MPC-504
January 21, 2016

Project Title:
Improved Element-Level Bridge Inspection Criteria for Better Bridge Management and Preservation

University:
North Dakota State University

Principal Investigators:
Zhibin Lin, Assistant Professor, zhibin.lin@ndsu.edu
Department of Civil and Environmental Engineering
North Dakota State University
Dept. # 2470, PO Box 6050
Fargo, ND 58108-6050
Phone: 701-231-7204
Fax: 701-231-6185

Research Needs:

Over 600,000 bridges in the United States are a critical component in the transportation network for economy and society need. Assessing bridge conditions and timely maintenance are critical to ensure bridge health and cost-effective decision making in preservation activities. Successful bridge-inspection programs nationwide is an important element of assessing bridge conditions, and ultimately extending service life of bridges.

Bridge owners nationwide have recognized the benefits of detailed condition assessments through the use of the raw inspection information, expanded performance measures, and bridge management system deterioration forecasting and evaluation, which are covered in the 2013 new AASHTO Manual for Bridge Element Inspection.

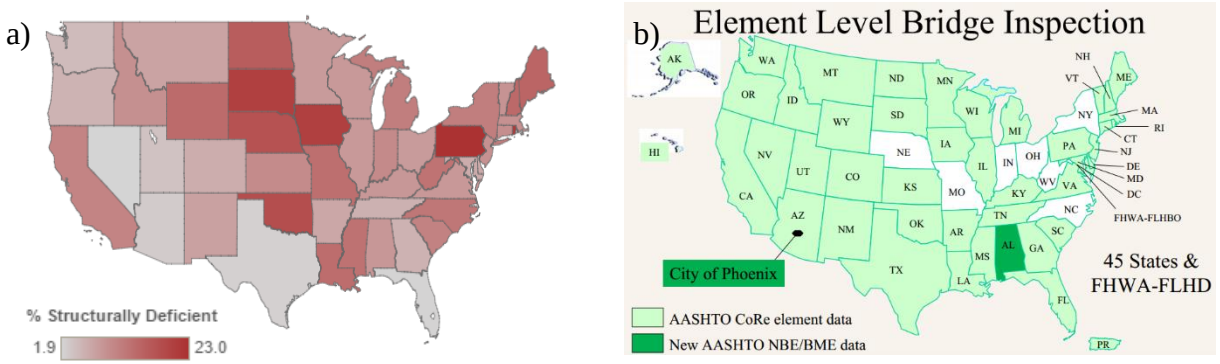

Fig. 1 Maps of a) bridge condition ratings (after 2013 U.S. FHWA, National Bridge Inventory) and b) implementation of element-level bridge inspection in the United States (after O'Donnell, 2013)

The bridge condition rating of the United States, illustrated in Fig. 1a, is based on the NBI data of national highway bridges (2013). Bridge owners and stakeholders used to assess the bridge conditions and make decision based upon these NBI data. As clearly illustrated in Fig. 1b, the vast majority of the states have already employed element-level inspection for more than a decade

based on the CoRe guide. The 2013 new AASHTO Manual, however, is significantly different from the former CoRe guide. As a result, the difference in frequency of inspections, element definition, qualifications of inspection personnel, defeat description and inspection reporting from state to state may cause inconsistency of data collection and ultimately affect the quality of element-level data collected under different states to be reported to the National Bridge Inventory (NBI). As newer bridge types become more common, demand of new guidelines for inspection ratings is needed to increase uniformity and consistency of inspections.

To improve consistency in assessment of bridge element conditions and establish accuracy levels for supporting bridge management system deterioration forecasting and evaluation, the following challenges must be addressed scientifically and systematically: a) there is a practical need for nationwide applications of high quality element-level bridge inspection. A more comprehensive, reliable and accurate levels for element conditions and defect types to accomodate this need is urgent; b) AASHTO 2013 Manual for data collection provides criteria for element condition rating and defects description, but without reliability-based calibration. The factors that affects the quality and consistence of data collection can cause high variability. Thus, reliability based indices to account for correlation between levels of element conditions and critical factors (including inspector qualification factor, structural importance factor, material vulnerability factor, defect type/location factor, age factor, and environmental factor) are necessary; and c) Existing Manuls introduce material distress for condition rating while overlook the assessment of bridge element conditions that account for performance, probability of failure and risk of failure, and thus cannot guarantee the desirable performance. New guidelines should address these concerns.

