Assessing National Bridge Inspection Standards (NBIS) Metrics Using Data Extracted from National Bridge Inventory Source Files

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ABSTRACT
Transportation agencies face significant challenges in the maintenance, repair and operation of the nation's bridge infrastructure as these structures continue to age and deteriorate. Compounding the issue is a chronic lack of adequate funding to perform recommended improvements, an increase in the frequency and magnitude of oversized commercial vehicles, and a reduction in the number of bridges built or reconstructed over in recent years. In response to a USDOT audit recommending the Federal Highway Administration (FHWA) to develop and implement minimum requirements for data-driven, risk-based bridge oversight during FHWA annual National Bridge Inspection Standards (NBIS) compliance reviews improve, and to develop a comprehensive plan to routinely conduct systematic, data-driven analysis to identify nationwide bridge safety risks for remediation in coordination with the States, FHWA identified twenty three (23) specific metrics to assess states’ compliance with NBIS requirements and to identify potentially at-risk structures using a data driven approach. These metrics were implemented in 2011 and revised in 2012. This paper presents the results of a collaborative effort between the New Mexico Department of Transportation and the New Mexico Division of the Federal Highway Administration to refine a prototype bridge information system developed in 2010 to include a simplified means to query data contained in the National Bridge Inventory database and to provide the means to prepare reports and randomized lists of bridges in categories related to these metrics to assist federal oversight personnel in assessing states’ compliance levels and recommending follow-up actions.
OVERVIEW
The National Bridge Inventory (NBI) database is comprised of state-specific data files compiled and maintained by the Federal Highway Administration. These files conform to data formatting conventions as documented in Federal Report No. FHWA-PD-96-001, “Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation’s Bridges” (Coding Guide) [1]. These encoded alpha-numeric text files are available for program years beginning in 1992, and in their totality constitute the most comprehensive historical source of publicly available information on the nation’s bridge inventory. As part of the national bridge inspection program administered by the Federal Highway Administration (FHWA), state DOTs are required to inspect bridges under their jurisdictions at regular intervals and to submit NBI data files with updated information to FHWA in April of each year. FHWA conducts annual reviews of state bridge inspection programs to ensure compliance with federal regulations.

In 2008 an audit of FHWA’s oversight of the national bridge inspection program conducted by the Office of Inspector General resulted in several recommendations. These included recommendations to develop and implement minimum requirements for data-driven, risk-based bridge oversight during FHWA annual National Bridge Inspection Standards (NBIS) compliance reviews, and to develop a comprehensive plan to routinely conduct systematic analysis to identify nationwide bridge safety risks for remediation in coordination with the States. In response to these recommendations, FHWA developed twenty three (23) metrics, each related to the requirements of 23 CFR 650, “National Bridge Inspection Standards” (NBIS) [2]. Along with these specific metrics, which are broadly categorized into areas of organization, qualification of personnel, and the frequency and procedures used in bridge inspections, FHWA proposed specific levels of compliance ratings, NBIS items to be evaluated, determination of how measurements would affect compliance ratings, and required actions to be taken based on compliance ratings. These 23 metrics are documented in the second chapter of FHWA’s publication “National Bridge Inspection Program (NBIP)” [3], which includes detailed guidance to federal oversight personnel on methods for analyzing data and evaluating compliance.

BACKGROUND
In 2010 the Research Bureau of the New Mexico Department of Transportation produced the SABIS Bridge Information System (SABIS), a prototype computer software application that processes NBI text files and presents the information through a simplified, user-friendly interface. SABIS, an acronym for Special Application Bridge Information System, provides both technical and non-technical users access to detailed information on virtually all of the approximately 600,000 public bridges currently in service throughout the United States for the twenty year period of available data. This effort was the subject of a technical paper published in the Transportation Research Record in 2010, “Development of a User Friendly Software Application for Extracting Information from National Bridge Inventory Source Files” [4]. On review of metric descriptions proposed by FHWA, it became apparent that the evaluation of many of these use information available in the NBI Database, and the authors began the process of creating subroutines in the SABIS system to incorporate the means to process NBI data and to produce customized maps and reports that document this information. In 2012, these metrics and the guidance for evaluating compliance with governing regulations were refined by FHWA. At that time the authors decided to completely re-design and re-code the SABIS system with the most recently available software development tools, and to incorporate the newly refined NBIS metrics into the program. The application is optimized for use on ultraportable notebook computers using the Windows 7 operating system. Figure 1 presents a screenshot of the main page of the application.

