance testing should be implemented to improve inspection quality and assess the agency's performance.</p>		<b>13. Type of Report and Period Covered</b> Final Report	
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## EXECUTIVE SUMMARY

### ELEMENT LEVEL BRIDGE INSPECTION: BENEFITS AND USE OF DATA FOR BRIDGE MANAGEMENT

#### Introduction

The Moving Ahead for Progress in the 21st Century Act (MAP-21) is the cornerstone for plans to improve the U.S. highway system. With the passage of MAP-21, Congress committed to the development of a data-driven, risk-based approach to asset management in the United States. This law required the collection and submission of element level bridge inspection data for all National Highway System bridges, in addition to the National Bridge Inspection condition rating data. All states were required to begin element level inspections by 1 October 2014 and submit the first round of data on 1 April 2015.

This report includes recommendations for element level inspection techniques, data collection, and inspector training based on a survey of Indiana Department of Transportation (INDOT) peer agencies and a literature review of existing research and bridge inspection guidance. Ultimately the data collected during these inspections must be detailed and reliable so that it can be used in INDOT's bridge management program to evaluate bridge condition, predict deterioration, and guide decision making.

#### Findings

- Data required by the Federal Highway Administration is sufficient for effective element level bridge inspections in the short term. This inspection program should be expanded over time to make it more useful to INDOT. Element level

data is commonly used for fund allocation, deterioration modeling, and making preservation, repair, and replacement decisions. Element level data can also be used to predict upcoming maintenance or repair work.

- Many states have long profited from the collection of element level inspection data. Most of the benefits are realized in the form of more reliable methods of setting performance goals, making decisions, and evaluating the effectiveness of those decisions in achieving the goals.
- A rigorous training program and detailed quality control procedures are necessary to ensure data consistency and reliability.

#### Implementation

During the initial stage of conducting element level inspections in Indiana, it is not necessary to collect more than what is required by the FHWA. With time, a collection of agency developed elements and defect data will become useful. This data can be used to simplify and focus inspections, track the conditions of elements not specified in the AASHTO Manual for Bridge Element Inspection, establish performance measures, and develop reliable deterioration models.

In order to collect consistent and reliable data, INDOT must provide inspectors with the tools to be successful, including clearly defined expectations and instructions, comprehensive training and technical support, and effective inspection equipment. Quality control measures, such as annual or semiannual calibration meetings, inspector rotation, and visual enhancements (e.g., standardized flashlights) should be implemented. State-specific training courses should be developed to address practice and policies unique to INDOT, and periodic performance testing should be used to evaluate inspector performance and verify the adequacy of agency training and support.

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## 1. LITERATURE REVIEW AND CURRENT PRACTICES

The purpose of Task I is to investigate current procedures used by other states who are already collecting and managing element level data and perform a critical review of existing literature, including previous research, inspection guidance manuals, and specifications as related to element level inspection. This is the second update to Task 1 of this study. Previous findings are outlined in the SPR-3819 interim report submitted in October 2014. The following sections summarize the findings under Task I of SPR-3819.

### 1.1 Introduction

The Moving Ahead for Progress in the 21<sup>st</sup> Century Act (MAP-21), enacted on July 6, 2012, is the cornerstone for plans to improve the U.S. highway system. In addition to requirements for improving safety, reducing congestion, and protecting the environment, MAP-21 outlines new requirements to combat deterioration of transportation infrastructure, including the increasing number of structurally deficient bridges. In MAP-21, the U.S. Congress declares that “it is in the vital interest of the United States to use a data-driven, risk-based approach and cost-effective strategy for systematic preventative maintenance, replacement, and rehabilitation of highway bridges and tunnels to ensure safety and extended service life” (H.R. 4348, 2012). As mandated by MAP-21, the Federal Highway Administration (FHWA) intends to use element level bridge inspection data to support a “data-driven, risk-based” management strategy. Element level inspections provide an in depth assessment of a bridge’s condition. Although not previously required by federal law, the collection of element level inspection data has been ongoing in many states since the early 1990s under the guidance of AASHTO’s Guide for Commonly Recognized (CoRE) Structural Elements. Many states who had previously collected element level data in accordance with the AASHTO CoRE guidance have incorporated the new FHWA requirements for element level bridge inspections into their inspection protocol. In accordance with the timeline presented in MAP-21, element level data was to be collected during all inspections of National Highway System (NHS) bridges performed after 1 October 2014 and this data is to be submitted to the FHWA in April of each year, beginning on 1 April 2015 (FHWA, 2014).

Following the passage of MAP-21, the FHWA issued the “Specification for the National Bridge Inventory Bridge Elements” which provides the framework for transportation agencies to collect and report element level data to the FHWA. The FHWA specification includes a list of bridge elements for which condition assessments are required and refers to the AASHTO Manual for Bridge Element Inspection (First Edition) for further details. The AASHTO Manual for Bridge Element Inspections builds on the AASHTO CoRE

guidance and provides descriptions of the various bridge elements and definitions of the four (4) possible condition states for each element. The AASHTO manual divides the bridge elements into three categories: National Bridge Elements (NBE), Bridge Management Elements (BME), and Agency Developed Elements (ADE). National Bridge Elements represent the primary load carrying elements of a bridge. Bridge Management Elements are elements which may affect the long term durability of NBEs, such as wearing surfaces or protective coatings. Agency Developed Elements are custom elements defined by an agency. ADEs may also be sub elements of NBEs or BMEs (AASHTO, 2013). For each element, a total quantity of the element and a quantified condition state rating must be recorded as outlined by the AASHTO Manual for Bridge Element Inspection. At this time, the FHWA requires the submission of inspection data for only specific NBEs and BMEs, although most agencies inspect far more elements. Additionally, the FHWA does not require the submission of specific element defects (FHWA, 2014).

Although the FHWA requires only a limited amount of data be submitted annually, the new requirement for element level inspections provides each agency an opportunity to improve inspection procedures and enhance bridge management systems.

### 1.2 Basics of Bridge Management

In order to understand how element level inspection data can be best utilized, a basic understanding of bridge management systems is required. The FHWA defines a bridge management system as “a systematic process that provides, analyzes, and summarizes the bridge information for use in selecting and implementing cost-effective bridge construction, rehabilitation, and maintenance programs” (FHWA, 2015). In a paper titled “Employing Asset Management to Control Costs and Sustain Highway Levels of Service,” the authors identified program budgets, trigger values, and condition ratings as the three major components of a bridge management system (Fricker, Kumares, Nouredin, & Stroshine, 2014). The program budget is the amount of money that a bridge agency has to spend on preservation, restoration, or replacement of its bridges. Trigger values are predetermined values of bridge performance measures that indicate maintenance, preservation, or replacement activities are necessary to maintain the desired level of service. Condition ratings are a quantitative assessment of the current condition of the bridge. Element level inspection data provides more accurate condition ratings and can be used to make informed decisions regarding trigger values and budgeting.

Within bridge management systems, National Bridge Inventory (NBI) condition ratings have traditionally been used to evaluate the condition of bridges. NBI condition ratings provide an assessment of how the major components will function, but fail to accurately portray the complete condition of the bridge. It is also

well documented that NBI condition ratings are subjective because they require the inspector to identify and determine the single-most severe symptom of distress. One inspector’s classification as “most severe” or interpretation as “most important” may differ from another inspector’s classification or interpretation of the distress. Finally, condition ratings may not convey the full extent of the distress. Element level inspections attempt to address these shortcomings because the condition of each element is recorded separately, and the type and extent of distress is reported quantitatively.

Trigger values are values implying a need for action. In bridge management systems, trigger values indicate the need for maintenance, repair or preservation work and can be established based on any performance measure. Performance measures provide a technical basis for decision making and a baseline for assessing the effectiveness of decisions over time (Fricker et al., 2014). Using element level inspection data, trigger values can be set for individual elements, rather than collections of elements. Additionally, the impact of trigger values can be monitored and refined to minimize cost and maximize benefit.

Project budgets are the amount of money available for bridge projects in a given time period. Typically, there are more possible projects than available funding, and so the projects need to be prioritized. Each state agency has a unique methodology for determining priority, but the overarching objective is to maximize the impact of the limited funding (Fricker et al., 2014). Element level inspection data may provide for greater

confidence in prioritizing projects and assist in establishing reasonable program budgets by delivering quantitative data that can be tracked and evaluated.

### 1.3 Review of the State of the Art

The main focus of this review is to compile the current inspection practices of various agencies around the country, particularly the ways these agencies incorporate element level inspection data into their bridge management programs. A survey was sent out to state agencies, specifically targeting those that have a presence in the Midwest Bridge Preservation Partnership (MWBPP) and the AASHTO T-18 Subcommittee. This survey was developed in combination with the Midwest Bridge Preservation Partnership (MWBPP) working group, “Strategies for Collecting Element Level Data” led by Mike Brokaw, an Assistant Administrator of the Bridge Inspection and Maintenance program at the Ohio Department of Transportation. The objective of this survey was to take a look at unique implementation techniques for element level inspections as well as the current progress of inspection agencies in starting element level inspections. The research team sent out a survey to twenty-five state level bridge inspection and management programs and fourteen responded (Table 1.1). The basic findings of this survey are summarized in the following discussion.

