Appendix B

Bridge Investment Analysis Methodology

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The National Bridge Investment Analysis System (NBIAS) was developed over the past 15 years as a tool for assessing national bridge investment needs and the trade-off between funding and performance. NBIAS, first introduced in the 1999 edition of the C&P report, is used to model investments in bridge repair, rehabilitation, and functional improvements. Over time, the system has been used increasingly as an essential decision support tool for analyzing policy and for satisfying the information needs of the U.S. Congress.

The NBIAS is based on an analytical framework similar to that used in the Pontis bridge program first developed by the Federal Highway Administration (FHWA) in 1992 and subsequently taken over by the American Association of State Highway and Transportation Officials (AASHTO). It incorporates economic forecasting analysis tools to project the multiyear funding needs required to meet user-selected performance metrics over the length of a user-specified performance period. The NBIAS is modified to work with bridge condition as reported by the States for the National Bridge Inspection System as well as the element/condition State inspection regime used in Pontis. The NBIAS combines statistical models with engineering judgment and heuristic rules to synthesize representative condition units so that they can be defined and manipulated using the same structure of condition states, actions, deterioration, costs, and effectiveness probabilities used in Pontis, making them compatible with Pontis' predictive models and analytical routines.

This appendix contains a technical description of the methods used in NBIAS to predict future nationwide bridge conditions and analyze bridge investment, including information on the system overview and determination of functional needs and of repair and rehabilitation needs.

NBIAS Overview

The NBIAS is an analysis tool used to analyze the investment needs associated with bridge repair, rehabilitation, and functional improvements. The system can be used to examine the backlog of needs, in dollars and number of bridges; distribution of work done, in dollars and number of bridges; agency and user benefits; benefit-cost ratios for work performed; and physical measures of bridge conditions. Outcomes can be presented by type of work, functional classification, whether the bridges are part of the National Highway System, and/or whether the bridges are part of the Strategic Highway Network.

Using the linear programming optimization of elements in the network, NBIAS generates a set of prototype maintenance policies for defined subsets of the Nation's bridge inventory. Models of element deterioration, feasible actions, and the cost and effectiveness of those actions are incorporated as major inputs for each subset of the inventory.

For functional deficiencies and improvements, NBIAS uses a model similar to the bridge level of service standards and user cost models of Pontis augmented by a bridge improvement model developed by Florida Department of Transportation (DOT).

Methodology

With a set of synthesized projects developed from the maintenance and functional improvement models, NBIAS calculates a trade-off structure showing the effect of hypothetical funding levels on each of more than 200 performance measures. For this analysis, it utilizes an adaptation of an incremental benefit-cost model

with a graphical output showing the trade-off between funding and performance. To estimate functional improvement needs, NBIAS applies a set of improvement standards and costs, which can be modified by the user, to each bridge in the National Bridge Inventory (NBI). The system uses the available NBI data to predict detailed structural element data for each bridge. The system measures repair and rehabilitation needs at the bridge element level using the Markov decision model and then applies the obtained maintenance strategy, along with the improvement model, to each individual bridge.

Determining Improvement Costs

The replacement costs for structures are determined based on State-reported values provided by the FHWA. Improvement costs are based on default costs from Pontis adjusted to account for inflation. In evaluating functional improvement needs and repair and rehabilitation needs, the system uses a set of unit costs of different improvement and preservation actions.

Determining Functional Improvement Needs

The standards for functional improvement include standards for lane widths, shoulder width, load ratings, and clearances (vertical and horizontal). The NBIAS includes a set of standards by functional class and additional standards derived from Sufficiency Rating calculations, as well as those prescribed by the models developed at Florida DOT.

The standards used in NBIAS initially were set to be the same as those specified by default in Pontis, which were established as an early effort to define level of service standards for AASHTO. The standards used in the previous editions of the C&P report were reviewed and compared with design standards in the AASHTO Green Book, and adjustments were made where warranted. A revised set of standards has subsequently been added that triggers consideration of a functional improvement whenever there is a deduction in Sufficiency Rating as a result of a lane width, load rating, or clearances. The adoption of the Florida improvement model allowed further fine tuning of the analysis logic of functional needs.

The NBIAS determines needs for the following types of bridge functional improvements: widening existing bridge lanes, raising bridges to increase vertical clearances, and strengthening bridges to increase load-carrying capacity. Functional improvement needs are determined by applying user-specified standards to the existing bridge inventory, subject to benefit-cost considerations. For instance, a need to raise a bridge will be identified if the vertical clearance under the bridge fails to meet the specified standard and if the increased cost of diverting commercial vehicles around the bridge exceeds the cost of improving the bridge.

