A Discussion on the Efficiency of NBI Translator Algorithm

Basak Aldemir-Bektas
Center for Transportation Research and Education
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010
basak@iastate.edu

Omar Smadi
Center for Transportation Research and Education
Iowa State University
2711 South Loop Drive,
Suite 4700, Ames, IA 50010
smadi@iastate.edu

ABSTRACT

The National Bridge Inventory (NBI) database is an extensive source of information on highway bridges in the United States. Among more than 100 NBI elements, four condition ratings are of special interest for bridge engineers and managers. These NBI elements are deck, superstructure, substructure, and culverts condition ratings (NBI items 58, 59, 60, and 62 respectively). The data for these condition ratings come from biannual bridge inspections in the field and stored in the NBI database. As a part of their bridge management programs, many states have been collecting element-level condition data (mostly Pontis inspections) for over 15 years. Element-level data provide more detailed condition data on sub-elements of the aforementioned general NBI element categories and allow bridge engineers and managers to make cost-effective decisions regarding bridge maintenance, rehabilitation, and replacement. Due to having such detailed condition data at hand, there has been an interest in developing algorithms that have the capability of estimating the NBI condition ratings for deck, superstructure, substructure, and culverts from the Pontis element inspection data. If a sound estimation tool could be developed, the biannual NBI inspections done for these condition ratings would be deemed unnecessary. The NBI Translator (developed by FHWA) is one of the algorithms that has been developed to achieve that goal. Recently, there has been some concern on the degree of accuracy of this algorithm by users of both Pontis and the translator. The Iowa Department of Transportation (Iowa DOT) uses the Pontis software for its bridge management system. The NBI Translator is part of Pontis and can be utilized to calculate the NBI ratings from element condition data. This paper presents a literature review on bridge management systems and bridge inspections in the United States. In addition, background on NBI Translator algorithm and discussions on the efficiency of the tool are provided. The paper is concluded by a comparison study between the calculated values of the NBI ratings using the translator and the field inspection data on NBI condition ratings collected by the Iowa DOT.

Keywords: asset management—bridge management—element condition ratings—NBI translator—NBI ratings

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INTRODUCTION

In the last 40 years, there has been a shift from constructing new infrastructure to maintaining and managing the built infrastructure in the United States. Assessment of the deficiencies for the nation's infrastructure gained significant importance during this period. As the infrastructure gets older, more resources are required to maintain it at an acceptable level of service. Since the funds eligible for maintenance and rehabilitation activities are limited, effective resource allocation is now more necessary than ever. Agencies are required to keep condition data on their pavements, bridges, and other infrastructure elements and justify their reasons for decision making and funding requests.

As an important segment of the infrastructure system, bridges and their management have also been in the spotlight for the last four decades. Unlike pavements, the failure of bridge structures may result in disasters. Agencies in the United States learned from these incidents and started implementing an extensive and comprehensive approach to bridge management.

Biannual National Bridge Inventory (NBI) rating is an effort to support bridge management and to form a basis for funding of bridge improvements in the United States. Agencies have also been collecting lower level detailed condition data for their bridge management systems. Modeling NBI ratings from lower level element condition data has been a topic of interest due to the significant resource savings it will facilitate (Al-Wazeer, Nutakor, and Harris 2007). There have been efforts but the degree of efficiency of the models is a discussion subject.

BRIDGE INSPECTIONS AND BRIDGE MANAGEMENT SYSTEMS IN THE UNITED STATES

On December 15, 1967, the Silver Bridge on U.S. Highway 35 suddenly collapsed into the Ohio River during rush hour (LeRose 2001). At the time of this tragic event, there were 37 vehicles crossing the bridge, and 31 of them fell down to the river. Forty-six lives were lost during this event, and nine people had severe injuries (National Transportation Safety Board 1967). In addition to the loss of life, an important road connecting West Virginia and Ohio was no longer in service. The catastrophe evoked concern over the reliability of the national network of bridges in the United States.

The 1968 Federal-Aid Highway Act put the states in action to collect and keep an inventory for Federal-aid highway system bridges. In the early 1970s, the National Bridge Inspection Standards (NBIS) that form the basis of bridge inspection and inventory in the United States today were developed and implemented by the Federal Highway Administration (FHWA). This legislation guided the data collection on bridge condition all over the nation. The failure of the Mianus River Bridge in 1983 and Schoharie Creek Bridge in 1987 were other two unfortunate events after the collapse of the Silver Bridge that drew attention to the importance of keeping the nation's bridges in sufficient condition and keeping up-to-date condition data (Small et al. 1999).

