Appendix B

Bridge Investment Analysis Methodology

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The National Bridge Investment Analysis System (NBIAS) was developed over the past 12 years as a tool for assessing national bridge investment needs and the tradeoff between funding and performance. NBIAS, first introduced in the 1999 edition of the C&P report, models investments in bridge repair and rehabilitation and functional improvements. Over time the system has seen increasing usage as an essential decision support tool for policy analysis and for satisfying the information needs of the U.S. Congress.

NBIAS is based on the same analytical framework as the Pontis bridge program first developed by the Federal Highway Administration (FHWA) in 1989 and subsequently taken over by the American Association of State Highway and Transportation Officials (AASHTO). AASHTO now owns and licenses Pontis to over 50 State transportation departments and other agencies.

Pontis provides the bridge engineer with the tools to conduct detailed analysis of the performance of bridges. In order to perform analysis at such a detailed level, Pontis requires data on over 100 elements pertaining to each individual bridge.

NBIAS incorporates economic forecasting analysis tools to provide budget and planning staff with the ability to forecast the multiyear funding needs required to meet user-selected performance metrics over the length of a user specified performance period. 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. NBIAS contains heuristics to synthesize representative projects 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, determination of functional needs, determination of repair and rehabilitation needs, and planned improvements to future versions of the system.

NBIAS Overview

The NBIAS is an investment analysis tool used to analyze bridge repair, rehabilitation, and functional improvement investment needs. 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; aggregate 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 network optimization of Pontis, NBIAS generates a set of prototype maintenance policies for defined subdivisions 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 subdivision of the inventory.

For functional deficiencies and improvements, NBIAS uses a model essentially similar in structure to the bridge level of service standards and user cost models of Pontis. This analysis is performed at the bridge level but is reported only at aggregate levels for Federal policy-making.

Methodology

With a set of synthesized projects developed from the maintenance and functional improvement models, NBIAS calculates a tradeoff structure showing how hypothetical funding levels may affect each of more than 50 performance measures. For this analysis it utilizes an adaptation of the same incremental benefit-cost model used in Pontis, with a graphical output showing the tradeoff between funding and performance. This graphical output and other network-level reports then become the basis of information presented to policy makers and the U.S. Congress.

To estimate functional improvement needs, NBIAS applies a set of improvement standards and costs that can be modified by the system 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 then measures repair and rehabilitation needs at the bridge element level using a Markov modeling, optimization, and simulation approach and default models derived from Pontis.

Determining Improvement Costs

The replacement costs for structures are determined based on State-reported values provided by FHWA. Improvement costs are based on default costs from Pontis adjusted to account for inflation.

Determining Functional Improvement Needs

The standards for functional improvement include standards for lane widths, shoulder width, load ratings, and clearances (vertical and horizontal). NBIAS includes a set of standards by functional class, and additional standards derived from Sufficiency Rating calculations.

The standards used in NBIAS were initially set to be the same as those specified by default in Pontis, which were established as an initial 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 to design standards in the AASHTO Green Book and adjustments were made where warranted. A revised set of standards added in the most recent version of the NBIAS trigger 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 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 to be consistent with the assumption used in the Highway Economic Requirements System (HERS), as discussed in Chapter 9. This approach assumes that the rate of traffic growth will decline over the course of the period being analyzed and is intended to provide more accurate estimates of benefits from functional improvements.

In evaluating functional improvement needs (as well as repair and rehabilitation needs discussed in the next section), the system uses a set of unit costs of different improvement and preservation actions.

Determining Repair and Rehabilitation Needs

To determine repair and rehabilitation needs, NBIAS predicts what elements 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. The following paragraphs discuss major aspects of the repair and rehabilitation modeling approach.

Predicting Bridge Element Composition

The NBIAS analytical approach relies on use of structural element data not available in the NBI. In order to develop this data, NBIAS uses a set of Synthesis, Quantity, and Condition (SQC) models to predict what elements 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, local-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 uses 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.

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 modeling approach from Pontis to determine the optimal set of repair and rehabilitation actions to take for each bridge element based on the condition of the element. 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.

Recent NBIAS Enhancements

Through participation in various professional organizations and National committees and from exposure to information while attending national conferences, FHWA staff began to question whether several, if not all, States using the Pontis software had modified the criteria to reflect their individual situations; and, if these State Departments of Transportation (DOTs) had modified the criteria, was the selected criteria acceptable for use in analysis at the national level. It was decided that since the NBIAS analysis was based on the default criteria and conditions developed for Pontis, any change in these criteria by State DOTs should be reviewed and evaluated to determine if the NBIAS default criteria should be modified. In addition, recommendations resulting from the review process described in the Appendix B of the 2006 C&P report were considered for inclusion in the next version of NBIAS.

Based on the research results, six enhancements were made to NBIAS. These are described in the following text.

1) Element, State, and Environmental Definitions

The review of the practices of several States indicated that many had modified the default values provided in Pontis to reflect the conditions existing in their States. The modifications provided a more accurate and useful measure of the performance, over time, of bridge elements. In addition, the modifications took into consideration the climate in different regions of the Nation.

2) Climate Zones and Deterioration Models

The latest version of NBIAS now supports deterioration models for the nine climate zones as defined in the Highway Performance Monitoring System (HPMS). The modification to support nine climate zones was one of the recommendations resulting form the review process.

3) Action Effectiveness

An action is defined as a maintenance activity, rehabilitation work, or some other activity applied to a structure to extend the useful life of the structure. The relative effectiveness of an action is the degree to which the action extends the useful life of the structure.

The relative effectiveness of multiple actions was reviewed to determine if it would be beneficial for NBIAS either to vary action choices by climate zone or to establish one set of actions at a national level but allowing variance when sufficient data from States within a region supporting the variance is available. The research concluded that the choice of an action is not dependent on the environment but on DOT maintenance policy. Therefore, it was decided NBIAS would support the second option.

4) Failure Cost

The selection of elements and materials used in bridge design is influenced by traffic demands. A study was conducted to model average traffic conditions experienced by each bridge element and to determine the average deck area of bridges containing each kind of element. These were instrumental in developing user failure costs by bridge deck type. An example of the results of this study indicated the unit user failure cost for a bridge with a timber deck is much lower than for a bridge with a concrete deck. Timber decks appear primarily on small bridges on low volume roads, while concrete decks are on larger bridges located on high volume roads. Updated failure costs based on this relationship were developed and provided for NBIAS.

5) Functional Improvement Model

NBIAS requires a variety of input to support the functional model analysis. This input comes from a variety of sources including level of service standards; design standards; unit costs; truck height and weight histograms; an accident risk model; and unit user costs of travel time, vehicle operation data, and accident data.

Many of these inputs have been developed for and are included in NBIAS. Two items recommended for addition to NBIAS were truck height/weight histograms and an accident risk model based on research conducted by the Florida DOT. The models generated from this work more closely reflect actual conditions. These enhancements were successfully tested and incorporated in the latest version of NBIAS.

6) Preservation Unit Costs

The unit costs for construction and maintenance activities for bridges were updated in the latest version of NBIAS. The preservation costs were derived during development of improved default preservation models based on additional research. NBIAS adjusts the preservation costs using State-specific cost coefficients calculated from the replacement cost data.

7) Value of a Statistical Live

The value of a statistical life was updated from $3.4 million to $5.8 million, consistent with a recent change in U.S. DOT guidance for benefit-cost analysis.