

NEW MEXICO DEPARTMENT OF TRANSPORTATION

RESEARCH BUREAU

Innovation in Transportation

Development of a User-Friendly Bridge Information System - Phase II:

Report 1: Assessing National Bridge Inspection
Standards (NBIS) Metrics Using Data Extracted from
National Bridge Inventory Source Files

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DEVELOPMENT OF A USER-FRIENDLY BRIDGE INFORMATION SYSTEM – PHASE II

Report 1: Assessing National Bridge Inspection Standards (NBIS) Metrics Using Data Extracted from National Bridge Inventory Source Files

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PREFACE

The research reported herein describes a software development project currently underway by the NMDOT Research Bureau. Phase I of the project was initiated in 2008 and served to develop a prototype bridge information system based on publicly available National Bridge Inventory source files. This prototype was completed in 2010, and in 2012 Phase II of the project was initiated with the objective of enhancing the program with additional functionality, including management of NBIS metrics as recently implemented by the Federal Highway Administration. This work is ongoing, and this paper presents the aspect of the project related to assessment of these metrics.

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DISCLAIMER

This report presents the results of research conducted by the author(s) and does not necessarily reflect the view of the New Mexico Department of Transportation. This report does not constitute a standard or specification.

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 dramatic reduction in the number of bridges built or reconstructed over the last decade. In response to a USDOT audit recommending the Federal Highway Administration (FHWA) 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 National Bridge Inspection Standards (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 efforts by the New Mexico Department of Transportation 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 state compliance levels and recommending follow-up actions.

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OVERVIEW

The National Bridge Inventory (NBI) Database is comprised of state-specific data files compiled and maintained by the Federal Highway Administration (FHWA). 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 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”* (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 Chapter Two 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 substantially completed work on 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 any of the approximately 600,000 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.

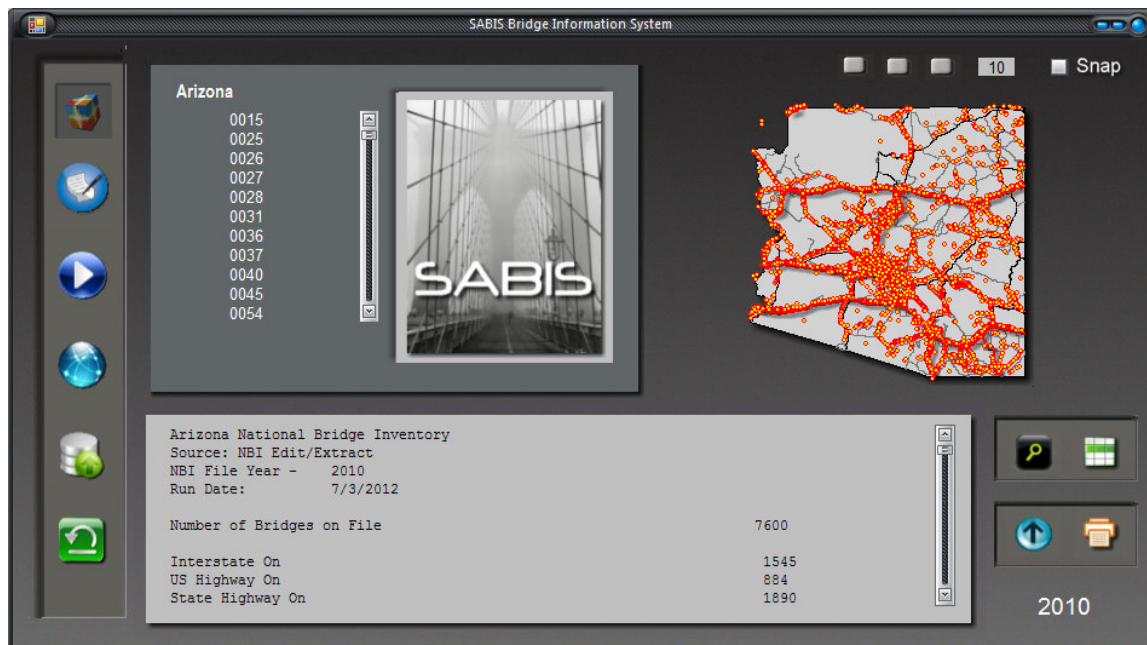


FIGURE 1 Main Page of the SABIS Bridge Information System. Source: 2010 NBI Database.

Unlike the *Pontis Bridge Management System*, an AASHTOware 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 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.