Of the fourteen states which responded to the survey, thirteen have a bridge management program and each uses or intends to develop a bridge management system. Additionally, all but one of the surveyed states was

TABLE 1.1  
Status of Element Level Inspections in 14 States as of September 2014

State	Performing Element Level Inspections before Map21?	Uses Aides or NBE/BME Sub Elements?	Collecting Defects?	State Has a Bridge Management Program?	BMS Software
Wyoming	Yes	Yes	No	Yes	AASHTOware
New York	Yes	No	No	Yes	In house database (BDIS)
Texas	Yes	No	Yes	Yes	In house database (PonTex)
California	Yes	Yes	Yes	Yes	AASTHOfware
Georgia	Yes	Yes	Yes	Yes	AgileAssets
Florida	Yes	Yes	No	Yes	AASTHOfware
Montana	Yes	Yes	No	Yes	Under development
Kentucky	Yes	Yes	Yes	Yes	AASTHOfware
North Dakota	Yes	Yes	Yes	Yes	AASTHOfware
Iowa	Yes	Yes	Yes	Yes	In house database (SIIMS)
Michigan	Yes	Yes	No	Yes	AASTHOfware
Wisconsin	Yes	Yes	Yes	Yes	In house database (HSIS)
Missouri	No	No	No	No	None
Ohio	No	Yes	No	Yes	Bentley SMS

collecting element level data in some form before the requirements of MAP-21 took effect. Many of these states have been collecting element level data for a number of years for use in their own bridge management systems and decision making processes. Georgia, Iowa, and Ohio began performing element level inspections between 2012 and 2014. New York indicated that, although they have been collecting element level data for three decades, they have not been collecting this data under the AASHTO CoRE format. Additionally, eleven states indicated that they are currently collecting data on ADEs in addition to the required NBEs and BMEs. New York and Texas intend to begin collection on ADEs in the future. Finally, seven states noted that they are collecting data on defects. The FHWA does not presently require data collection on ADEs or defects.

Some of the more specific survey questions were focused on identifying beneficial ADEs, successful training tips and techniques, common uses for element level inspection data, and common obstacles during the transition to element level inspections. Since most states performing element level inspections are collecting data on ADEs, it stands to reason that these states see a benefit despite the additional effort. ADEs are defined by state agencies for a variety of reasons. The respondent from Wisconsin stated that ADEs are used to capture general maintenance needs and record the existence of bridge accessories such as signage, slope protection, and utilities. The respondent from Michigan mentioned that the Michigan Department of Transportation subdivides the “Reinforced Concrete Deck/Slab” NBE based on the type of reinforcement (epoxy coated, plain carbon, stainless, and non-metallic) so that performance

of each can be tracked separately. Finally, the respondent from Florida indicated that the Florida Department of Transportation has defined ADEs for movable bridges since the NBEs do not include elements specific to this type of bridge.

The AASHTO Manual for Bridge Element Inspection includes a list of specific defects that can be recorded during a bridge inspection. Defects are specific indications of distress on an element that may not be reflected in the condition state language. These are typically recorded so that the severity of the defect can be tracked and the distress can be included in deterioration models. Typical defects include concrete efflorescence, pack rust, settlement, and distortion. Many respondents are not currently collecting defect data, indicating that its use is not yet widespread. Most are planning to begin collection in the future. The respondents from Florida and Michigan indicated that defect data will be collected after inspectors become more familiar with the new inspection practices.

The survey included multiple questions about training techniques and frequency of training for bridge inspectors. At this time, most states are utilizing the FHWA training for element level bridge inspections and DOT instructor led trainings (Figure 1.1). One of the main challenges identified by the respondents was finding the time and resources to adequately train inspectors, especially within the timeframe allowed by MAP-21 for implementation of the new inspection protocols. This is especially difficult when inspectors are scattered throughout the state. One possible solution is web or video based training. The Ohio Department of Transportation, for example, has posted a number of videos on condition state assessments on YouTube. One such

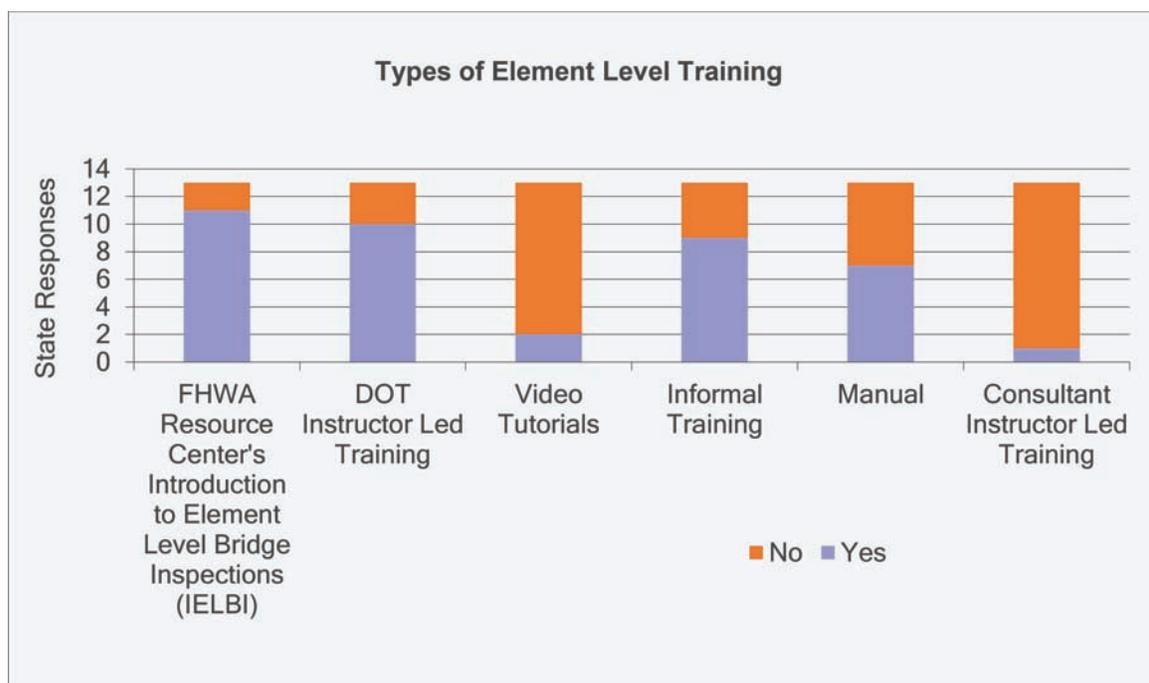


Figure 1.1 Types of element level training utilized in thirteen states.

video can be found at the following URL: <https://www.youtube.com/watch?v=4gwJfMa1rUA>.

The survey included one question requesting information on acceptable tolerance limits for quantity calculations, element identifications, and condition level assignments. Most respondents stated that their agencies did not have any guidance on this issue. Some respondents stated that the quantities were assumed to be accurate or reasonably accurate. The respondent from Iowa stated that the reported quantities need to be accurate enough that a second inspector could calculate quantities within 10% of the reported quantities on the following day. The Ohio Department of Transportation has established target accuracies for the first cycle of element level inspections. Total element quantities are expected to be within 5% of the actual value and condition state quantities are expected to be within 1% to 15% of the actual value, depending on the severity of the condition state (ODOT, n.d.). Given the difficulties in accessing and measuring members in the field, expectations for accuracy must be reasonable, but still stringent enough that the data can support the agency's bridge management practices.

Finally, the survey asked respondents to indicate how element level inspection data is or will be used for decision making (Figure 1.2) within their agency. Most respondents intend to or currently use the inspection data for project programming decisions and deterioration

modeling. In California, the element level data is used to calculate the bridge health index, which is one of the state's performance measures. Montana and Missouri indicated that the data will be reported to the FHWA, but they do not intend to use it for decision making.

#### 1.4 A Brief Look into Bridge Management Programs around the Country

Developing recommendations and compiling best practices from other states' bridge inspection programs were key efforts during Task I of SPR-3819. Most state agencies that are using element level data also appear to have robust bridge management programs. The overarching objective of any bridge management program is to determine when, where, and how to expend limited funding for maximum benefit to the overall inventory. California and Florida are leading the way in collecting element level data and utilizing computer software to analyze this data. Other states, such as Idaho, take a simpler approach that is based on the analysis and recommendations of their inspectors and bridge management engineers. Finally, a few states, like Washington, operate under completely revised portions of the AASHTO Manual for Bridge Element Inspections. Each approach offers a viable method of utilizing element level inspection data, and these perspectives will be presented in this section.

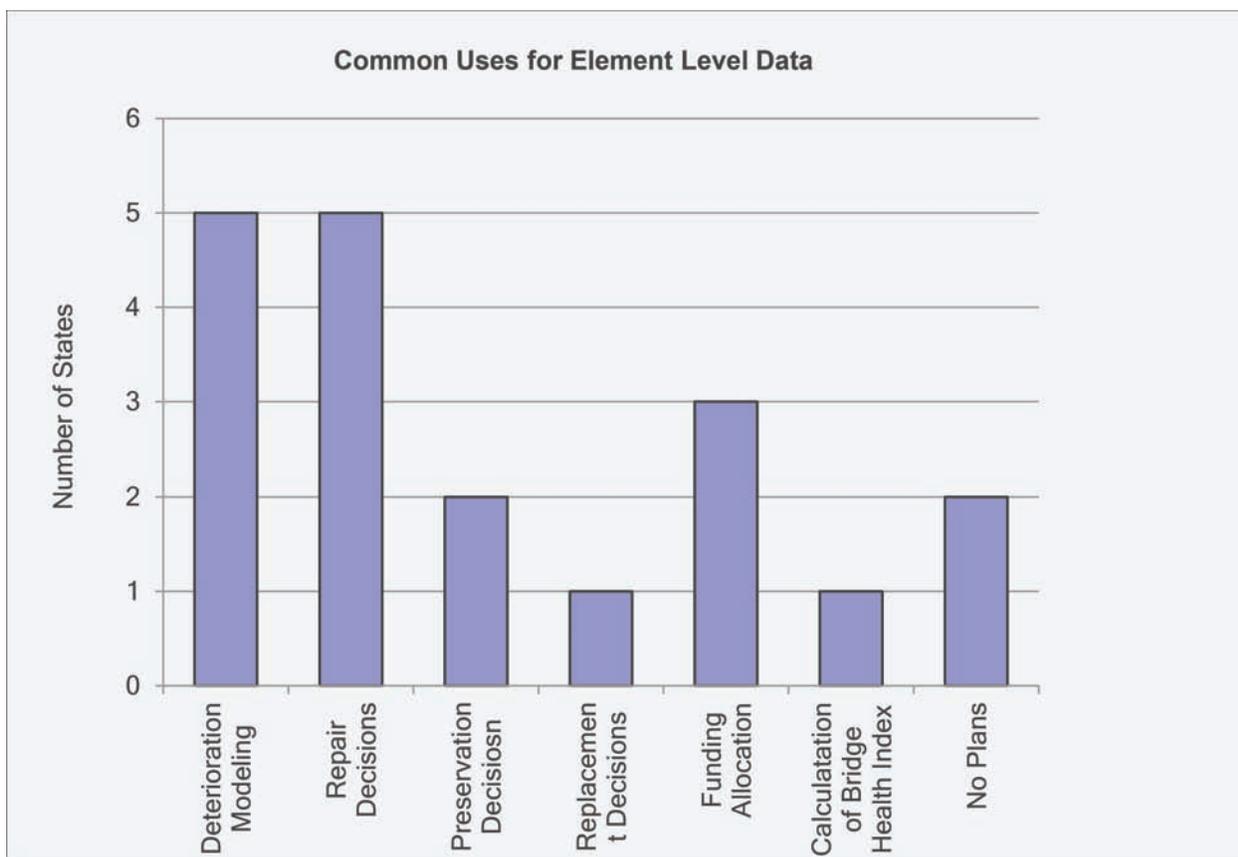


Figure 1.2 Uses for element level data in thirteen states.