In general, bridges are inspected every two years, and the condition ratings are reported to the FHWA. The inspection data are compiled by the FHWA into the NBI. After the analysis of the data, reports on bridge conditions are prepared and submitted to Congress. Decisions on the distribution of federal funding through programs such as Highway Bridge Replacement and Rehabilitation Program are based on these reports (Dunker and Rabbat 1995).

In addition to the biannual NBI inspections, many states also collect element-level bridge condition data for the bridge management systems. Along with the Intermodal Surface Transportation Efficiency Act of 1991, which required the states to develop and implement bridge management systems, most of the states realized the importance and advantages of implementing bridge management systems. Although development of bridge management systems was made optional later in 1995 by the National Highway System Designation Act, many states decided to implement bridge management systems and took action (Sanford, Herabat, and McNeil 1999). Forty-eight states were reported to be implementing a bridge management system as of September 1996 (Scheinberg 1997). Efforts to develop efficient national bridge management tools encouraged research in the area. A research project initiated by FHWA resulted in the development of Pontis Bridge Management System which later became the most popular bridge management tool in the United States. Forty-two states reported that they considered implementing Pontis Bridge Management System. Few states preferred to develop their own bridge management systems (Pennsylvania, Alabama, New York, and North Carolina). The state of Maine implemented BRIDGIT which was developed as a result of a National Cooperative Highway Research Program (NCHRP) Project (Sanford, Herabat, and McNeil 1999).

Pontis Bridge Management System

As previously stated Pontis (Cambridge Systematics 2007) is the most popular bridge management system in the United States that aims to help transportation agencies in the decision making process regarding maintenance, rehabilitation, and replacement of bridge structures. Agencies are now aware that the aging highway system has considerable improvement needs; however, funding resources are limited. Therefore, they need to make the best possible decisions for improvement, and these decisions should be based on facts. Pontis input data structure is a relational database which contains complete bridge inventory and inspection data. FHWA and American Association of State Highway and Transportation Officials (AASHTO) adopted Commonly Recognized (CoRe) Elements for Bridge Inspection in order to standardize element-level condition data collection within the United States. Bridges are presented by the CoRe elements in Pontis, and percentage of condition states for bridge elements are inspected and stored in the database. For each bridge element, specific condition states and related deterioration models were developed. Based on this detailed element inspection data, the program keeps track of current situation, simulates future condition, identifies bridge and network level needs and makes project recommendations in order to gain maximum benefits from scarce funds.

Although Pontis has been extensively used for maintaining bridge element condition data inventory, not all states benefit from the tool for resource allocation and identifying future projects literally for the time being. Implementing a bridge management system is a big organizational change, and it takes time to prepare the organization for such a strategic change and customize the implementation.

NBI CONDITION RATINGS AND BRIDGE ELEMENT CONDITION DATA

The FHWA Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation’s Bridges (Coding Guide) helps inspectors for the data collection process. States are encouraged to use the coding guide for standardization purpose (Dunker and Rabbat 1995). The Structure Inventory and Appraisal Sheet (SI&A) lists the NBI items necessary for inspecting individual structures, and these items can be divided into three main categories: inventory items, condition rating items, and appraisal rating items. NBI condition rating for an element is an evaluation of its current condition when compared to its new condition. In order to make the NBI condition ratings as objective as possible the inspectors are provided with the general condition rating guidelines listed in Table 1. NBI condition rating elements are different from bridge management system elements. Three subsystems of bridges and culverts receive overall condition ratings in NBI inspections (Dunker and Rabbat 1995):

- Item No. 58 Deck
- Item No. 59 Superstructure

- Item No. 60 Substructure
- Item No. 62 Culverts

Table 1. NBI general condition rating guidelines*

Code	Description
N	NOT APPLICABLE
9	EXCELLENT CONDITION
8	VERY GOOD CONDITION (No problems noted)
7	GOOD CONDITION (Some minor problems)
6	SATISFACTORY CONDITION (Minor deterioration in structural elements)
5	FAIR CONDITION (Sound structural elements with minor section loss)
4	POOR CONDITION (Advanced section loss)
3	SERIOUS CONDITION (Affected structural elements from section loss)
2	CRITICAL CONDITION (Advanced deterioration of structural elements)
1	“IMMINENT” FAILURE CONDITION (Obvious movement affecting
0	FAILED CONDITION (Out of service)