Unlike the Pontis bridge management system, an AASHTOWare Bridge product that serves the inventory, planning and maintenance information needs of owner agencies, SABIS is a more modest application that provides simplified access to publicly available information and includes the means to generate maps and reports of commonly requested information and to manage multimedia data.
resources and web content. A full description of program operation is beyond the scope of this report, but Figure 2 presents an example of a representative standard report generated by the system.

NATIONAL BRIDGE INSPECTION STANDARDS (NBIS) METRICS

The National Bridge Inspection Standards (NBIS) sets forth the conditions for compliance with requirements related to the inspection and management of the nation’s bridges. The NBIS addresses requirements related to the organization of each state Department of Transportation, the qualification requirements of personnel involved in bridge management and inspection, and requirements related to the documentation of inspection and management of bridges subject to the NBIS. Following a number of high profile bridge collapse events, notably the collapse of the I-35W Missouri River bridge in Minnesota in August 2007, the federal government initiated efforts to improve the information management of the nation’s bridge inventory based on data-driven risk assessment. Among these efforts was the establishment by the Federal Highway Administration of twenty three (23) metrics by which to assess the condition of the nation’s bridges, to measure compliance with NBIS requirements and to promote consistency among the states in measurement and reporting. Following is a list of these metrics, annotated for the corresponding regulatory requirement.

Metric # 01: 23 CFR 650.307  Bridge Inspection Organization
Metric # 02: 23 CFR 650.309  Qualifications of Personnel – Program Manager
Metric # 03: 23 CFR 650.309  Qualifications of Personnel – Team Leader(s)
Metric # 04: 23 CFR 650.309  Qualifications of Personnel – Load Rating Engineer
Metric # 05: 23 CFR 650.309  Qualifications of Personnel – UW Bridge Inspection Diver
Metric # 06: 23 CFR 650.311  Routine Inspection Frequency – Lower risk bridges
Metric # 07: 23 CFR 650.311  Routine Inspection Frequency – Higher risk bridges
Metric # 08: 23 CFR 650.311  Underwater Inspection Frequency – Lower risk bridges
Metric # 09: 23 CFR 650.311  Underwater Inspection Frequency – Higher risk bridges
Metric # 10: 23 CFR 650.311  Inspection Frequency – Fracture Critical Member
Metric # 11: 23 CFR 650.311  Inspection Frequency – Frequency Criteria
Metric # 12: 23 CFR 650.313  Inspection Procedures – Quality Inspections
Metric # 13: 23 CFR 650.313  Inspection Procedures – Load Rating
Metric # 14: 23 CFR 650.313  Inspection Procedures – Post or Restrict
Metric # 15: 23 CFR 650.313  Inspection Procedures – Bridge Files
Metric # 16: 23 CFR 650.313  Inspection Procedures – Fracture Critical Members
Metric # 17: 23 CFR 650.313  Inspection Procedures – Underwater
Metric # 18: 23 CFR 650.313  Inspection Procedures – Scour Critical Bridges
Metric # 19: 23 CFR 650.313  Inspection Procedures – Complex Bridges
Metric # 20: 23 CFR 650.313  Inspection Procedures – QC/QA
Metric # 21: 23 CFR 650.313  Inspection Procedures – Critical Findings
Metric # 22: 23 CFR 650.315  Inventory – Prepare and Maintain
Metric # 23: 23 CFR 650.315  Inventory – Update Data

Metrics 01 through 05 pertain to bridge organization and inspection personnel qualification requirements, and metrics 12 through 23 pertain to management practices. Metrics 06 through 11 require an evaluation of data available through the states’ NBI database. In recognition of the magnitude of effort required in evaluating this large volume of data and to assist federal oversight personnel in ensuring consistency and optimal use of the information, the Federal Highway Administration prepared a document that sets forth the requirements for compiling, analyzing and reporting this information and for evaluating states’ compliance with governing regulations. This guidance is provided in the second chapter of a document referenced by FHWA as the “National Bridge Inspection Program (NBIP)” [4]. This publication sets forth procedures for preparing lists of bridges relevant to the corresponding metric, for developing abbreviated lists of bridges randomly
selected for detailed review, for establishing criteria for evaluation of compliance with the governing metric, and for reporting results and recommended actions.