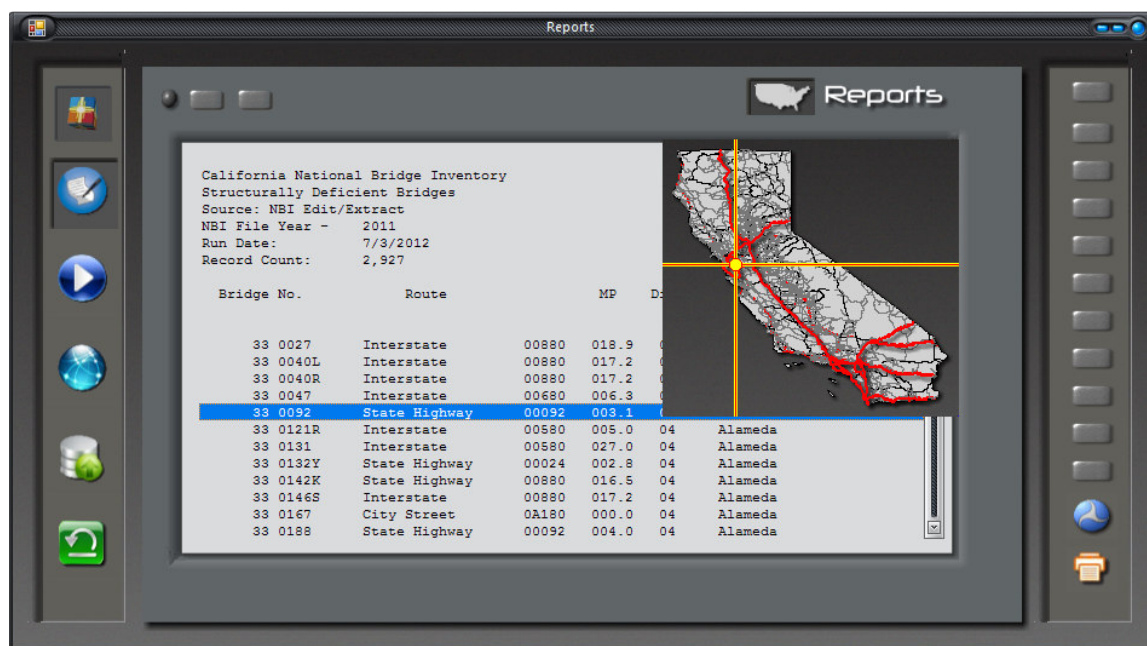


FIGURE 2 List of structurally deficient bridges in California as generated by SABIS. Source: 2011 NBI Database.

NATIONAL BRIDGE INSPECTION STANDARDS METRICS

The NBIS set 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 FHWA 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
- 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 Inspection Frequency – Routine
- Metric # 07: 23 CFR 650.311 Inspection Frequency – Routine Extended
- Metric # 08: 23 CFR 650.311 Inspection Frequency – Underwater
- Metric # 09: 23 CFR 650.311 Inspection Frequency – Underwater Extended
- Metric # 10: 23 CFR 650.311 Inspection Frequency – Fracture Critical Member
- Metric # 11: 23 CFR 650.311 Inspection Frequency – Damage, In-Depth or Special
- Metric # 12: 23 CFR 650.313 Inspection Procedures – Team Leader
- 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 20 through 23 pertain to management practices. Metrics 06 through 19 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, FHWA 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 Chapter Two of a document referenced by FHWA as the "*National Bridge Inspection Program (NBIP)*" (3). 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 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, 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 a) these bridges be reviewed to ensure that they have been inspected at regular intervals not to exceed 24 months, and b) that criteria for the level and frequency for which FCMs that require less frequent inspections have been established. While compliance with the requirements of a) may be determined through an examination of NBI data, evaluation of compliance with b) must be made by oversight personnel. The NBI Database codes FCM status in Item No. 92A, with a value of “Y” identifying the bridge as fracture critical.

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.