#### 1.4.1 California

The California Department of Transportation (Caltrans) has shown to be consistently ahead of the curve in applying bridge management techniques and using element level inspection data. Caltrans began collecting element level data in 1992 in accordance with the AASHTO Guide for Commonly Recognized Bridge Elements (FHWA, 2005). After an inspection, an inspector's findings, including element level condition assessments, photos, commentary, and recommendations are entered into an electronic database for use throughout Caltrans. These findings populate a bridge inspection report used to convey the results of the inspection to the bridge owner, and are the basis for automatically generated priority lists for maintenance crews, bridge management engineers, project planners, and the California Transportation Commission (FHWA, 2005). Bridge management engineers review and prioritize the recommendations from each inspection and compare them with the priority lists generated by AASHTOware. Projects are selected to minimize impact to traffic and maximize improvements within the given budget. The effectiveness of this decision-making process is assessed using the "bridge health index," a performance measure focused on preservation of the state's bridge inventory (FHWA, 2005). The bridge health index is a single number from 1 to 100 that indicates the remaining value of the structure (Adams & Myungook, 2009). The determination and uses of health indices will be discussed in-depth in Section 1.5 as it seems to be one of the more prevalent and useful performance measures that is derived from element level inspection data.

#### 1.4.2 Florida

Florida relies heavily on element level inspection data in their bridge management system. The Florida Department of Transportation (FDOT) has been collecting element level data since 1998 using a modified version of the AASHTO Guide for CoRE Structural Elements (FHWA, 2005). After an inspection, the findings are forwarded to the Feasible Action Review Committee (FARC), a group of engineers tasked with recommending and prioritizing projects based on the deficiencies noted by inspectors (FHWA, 2005). This committee utilizes a project level analysis tool that was developed by FDOT to support programming decisions. This tool predicts the deterioration of an element over time and adjusts the predictions based on proposed repair or preservation actions. The project level tool interacts with AASHTOware to develop a network level assessment. This allows the FARC to consider different repair scenarios and determine the most cost effective solution for the individual bridge and the overall network. Florida uses this forecasting tool to develop a plan of action that includes routine maintenance, periodic maintenance and repair, or replacement (FHWA, 2005).

#### 1.4.3 South Dakota

The South Dakota Department of Transportation (SDDOT) collects element level inspection data on the AASHTO CoRE elements and agency developed elements (FHWA, 2005). SDDOT utilizes a FHWA-provided translator to generate NBI condition ratings from the element level assessment. SDDOT uses an electronic system to check in and check out inspection files for each bridge. This allows private consultants to submit inspections electronically through the "checked out" database, while limiting their access to specific bridges and fields. The transition from paper inspection forms to the electronic database reportedly saved over 900 man hours in the first year (FHWA, 2005). Since 2002, SDDOT efforts have also focused on the development of a bridge preservation program. Using AASHTOware, SDDOT has developed deterioration models and specific preservation policies by element. Initial deterioration models were derived from expert elicitations, but SDDOT hopes to supersede these expert opinions with historic data in the future. SDDOT first concentrated on programming the most common elements in the inventory and the most common types of preservation work. Eventually, they intend to include programming policies for all the NBI bridge elements (FHWA, 2005). Similarly, SDDOT currently relies on the AASHTOware calculated failure costs, but may eventually calculate failure costs per element based on actual experiences. The phased approach that SDDOT took outlines a good methodology for gradually incorporating element level data into decision making processes.

#### 1.4.4 Idaho

The Idaho Transportation Department (ITD) collects NBI condition ratings and element level condition reports during inspections of state owned bridges. ITD reports the performance of their bridges based on the total percentage of their bridge network deck area that is in good condition (FHWA, 2012). From 2006 to 2014, the percentage of structures in good condition (NBI condition rating greater than 5) improved from 67% to 74% (Idaho Transportation Department (ITD), 2015). In 2009, ITD conducted a study on transportation funding to compare the effects of funding bridge preservation projects versus funding bridge restoration projects. The analysis demonstrated that a mixture of project types was most effective in improving the overall network condition. ITD's current management strategy divides funding 80%/20% between preservation activities and restoration activities (FHWA, 2012). Examples of preservation activities include painting projects, crack sealing, and thin overlays. The variety in programming differs from the state's former approach of "worst first" programming. Under the "worst first" approach, bridges in the worst condition were the first to be fixed, without regard for preservation of bridges in good condition. Decisions regarding preservation

and restoration are made by the Bridge Design Unit based on inspection data, including condition ratings and element level condition reports, structure age, structure vulnerabilities, and known structural deficiencies. Previously, IDT invested in the development of deterioration and cost models, but found that the staff level decision making process was more effective (FHWA, 2012). By using this basic bridge management strategy, which partially relies on element level data, ITD systematically improved their overall bridge network condition.

#### *1.4.5 Michigan*

The Michigan Department of Transportation (MDOT) makes extensive use of deterioration models to schedule preservation and repair activities for state owned bridges and culverts (FHWA, 2012). In 1998, MDOT established a strategic plan to improve deficient bridges and preserve good bridges. This plan identified bridge condition as a performance measure and set goals based on this measure. Under this plan, MDOT transitioned from a “worst first” programming policy to a policy that balances preservation, repair, and replacement projects (FHWA, 2012). The results of this program were positive. In 1998, 76% of MDOT’s inventory was in good to fair condition (NBI condition rating greater than 4). By 2011, this percentage had increased to 92% (FHWA, 2012). MDOT uses element level data for tracking the performance of the concrete deck, and has defined ADEs aimed at tracking various features of the deck, such as concrete reinforcing materials and joint types. Although MDOT does not yet make full use of element level data, they have identified a few simple and effective uses for this information.

#### *1.4.6 Virginia*

Approximately 94% of the bridges maintained by the Virginia Department of Transportation (VDOT) are reported to be in good to fair condition (VDOT, 2015). In order to effectively manage the bridge network in Virginia, VDOT has identified program goals focused on reducing the number of structurally deficient bridges and preventing or delaying at risk bridges from becoming structurally deficient (FHWA, 2012). To evaluate their progress, VDOT tracks various performance measures including the number of structurally deficient or functionally obsolete structures, the number of structurally deficient structures removed, restored, or deteriorated each year, and bridge health index (FHWA, 2012). Virginia has been collecting element level condition data, in addition to NBI condition ratings, since 2007 and collects data on ten agency developed elements (FHWA, 2012). VDOT uses element level data to determine current and future maintenance needs and for the calculation of the bridge health index (VDOT, 2014). VDOT is an example of an agency that has successfully adopted the performance based approach to bridge management.

#### *1.4.7 Kansas*

The Kansas Department of Transportation (KDOT) is committed to a data based approach for maintaining their bridge network (Whisler, 2010). KDOT collects and uses element level data in the management of their bridge network. In addition to the AASHTO defined elements, KDOT has identified 300 additional agency items. Element level data is used to determine the bridge health index and KDOT has developed a unique method of adjusting the bridge health index using defect data, which may not be captured in the element condition rating (Whisler, 2010). KDOT calculates a separate health index for the deck, substructure, and superstructure (Adams & Myungook, 2009). This categorization allows them to apply different subsets of the health index in different decision making processes. KDOT uses the health index extensively for bridge management decisions, including setting performance goals, determining actual performance levels, and supporting budget projections (Whisler, 2010). KDOT collects a vast quantity of data in order to make the data-driven decisions their agency desires.

#### *1.4.8 Washington*

The Washington State Department of Transportation (WSDOT) has taken a different approach to the implementation of element level inspections. WSDOT chose to define their own condition states rather than following the definitions provided in the AASHTO Manual for Bridge Element Inspection. Condition State 1 represents elements that are in generally good condition, but may have some insignificant defects. Condition State 2 represents structural members that have been correctly repaired, but not completely replaced. Condition State 3 represents elements with significant defects that have not reduced the load carrying capacity of the element. Condition State 4 represents members with significant defects that have reduced the load carrying capacity of the element (WSDOT, 2014). The most significant deviation from the AASHTO definitions appears in the definition of Condition State 2. Using the WSDOT definition, Condition State 2 can be easily identified in the field and addresses the repair history of the bridge. The rest of the definitions mirror the AASHTO definitions with only minor adjustments. In order to comply with the directives from the FHWA regarding element level bridge inspections, WSDOT has developed a translator to convert their ratings to National Bridge condition ratings. WSDOT has demonstrated that an agency can deviate from the FHWA and AASHTO guidance to suit their needs, provided the approach provides a defensible assessment of the condition of the bridge and its ability to function as intended.

In order to efficiently develop element level condition ratings and NBI component condition ratings during the same inspection, WSDOT developed a relationship between the two systems for certain elements. Table 1.2

TABLE 1.2  
Concrete Deck Element Condition State to NBI Deck Condition State Conversion (WSDOT, 2014)

Percent of Concrete Deck Patches, Spalls, and Delaminations (CS2, CS3, CS4)	Percent of Concrete Deck Soffit in CS3 (CS3 only)	NBI Deck Condition Code
N/A	N/A	9
None	None	8
None	None	7
<1%	<2%	6
1% to 2%	2% to 5%	5
2% to 5%	5% to 10%	4
>5%	>10%	3

shows the conversion from the reinforced concrete deck/slab element condition state to the NBI deck component condition state (WSDOT, 2014). This method for obtaining NBI condition ratings provides an objective assessment that allows the NBI rating to be used as a reliable performance measure. Additionally, this relationship may be beneficial in helping inspectors transition from condition rating inspections to element level inspections.