The National Bridge Inspection Program (NBIP) establishes four levels of compliance to be evaluated by oversight personnel: 1) Compliance; 2) Substantial Compliance; 3) Non-Compliance; and 4) Conditional Compliance. The NBIP provides specific guidance for criteria to be used in evaluating compliance for each metric. The NBIP further establishes specific methods for selecting bridges to be evaluated during annual reviews, the process to be followed in planning and scoping annual reviews, criteria for selecting bridges subject to a specific metric, guidance in follow-up activities, and other activities. A full review of the NBIP is beyond the scope of this report, which is limited to a discussion of the potential for using an application like SABIS as a means to streamline and simplify some of the data intensive activities documented in the NBIP, specifically those that relate to extracting and reporting information available through the NBI Database.

THE SABIS BRIDGE INFORMATION SYSTEM

While the SABIS Bridge Information System was originally conceived as a means to provide simplified access to detailed bridge information to a broad spectrum of end users, in consultation with the New Mexico Division of the Federal Highway Administration and on review of the National Bridge Inspection Program, the authors believed that it might be feasible to modify the system to provide a simplified process for identifying and reporting information on bridges related to particular NBIS metrics. The authors developed a series of subroutines that filter the database for bridges that meet the established criteria for a specific metric, prepare abbreviated lists of randomly selected bridges that meet these criteria according to statistical methods set forth in the NBIP, and produce reports and maps that present this information in a visual and interactive format. For example, Metric No. 10 relates to the inspection frequency of bridges with fracture critical members (FCMs). In evaluation of compliance with the corresponding regulation (23 CFR 650.311 Inspection Frequency – Fracture Critical Member), the NBIP directs that bridges in the established population be reviewed to ensure that they have been inspected at regular intervals not to exceed 24 months. The NBI Database codes FCM status in Item No. 92A, with a value of “Y” identifying the bridge as fracture critical, along with a two digit numeral representing the required inspection frequency in months.

Figure 3 presents a screenshot of bridges in Missouri identified as having fracture critical members. If the user clicks a bridge number on the report, the program will plot the location on a map and jump to a detailed NBI item report for that bridge. The user may then review detailed bridge information, print the report to the system printer, or visit the location on Google Maps using the command button in the Details pane. Figure 4 presents a screenshot of the detailed bridge report on the main page.

Figure 3 identifies the selection criteria and the metrics to which the report applies (Metric 10 – Inspection Frequency, and Metric 16 – Inspection Procedures). Note the relatively high number (1,033) of bridges that meet the selection criteria. Many of the 23 metrics use the same population of bridges, which reduces the total number of reports that must be produced. In this example the same population of bridges applies to both Metric No. 10 and Metric No. 16.

Selection of Bridges and Assessment Levels

In recognition of the fact that an individual detailed review of records for each bridge in a given metric category is impractical, the NBIP provides direction on using statistical methods for the random selection of a manageable number of bridge records. The NBIP specifies three distinct levels of assessment for NBIS metrics: 1) Minimum Assessment – a review based primarily on general knowledge of the metric and awareness of the state’s program as it applies to the metric; 2) Intermediate Assessment – verifying the minimum level assessment through random sampling of inspection records, analysis of bridge inventories, site visits, interviews and documentation; 3) In-Depth Assessment – supplementing the intermediate assessment with larger sample sizes, more interviews, and research of records and other documentation.
The Intermediate and In-Depth assessments require that the bridge inventory be sampled for random records using statistical methods. For intermediate assessments, the NBIP specifies random sampling of the population of bridges meeting the selection criteria using a margin of error (MOE) of 15% and a level of confidence (LOC) of 80%, or an MOE of 10% and an LOC of 80% where improved certainty in assessment of the metric is desired. The NBIP refers to the subset of bridges selected using these differing statistical parameters as “Tier 1” and “Tier 2” respectively. For in-depth assessments, the NBIP specifies Tier 1 parameters of MOE=15% and LOC=90%, and Tier 2 parameters of MOE=10% and LOC=90%.

Using these statistical methods to develop two “tiers” of randomly selected records for each of two assessment levels for NBIS metrics that may share common populations of bridges has the potential to cause confusion among practitioners, and the authors therefore sought to automate this process through SABIS. Following the creation of a report in SABIS of a list of candidate bridges meeting the selection criteria for a given metric, the user has the option to prepare an abbreviated list of bridges for Tiers 1 and 2 using either the intermediate or in-depth assessment level. Given statistical parameters of MOE, LOC and population size, SABIS calculates the sample sizes for Tiers 1 and 2, and prepares a list of randomly selected bridges. Figure 5 presents a screenshot of the user interface in SABIS that provides these options.