*Adapted from (Dunker and Rabbat 1995)

While the NBI condition ratings are assigned according to the 0-9 scale given in Table 1, element-level data collected for bridge management systems are assigned on a scale of 1 to 3, 1 to 4 or 1 to 5 based on the particular element. Of 106 CoRe bridge elements, 21 CoRe elements describe bridge decks, 35 CoRe elements describe superstructures, 20 CoRe elements describe substructures and 4 CoRe elements describe culverts. In addition, smart flags are defined to describe special defects in miscellaneous bridge elements such as each beam, column, or girder. The rest of the CoRe elements are a variety of items such as bridge railings, joints, or bearings (Al-Wazeer, Nutakor, and Harris 2007). Condition State 1 for an element is the best condition while condition states 3, 4, or 5 present the worst conditions for particular elements. In Table 2 condition state definitions of unprotected concrete deck from Pontis element configurations are provided as an example (AASHTOWare). The percentage/quantity of an element for each defined condition state is recorded during Pontis inspections.

Table 2. Condition state definitions of unprotected concrete deck

Code	Description
1	No damage
2	Distress <= 2%
3	2-10% distress
4	10-25% distress
5	Distress >=25%

The Pontis condition inspection data with extensive detail down to each individual element made agencies and experts in the field question the redundancy of NBI inspections for the same inspected bridges. Pontis inspection results provided agencies with much more detailed condition data for the aforementioned NBI items. Using the data at hand for other data requirements when possible is essential because data collection is a time- and resource-consuming process. For the year 1986, NBI costs were estimated to be approximately $150 to 180 million (National Council on Public Works Improvement 1986). Although NBI data and Pontis inspection data have discrepancies in item definition and rating scales, researchers have been trying to make a translation from bridge element condition data to high-level NBI ratings to reduce the huge cost and time spent for data collection (10, 11). Hearn et al. (1993) developed an estimator model for the purpose which was later developed as a software tool known as the NBI Translator or BMSNBI. Pontis program has this software tool as a built-in module, and the tool can be used for the translation from a defined set of element inspection state for specified bridges in the Pontis environment.

NBI TRANSLATOR

Hearn et al. (1993) and Hearn, Cavallin, and Frangopol (1997b) developed the NBI Translator at the University of Colorado, Boulder, with the collaboration of Colorado Department of Transportation. The translator generates condition ratings for deck (Item 58), superstructure (Item 59), substructure (Item 60) and culverts (Item 62) "by linking CoRe elements to corresponding NBI fields and mapping bridge management system condition states to NBI rating scale" (Hearn et al. 1993). Bridge inspection data that contains both the NBI ratings and element level condition state data of approximately 35,000 bridges were used to calibrate the NBI Translator (Hearn, Cavallin, and Frangopol 1997b).

Generation of NBI condition ratings is realized in four main steps (Hearn, Cavallin, and Frangopol 1997b). First, CoRe elements are grouped into matching NBI fields. Then, NBI condition ratings are generated for individual elements based on the quantities of that element in the different condition states. This table-driven procedure is shown in Figure 1 (adapted from Hearn, Cavallin, and Frangopol 1997b).

Requirements on element quantities		NBI Rating
P_1	$M_{1,9}$	9
P_1+P_2	$M_{2,9}$	
$P_1+P_2+P_3$	$M_{3,9}$	
$P_1+P_2+P_3+P_4$	$M_{4,9}$	
P_1	$M_{1,8}$	8
P_1+P_2	$M_{2,8}$	
$P_1+P_2+P_3$	$M_{3,8}$	
$P_1+P_2+P_3+P_4$	$M_{4,8}$	

