APPENDIX B: Bridge Investment Analysis Methodology

Bridge Investment Analysis Methodology

The National Bridge Investment Analysis System (NBIAS) is an investment analysis tool developed by the Federal Highway Administration (FHWA) to assess national bridge investment needs and evaluate the tradeoff between funding and performance. First introduced in the 1999 Conditions and Performance Report (C&P Report), NBIAS models the improvement needs of the more than 600,000 highway bridges in the National Bridge Inventory (NBI) and allows for the simulation of various investment scenarios. 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.

This appendix contains a brief overview of NBIAS, a technical description of the methods used in NBIAS to predict future nationwide bridge conditions and investment scenarios, and information on planned improvements to future versions of the system.

Overview

NBIAS is a software application that consolidates data from the NBI and other sources and incorporates economic forecasting analysis tools to estimate multiyear bridge repair, rehabilitation, and construction needs under multiple scenarios and budget constraints. It has multiple analytical capabilities and can be used to examine:

- Backlog of needs, in dollars and number of bridges;
- Schedule of work to be done under various investment scenarios (in dollars and number of bridges);
- User and aggregate economic benefits;
- Benefit-cost ratios for work performed; and
- Physical measures of bridge conditions.

NBIAS estimates functional and investment needs for bridges in the NBI through a combination of statistical models, engineering principles, and heuristic rules. Its analysis considers needs such as expansion (widening existing lanes), enhancement (raising or strengthening bridge structure), rehabilitation (maintenance and repair), and replacement. The system incorporates economic forecasting tools to project the multiyear funding needs required to meet user-selected performance objectives over the length of a user-specified performance period.

General Methodology

NBIAS analyzes each bridge in the NBI for each year in a multiyear analysis period through a program simulation model. The model simulates deterioration, traffic, preservation needs, functional needs, and costs. Outcomes can be grouped by type of work performed (i.e., maintenance, repair, widening), bridge functional classifications, bridges within the National Highway System, or bridges that are part of the Strategic Highway Network. Multiple financing scenarios can be run to better understand the impacts on overall bridge conditions of different budget constraints and investment approaches.

As illustrated in *Exhibit B-1*, the overall NBIAS approach can be summarized as follows:

- Data on the number, location, physical conditions, and traffic for the 600,000 highway bridges are pulled in from the NBI;
- Cost estimates for individual bridge elements and user parameters are pulled in from other FHWA sources;
- Deterioration algorithms for bridge elements are applied;

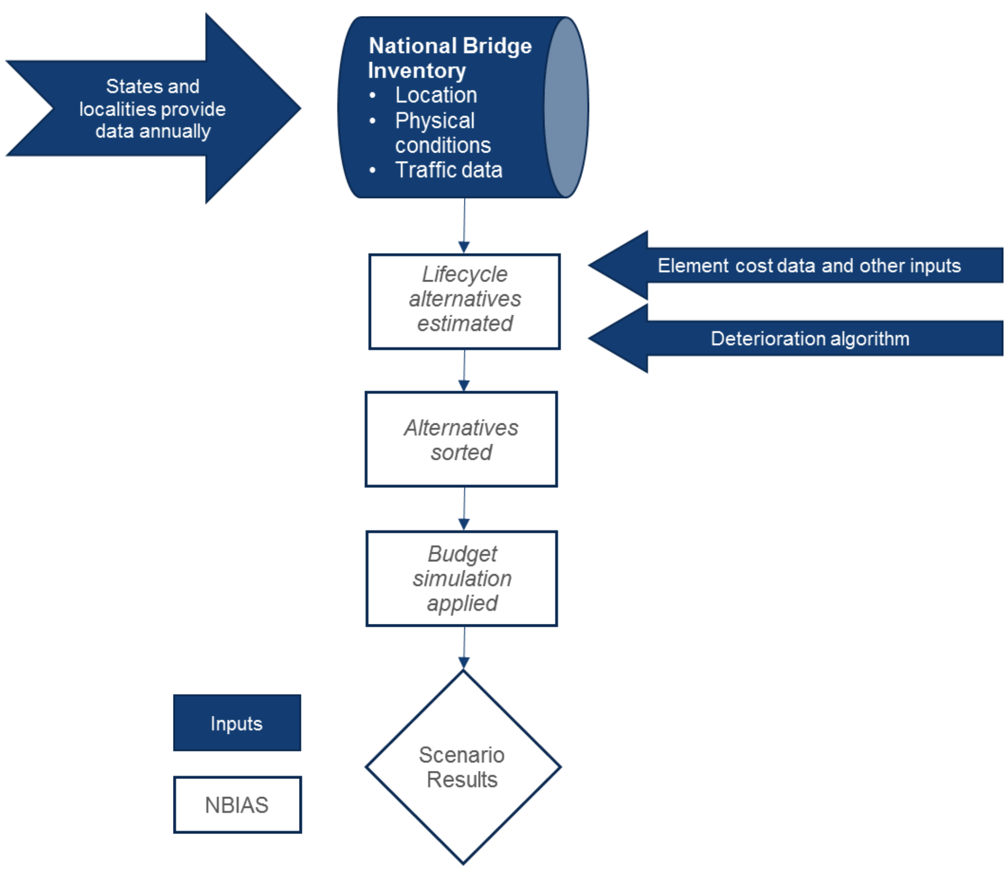
- Needs and estimates of alternative investment approaches for repair, rehabilitation, or replacement are estimated (based on the compiled data regarding conditions, projected deterioration, and cost estimates), and then sorted based on the performance implications of the different approaches along with their benefit-cost ratios;
- Budget constraints are applied to the set of bridges being analyzed; and
- Scenario results are presented for analysis.