### 1.5 An In-Depth Look at the Health Index

Element level inspection data is used extensively in the determination of the bridge health index. The bridge health index compares the current value of the bridge to its initial value. Caltrans developed this index because the FHWA’s sufficiency rating did not suit their needs. In contrast to the sufficiency rating, the bridge health index offers an objective measure of the condition of a bridge unbiased by its functional adequacy (Shepard & Johnson, 2001). Additionally, the bridge health index provides a direct relationship between the condition and economic value of the bridge. This makes the bridge health index especially useful in making budgetary decisions.

The bridge health index can be calculated from element level inspections or predicted by deterioration models (Shepard & Johnson, 2001). Due to the increasingly widespread use of the health index, it is important to understand how this value is calculated and utilized in programming decisions. In the most commonly used formula, developed by Caltrans, the bridge health index relies on the element condition state and the predicted failure cost of the element (Shepard & Johnson, 2001) and is expressed in Equation 1.1:

$$Health\ Index = \frac{\sum Current\ Element\ Value}{\sum Total\ Element\ Value} \times 100 \quad (1.1)$$

where

$$Total\ Element\ Value = Total\ Element\ Quantity \times Failure\ Cost$$

$$Current\ Element\ Value = \sum (Quantity\ in\ Condition\ State \times WF) \times Failure\ Cost$$

$$Weighting\ Factor\ (WF) = \left[ 1 - \frac{Condition\ State\ No. - 1}{Total\ Condition\ States - 1} \right]$$

Table 1.3 presents the calculation of the element health indices and the bridge health index for a sample bridge. The health index for a bridge network could be calculated by summing all the element quantities and condition states within the entire network.

AASHTO has embraced this performance measure and incorporated it into their AASHTOWare software, thereby making it relatively simple for state agencies to use it. There are two different approaches to determining the failure cost of an element. In both methods, failure cost is used to express the relative importance of the elements. In the first approach, the failure cost of an element reflects the total economic impact of its failure. For instance, if failure would result in bridge closure, the failure cost of that element should represent the total economic impact of closing the bridge. The second methodology uses only the replacement cost of the element as the failure cost (Adams & Myungook, 2009). Both philosophies are appropriate when developing a bridge health index. Since the second approach is simpler, it is often used by agencies when they are first calculating a health index.

In 2009, the University of Wisconsin conducted a study aimed at assessing the sensitivity of the health index to element level condition data and element failure cost. In the study, the research team independently varied the element condition states and element failure costs for bridge elements in increments up to 50% from the actual condition state or assumed failure cost. Element failure costs were developed by the FHWA and obtained through the Transportation Asset Management Today website (Adams & Myungook, 2009). There were three primary conclusions from this work. First, bridge health index is more sensitive to bridge condition rating than failure cost. Second, the bridge health index for bridges in good condition is less sensitive to failure cost than bridges in poor condition. This means that a bridge in good condition will

TABLE 1.3  
Sample Calculation of Bridge Health Index (Adapted from Shepard & Johnson, 2001)

Element Description	Unit	Total Quantity	Condition State (Condition State Weighting Factor)			
			1 (1.0)	2 (0.67)	3 (0.33)	4 (0.0)
Reinforced Concrete Deck	ft <sup>2</sup>	300		100	200	
Steel Girder	ft	105	75	25	5	
Reinforced Concrete Abutment	ft	34	34			
Reinforced Concrete Column	EA	4	4			
Joint Seal	ft	24			24	
Element Description	Unit Failure Cost	Total Economic Value	Current Economic Value	Element Health Index		
Concrete Deck	\$600.00	\$180,000.00	\$79,998.00	44		
Steel Girder	\$3,500.00	\$367,500.00	\$326,669.00	89		
Reinforced Concrete Abutment	\$7,700.00	\$261,800.00	\$261,800.00	100		
Reinforced Concrete Column	\$9,000.00	\$36,000.00	\$36,000.00	100		
Joint Seal	\$556.00	\$13,344.00	\$4,447.56	33		
<b>Total:</b>		<b>\$858,644.00</b>	<b>\$708,914.56</b>			

**Bridge Health Index: 82.6**

likely have a high bridge health index regardless of the assumed element failure or replacement costs. Third, smart flags (defects, e.g., steel fatigue, deck cracking, etc.) can considerably reduce the health index of a bridge. Since smart flags are not elements, the Caltrans formula does not automatically capture them; however, the study recommends that health index ratings be adjusted for smart flags (Adams & Myungook, 2009). KDOT has developed one commonly used method for applying smart flag data to the bridge health index. The KDOT method considers four smart flags – deck cracking, steel fatigue, section loss and pack rust – and limits the maximum health index that can be achieved if these signs of distress are noted. For instance, if a single smart flag for fatigue is recorded, the health index for the superstructure cannot exceed 95 (Adams & Myungook, 2009). Similar rules exist for the other smart flags.

In addition to the sensitivity analysis, the University of Wisconsin research team also distributed a survey to eighty-seven AASHTO Pontis users in order to understand the role of the bridge health index in bridge management programs. Out of the thirty responses, fifteen agencies stated that they use a bridge health index, or a modified bridge health index, for bridge management, while the other fifteen respondents did not calculate a bridge health index for their inventory (Adams & Myungook, 2009). For the agencies calculating a bridge health index, the respondents also explained how this health index was used (Figure 1.3). For bridge level management, the health index is most commonly used to measure maintenance needs and to predict the future condition of a bridge. For network level

management, the health index is typically used as a performance measure and to prioritize future projects.

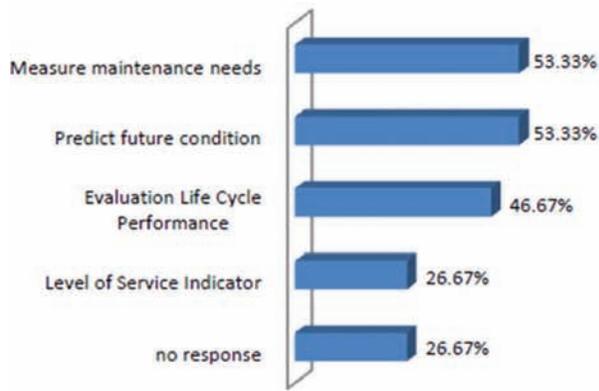
Since Caltrans developed the bridge health index, it is reasonable to closely examine how they use this value. Caltrans uses the bridge health index to allocate funds, evaluate district level performance, convey level of service expectations to the public, and predict the benefit of maintenance or rehabilitation activities (Shepard & Johnson, 2001). Caltrans has also developed a visual representation of bridge health index by equating specific ranges in bridge health index with specific condition states. For example, a bridge health index between 80 and 89 is equivalent to a condition state of 3 (Shepard & Johnson, 2001).

After taking an in-depth look at the determination and uses of the bridge health index, it is apparent that this is one of the most valuable applications of element level inspection data. In order to profit from the health index, an agency needs to do three primary things:

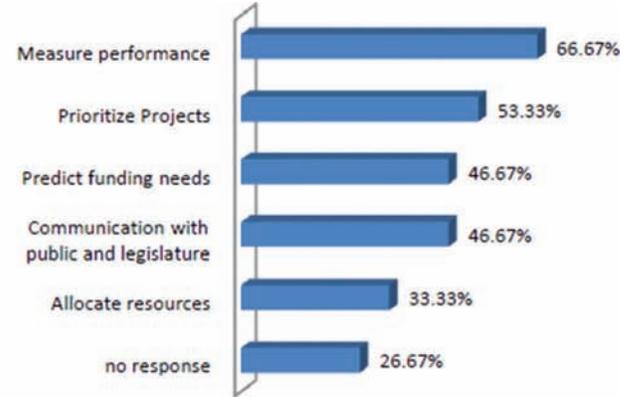
1. Compile reliable element level condition data
2. Develop accurate baseline element failure costs (possibly relying initially on the AASHTOware failure costs as SDDOT has done)
3. Identify specific guidelines for the use of the health index, including trigger values for repair activities or guidelines for allocating resources

### 1.6 Inspection Data Accuracy, Consistency and Reliability

One of the primary objectives of element level data collection is to “obtain quality data that reflects current



**Bridge Level Management**



**Network Level Management**

**Figure 1.3** Use of bridge health index for bridge management decisions (Adams & Myungook, 2009).

conditions at a more detailed or granular level” (Lwin, 2013). In order for this goal to be realized, the data collected in the field must be consistent with the definitions in the AASHTO Manual for Bridge Element Inspection.

In 2004, the ASCE Journal of Bridge Engineering published an article titled “Routine Highway Bridge Inspection Condition Documentation Accuracy and Reliability” by Phares, Washer, Rolander, Graybeal, and Moore. This publication summarized the findings of a FHWA investigation into the reliability of visual inspection data collected during routine highway inspections and element level inspections performed using the CoRE structural elements. Sixteen teams of two inspectors completed an element level inspection of the Van Buren Bridge in Northern Virginia. Results from this investigation noted inconsistencies in element identification, condition state assignments, and quantity calculations (Phares et al., 2004). While the major structural elements – deck, girders, and bearings – were correctly identified by all the inspection teams, other sub- and superstructure elements were defined inconsistently. For instance, the same bridge railing was classified as four different element types – “Bridge Railing-Metal, Coated,” “Bridge Railing, Reinforced Concrete,” “Bridge Railing-Other,” and “Bridge Railing-Metal Uncoated” (Phares et al., 2004). Since the rail was a combination of concrete and metal, it should have been classified as “Bridge Railing-Other,” in accordance with the AASHTO CoRE Structural Element Guide. Similar misapplications of the code were noted in the quantity calculations. Incorrect units were used for some quantities. The primary example of this was in the calculation of the bridge deck area. Under CoRE guidance, the bridge deck is quantified per each, not per unit area, and so the entire deck should be assigned to a single condition state. Most teams reported the deck quantity in area units and provided quantified condition ratings (Phares et al., 2004). Finally, the study revealed significant variability in the condition state assignments, as well. Since the

sample size was small, the authors did not analyze the condition state data in great detail or attempt to draw any conclusions from it. Based on the findings of this study, it seems that either the code is not detailed enough or inspector trainings are not rigorous enough to deliver consistent inspection findings. It should be noted that this study included teams of inspectors from multiple states, so some of the variability in the inspection results may be attributed to differences in state practices and policies.