Figure 5 illustrates the method recommended in the NBIP and used by SABIS in calculating the sample size for fracture critical bridges in Missouri. In this example, given a population size of 1,033 bridges, an in-depth evaluation with an LOC of 90% and an MOE of 15% and 10% for Tier 1 and Tier 2 respectively, the application calculates sample sizes of 30 and 38 using the equation displayed in the Figure. When the user clicks the Run Report button displayed in Figure 5, SABIS sorts the list of bridges by the random number assigned to each bridge by SABIS in ascending order and displays the subset of bridges in the sample populations, the number of which was determined in the previous step. The result is a randomly selected subset of bridges that meet the criteria established for the metric, which may be plotted on a map of the state. Figure 6 displays this result.

In the example illustrated above, oversight personnel would then use the list of randomly selected bridges to perform an in-depth assessment of compliance with requirements pertaining to Metric Nos. 10 and 16 for these structures. Following generation of these lists of randomly selected bridges, SABIS may then be used to prepare detailed reports on each bridge in the subset, as illustrated in Figure 4. Detailed reports are comprised of an itemized list of all of the NBI items, decoded and converted into standard units of measurement as appropriate. Any of these reports may be printed to the system printer.

The procedure described above may be used to prepare lists of randomly selected bridges for each of the corresponding metrics. In the example of fracture critical bridges, the same population of bridges apply to two metrics, 10 and 16. Similarly, other metrics share common bridge populations, reducing the number of unique subsets of bridges that must be prepared. In the interest of simplifying the process for practitioners, SABIS automates the generation of reports that share common metrics. Figure 7 presents a screenshot of the module used for selecting NBIS metric reports. When Metric 12 is selected, for example, the user is advised to use the report generated for Metric 13.

Figure 8 displays the report generated when Metric No. 13 is selected. As shown, this metric applies to the entire population of bridges as common to six metrics. This list of bridges may therefore be used to evaluate compliance with all of the identified metrics. This significantly reduces the total number of bridge records that must be examined during any given program year.

**Governing Regulations**

The prevailing regulation in the inspection and management of the nation’s bridges is 23 CFR 650, *National Bridge Inspection Standards*. This regulation sets forth the minimum requirements for states’ compliance, and each of the 23 NBIS metrics implemented by the Federal Highway Administration is associated with at least one of the sections within the regulation. The *National Bridge Inspection Program* provides guidance to oversight personnel in the implementation of
requirements for evaluating NBIS Metrics. The NBI Coding Guide provides an item-specific description of each item in the NBI Database.

As a convenience for users of SABIS, the application incorporates the means to review the regulation in its entirety, the second chapter of the National Bridge Inspection Program which provides guidance to practitioners in evaluating NBIS metrics, and a detailed metric description available for review when a particular metric is selected. The application also includes a link to the NBI Coding Guide. This feature provides an interactive means for users to quickly access relevant resources while preparing reports, reviewing bridge details and evaluating metrics. Figure 9 displays a screenshot of the description of a particular metric selected by the user.

Summary Report
Following the preparation of reports and evaluation of compliance with NBIS requirements, oversight personnel may enter compliance ratings and comments into a database using a module in SABIS. Figure 10 illustrates the use of this module.

Following entry of compliance ratings and comments, SABIS may be used to print the summary report, as illustrated in Figure 11. SABIS stores comments and ratings in a separate database, and uses Crystal Reports® for generating the summary report.

OTHER USES FOR THE SABIS BRIDGE INFORMATION SYSTEM
While SABIS was originally conceived as a simple supplement to the more advanced bridge management systems used by state DOTs for use by a general audience of end users, during development it became apparent that there were potential opportunities to modify the system to serve specific needs.

Federally Owned or Maintained Bridges
In addition to the NBI data files submitted annually by state DOTs, there are approximately two dozen federal agencies that compile information on federally owned or maintained bridges. Because this information uses the same record structure as state DOTs as documented in the NBI Coding Guide, it is reasonably straightforward to use SABIS to process these files and to produce standard maps and reports. Accordingly, the authors developed the subroutines to process NBI files from some of these agencies. Figures 12 and 13 present program output from bridges under the jurisdiction of the federal government.