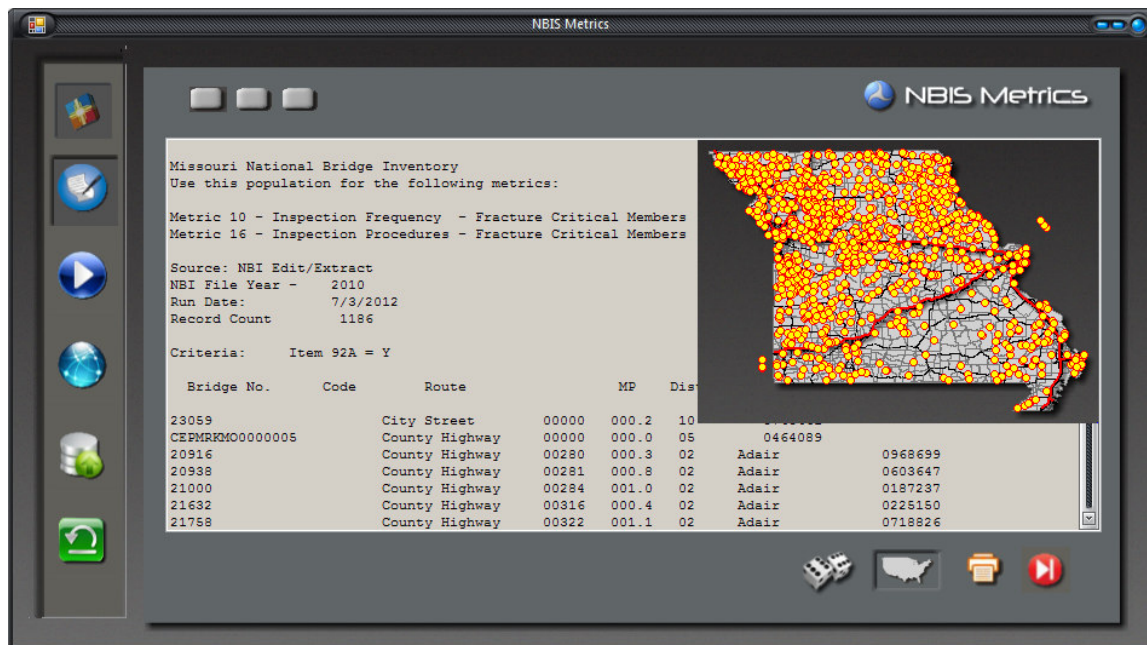


FIGURE 3 List of fracture critical bridges in Missouri. Source: 2010 NBI Database.

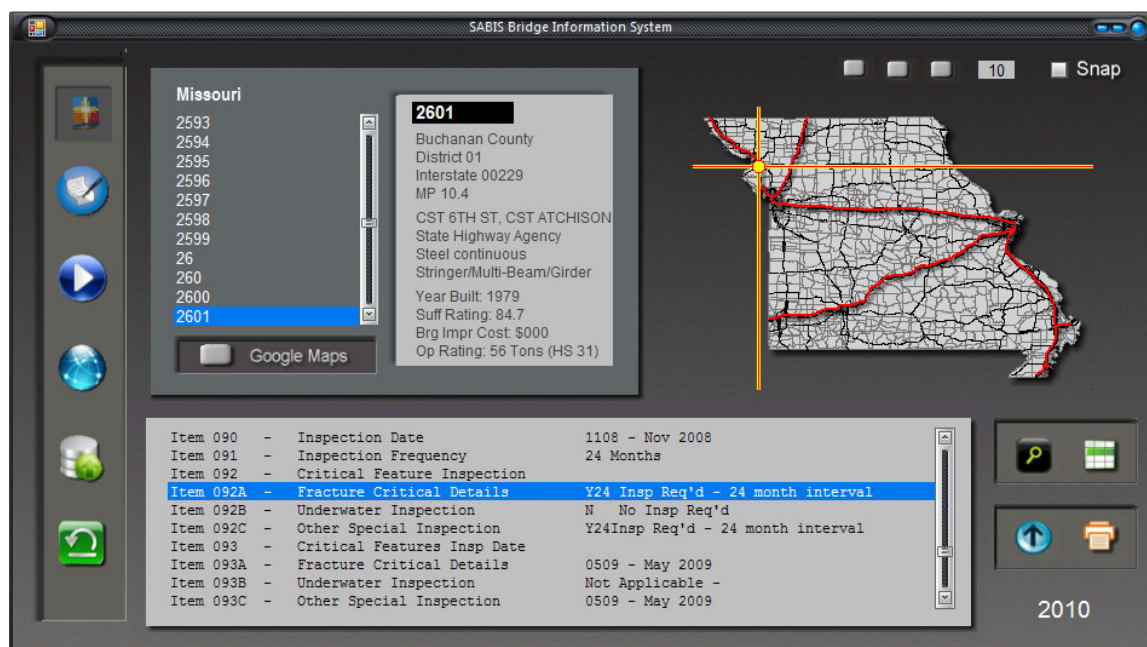


FIGURE 4 Detail report of a fracture critical bridge in Missouri. Source: 2010 NBI Database.