When estimating bridge needs, NBIAS draws on the reported bridge conditions ratings to assess the condition of each bridge's elements and considers what changes are needed for those elements (see the "Bridge Element Data" box in Chapter 6 for more information on bridge elements in the NBI). NBIAS then assesses whether repairs or replacement of individual elements are needed, or if functional improvements—such as widening existing lanes and shoulders, increasing vertical or horizontal clearances, and strengthening (to carry heavier loads)—would be required.

NBIAS allows for multiple user-specified budget constraints. Users can set (1) a range of constant budgets, which directs the software to find the performance levels achievable with each budget level within the range; (2) a range of budget growth rates; or (3) a minimum benefit-cost ratio, in which case the software determines the funding level corresponding to that benefit-cost ratio.

Once data are updated and the budget constraint applied, NBIAS calculates a tradeoff showing the effect of hypothetical funding levels on multiple performance measures using an adaptation of an incremental benefit-cost model.

Exhibit B-1 ■ Overview of NBIAS Approach

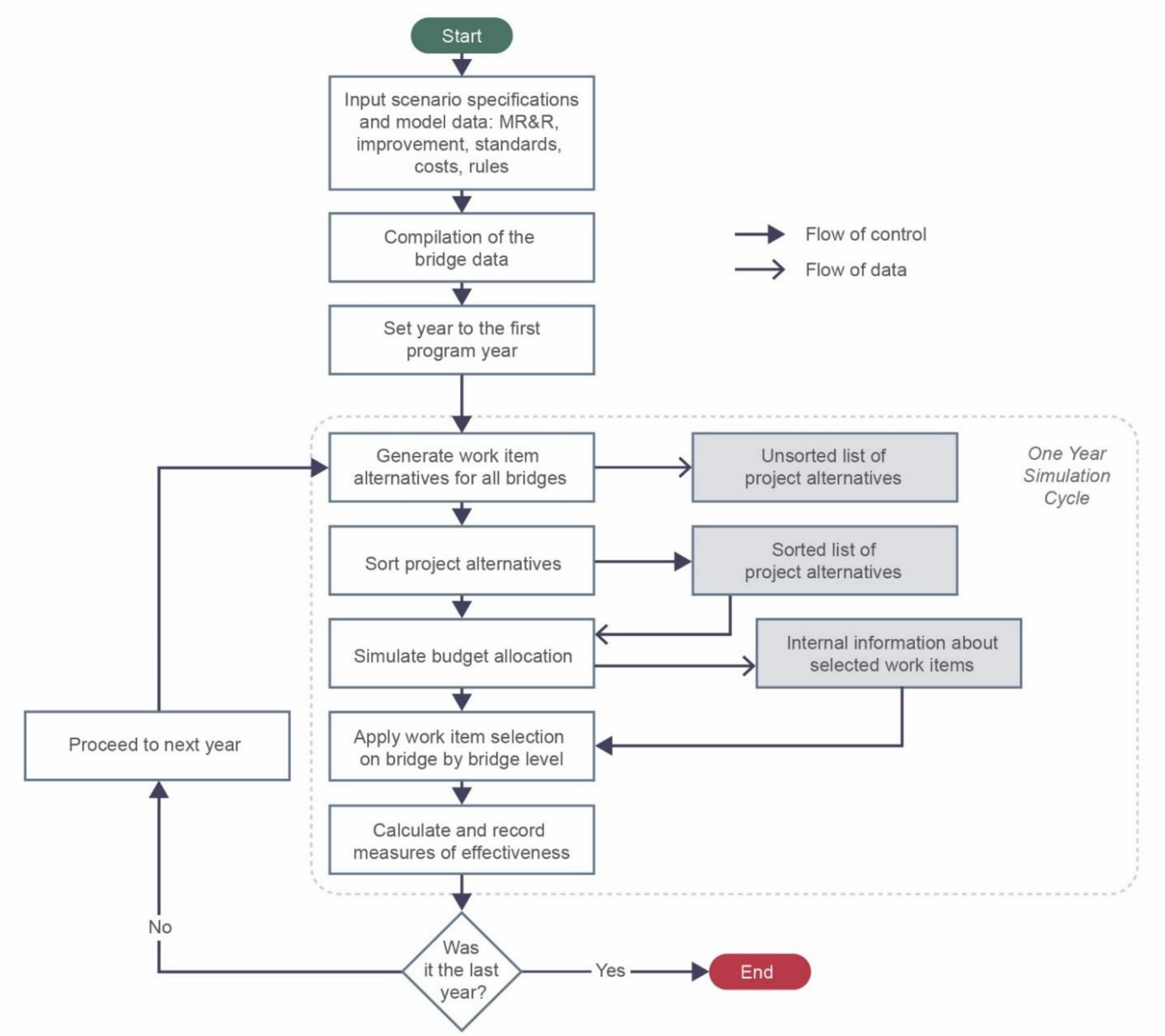


Note: NBIAS is National Bridge Investment Analysis System.

Exhibit B-2 is a more detailed flow chart of the series of steps in the NBIAS modeling and decision-making approach, performed for each year of the analysis period. The process begins with specifying scenarios and model data, compiling the bridge data, and then conducting multiple one-year simulation cycles. Models of element deterioration, feasible actions, and the