The New York State Department of Transportation (NYSDOT) conducted a similar study in 2013 to assess the consistency of their inspection data. Unlike the FHWA study, the NYSDOT found the overall consistency in their inspection data to be quite high (Agrawal & Washer, 2013). During the literature review for this study, the researchers identified the following quality control procedures used throughout the country that could improve inspection quality.

- a. Calibration Meetings: Several states, including New York, hold an annual inspector meeting to address programmatic “hot topics” and changes in inspection procedures. Most states also use this meeting as a chance to deliver training aimed at ensuring consistency in condition ratings (Agrawal & Washer, 2013).
- b. Bridge Inspection Pocket Guide: The Oregon Department of Transportation distributes a bridge inspection pocket guide to all inspectors. This guide includes example photographs and element condition ratings in a format that can be easily referenced in the field (Agrawal & Washer, 2013).
- c. Inspector Rotation: Rotating inspectors among structures is a common strategy for improving the likelihood that critical issues are not repeatedly missed. Additionally, this allows inspectors to evaluate their ratings versus those of the previous team as an informal quality control check (Agrawal & Washer, 2013). The FHWA investigation into the reliability of visual inspection for bridges found that inspector rotation was the only QA/QC procedure that may have influenced condition rating assignments in the study (Moore, Phares, Graybeal, Rolander, & Washer, 2001).
- d. Inspector Performance Testing: The Oregon Department of Transportation (ODOT) requires that new inspectors

pass a proficiency exam to become a certified bridge inspector. ODOT instituted the test to ensure that all inspectors start with the same basic knowledge and understanding of the code. The exam assesses the ability of an inspector to apply the provisions of the code during an in-field inspection (Agrawal & Washer, 2013).

- e. Visual Enhancements: Since the vast majority of inspections are 100% visual, improvements in visual acuity are valuable. To improve lighting during inspections, inspectors should be encouraged to use flashlights which provide at least 100 ft-candles of illumination during inspections. Similarly, inspector eyesight should be measured and corrected to 20/20, if needed (Agrawal & Washer, 2013).
- f. Control Bridge Inspections: As part of the continuing education requirement in Oklahoma, bridge inspectors are required to inspect one of two control bridges each year (Agrawal & Washer, 2013). During the annual inspector's meeting, results from the control bridge inspections are reviewed and discussed. Although demanding, the benefits of this approach are twofold. First, inspectors are able to evaluate their findings in comparison with other inspectors and the "control" inspector to gauge their proficiency. Second, the source of inconsistencies in inspection findings can be determined and corrective action plans can be developed (Agrawal & Washer, 2013).

The practices mentioned above vary in complexity and come at variable costs, but each is believed to have attributed to quantifiable successes in states where inventory ratings have improved. Like most things, the implementation of such policies and practices has a cost-benefit relationship. Chapter 2 of this report discusses the benefits and challenges of implementation.

### 1.7 Summary of Findings for State of the Art

One of the main objectives of this research was identifying common practices among states conducting element level inspections. Specifically, the research team sought to determine how element level inspection data can be used beyond the requirements of MAP-21. Many states have long profited from the collection of element level inspection data. Most of the benefits are realized in the form of more reliable methods of setting performance goals, making decisions, and evaluating the effectiveness of those decisions in achieving the goals. Element level data also allows agencies to track the condition of elements which require regular maintenance.

A survey was distributed to twenty-five state transportation departments and the fourteen responses provided insight into collection and management practices that can be utilized by INDOT. Results indicated that most states are using bridge management systems to organize and analyze their data; most states are collecting data on agency developed elements to better predict upcoming maintenance and repair work; and element level data is being used for fund allocation, deterioration modeling, and making repair/replacement decisions.

The bridge health index is becoming an increasingly common performance measure, and this is possible only because of the rise in element level inspections. The bridge health index provides a direct link between the

condition of a bridge and its economic value, making it a valuable tool in fund allocation and the prediction of future maintenance costs.

Survey results showed that each state has a different method of incorporating element level data into their bridge management system. Specific recommendations for data collection and use will be discussed in Section 2.

## 2. RECOMMENDATION FOR DATA COLLECTION AND METHODS TO IMPROVE DATA RELIABILITY

The purpose of this section is to assess the findings discussed above, determine if the element level data required by MAP-21 is sufficient to satisfy the FHWA's objectives, and recommend methods for improving the quality, consistency, and reliability of element level inspection data.

The research team found that the data required by the FHWA is sufficient for effective element level bridge inspections at this point. The required element level data as described by the FHWA can be used to develop performance measures, evaluate performance, and allocate resources. In time, additional inspection data on agency developed elements and defects should also be collected and incorporated in INDOT's bridge management program.

This section includes preliminary recommendations for improving the quality and consistency of element level data. More detailed recommendations will be developed as part of NCHRP 12-104 "Guidelines to Improve the Quality of Element-Level Bridge Inspection Data," a project that is specifically aimed at addressing data reliability in element level inspections.

### 2.1 Uses and Recommendations for Agency Developed Elements

The AASHTO Manual for Bridge Element Inspection creates a framework for the performance of element level inspection. The manual outlines how to collect the data that is *required* by the FHWA, but it also permits the collection of agency specific data. Agency developed elements are a helpful tool in tailoring element level inspections to specific bridge management programs. At the most basic level, these elements allow an agency to track the conditions of elements that are not specified in the AASHTO Manual for Bridge Element Inspection. Additionally, ADEs may be used to simplify bridge inspections and to ensure that their condition is included in the calculation of performance measures.

The research team collected a variety of example ADEs through the survey. In some cases, these elements were found to further refine the condition state of a bridge by providing data on specific elements that were not in the AASHTO Manual, such as curbs and sidewalks. In other cases, ADEs are subdivided NBES or BMEs. For instance, "beam ends" is often used as a sub-element of the beam element. This allows the inspector to fully capture the condition of the beams

around joints and bearings, where rapid deterioration is common (AASHTO, 2013). This element would need to be combined with the beam NBE for the FHWA data submission. Similarly, footings may be subdivided into “above water footings” and “below water footings” to clarify inspection responsibilities. Some agencies use ADEs to track an element that requires regular maintenance, such as bridge drains. Other ADEs are defined to track the performance of new bridge elements that have not been used extensively in the past. An example of this is the development of the “Deck Wearing Surface – Epoxy” element. Another use of ADEs is to establish a quantity for a bridge element that is of particular interest to an agency, for instance “painted steel.” State agencies may want to know how much painted steel is in their inventory to help predict funding needed for future painting projects. Finally, agency developed elements are used to refine certain performance measures, like the bridge health index. An agency may define a new element so that its condition is captured in the performance measure. For example, an agency may believe that slope protection is an important consideration in the health of river bridges, so they can create an element for slope protection and include the condition of that element in health index calculations.

Many of the advantages of the ADEs will be illustrated in the following analysis of the “Truss” NBE. In the AASHTO Manual for Bridge Element Inspection, the quantity calculation for this element is described as “the sum of all of the lengths of each truss panel measured longitudinal to the travel way.” (AASHTO, 2013). This definition does not differentiate among truss members or even between truss lines (i.e., upstream or downstream). Without identifying the condition of each individual member, inspectors will not know where to look for defects in the future. This lack of information could create inconsistencies in data from different inspections, and it could result in an inspector missing those condition states all together. At the very least, it would require a close scrutiny of every member during subsequent inspections, costing time that could have been saved otherwise. An easy way to remedy this possible gap in data would be to divide this element into sub elements. The Ohio Department of Transportation (ODOT) has defined individual sub-elements for truss diagonals, truss lower chords, truss upper chords, truss verticals, and truss gusset plates (ODOT, 2014). The definition of the “Truss Gusset Plate” element is noteworthy because this highlights a vulnerable area of the bridge and ODOT provides specific guidelines for rating gusset plates based on distortion, section loss, connectivity and general deterioration (ODOT, 2014). Since these elements are sub-elements of a NBE element, the individual truss elements need to be rolled back into a single “truss” element for data submission. This could be done by determining the percentage of steel that the sub-element contributes to the full truss, and calculating the condition state quantities for the full truss as a weighted average based

on the condition state quantities of the sub-elements. Although additional work would be required to combine the sub-elements into a single element, the improvements in data consistency and inspection efficiency outweigh this drawback.

The ADEs selected by state agencies are likely driven by their location and the types of bridge details that are common in their network. Before defining ADEs, there must be an understanding of how these elements are going to be used. Through the survey, the respondent from Ohio recommended that not all legacy ADEs be carried forward into element level inspection procedures because this may result in the collection of data which serves no purpose. During the transition to element level inspections, INDOT should first define ADEs that will focus inspection efforts on well-known problem areas, and then consider the other purposes discussed in this section.

## 2.2 Uses and Recommendations for Defects

Based on current directives for element level bridge inspection from the FHWA, the specific defects for each element need not be submitted (FHWA, 2014). This means that an inspector will have to categorize the condition state of an element based on the defect, but the agency does not actually have to *record* the defect. For example, while inspecting a typical multi-girder steel bridge, an inspector might notice that there is surface corrosion on the bottom of a girder. The inspector would then follow up by classifying the condition state based on the severity of the corrosion defect. Finally, the inspector would measure the quantity of the surface corrosion defect and record the quantity of the element under the appropriate condition state. Even though the inspector had to categorize the condition of the element by the defect, the inspector does not actually have to write down that the defect was found. Instead of recording just the condition state quantity, it would be relatively simple to start recording the defect with the condition state quantity. Table 2.1 and Table 2.2 show the minor differences between documenting an element’s condition state without recording defects and including defects.