Figure 1. Table for NBI Generation modify according to the guide

Hearn, Cavallin, and Frangopol (1997b) describe the table-driven element NBI generation as follows: Percentages of element quantities in condition states are denoted by P_i and taken from element inspection records. Each row in Figure 1 checks the sum of percentages for a minimum required sum. These minimum required sums, denoted by $M_{i,j}$, are called mapping constants. As previously mentioned, number and definition of condition states differ for CoRe elements for each material and use. For example, the condition states for steel deck are different from reinforced concrete deck. Overall, 20 different maps are required for generating NBI ratings. The four requirements for each NBI rating should be satisfied at the same time to assign that particular NBI rating to that particular element. The calibration process estimates these mapping constants. After assigning the NBI ratings for all elements, NBI ratings for each item (deck, superstructure, substructure, and culverts) are calculated by a weighted combination of element ratings. While the weights for deck and superstructure fields are based on relative quantity, the weights for substructure field are based on number of spans. Finally, NBI condition ratings are modified based on the smart flag condition reports. Smart flags may reduce the NBI ratings by a maximum of three points.

The objective of the calibration process is to find the mapping constants that will lead to the minimum difference between the NBI ratings given by inspectors and the generated NBI ratings from the element condition data.

Discussions on the NBI Translator Algorithm

Although the PC-based version of the NBI Translator algorithm has been available since 1994, the traditional NBI inspections for bridge subsystems are still being done since the translator results are not accepted as satisfactory. In some of the states that have access to the NBI Translator through Pontis, bridge engineers reported that they have concerns regarding the efficiency of the tool. A recent study (Hale, Hale, Sharpe 2007) on bridge management involving 17 state DOTs reported a general skepticism on the estimation accuracy of the NBI Translator. Among these states only Oklahoma has been using the rating translator. However, due to the variance of the generated ratings they are in the process of stopping the use of the translator. In another study, Scherschligt (2005) reports that Kansas Department of Transportation (KDOT) evaluated NBI Translator results as an alternative of performance measure for bridge prioritization. The coefficient of determination between generated and real ratings was only 25%. This implies that the translator was able to explain only 25% of the variation in the NBI ratings in the best case. KDOT decided that the translator results were statistically insufficient and inconsistent. Therefore, they eliminated the NBI Translator results from their alternatives of performance measures.

A study by Al-Wazeer, Nutakor, and Harris (2007) proposes an alternative for NBI generation to improve the results of NBI Translator. Based on data from Wisconsin and Maryland, artificial neural network (ANN) models were developed, and results of ANN models were statistically compared with the NBI Translator results. The statistical comparison was based on the differences between the predicted and the actual observed NBI ratings. NBI error ranges were defined such as:

- NBI Error = 0 (the difference between the predicted and the actual observed NBI rating is zero)
- NBI Error = 1 (the difference is equal to the absolute value of one)
- NBI Error = 2 (the difference is equal to the absolute value of two)
- NBI Error > 2 (the absolute value of the difference is greater than two)

Comparisons based on aforementioned error ranges showed that ANN model had a higher estimation capability with respect to the NBI Translator model for a particular state when the data used for ANN training is from the same state. The superiority of ANN model to NBI Translator cannot be generalized since the statistical results are valid for only the data used in the study. However, the study drew attention to the importance of customizing the prediction model for each state.

STATISTICAL COMPARISON OF ACTUAL AND GENERATED RATINGS FOR IOWA BRIDGES

For the state of Iowa, NBI generation from the element-level condition data was performed using the built-in NBI Translator in Pontis software. Six hundred and eighty data points were used for the analysis of culvert ratings and 3,038 data points were used for the analysis of substructure, superstructure, and deck ratings. Before using NBI Translator for Iowa bridges, it was customized according to the element configuration of the Iowa Bridge Management System. This customization was done by modifying the driver file, Elements.prn, in the Pontis program folder which defines the elements to be included in NBI generation (Hearn, Cavallin, and Frangopol 1997b). First, the list of elements defined in original Elements.prn file in the program folder and Iowa elements defined in the Pontis inspection manual were compared to find the differences. Some elements that were included in the original Elements.prn file were not being used in the Iowa Pontis system; therefore, those elements were discarded in the modified Elements.prn file. Some elements had different numbers in the Iowa system, and they were also renumbered accordingly in the driver file.