Note that the report displayed in Figure 3 identifies the selection criteria (Item 92A = Y) and the metrics to which the report applies (Metric 10 – Inspection Frequency, and Metric 16 – Inspection Procedures). Note also the relatively high number (1,186) 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 90% 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.

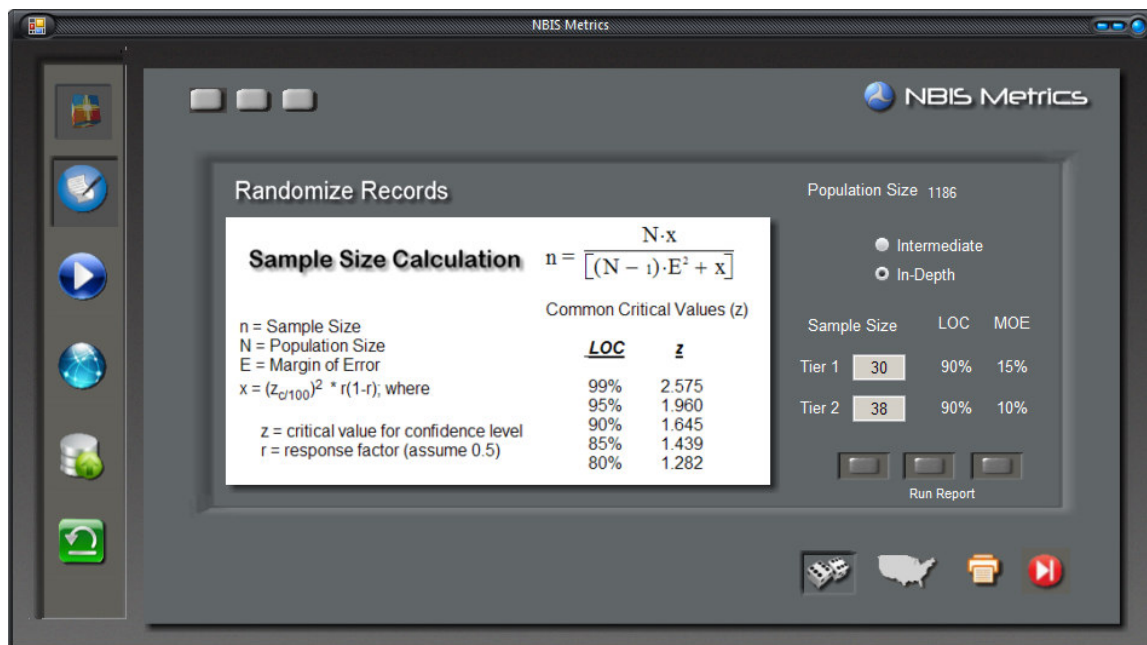


FIGURE 5 Module to calculate sample size and develop a list of randomly selected records.

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

1,186 bridges, 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. The last column in the report illustrated in Figure 3 displays a random number generated by SABIS for each bridge record. When the user clicks the *Run Report* button displayed in Figure 5, SABIS sorts the list of bridges by the random number 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.

