APPENDIX B

Bridge Investment Analysis Methodology

Bridge Investment Analysis Methodology

The National Bridge Investment Analysis System (NBIAS) was developed for assessing national bridge investment needs and the trade-off between funding and performance. NBIAS, first introduced in the 1999 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 providing information to 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. NBIAS extends the Pontis element model by introducing the climate zone dimension into the stratification scheme and adding user cost components into the cost model. Effective in version 4.0 (2011), NBIAS also features an enhanced element optimization model that integrates selected maintenance policies.

General Methodology

Using linear programming optimization, 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 the Florida Department of Transportation (DOT).

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.

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. State-specific cost adjustment factors are applied to the unit costs.

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 by 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 road width, load rating, or clearances. The adoption of the Florida improvement model allowed for 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 stream of discounted increased cost of diverting commercial vehicles around the bridge exceeds the cost of improving the bridge.

If functional improvement is infeasible due to the bridge design or impractical because of its inferior structural condition, then the replacement need for the bridge is determined. Replacement need may also be identified if a user-specified replacement rule is triggered. For example, it is possible to introduce in NBIAS one or more replacement rules based on the threshold values of age, Sufficiency Rating, and Health Index.

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 demands 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 synthesis part of the SQC model is implemented as the decision tree, in which the choice of the elements for a bridge is dictated by its design, material, and several other characteristics available in the NBI. Element quantities are evaluated based on the geometric dimensions of the bridge, its design, and material. The condition of the synthesized elements is modeled in the form of percentage-based distribution of element quantities across condition states. Such distributions are evaluated based on the structural ratings (superstructure, substructure, and deck) of the bridge to which the statistically tabulated lookup data and Monte Carlo simulation are applied.

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.

MAP-21 requires the use of element-level data to analyze the performance of the bridges on the National Highway System (NHS). All other bridges will have the minimum data recorded and will require element-level data to be generated. Therefore, bridges on the NHS with detailed data will be combined with bridges with generated element data. This will require NBIAS to conduct analysis using a database containing bridges with detailed element information and bridges with generated detained information.

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.

Forming of the Optimal Preservation Policy

The policy of maintenance, repair, and rehabilitation (MR&R) of NBIAS is generated with the help of two optimization models: long-term and short-term. The long-term model is formulated as a linear problem with the objective of keeping the element population in a steady-state condition that requires the minimum cost to maintain. The short-term model, not being concerned with the steady state, seeks to find such prescription of remedial actions for condition states that minimize the subsequent costs of the actions including the discounted future costs. The short-term model of MR&R is implemented as the Markov Decision Model solved as a linear programming problem.

In the previous versions of NBIAS, only one MR&R strategy was available. In the course of the development of the NBIAS version 4.0, a study was conducted to develop alternative MR&R models. The result was the development of three additional MR&R strategies reflecting more diverse approaches to the maintenance of a bridge network.

Minimize MR&R Costs

This strategy involves identifying and implementing a pattern of MR&R improvements that minimizes MR&R spending. This model was adopted from Pontis, and used for the NBIAS analyses presented in all previous editions of the C&P report. This strategy is intended to prevent a catastrophic decrease in bridge network performance rather than to maintain or improve the overall condition of the bridge network. Some Pontis users and participants on expert peer review panels for NBIAS had raised concerns that this strategy was not consistent with typical bridge management strategies, and that following such a strategy may advance the point in time when a bridge would require replacement than might be the case if a more aggressive MR&R approach were utilized.

One of the side effects of having initially built this strategy as the only MR&R option in NBIAS was that most measures of bridge performance (such as the health index or sufficiency rating) would always get worse over the 20-year analysis period, even if all the potential bridge improvements identified as NBIAS as cost-beneficial were implemented. The exception was the estimated backlog of bridge needs, which is why this report has focused on that metric in the past. The estimated backlog is affected by the MR&R strategy; assuming a less aggressive MR&R strategy reduces the estimate of the MR&R backlog but increases the estimate of the bridge replacement backlog, generally resulting in a higher combined backlog estimate.

Maximize Average Returns

This strategy seeks to maximize the degree of bridge system performance improved per dollar of MR&R expenditure. Following this strategy results in more MR&R spending than under the Minimize MR&R strategy, but still generally results in deterioration in bridge performance over time.

State of Good Repair

This strategy seeks to bring all bridges to a relatively high condition level that can be sustained via ongoing investment. MR&R investment is front-loaded under this strategy, as large MR&R investments would be required in the early years of the forecast period to improve bridge conditions, while smaller MR&R investments would be needed in the later years to sustain bridge conditions.

This strategy would be optimal from a theoretical perspective if sufficient funding were available to implement it, but the high level of investment funds required in the initial years would make it challenging to follow this strategy given real-world financial constraints.

Sustain Steady State

This strategy involves identifying and implementing a pattern of MR&R improvements that would reach and achieve an improved steady state in terms of overall bridge system conditions, without frontloading MR&R investment. Following this strategy results in more MR&R spending than under the Maximize Average Returns strategy, but less than under the State of Good Repair strategy.

This Sustain Steady State strategy appears to be more consistent with current bridge agency practices than the other three strategies considered by NBIAS, and has been adopted for use in the baseline analyses presented in Chapters 7 and 8 of this report.

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.

In analyzing potential improvement options, the NBIAS compares the cost of performing preservation work with the cost of completely replacing a bridge, to identify situations where replacement is more cost effective. If the physical condition of the bridge has deteriorated to the point where it 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.