Developing Implementation Strategies for Risk Based Inspection
Progress Report – 1/8/2024

Project Number: TR201910

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Co-PI(s): Henry Brown

Award date:	11/1/2018		
Scheduled completion date:	**3/31/2024**	**% of project completed to date:**	**90%**
Total budget:	$850,000	**% of budget expended to date:**	**85%**
Draft report due:	8/31/2023	**Final report due:**	10/31/2023

Dates should match those listed in the contract. If unsure, contact your MoDOT project manager.

Noteworthy items achieved this quarter. *Provide a 4-5 sentence summary of work completed this quarter. Include meetings, work plan status, significant progress, etc. Additional details can be included in "Additional project information" below.*

During this quarter, the primary activities included developing an effective methodology for analyzing the back-casting results, work toward completing the back-casting report, and preparing appendices for the final report. Additional research to determine the probabilities of different attributes in the risk models was completed to support Monte Carlo (MC) simulations. The analyis of back-casting results for individual components was analyzed statistically and compared with MC simulations in order to develop systematic process for "calibrating" the risk models developed by Reliablity Assessment Panels (RAPs). A section for the back-casting report that analyzes the new NBIS requirements as compared with results from back-casting and MC simulations was developed. In summary, this section of the report links the research to practical implementation within the constraints of the new NBIS rules. Sensitivity studies that assess the effect on the risk models of weighting individual attributes were completed to provide a methodology for calibrating the risk models to obtain results consistent with the NBIS requirements. The process for analyzing the risk models and the back-casting results has been very challenging, but an effective methodology has finally been developed after multiple unsuccessful attempts. Additional information on the procedure is provided below and is being detailed for the back-casting report. See additonal information below.

Anticipated work for next quarter. *Provide a 4-5 sentence summary of work planned for next quarter.*

The research team is focused on documenting the results of the research into a back-casting report that details the analysis of the risk models when applied to actual bridges and compiling a final report that documents the results of all of the research.

Identify any circumstances or issues that may need to be addressed. *Provide a summary of issues that are important for the TAC to know. For example, staffing difficulties or supply chain delays.*

The research progress met a challenge with the back-casting step of the process and related tasks in the research. A significant effort was required to develop an effective strategy and analysis methodology, to test that methodology, and compare results with NBIS requirements. The process took much longer than anticipated. Significant progress was made in the last quarter, and the research team is documenting the research results at this time.

Deadline for next deliverable. *For example, quarterly report, draft report, presentation, etc.*

The due date for a back-casting report was October 31, 2023. The back-casting report is currently being completed and will be submitted in the first month of 2024. The revised date is shown below.

Back-casting report **1/31/2024**

Additional project information that MoDOT and technical committee should know.

The analysis from the back-casting of 60 sample bridges was substantially completed in this quarter, with the results developed for all individual components being analyzed with appropriate weights for attributes. Detailed information is included in the back-casting report currently being completed, but some results are shown here to illustrate the progress in the project.

The weighting of the risk models developed by the Reliability Assessment Panels (RAPs) has been studied in a number of different ways, with the final methodology being developed that utilizes a Monte Carlo (MC) simulation to estimate the potential outcomes of a given risk model such that the weighting of the model can be tested/measured and the results of implementing the RBI model can be demonstrated.

Statistical analysis was conducted on the results from the back-casting, and those results provide actual results from real bridges. In this way, the back-casting results provide a verification of MC simulations. A bridge owner can use the MC simulations to determine the likely results from a risk model, and the back-casting statistical analysis has shown these results are effective when applied to actual bridge components. In this way, the risk model results can be summarized and demonstrated for various purposes, for example, determining how the model's attributes should be weighted, or demonstrating the effectiveness of the model as compared with NBIS requirements regarding extended intervals for RBI. This is a key element that has been elusive in the research.

For example, risk models were developed for spalling and delamination in a bridge deck, corrosion/section loss in a steel superstructure, etc. by the individual RAPs, each with their own analysis of attributes and criteria for the attributes. Based on the attributes and criteria provided by the RAP, these risk models were applied to the subject components (i.e., deck, superstructure, substructure) from the sample bridge population to determine the resulting risk score. Weighting of the attributes was guided by sensitivity studies of the data from sample bridges, and the interaction of the risk model results with the new NBIS requirements. Details of this process are documented in the back-casting report and an example of the results is shown below.

Figure 1A shows the results from applying the risk models to actual bridges. The figure shows statistical data, namely the cumulative probability distribution for the data, based on the mean and standard deviation from the sample of 60 bridge **decks** with six different risk models from RAPs applied (10 bridges for each RAP model). Separate curves are shown for decks with condition ratings (CRs) of CR 7, CR 6, and CR 5. For each CR, two curves are shown. The solid line show results from the risk models developed by the RAPs with the original scoring, and the dashed line show results that have been weighted to increase the proportion of the model stemming from condition assessment data. Focusing on the CR 7 bridges (noting that NBIS requirements only allow a 72-month interval for bridges in “good” condition) the data shows that ~54% of CR 7 bridge decks would be expected to be rated with *remote* likelihood in an unweighted model and ~72% would be rated with *remote* likelihood when the model is weighted.