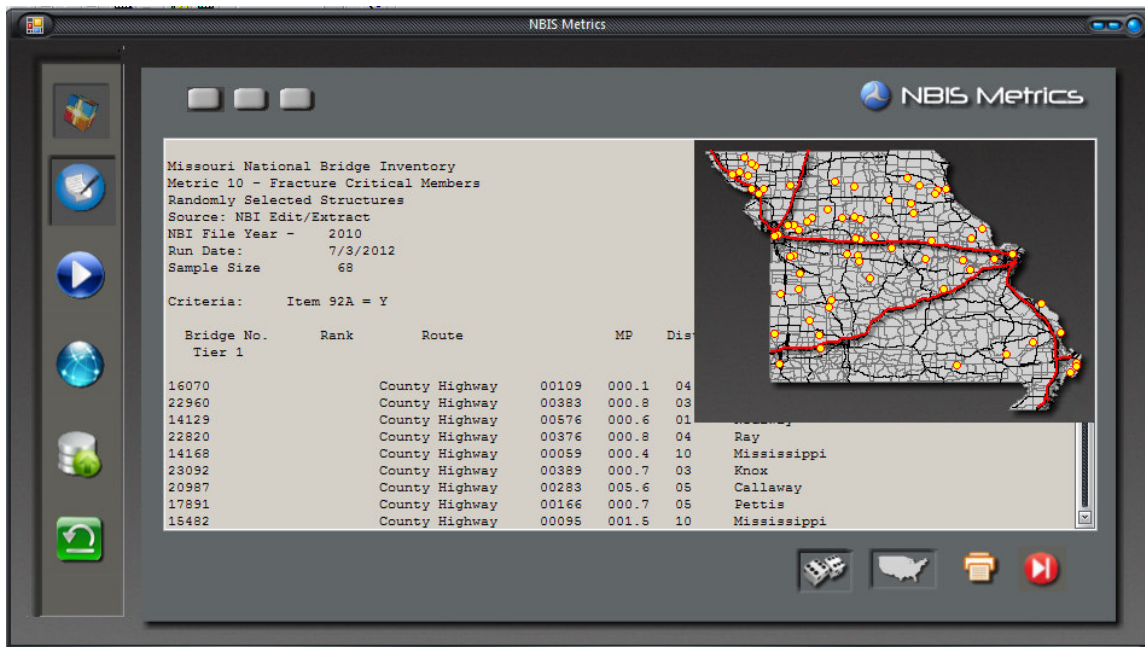


FIGURE 6 Subset of randomly selected fracture critical bridges in Missouri. Source: 2010 NBI Database.

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 by clicking the printer icon.

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 applies to two metrics, 10 and 16. Similarly, other metrics share common bridge populations, and of the 23 metrics, evidently only 10 unique subsets of bridges 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.

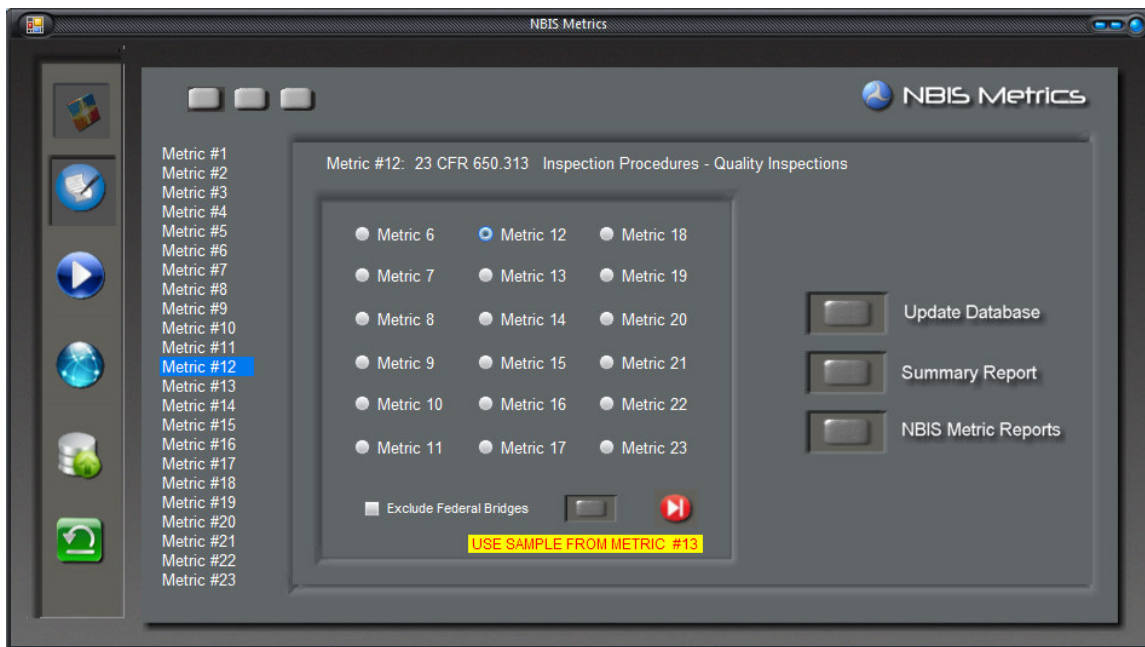


FIGURE 7 Screenshot from SABIS illustrating the module used to generate NBIS Metric reports.

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 seven 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.