Elements.prn file contains seven fields of information. These information fields are element ID (element number), element NBI field (deck, superstructure e.g.), element material (unpainted steel, masonry, smart flag e.g.), element type (slab, truss bottom chord e.g.), element dimension (each, square feet e.g.), element name in both long and short forms (Hearn, Cavallin, and Frangopol 1997b). There were some elements in the Iowa Pontis elements which were not defined within the original Elements.prn file. In order to include these elements in the NBI generation, all seven fields of information for each element were coded into the modified Elements.prn file. The list of codes necessary for modifying Elements.prn file is provided by Hearn et al. (1993). After making all the modifications to the driver file, the modified file in the Pontis program folder is replaced by the modified version and used in NBI generation.

Figures 2–5 summarize the findings of the comparison. For each rating item the percentage distribution of actual and generated ratings among the data set are presented as pie charts. Figure 2 shows that the NBI Translator estimates lower deck ratings than the actual observed deck ratings. While 34% of actual deck ratings have values of 8 and 9, the NBI Translator estimates no deck rating within this range.

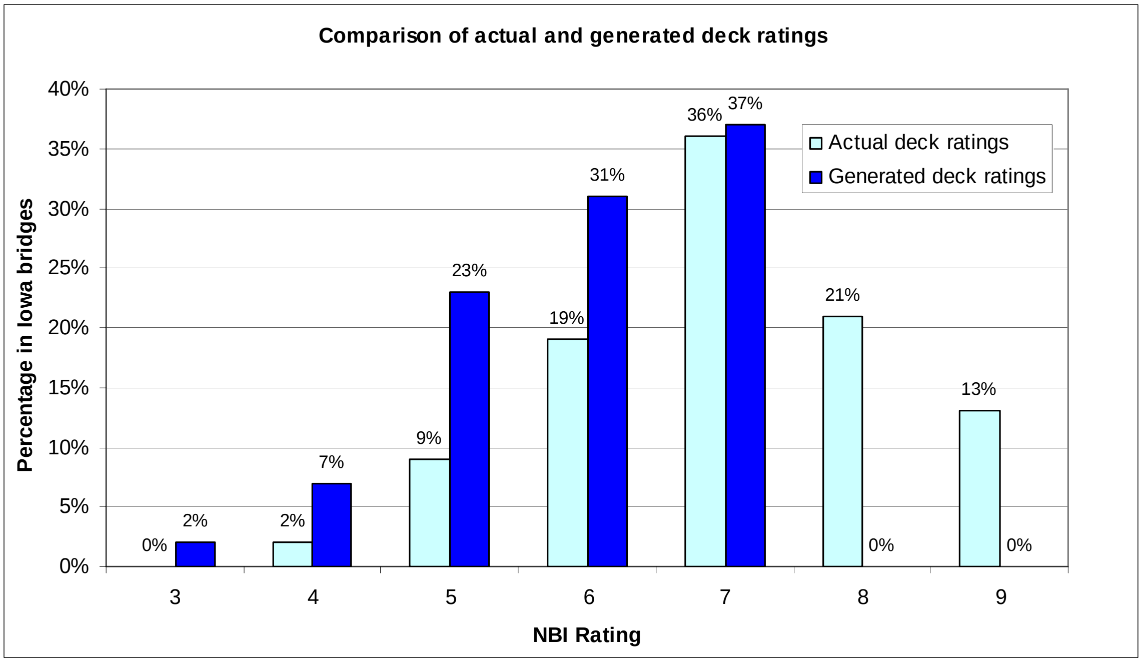

Figure 2. Comparison of actual and generated deck ratings

Figure 3 shows the comparisons for superstructure ratings. While 19% of the actual ratings are equal to 9, no observation equal to 9 appears in the generated ratings. The percentages of generated 5, 6, and 8 ratings are greater than the actual case, while the percentage of generated 7 ratings is lower than the actual case.