Figure 1B shows the MC results based on the RAP model from one state. These curves are similar to those in Figure 1A, but were determined from a MC simulation for bridge decks in one state. The MC simulation is based on the bridge inventory data from the subject state. Data from NHS bridges with element-level inspection results were used to determine, for example, the probability of a CR 7 deck having element-level inspection results indicating more the 5% of the deck in CS 3. Probability estimates were made for each of the 9 attributes, based on either element-level inspection results, data from the National Bridge Inventory, or estimates based on engineering judgement. The results from the MC simulation are very similar to the results from actual decks shown in figure 1A. The results would not be expected to match, since figure 1A is from real bridges from different states with different risk models from the individual RAPs, and figure 1B is based on a single state’s RAP model and inventory data, but the curves show similar trends. Again focusing on CR 7 bridges, figure 1B shows the effect of increasing the weight of condition attributes to increase the proportion of CR 7 bridges that would be ranked as having *remote* likelihood. Similar analysis can be completed to test the sensitivity of the models to different criteria and attributes weights for any of the attributes.

The data in both figures illustrate that CR 6 bridge are generally rated in the *low* or *moderate* range. Noting that components in CR 6 are eligible for 48-month intervals under Method 1 of the new NBIS without additional FHWA approval, this provides some target ranges when considered against the data from actual decks (Figure 1A) and from MC simulations (Figure 1 B). In this way the analysis and risk models can be demonstrated in comparison with NBIS requirements and the framework of the Method 1 criteria in order to gain insight into the results that should be expected from a Method 2 analysis.

It should be noted here that almost all the data used in the analysis is already available for NHS bridges; non-NHS bridges would need to have an estimate of the condition state data obtained from inspection notes or other means. Otherwise, the majority of the data used is already available from existing bridge files. The MC simulations were completed using a data array function in Microsoft Excel, so the procedure is accessible and practical to apply. The results are data-driven largely from existing data such that the analysis procedure can be integrated into existing asset management frameworks.

The analysis of the data and modeling have been compared to the new NBIS requirements to develop target ranges for calibrating the risk models that are consistent with the new policies. An analysis of the new NBIS requirements is included in the upcoming report, along with recommendations regarding implementation of RBI within those requirements when considering the results from real bridges provided by the back-casting and the MC simulation results.

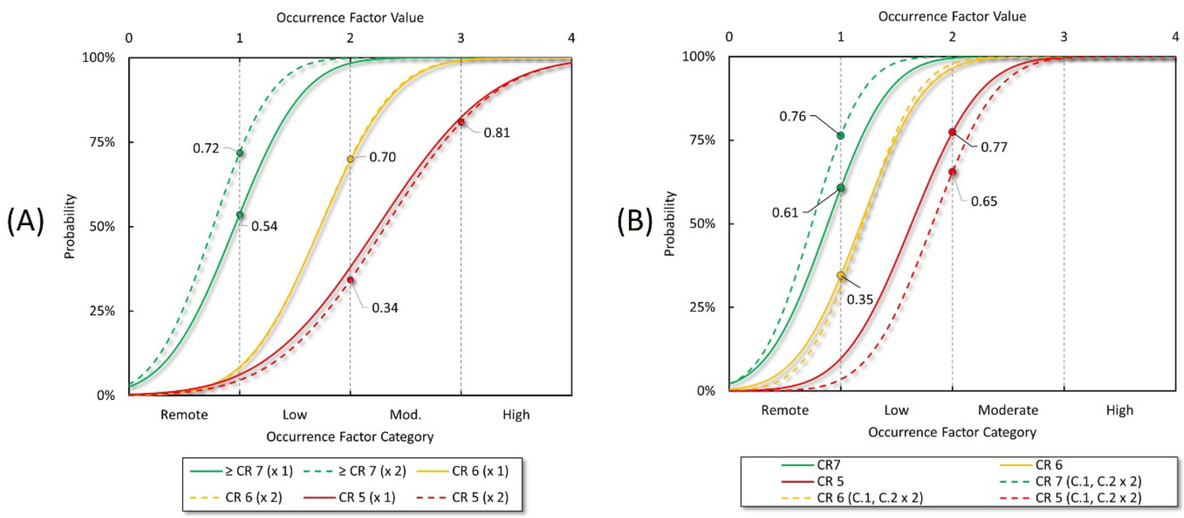

Figure 1. Results from back-casting (A) and Monte Carlo simulations (B) for bridge deck components.