Thus, to meet the requirements in the "Moving Ahead for Progress in the 21st Century Act (MAP-21)" legislation and to ensure the safety of the motoring public, a methodology for assisting bridge inspectors and bridge owners to improve the quality of element-level bridge inspection data and enhanced bridge management is needed. Significant effort is required to develop the guidelines for practicing engineers, from bridge inspectors, and inspection trainers, to local and state DOT bridge owners, to promote consistency in the collection of reliable data that support bridge asset management practices. The proposed research will address this important technical need by characterizing quality of element-level data, generating a reliability-based correlation between levels of element conditions and critical factors, and developing new data-driven based guidelines.

Research Objectives:

The main objective of the research is to develop guidelines to improve the quality of element-level data collection for better bridge management and bridge preservation. The specific research goals of the project are:

- To identify the key factors that affect the quality and consistency of bridge element inspection and the corresponding bridge asset management;
- To develop a reliability based methodology to define the data collection criteria, and
- To establish accuracy levels for element conditions and applicable defect quantities through a reliability based correlation between levels of element conditions and critical factors (including structural importance factor, defect location factor, material vulnerability factor, and environmental factor) for supporting bridge asset management.

Research Methods:

To address the technical challenges in the research need, the research plan is to conduct a comprehensive study from critical literature review and survey, to analytical plan and its applications to the collected field data for calibration.

Critical literature review is to collect and critically understand the state-of-the-art of nationwide and worldwide specifications and guidelines in element-level bridge inspection, and the corresponding bridge asset management and preservation. The detailed information will include existing element-level bridge inspection manuals nationwide and worldwide, covering from frequency of inspection, element type, inspection protocols, to bridge inspection quality control (QC) and quality assurance (QA) for determining the current state of knowledge and how the bridge element inspection data are used in bridge asset management.

To further quantify the current state of research and practice in the bridge element inspection practices, as a part of an extensive literature review, a survey of bridge owners and other stakeholders to collect data will be conducted. Critical information will be expected for understanding potential factors that may affect the quality and consistency of data collection, such as element types, frequency of inspection, inspection methods, qualification of inspectors and inspector training, and methods used for bridge asset management. Based on characteristics of bridge inspection data obtained in critical literature review and extensive survey, the critical factors that affect the quality of bridge element inspection and the corresponding bridge asset management and preservation practices will be identified as the basis of the analytical plan in the second stage.

Analytical plan includes two stages: the first stage is I) Consistency study of manuals to place data-driven quantitative description in manual language, including element description, defect description, element condition rating, inspector qualification and quality check of data reporting. The second stage of the analytical plan consists of: II) Reliability-based indices for identified critical factors; and III) Development of a unified element condition rating and the corresponding bridge management system. This stage is to quantify the reliability indices for identified critical factors, and develop a unified element condition rating using a frame of reliability to offer more accurate level of element conditions and the bridge management system.

Bridge asset management system is to develop an understanding of what set of performance measures that can serve good asset management and, in particular, establish a format for clear communication of bridge performance information to management. The preliminary review reveals that a variety of factors may affect bridge performance and thus the quality of bridge inspection. For example, early studies by Atkins (2009) shows that inspectors could have different experience (Fig. 2a), and training duration (Fig. 2b), while inspection activities could involve different number of inspectors (Fig. 2c) and these inspectors may have no reassessment after trainning (Fig. 2d). These high variations of inspector qualification can highly impact the quality of bridge inspection data and the corresponding bridge management decision making.