By saving the time not recording the defects during the inspection, the agency might actually be costing themselves more time down the road, as well as denying themselves valuable information about the bridge. The AASHTO Manual for Bridge Element Inspection includes defects such as steel cracking/fatigue, concrete efflorescence, and deck traffic impact. Individual states can define additional or different defects. From a routine inspection perspective, it would be helpful to have defect information because in each inspection it would be simple to update the quantity of a specific defect, if needed, and carry that over to the appropriate condition state. Defects should be recorded in sufficient detail such that the next inspector can identify them and does not record a new defect in the same location. With a clear record of existing defects, future bridge

TABLE 2.1  
Element Condition Assessment (without Defects)

Element Description	Units	Total Quantity	Condition State				Env.
			1	2	3	4	
Steel Girder	ft	103	75	25	3	0	2 (Low)

TABLE 2.2  
Element Condition Assessment (with Defects)

Element Description	Units	Total Quantity	Condition State				Env.
			1	2	3	4	
Steel Girder	ft	103	75	25	3	0	2 (Low)
<i>Corrosion</i>	<i>ft</i>	25	0	25	0	0	
<i>Cracking</i>	<i>ft</i>	0	0	0	0	0	
<i>Distortion</i>	<i>ft</i>	0	0	0	0	0	
<i>Impact Damage</i>	<i>ft</i>	3	0	0	3	0	

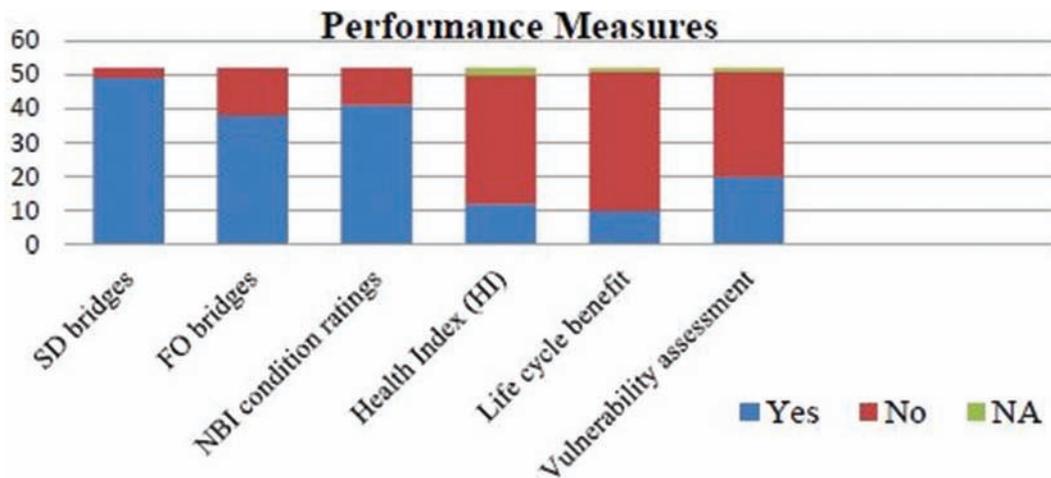
inspections should proceed more efficiently. After the preliminary step of collecting defect data, an agency may consider a flagging policy similar to NYSDOT. NYSDOT categorizes defects as “red,” “yellow” or “green” based on severity. Each category carries with it its own requirements for reporting and developing action plans to ensure that critical defects are addressed in a timely manner (Agrawal & Washer, 2013).

The next aspect of defects that should be discussed is whether to categorize them as structural defects or operational environment defects. A structural defect would be a defect that is caused by any type of loading – live load, dead load, overload, impact load, or construction load. Whereas, an operational environment defect would be a defect that is caused by any environmental factor, such as deicing salts, heavy rain, ocean water, dry weather, or high water events. Although it would be useful to identify the cause of the defect, it may be unrealistic to expect inspectors to identify this in the field. With an accurate description, sketch, and pictures, this could be done by an engineer, or other expert, after the inspection. However, the inspector should be required to assess the environmental condition of the element during the inspection. For instance, an inspector should recognize the importance of noting whether an element is beneath a deck joint, located within the splash zone, exposed to ponding water, or collecting dirt and debris, since these conditions may explain the presence of rust or severe section loss.

The AASHTO Manual for Bridge Element Inspection identifies four environmental factors (or states) because elements deteriorate differently under different circumstances. The environmental states are: 1 (Benign), 2 (Low), 3 (Moderate), and 4 (Severe). The environment ratings from AASHTO capture both operation activities, such as truck and traffic patterns, and exposure to environmental extremes, such as water, salt, and temperature. Additionally, these ratings account

for the presence or absence of a protective system (AASHTO, 2013). The Iowa Department of Transportation Element Inspection Manual identifies the possible environmental states for each element. For instance, for the “Reinforced Concrete Deck” element the environmental rating is based on ADT. A benign environment is one in which the ADT is between 0 and 200, while a severe environment corresponds with an ADT over 5,000. Conversely, for a steel girder the environmental rating is based on exposure to water; a moderate environment is one in which the girder is not under a joint, but is exposed to moisture or within the splash zone (IowaDOT, 2014). Although the FHWA does not require submission of element environment, this information is necessary for the development of deterioration models. In addition to simplifying inspections, deterioration modeling is one of the primary motivations for collecting defect data.

During the transition to element level inspections, there needs to be a significant amount of discussion as to when and how this defect data will be used. In the short term, defect data focuses inspections and allows agencies to better allocate resources. However, the greatest benefits may not be realized for decades. For most state agencies, the eventual objective is to collect enough data to reliably model deterioration of the bridge elements individually and collectively. Deterioration models can be used to predict future bridge conditions under varying funding levels and preservation, repair, and replacement policies. In an editorial titled “White Paper on Bridge Inspection and Rating” published in the ASCE Journal of Bridge Engineering, an ad-hoc committee of ASCE-SEI and AASHTO members laments the lack of a nationwide deterioration database (ASCE SEI-AASHTO, 2009). The article explains that “the effect of maintenance procedures, innovative materials, environmental parameters, loading, permit operations, and construction and fabrication



**Figure 2.1** Performance measures used by state agencies (FHWA Office of Asset Management, 2010).

procedures” are not known (ASCE SEI-AASHTO, 2009). Although, the development of a nationwide database is a significant undertaking, the same benefits could be realized at the state level with a rigorous deterioration database.

For these reasons, any agency collecting element level data should also focus on recording defects. The AASHTO Manual for Bridge Element Inspection provides no guidance on which defect should be recorded if there are two defects categorized under the same condition state. It is recommended that the inspector record ALL defects that warrant a condition rating other than 1. By recording multiple defects, it will be possible to observe how quickly certain defects deteriorate on their own, and in the vicinity of other defects. This will also provide the most accurate data for deterioration models.

### 2.3 Recommendations for Performance Measures

Developing a performance based approach to bridge management is critical for establishing accountability and improving the effectiveness of decision making processes. Performance measures should be policy-sensitive, easy to communicate, feasible to monitor and predictable (Harrison, 2005). NCHRP Report 551, “Performance Measures and Targets for Transportation Asset Management” presents a step-by-step guide for identifying performance measures and establishing target values.

In 2010, the FHWA Office of Asset Management distributed a questionnaire to gather information on bridge management systems used throughout the country. The objective of this study was to identify ways that the FHWA could assist states in improving their bridge management systems. Through the survey, the FHWA created a list of commonly used performance measures (Figure 2.1) and found that most states use the number of structurally deficient or functionally obsolete bridges in their network as a metric for assessing performance (FHWA Office of Asset Management, 2010). These

values are easily calculated and tracked, making them obvious choices for performance measures. With the increase in element level inspections and the development of more sophisticated databases to store the data, other performance measures such as bridge health index, level of service, and vulnerability assessments are becoming more common.

The bridge health index can be calculated with relative ease and smoothly integrated into the decision making process of a managing agency. The health index can be determined using element level condition data and baseline failure costs. With time, actual failure cost data can be incorporated into the equation. Since the bridge health index provides a direct relationship between the condition of a structure and its asset value, its benefit in the budgetary decisions cannot be overstated. Using Caltrans as a guide, the bridge health index can be used in a variety of ways – as a level of service indicator, to allocate funding, and to gauge the impact of proposed preservation or repair efforts. Similarly, Caltrans’ performance target – no more than 5% of the inventory with a bridge health index less than 80 – offers a reasonable starting point for any state agency looking to incorporate the bridge health index into their bridge management program (Shepard & Johnson, 2001).

### 2.4 Miscellaneous Recommendations

Below is a list of recommendations that should be considered for implementation along with element level inspections. These recommendations are based partly on findings from reviewing inspection methods of other states, and partly on a logical assessment of proposed methods for element level bridge inspections. Although the collection of additional element level data may be cumbersome, if done properly, it may actually reduce inspection time in the long run and will provide valuable information about each bridge that can be used within a bridge management program.

- a. Approach all inspections with the objective of satisfying the element level inspection requirements. Use element

level inspection data to develop NBI condition ratings for the deck, superstructure and substructure. Conducting an inspection with the focus on collecting element level data is also congruent with FHWA methodologies. The FHWA currently offers a “translator” that converts CoRE structural element condition ratings into NBI component condition ratings, and a similar tool could be developed for elements defined in the 2013 AASHTO Manual for Bridge Element Inspections.

- b. Prepopulate Inspection reports as much as practicable so that inspectors can focus more on the inspection and less on the paperwork when they are in the field. Total element quantities should be totaled by others before the inspection and provided to the inspector. Inspectors should also have a sketch, or sketches, of the bridge on hand during the inspection. These drawings and sketches could be used to note symptoms of distress and defects. These sketches could also be useful when calculating quantities.
- c. Develop a web-based forum where inspectors can submit questions regarding inspections, quantity calculations, condition state definitions, etc. An ongoing list of FAQs should be compiled and maintained online. The FHWA and Michigan DOT are two agencies which currently do this.
- d. Maintain an electronic database with all bridge records, including as-built drawings, repair drawings, previous inspection reports, and correspondence. The inspection team leader should be required to review this information prior to planning and performing an inspection.
- e. Develop a state-specific supplement to the AASHTO Guide for Bridge Element Inspection that includes more descriptions of quantity calculations, condition states, etc. This manual should include numerous photos and sketches. This manual should also define all agency developed elements and typical associated defects. The transportation departments in Iowa, Nebraska, and Ohio have developed detailed manuals that could be used as guidance.
- f. Expect longer inspection durations for the first round of element level data collection. Account for the learning curve in the schedule and the budget. During the first inspection, focus on NBEs and BMEs required by the FHWA. Incorporate ADEs as they are developed.