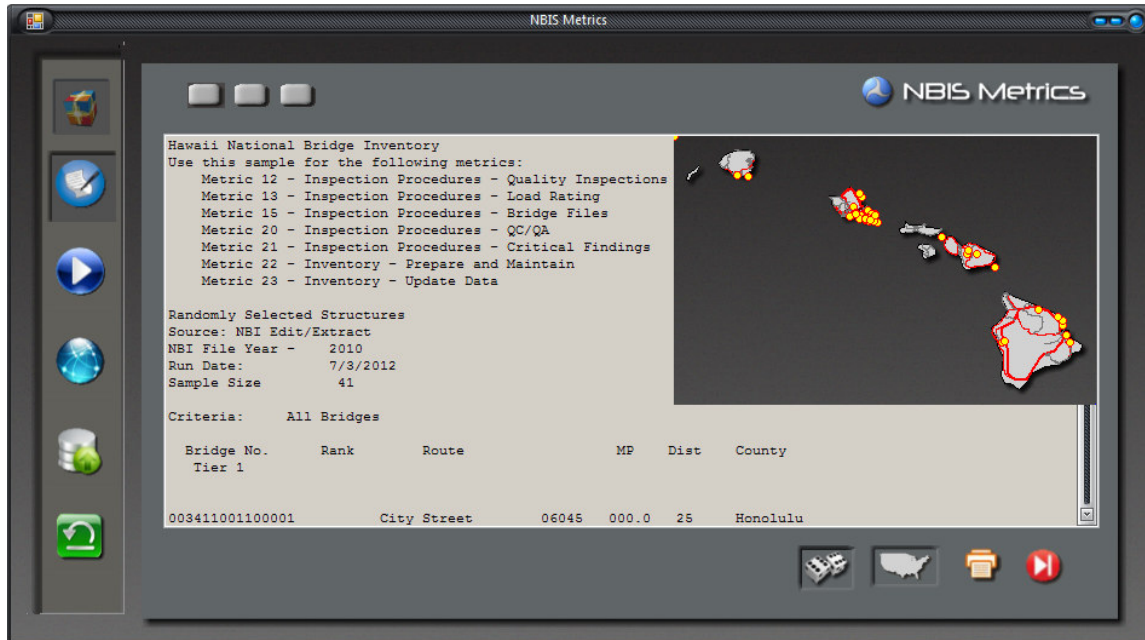


FIGURE 8 Example report that uses the same population of bridges for several metrics.

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 FHWA is associated with at

least one of the sections within the regulation. The *NBIP* 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, Chapter Two of the NBIP 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.

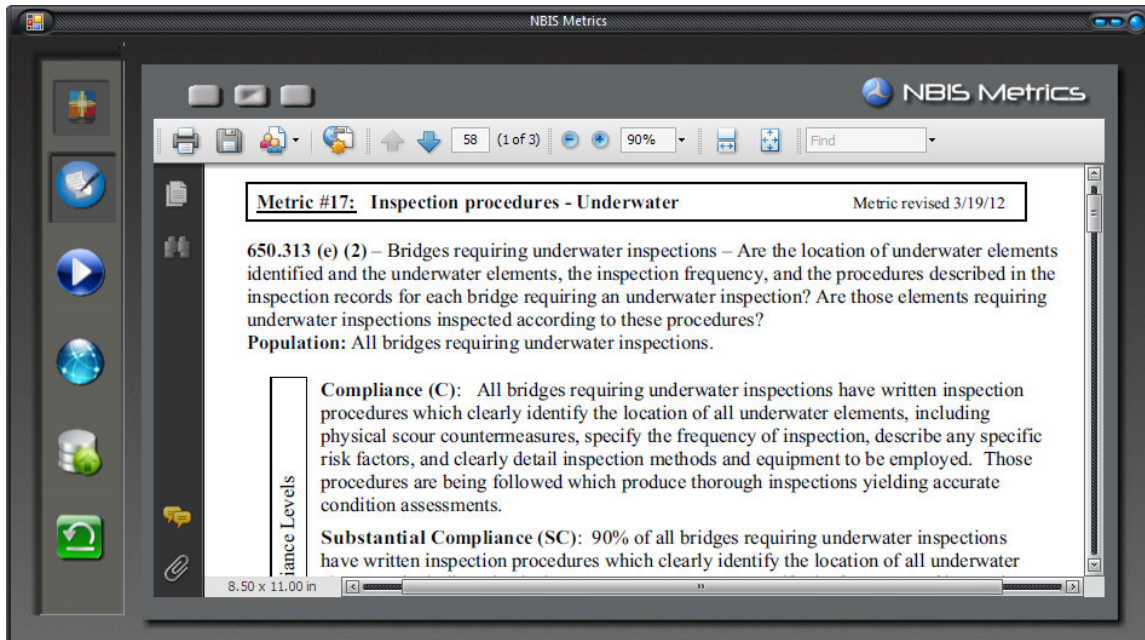


FIGURE 9 Screenshot of the description for Metric No. 17. Source: *National Bridge Inspection Program*, FHWA.