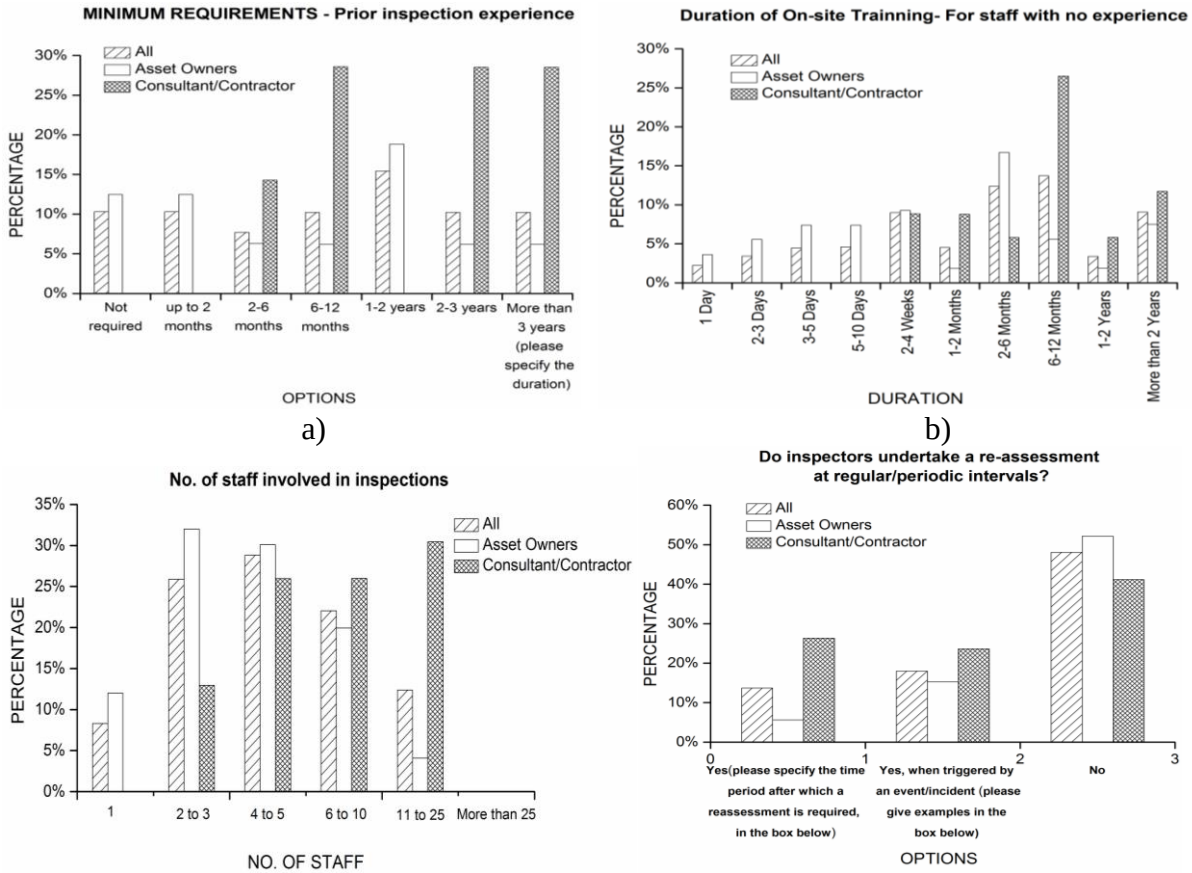

Fig. 2 Variation of inspector qualification (Re-plot after Atkins, 2009)

Moreover, several studies in the literature (Tee et al., 1988; Melhem and Aturaliya, 1996; Abu Dabous and Alkass, 2010; Rashidi and Gibson, 2012) have been conducted to assess the importance of bridge elements. Tee et al. (1988) reported their findings based on a survey study of 46 bridge inspectors and bridge experts to quantify the structural importance factor through a comparison of elements at different condition rating. Abu Dabous and Alkass (2010) generated the structural importance factor through the level of element against the overall structural safety using Analytical Hierarchy Process (AHP) to estimate the value of that parameter. These studies highlight the impact of the structural importance on the bridge assessment, while their performance measurement will be determined based on a frame of reliability analysis. Accordingly, the difference of element description, defect description, requirements of inspector qualification, inspection methods and technologies, documentation and reporting or the combined multiple effects will affect the quality of bridge inspection and their assessment. Thus, the consistency study will be conducted through performing a comprehensive set of sensitivity analysis based on current manuals, and state-collected bridge element inspection data in the literature review.

With the identified critical factors, including structural importance, defect location, material vulnerability, and environments, reliability based correlations between levels of element conditions and critical factors are categorized and quantified in terms of condition rating with the corresponding performance measures as commentary. Without factors considered, the element condition rating is defined by (Rashidi and Gibson, 2012)

$$\text{ECR} = \sum_{j=1}^{4}(q_j \times CS_j) / \sum_{j=1}^{4}(q_j), \quad (1)$$

where, CS_j = the condition state *j*, CS_1=1, CS_2=0.75, CS_3=0.5 and CS_4=0. To develop the unified condition rating within a frame of reliability analysis of various uncertainty, with reliability indices for critical factors in place, the unified element condition rating will be derived in terms of reliability indices of the critical factors.