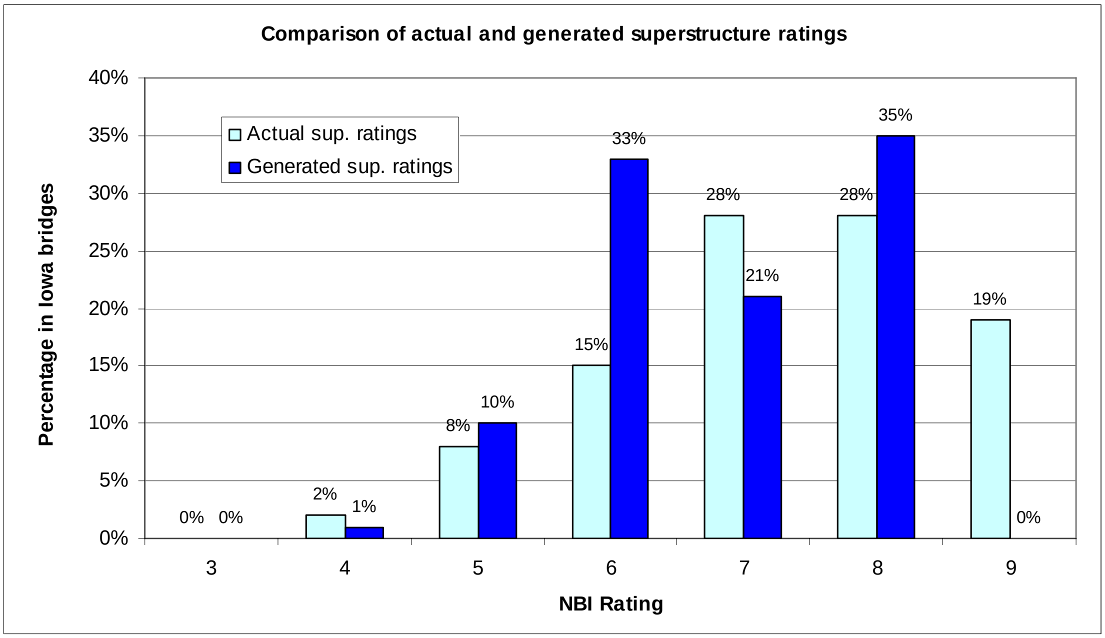

Figure 3. Comparison of actual and generated superstructure ratings

For the substructure ratings, once again, the NBI Translator algorithm tends to estimate lower values than the actual assigned ratings (Fig. 4). The percentages of 4, 5, and 6 ratings are very close for substructures. However, approximately 45% of the actual ratings that are equal to 8 and 9 are lost in the generated ratings.

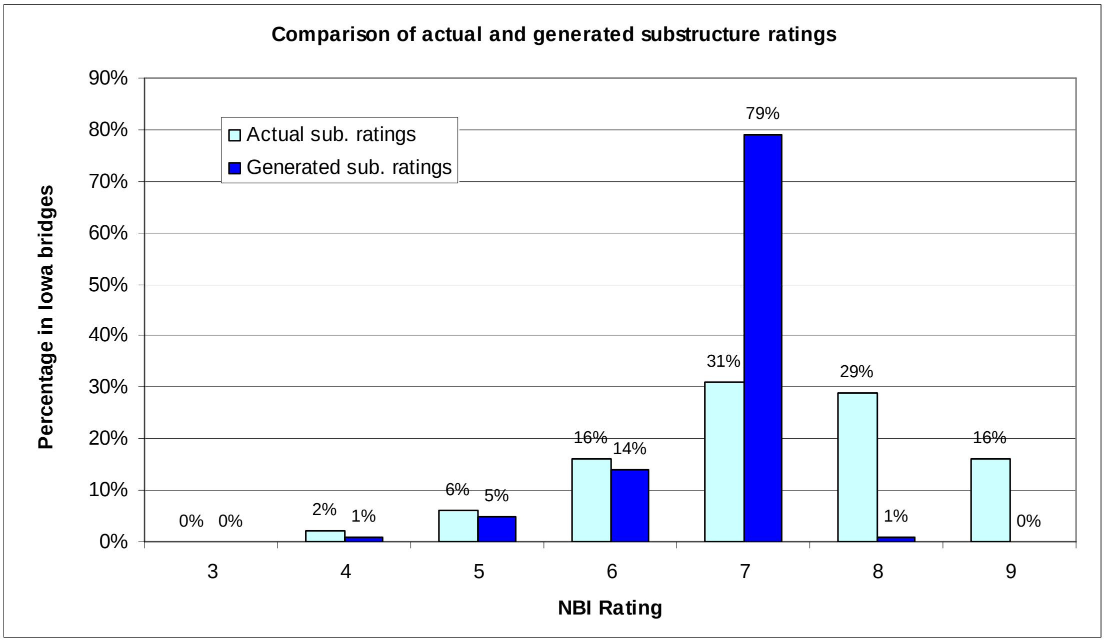

Figure 4. Comparison of actual and generated substructure ratings

For culverts, the algorithm generates 20% more 8 ratings, 22 % more 7 ratings, and 19 % fewer 6 ratings than the actual case. Once again, no 9 rating is generated by the algorithm (Fig. 5).