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.

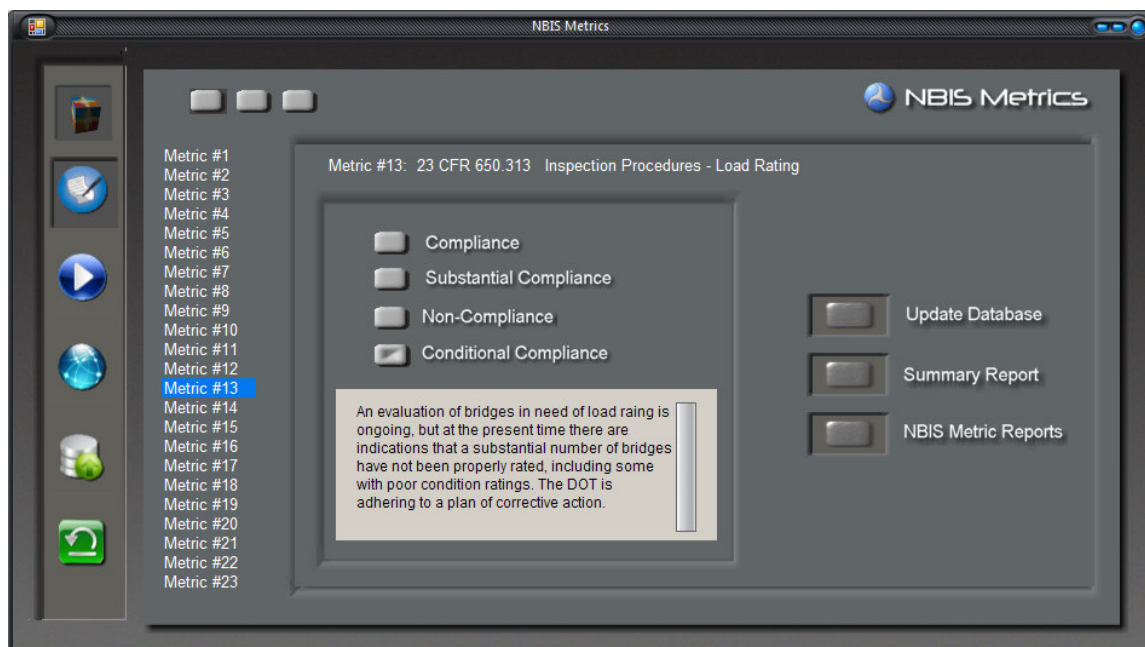


FIGURE 10 Module used to enter compliance ratings and comments.

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.

National Bridge Inspection Standards (NBIS) Metrics		
Annual NBIS Compliance Review Summary Report		
New Mexico		
Metric No 1	Bridge Inspection Organization	Conditional Compliance
Comments	See supplemental report and plan of corrective action.	
Metric No 2	Qualifications of Personnel - Program Manager	Compliance
Comments	The Program Manager is a registered P.E. and has successfully completed the certification requirement in NBIS training conducted by New Mexico State University.test	

FIGURE 11 Partial output for a prototype summary report using dummy comments and compliance ratings.

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 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 subroutines to process NBI files from some of these agencies. Figure 12 present program output from bridges under the jurisdiction of the federal government.