Toward the end, to effectively implement/calibrate the proposed concept in the field, the collected field inspection data from state DOTs and local industry consulting companies will be used. In addition, PI will plan to coordinate with North Dakota DOT, including Kevin Gorder, bridge engineer at Fargo district Department of Transportation (DOT) to use one or two bridge existing inspection data to demonstrate the effectiveness of the proposed concept.

Expected Outcomes:

The project, if accomplished, will have great impact and significance on quality of element-level bridge inspection data, and the corresponding bridge management system. The proposed concept is expected to develop reliability based bridge inspection criteria for assisting bridge inspectors and bridge owners to improve the effectiveness of element-level bridge inspection data and the bridge management practices. Toward the end, the guidelines will be developed to help practicing engineers, from bridge inspectors, and inspection trainers, to local and state DOT bridge owners, to promote collection of reliable data that support asset management practices and other decision makers determine when and where to spend bridge funds.

Relevance to Strategic Goals:

Timely bridge inspection and evaluation have a significant impact on freight transportation and public safety. This present proposal is well within the current Transportation Strategic Goal of "State of Good Repair, Safety, and Economic Competiveness" and to ensure the safety of the motoring public. A thorough understanding of parameters and sound engineering as proposed in this research would lead to better bridge management and preservation.

Educational Benefits:

Two graduate students are expected to help the PI on the conduct of this research. They will be trained to design, control, and perform experimental investigations, and to help write technical articles on research findings. Research findings will also be presented in weekly Civil Engineering seminars as well as presentation by the PI in core courses (1: Bridge Evaluations and Rehabilitations; 2: Reinforced Concrete Structure Design).

Work Plan:

The project is subdivided into the following six tasks:

Task 1: Conduct a critical literature review and extensive survey for understanding the current state of knowledge, what the characteristics of quality bridge element inspection data is and how various factors affect the quality and consistency of bridge element inspection (Months 1-4).

Task 2: Identify factors that affect the quality and consistency of bridge element inspection, which affects the bridge management and preservation. This task is expected to be completed within 3 months (Months 1-7).

Task 3: Conduct a thorough parametric study and develop reliably-based methodology to derive reliability indices with a frame of reliability analysis for critical factors (Months 8-12).

Task 4: Development of Guidelines in accordance with reliability indices with a frame of reliability analysis for critical factors, and unified element condition rating and the corresponding bridge management system. (Months 10-18).
Task 5: Validation of proposed guidelines using the collected field data. (Months 19-22).
Task 6: Prepare and finalize the report for submission and publication. (Months 23-24)

Project Cost:
Total Project Costs: $127,786
MPC Funds Requested: $63,893
Matching Funds: $63,893 Source of Matching Funds: two student tuition support ($63,893)

TRB Keywords:
Reliability analysis; element-level bridge inspection, bridge management and preservation.

References:

AASHTO Manual for Bridge Element Inspection, 1st edition, 2013.
AASHTO. Guide for Commonly Recognized (CoRe) Structural Elements, 2002
Abu Dabous S and Alkass S "A Stochastic Method for Condition Rating of Concrete Bridges". ASCE Conf. Proc, 2010.
Abu Dabous S and Alkass S "A multi-attribute ranking method for bridge management", *Journal of Engineering, Construction and Architectural Management* Volume 17(3), pp 282-291, 2010.
ATKINS, Review of Bridge Inspection Competence and Training, Report, No. PPRO 04/045/004, 2009
Melhem H. G and Aturaliya S. "Bridge Condition Rating Using an Eigenvector of Priority Settings." *Computer-Aided Civil and Infrastructure Engineering* 11(6): 421-432, 1996.
Rashidi, M. & Gibson, P. A methodology for bridge condition evaluation. Journal of Civil Engineering and Architecture, 6 (9), 1149-1157, 2012.
Tee. A.B , Browman M. D. and Sinha K.C "A fuzzy mathematical approach for bridge condition evaluation" *Journal: Civil engineering systems*, Vol.2, 1988.