Historic Bridges
Bridges of historic significance are of considerable interest to owner agencies, and great care must be exercised when performing construction and maintenance on or around these structures. Section 106 of the National Historic Preservation Act, as codified in 36 CFR 800, requires that agencies using federal funds for bridge rehabilitation must assess whether the bridge is eligible for inclusion in the National Register of Historic Places, and how to resolve any potential effects to a bridge that has been determined eligible to state and national registers. State laws may also require the same kind of assessment for bridge work completed with state monies.

At present, the FHWA is investigating if case-by-case Section 106 assessments of potentially eligible historic bridges can be streamlined. This can be accomplished by identifying bridges that meet the minimum assessment of being 50 years old (and therefore historic), but which may not be significant due to use of common materials like concrete or steel, and which use standard designs that make these structures undistinguished as engineered features. As part of an alternative compliance method detailed in 36 CFR 800.14(e) of Historic Preservation regulations, a federal agency can submit a “Program Comment” to the Advisory Council on Historic Preservation, to request that a single action be applied to a class of undertakings. The FHWA is in the process of eliciting responses from each state on how a Program Comment can be developed and submitted to the Advisory...
Council, for bridges that clearly lack distinctive characteristics that may make them significant historic resources.

The NBI Database is a valuable source of information for identification of classes of candidate bridges relevant to this proposed Program Comment. Specifically, the NBI Database may be queried for bridges of specified age range, historic significance, and material and design type for consideration by owner agencies. Accordingly, the authors developed the subroutines in SABIS to perform this query and the means to produce maps and reports of the results. Figure 14 displays the module used to produce these reports.

SUMMARY
Detailed information on public bridges is compiled and submitted annually by owner agencies to the Federal Highway Administration in April of each year. The information is submitted in the form of an encoded text file by all of the states in the United States, in addition to the District of Columbia and Puerto Rico, and is available for each program year since 1992. This repository of data, collectively known as the NBI database, represents the most comprehensive source of publicly available information on the nation’s bridges, with approximately 100 items of information collected on each bridge over a twenty year period, including age, material type and design, location, load ratings, dimensions, safety features, annual daily traffic, condition ratings, posting status, improvement cost, last inspection date and much more. While this information is readily available through public websites, many users find these encoded files difficult to use, since the data must be decoded and processed in order to be of practical value.

The SABIS Bridge Information System is a computer application designed to process these publicly available data sources and to provide simplified access to detailed bridge information to a broad spectrum of technical and non-technical end users. The effort began as a collaborative initiative between the Federal Highway Administration and the New Mexico Department of Transportation, and development of a prototype was completed in 2010. During the course of development, the authors created in excess of 1000 state-specific databases of annual National Bridge Inventory information from owner agencies over the twenty years period of available data. SABIS provides access to these processed databases and the means to produce 25,000 standard reports and to review over 10 million individual bridge records spanning these two decades of data. This resource is of considerable value to industry practitioners, the research community and a wide variety of technical and casual users. While SABIS is in the prototype stage subject to further testing and refinement as of the time of this report, the application is available for limited use and evaluation to interested parties.

In 2010 the Federal Highway Administration identified and implemented twenty three (23) metrics designed to improve and standardize the oversight of states’ compliance with requirements embodied in 23 CFR 650, “National Bridge Inspection Standards”. Each of these metrics relates to one or more sections within the regulation. On review of these metrics and the guidance provided to oversight personnel, the authors believed that it might be feasible to modify SABIS to include the means to prepare maps and reports related to the evaluation of these metrics. This paper presents a description of a collaborative effort between the New Mexico Department of Transportation and the New Division of the Federal Highway Administration to refine the application prototype to serve this purpose. The authors believe that this prototype, while subject to further review, improvement and refinement, demonstrates the potential value of automating this process using commercial software development tools and publicly available data files. While the SABIS Bridge Information is considered to be in the development stage and has not been adopted for use by the Federal Highway Administration, incorporation of NBIS metrics into the application demonstrates the potential for customization of a bridge information system that uses readily available NBI data files as its information source for a variety of purposes. This paper also explores other potential uses of SABIS, including processing NBI data files for bridges owned or maintained by various federal agencies, and querying the NBI Database for classes of bridges subject to the provisions of 36 CFR 800, “Protection of Historic Structures”.

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