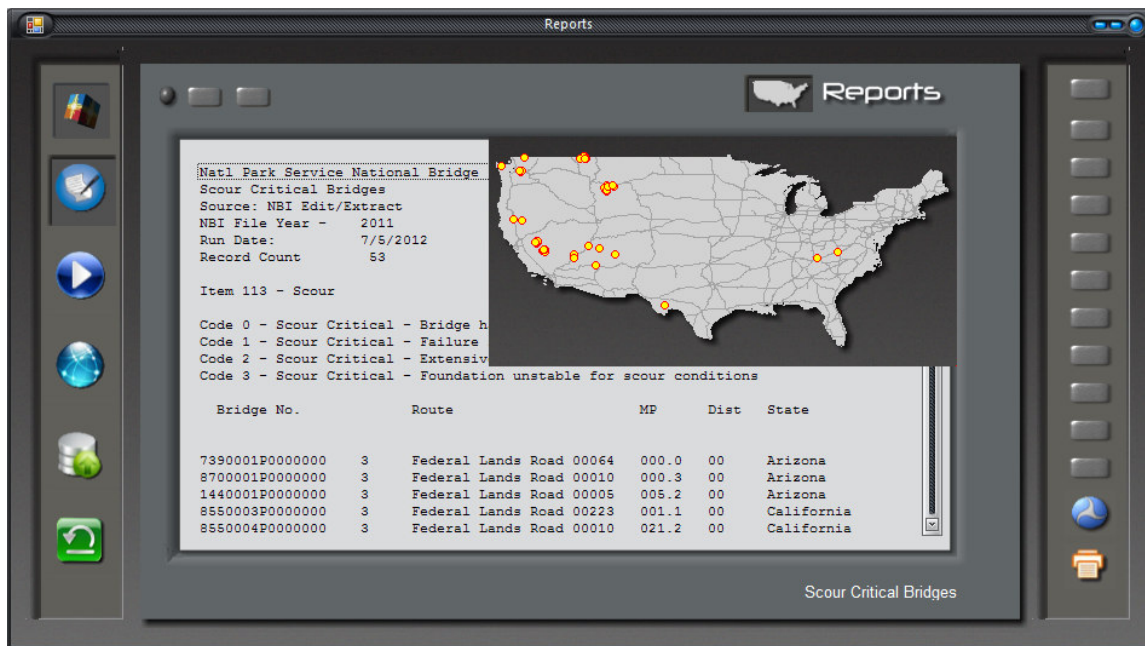


FIGURE 12 Map and list of scour critical bridges maintained by the National Park Service. Source: FHWA.

Historic Bridges

Bridges of historical 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 16 USC 470f (*"National Historic Preservation Act"*) (5) requires that agencies using federal funds for bridge rehabilitation must assess whether the bridge is eligible for inclusion in the National Register and how to resolve potential effects to any bridge that is deemed historic. Regulations developed by the Advisory Council on Historic Preservation (ACHP) and codified in 36 CFR 800 (*"Protection of Historic Properties"*) (6) describe the procedures that federal agencies must follow to meet this obligation. Many of the hundreds of bridges potentially subject to these regulations were built prior to 1935, are of common reinforced concrete or steel construction and have standardized designs. Many of these bridges are undistinguished and are of little value for preservation in place and are not viable candidates for relocation. Yet, all federally funded or permitted projects affecting these bridges require review and consultation pursuant to the regulation. This has the potential to significantly delay the approval process for bridge rehabilitation activities.

Alternate compliance methods provided by the Section 106 regulations allow agencies to meet these Section 106 obligations, but tailor the process to their mission and needs. Section 800.14(e) of the regulation provides that any agency may request a "Program Comment" from the ACHP in lieu of case-by-case review. The benefit of a program comment is that it allows a federal

agency to comply with Section 106 in a single action for a class of undertakings rather than addressing each undertaking as a separate action. In 2012 FHWA proposed a draft program comment in accordance with 36 CFR 800.14(e) in order to waive case-by-case Section 106 consideration of effects on common mid-20th century bridges. This program comment would apply to effects of undertakings on certain types of bridges, and only bridges lacking distinctive treatments, of little value for preservation in place, and not located within or adjacent to historic districts.

On review of this draft document, designated as “*Program Comment for Certain Mid-20th Century Concrete and Steel Bridges*” (7), it’s apparent that the NBI Database is a valuable source of information for the identification of classes of candidate bridges to be considered for exclusion in consideration of historical significance as required by the regulation. Specifically, the NBI Database may be queried for bridges of specified age range, historical significance, 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 13 displays the module used to produce these reports.

FIGURE 13 Queries for Bridges of Historical Significance.

SUMMARY

Detailed information on public bridges is compiled and submitted annually by owner agencies to FHWA 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 FHWA and the New Mexico Department of Transportation, and development of a prototype was substantially completed in 2010. During the course of development, the authors created in excess of 1000 state-specific databases of annual NBI information from owner agencies over the twenty years period of available data. SABIS provides access to these processed databases and the means to produce 10,000 standard reports and to review over 10 million individual bridge records spanning 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.

In 2010 FHWA 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*". 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 efforts by the authors to develop a prototype that serves 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. 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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