## 2.5 Inspection Data Quality, Consistency and Reliability

One of the main challenges facing element level inspections is data quality and consistency. Programmatic decisions regarding safety and funding are based on this data, and so its reliability is of utmost importance. In fact, ongoing NCHRP Project 12-104, “Guidelines to Improve the Quality of Element-Level Bridge Inspection Data,” is focused on developing guidelines to improve the quality of element level data. This project will provide recommendations for improving consistency in data collection and establish accuracy levels for quantities and condition states. The research for SPR-3819 developed the following recommendations based on the survey of state agencies and the literature review. However, the NCHRP report will provide a more in-depth discussion of this topic.

When considering acceptable tolerances for quantity calculations, it is critical to know how the quantity data

will be used within the bridge management system. The AASHTO Manual for Bridge Evaluation states that “measurements are to be made only with sufficient precision to serve the purpose for which they are intended. Unnecessarily precise measurements lead to a waste of time and a false sense of value from the derived results” (AASHTO, 2011). Most states do not provide guidance on acceptable tolerance limits to their inspectors. The Iowa Department of Transportation expects reported quantities to be within 10% of the actual quantities. A second inspector may recalculate the quantities on the following day to spot check accuracy. The Ohio Department of Transportation has established tolerances for the first cycle of inspections and expects that as inspectors become more familiar with the procedures, these tolerance limits will be reduced. Both approaches seem reasonable, especially during the transition to element level inspections. In all cases, expectations for accuracy should be clearly communicated to inspectors, and inspectors should be provided with the training and tools necessary to meet these expectations.

The literature review revealed that misinterpretation of the code is a common source of inconsistency in inspection results. Occurrences of this can be reduced with additional inspector training. Annual calibration meetings are a common method of distributing information to inspectors and maintaining a consistent understanding of the code. While it would be most beneficial to hold these meetings at a single site with all inspectors present, they could also be conducted remotely using a webinar format. Participants should be required to submit questions and proposed ratings in real time through online polling software.

The NYSDOT study on the consistency of inspection data identified a few tools that inspectors could use in the field to improve inspection quality and consistency. A pocket reference guide can be used in the field to address uncertainties inspectors might have when identifying elements, calculating quantities, or assigning condition states. This guide should be an abridged version of the bridge inspection manual that includes only information that inspectors may need in the field. This guide could also be available electronically, so that it could be accessed on smartphones or tablets. The pocket guide produced by the Oregon Department of Transportation could be used as a go-by. Similarly, inspectors should be given flashlights and encouraged to use these flashlights during inspections. Adequate lighting improves the likelihood of defect detection. These are both cost effective tools that may yield higher quality inspection results.

In 2013, INDOT updated its bridge inspection quality control program to require a biannual “control bridge” inspection exercise. Every twenty-four months, inspection team leaders are required to inspect a control bridge and are evaluated based on their inspection findings as compared to the findings of a panel of experts (Dittrich, 2015). In 2014, INDOT piloted this program and results were presented at the 2015 Bridge

Inspection Conference. This exercise was voluntary and provided INDOT with an opportunity to assess and refine the process. During this inspection, inspectors were required to assign NBI condition ratings to the deck, substructure, superstructure, and channel. Additionally, inspectors were requested to assess the bridge's vulnerability to scour (Hoernschemeyer, 2015). In the future, this exercise should be expanded to include an element level inspection in accordance with the AASHTO Manual for Bridge Element Inspection and should be scheduled for each inspection team as a form of training and feedback.

Finally, periodic performance testing of individual inspectors and inspection teams in a controlled environment, such as at the S-BRITE Center, should be part of a comprehensive bridge inspection training program. The potential financial and life-safety costs of poor performance among bridge inspectors could be significant. Performance testing provides a systematic and structured evaluation of inspection performance. This can be used to ensure qualified inspectors are inspecting INDOT bridges, and to uncover agency-wide inspection procedures that may need to be corrected. For example, this process would reveal equipment deficiencies, lack of use of available equipment, incorrect use of available equipment, misunderstanding of element, condition state or quantity definitions, and inadequate documentation practices. Performance testing allows an agency to evaluate the individual inspectors as well as the agency inspection program.

Improved data quality, consistency, and reliability will be a direct result of organized policy and agency expectations sufficiently communicated to well-equipped inspectors. The earlier a state DOT can establish its goals for the element level data, the better. Consistent, quality training and performance testing of inspectors who are equipped with the right tools, from manuals to flashlights, are essential aspects of collecting the reliable data that a successful bridge management program requires.

## **2.6 Summary of Data Collection and Methods to Improve Data Reliability**

After researching the bridge management and inspection practices of other states, a variety of recommendations were developed. During the initial stage of conducting element level inspections in Indiana, it is not necessary to collect more than what is required by the FHWA. Under the current FHWA requirements, the data collected is sufficient to support basic bridge management efforts including project prioritization and level of service assessments. With time, a collection of agency developed elements and defect data will become useful. This additional data can improve bridge management in Indiana, allowing for deterioration modeling and the establishment of performance measures. Since this data is used to support multi-million dollar decisions with user safety implications, its accuracy is critical. A rigorous training program and detailed quality control

procedures are necessary to ensure data consistency and reliability. The recommendations in this section provide a summary of what *can* be accomplished with element level data. However, INDOT must determine how to effectively and efficiently utilize this data to support its own bridge management goals.

## **3. RECOMMENDATIONS FOR TRAINING**

In the survey of state agencies, the respondents identified inadequate training as one of the main challenges to implementation of element level inspections. In the timeframe provided by MAP-21, state agencies struggled to establish new inspection procedures and policies, never mind train their inspectors in how to apply these new procedures. Training effective bridge inspectors is the first safeguard against unreliable or inaccurate inspection data, and so significant money and resources should be invested in training.

### **3.1 Currently Available Training**

Current opportunities for element level inspection training at the national level are limited. Following the passage of MAP-21, the FHWA and the NHI updated existing training courses, such as "Safety Inspection of In-Service Bridges" and "Bridge Inspection Refresher Training," to include information on element level bridge inspections. Additionally, the FHWA Resource Center developed one and two-day training courses titled "Introduction to Element Level Bridge Inspection." These are primarily classroom based courses, and should only be used to provide a background in element level inspection practices.

Beyond these options, several states have developed their own training courses to supplement or supplant the FHWA courses. The discussion below is not intended to be a comprehensive list of courses available, but an overview of the types of training that other states are offering.

Through the Local Technical Assistance Program, the Washington Department of Transportation offers three-day courses in inventory coding and inspection fundamentals. These courses are free to inspectors that work in Washington and the inspection fundamentals course includes a field inspection (WSDOT, 2015). The Minnesota and Ohio Departments of Transportation both offer state-specific, single-day refresher courses as an alternative to the NHI Bridge Inspection Refresher Training course. These courses allow the state departments of transportation to disseminate topical or unique information to their inspectors. Similarly, the Illinois Department of Transportation (IDOT) offers a two-day Bridge Inspection Calibration Class as an alternative to the NHI refresher course. This class focuses on consistent application of the code and makes inspectors aware of common deficiencies in data collection and recent changes in policy (IDOT, 2015). Additionally, IDOT has developed a ninety-minute webinar titled "Calculating Section Loss in Steel Members."

### 3.2 Recommended Training Topics

In order to complete a thorough and accurate inspection, a bridge inspector must understand how a bridge functions, possess a thorough knowledge of the inspection manual, and be adept at applying the requirements of the manual in the field. In order to develop these skills, a variety of training exercises are required. In addition to the training courses offered by the FHWA and the NHI, the following state-specific training courses are recommended:

- a. *Inspection Fundamentals Training Course with Mock Inspection:* Since the FHWA allows state agencies the freedom to define their own agency developed elements and defects, state-specific training is necessary to communicate these requirements to new inspectors. This information could likely be conveyed in a half-day or full-day course, conducted in person or through a webinar. One of the shortcomings of the NHI and FHWA training courses is the lack of actual field training. As an extension to these courses, new inspectors should conduct mock field inspections under the guidance of an instructor and preferably in a controlled environment. This will help ensure that inspectors understand not only how to apply the requirements of the inspection manual, but that they understand specific inspection techniques and documentation practices. This experience will also expose inspectors to common challenges in the field, such as limited access, undocumented modifications to a bridge, or what to do with a critical finding. The FHWA investigation into the reliability of visual investigation for bridges found that many inspectors were unable to identify the critical characteristics of a bridge, such as support conditions or bridge skew, that may focus or direct an inspection (Moore et al., 2001). The inspection fundamentals course should include a discussion of basic bridge engineering and review the critical features of various bridge types so that the inspectors understand where and how defects may occur.
- b. *Inspection Refresher Training Course:* A state-specific refresher course can be used to improve consistency in inspection findings. This could be held in conjunction with INDOT's Annual Bridge Inspection Conference and would allow INDOT to address noted shortcomings in inspection data and changes to inspection procedures and policies.
- c. *Focused Training Modules:* Short webinars should be developed to address persistent issues in element level inspections. These webinars can be developed gradually as areas of concern or special interest are noted. For instance, a state with a large inventory of steel truss bridges could develop a short webinar explaining how to classify and quantify the various members of the truss. Additionally, as a library of ADEs is compiled, succinct webinars could be used to introduce the ADEs to the inspectors and explain how to inspect and document findings.