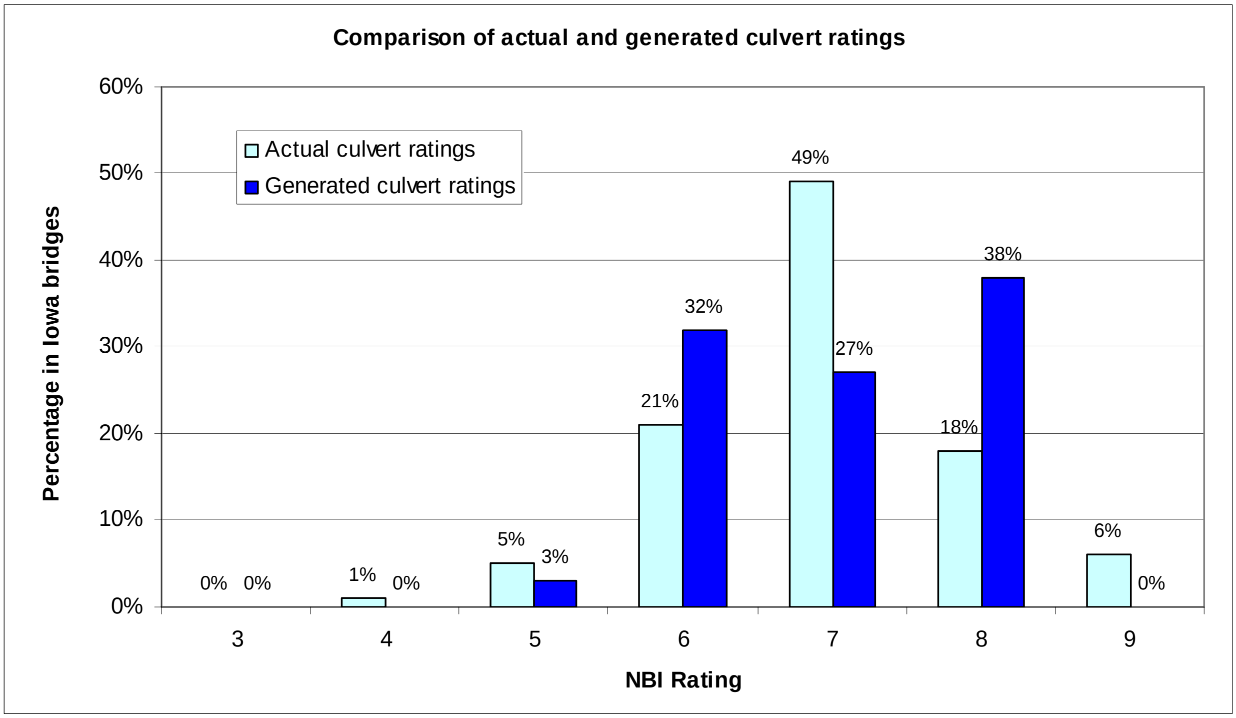

Figure 5. Comparison of actual and generated culvert ratings

CONCLUSION

This research paper reviewed bridge condition data and management in the United States and focused particularly on the estimation of NBI ratings from already collected bridge element condition data. The best-known algorithm for the purpose, which is also available within the most popular bridge management software in the United States was investigated and evaluated by a case study for Iowa bridge data.

The results of the statistical comparison for Iowa bridges showed that the generated ratings by NBI Translator algorithm with its current configuration are not representative of the actual NBI ratings. The results are supporting the concerns on the efficiency of the algorithm that have been previously reported. A more customized model for Iowa can lead to a more sufficient model. Using mapping constants specific to only Iowa bridge data instead of using the mapping constants calibrated with the data from 11 different states while creating the translator algorithm may be an option. An improved and more customized algorithm may yield better estimates of NBI ratings. A follow up to another study in the literature, an artificial neural network model can be developed for Iowa as another future research alternative. The current NBI rating system is prone to variation from the subjectivity of inspector decisions. An ultimate rating system based on more objective element condition data would result in a more consistent evaluation for the bridges in the states.

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