Because the benefit predicted for a functional improvement increases proportionately with the amount of traffic, the determination of whether a functional improvement is justified and the amount of benefit from the improvement is heavily dependent upon predicted traffic. In the current version of NBIAS, traffic predictions are made for each year in an analysis period based on NBI data. The NBIAS allows the user to apply either linear or exponential traffic growth projections. Linear growth was selected for this edition of the C&P report, consistent with the assumption used in the Highway Economic Requirements System (HERS).

When NBIAS selects a structure for replacement, the cost of the replacement is based on the number of lanes on the existing bridge. The cost of adding lanes to satisfy increased capacity needs is not included in the cost to construct the replacement structure. Additional costs for expanding bridges to meet increased capacity demands are included in the cost to construct a lane-mile of highway used in the HERS model.

Determining Repair and Rehabilitation Needs

To determine repair and rehabilitation needs, NBIAS predicts the elements that exist on each bridge in the U.S. bridge inventory and applies a set of deterioration and cost models to the existing bridge inventory. This allows NBIAS to determine the optimal preservation actions for maintaining the bridge inventory in a state of good repair while minimizing user and agency costs.

Predicting Bridge Element Composition

The NBIAS analytical approach relies on structural element data not available in the NBI. To develop this data, NBIAS uses a set of Synthesis, Quantity, and Condition (SQC) models to predict the elements that exist on each bridge in the NBI and the condition of those elements.

The current version of NBIAS has the capability to accept the direct import of structural element data where these data are available, but this capability was not used for the development of this report. While most of the States now routinely collect such data on State-owned bridges as part of the bridge inspection process, these data are not currently part of the NBI data set. It is expected that, in the future, structural element data may be provided by some or all States. It should be noted, however, that locally owned bridges may not have structural element data available. Once a mechanism is established for sharing these data, they could be incorporated in future NBIAS analyses to improve the prediction of bridge element composition.

Calculating Deterioration Rates

The NBIAS takes a probabilistic approach to modeling bridge deterioration based on techniques first developed for Pontis. In the system, deterioration rates are specified for each bridge element through a set of transition probabilities that specify the likelihood of progression from one condition state to another over time. For each element, deterioration probability rates vary across nine climate zones.

Applying the Preservation Policy

Using transition probability data, together with information on preservation action costs and user costs for operating on deteriorated bridge decks, NBIAS applies the Markov decision model to determine the optimal set of repair and rehabilitation actions to take for each bridge element based on the element's condition. During the simulation process, the preservation policy is applied to each bridge in the NBI to determine bridge preservation work needed to minimize user and agency costs over time.

Because the current version of the system models maintenance, repair, and rehabilitation needs for each bridge, the cost of performing preservation work can be compared with the cost of completely replacing a bridge. The NBIAS may determine that replacement of a bridge is needed if replacement is the most cost-effective means to satisfy the existing needs. Alternatively, if the physical condition of the bridge has deteriorated to a point where the bridge is considered unsafe (where the threshold for such a determination is specified by the system user), the system may consider bridge replacement to be the only feasible alternative for the bridge.

Expert Peer Review Panel

Peer reviews by panels of outside experts are an effective way to ensure that the methodologies and analytical tools used in the C&P report continue to meet acceptable standards of technical merit. Under the Office of Management and Budget's *Final Information Quality Bulletin for Peer Review,* such reviews are also required for any "highly influential scientific disseminations," a category that includes the C&P tools used for analyzing highway and bridge investments, HERS and NBIAS.

Both HERS and NBIAS have been subject to ongoing updates since their initial development. To ensure that significant conceptual changes in the models are scientifically sound, the FHWA periodically subjects the models to technical reviews by panels of outside experts. This vetting process is beneficial, providing feedback and helping to point the way for future research, as well as establishing the credibility of the models within the transportation community. A technical review focusing on the construction cost inputs applied in both models was conducted in 2009.

The review panel included a mix of State practitioners, university researchers, and consultants, with different areas of relevant expertise including highway and bridge engineering and construction, economics, and asset management. The panelists were asked to consider their recommendations and suggestions within the context of four focus areas:

- Review of Cost Data Currently Being Used in HERS and NBIAS
- Recommendations for Determining Cost Factors in the Future
- Consideration and Input on Adjusting the Cost Factors in the 2010 and 2012 C&P Reports
- Long-Term Approaches for Developing Cost Data for the C&P Report.

Some of the key recommendations of the panel regarding NBIAS were as follows:

- Unit cost inputs should be updated more frequently to account for changes in relative costs.
- The costs of risk mitigation activities should be included.
- The potential to measure costs on a bridge component level should be explored.
- A study should be conducted to gather construction cost data from States to estimate unit costs.
- The NBIAS software should be adapted to analyze culverts.

The final report of the panel will be made available at http://www.fhwa.dot.gov/policy/otps/index.htm.