### 3.3 Summary of Training Needs

The accuracy of inspection data is paramount, and accurate data can only be provided by well trained and diligent inspectors. There is no purpose in investing large amounts of money into the development of an

extensive bridge management program without first investing money in the education and training of inspectors. A combination of national and state-specific training courses should be used to ensure that inspectors are capable of producing consistent results because the condition rating of a bridge should be independent of the inspector. While the courses offered by the FHWA and the NHI provide a strong background in the fundamentals of element level inspections, supplementary training courses should be developed to address practices and policies unique to that state. Additional courses should take into consideration the education and experience of the inspection staff and long-term goals of the inspection program.

## 4. CONCLUSION

With the passage of MAP-21, Congress committed to the development of a data-driven, risk-based approach to asset management in the United States. This law required the collection and submission of element level data for all NHS bridges, in addition to the NBI condition rating data. All states were required to begin element level inspections by 1 October 2014, and submit the first round of data on 1 April 2015. The purpose of this study was to examine the current practice of INDOT peer agencies and recommend the most effective ways to collect accurate and reliable element level data and subsequently, make use of it within a bridge management program. The following summarizes the recommendations resulting from findings of this research:

- Data required by the FHWA is sufficient for effective element level bridge inspections in the short term. This inspection program should be expanded over time to make it more useful to INDOT.
- Approach each inspection from the element level inspection perspective and use that data to derive the NBI condition states. This approach may take time and training as it requires a shift in the inspector mindset.
- Agency Developed Elements (ADEs) should eventually be added to the INDOT element library. Examples such as beam ends and truss elements were discussed in the report and are strong examples of how ADEs will improve the usefulness of the element level inspection data. These elements can be phased into the inspection program through manual updates and regular training meetings.
- A number of quality control measures could be implemented by INDOT to improve data accuracy and reliability, namely: annual or semiannual calibration meetings, inspector rotation, performance testing using a controlled setting and known element conditions, and visual enhancements (e.g., standardized flashlights).
- Although not currently required by the FHWA, it is recommended that the type of defect be recorded along with the element level condition data adding an important dimension to the data and providing for future deterioration modeling capability.
- Prepopulate inspection reports as much as practicable so that inspectors can focus more on the inspection and less on the paperwork when they are in the field.

- Develop a web-based forum where inspectors can submit questions regarding inspections, quantity calculations, condition state definitions, etc.
- Develop a state-specific supplement to the AASHTO Guide for Bridge Element Inspection that includes more descriptions of quantity calculations, condition states, etc. This manual should include numerous photos and sketches.
- Expect longer inspection durations for the first round of element level data collection.
- Take advantage of the S-BRITE Center for holding periodic performance testing to evaluate individual inspectors, inspection teams, and the overall inspection program and encourage learning at all levels in a controlled environment.
- Develop additional or alternative training such as an inspection fundamentals training with instructor observed inspections, state-specific inspection refresher training, and focused, web-based training modules.

## REFERENCES

- American Association of State Highway and Transportation Officials (AASHTO). (2011). *The manual for bridge evaluation*. Washington, DC: AASHTO
- American Association of State Highway and Transportation Officials (AASHTO). (2013). *Manual for bridge element inspection*. Washington, DC: AASHTO.
- Adams, T., & Myungook, K. (2009). *Sensitivity analysis of bridge health index to element failure costs and conditions*. Madison, WI: Midwest Regional University Transportation Center. Retrieved from [http://ntl.bts.gov/lib/32000/32300/32363/08-07\\_MRUTC\\_FR.pdf](http://ntl.bts.gov/lib/32000/32300/32363/08-07_MRUTC_FR.pdf)
- Agrawal, A. K., & Glenn, A. W. (2013). *Consistency of the New York State Bridge Inspection Program*. New York, NY: New York State Department of Transportation. Retrieved from [https://www.dot.ny.gov/divisions/engineering/technical-services/trans-r-and-d-repository/C-07-17%20Final%20Report\\_9-30-13.pdf](https://www.dot.ny.gov/divisions/engineering/technical-services/trans-r-and-d-repository/C-07-17%20Final%20Report_9-30-13.pdf)
- ASCE SEI-AASHTO Ad-Hoc Group on Bridge Inspection, Rating, Rehabilitation, and Replacement. (2009). White paper on bridge inspection and rating. *ASCE Journal of Bridge Engineering*, 14(1): 1–5. Retrieved from [http://ascelibrary.org/doi/pdf/10.1061/\(ASCE\)1084-0702\(2009\)14%3A1\(1\)](http://ascelibrary.org/doi/pdf/10.1061/(ASCE)1084-0702(2009)14%3A1(1))
- Dittrich, B. (2015). *CONTROL (test) bridge: Set-up*. Presentation at the INDOT Bridge Inspection Conference, February 12, 2015, Indianapolis, IN.
- Federal Highway Administration (FHWA). (2005). *Bridge management: Experiences of California, Florida, and South Dakota*. Washington, DC: FHWA.
- Federal Highway Administration (FHWA). (2012). *Bridge management practices in Idaho, Michigan and Virginia*. Washington, DC: Federal Highway Administration. Retrieved from <https://www.fhwa.dot.gov/asset/hif12029/hif12029.pdf>
- Federal Highway Administration (FHWA). (2014). *Specification for the National Bridge Inventory*. Washington, DC: FHWA.
- Federal Highway Administration (FHWA). (2015). Planning glossary. Accessed October 30, 2015, at [http://www.fhwa.dot.gov/Planning/glossary/glossary\\_listing.cfm?TitleStart=B](http://www.fhwa.dot.gov/Planning/glossary/glossary_listing.cfm?TitleStart=B)
- Federal Highway Administration (FHWA) Office of Asset Management. (2010). *Bridge management questionnaire report*. Washington, DC: Federal Highway Administration. Retrieved from <https://www.fhwa.dot.gov/bridge/management/bms.pdf>
- Fricker, J. D., Kumares, C. S., Noureldin, M., & Strohshine, T. (2014). Employing asset management to control costs and sustain highway levels of service: Volumes I and II (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2014/02). West Lafayette, IN: Purdue University. <http://dx.doi.org/10.5703/1288284315341>
- H.R. 4348. 112<sup>th</sup> Cong. (2012.) *Moving ahead for progress in the 21st century act (Map-21)*.
- Harrison, F. D. (2005). *Performance measures and targets for transportation asset management* (NCHRP Project 20-60). Washington, DC: Transportation Research Board.
- Hoernschemeyer, K. (2015). *INDOT/FHWA control bridge: Results*. Presentation at the INDOT Bridge Inspection Conference, February 12, 2015, Indianapolis, IN.
- Idaho Transportation Department (ITD). (2015). Dashboard: Performance measures. Accessed October 30, 2015, at <http://itd.idaho.gov/dashboard/>
- Illinois Department of Transportation (IDOT). (2015). National bridge inspection standards training. Accessed October 30, 2015, at <http://www.idot.illinois.gov/doing-business/procurements/engineering-architectural-professional-services/consultants-resources/national-bridge-inspection-standards-training>
- Iowa Department of Transportation (IowaDOT). (2014). *Bridge element inspection guide* (Rev. 4). Des Moines, IA: IowaDOT. Retrieved from [https://siims.iowadot.gov/MM149\\_Element%20Inspection%20Manual\\_2014.pdf](https://siims.iowadot.gov/MM149_Element%20Inspection%20Manual_2014.pdf)
- Lwin, M. M. (2013, March, 12). *Collection of element level data for National Highway System bridges* [Memorandum]. Accessed at <https://www.fhwa.dot.gov/map21/guidance/guideeldnhsb.cfm>
- Moore, M., Phares, B., Graybeal, B., Rolander, D., & Washer, G. (2001). *Reliability of visual inspection for highway bridges: Volume I—Final report* (FHWA-RD-01-020). Retrieved from <https://www.fhwa.dot.gov/publications/research/ndepdfs/01020a.pdf>
- Ohio Department of Transportation (ODOT). (n.d.) SMS transition estimates. Accessed at <http://www.dot.state.oh.us/Divisions/Engineering/Structures/bridge%20operations%20and%20maintenance/Bridge%20Inspection%20Field%20Report/Forms/DispForm.aspx?ID=9>
- Ohio Department of Transportation (ODOT). (2014). *Manual of bridge inspection* (Revised 2014, v. 8). Retrieved from <https://www.dot.state.oh.us/Divisions/Engineering/Structures/bridge%20operations%20and%20maintenance/Manual%20of%20Bridge%20Inspection%202014%20v8/Manual%20of%20Bridge%20Inspection%202014%20v8%20without%20Appendix.pdf>
- Phares, B. M., Washer, G. A., Rolander, D. D., Graybeal, B. A., & Moore, M. (2004). Routine highway bridge inspection condition documentation accuracy and reliability. *Journal of Bridge Engineering*, 9(4), 403–413.
- Shepard, R. W., & Johnson, M. B. (2001). California bridge health index: A diagnostic tool to maximize bridge longevity, investment. *TR News*, 215, 6–11.
- Virginia Department of Transportation (VDOT). (2014). *State of the structures and bridges report*. Retrieved from [http://www.virginiadot.org/info/resources/bridgeReports/2015-07-FY2015-State\\_of\\_the\\_Structures\\_and\\_Bridge\\_Report-Generated\\_2015-10-09.pdf](http://www.virginiadot.org/info/resources/bridgeReports/2015-07-FY2015-State_of_the_Structures_and_Bridge_Report-Generated_2015-10-09.pdf)
- Virginia Department of Transportation (VDOT). (2015). VDOT Dashboard v3.0. Accessed October 30, 2015, at <http://dashboard.virginiadot.org/>

Washington State Department of Transportation (WSDOT). (2014). *Washington State bridge inspection manual*. Olympia, WA: WSDOT.

Washington State Department of Transportation (WSDOT). (2015). LTAP sponsored classes for local agencies. Accessed

October 30, 2015, at <http://www.wsdot.wa.gov/LocalPrograms/Training/LTAP.htm>

Whisler, D. E. (2010). *Kansas's use of pontis to set bridge priorities*. Presentation at the 2010 MWBPP Annual Meeting, October, 12, 2010, Detroit, MI.

## About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: <http://docs.lib.purdue.edu/jtrp>

Further information about JTRP and its current research program is available at: <http://www.purdue.edu/jtrp>

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