cost and effectiveness of those actions are incorporated as major inputs into the analysis. Each simulation includes generating potential work, sorting the list of project alternatives, allocating the available budget, and simulating the results of the budget allocation.

Once the set of needs is established, the list of needs is sorted in decreasing order of incremental benefit-cost ratio (IBCR) of each alternative relative to the next cheaper alternative.[143] Projects are selected from that sorted list until the available budget is expended. This approach is repeated for each year of the analysis period, which may be up to 50 years.

Exhibit B-2 ■ NBIAS Program Simulation Steps



Note: NBIAS is National Bridge Investment Analysis System.

[143] The IBCR is essentially calculated by determining the differences in benefits and costs between two alternatives and then calculating the ratio of the equivalent worth of incremental benefits to that of incremental costs.

Bridge Data, Conditions, and Analysis Parameters

Before NBIAS can begin modeling bridge needs or any improvement scenarios, values for key inputs are needed. NBIAS must pull data on bridges and updated information costs for repairs and replacements and deterioration algorithms as needed. These key building blocks are discussed below.

Data on Bridge Inventory, Characteristics, and Cost

The NBIAS analyses presented in the 24th C&P Report build off the NBI database. The NBI covers nearly 600,000 bridges on public roads, including Interstate highways, U.S. highways, State and county roads, and publicly accessible bridges on Federal lands. Any bridge more than 20 feet long used for vehicular traffic is included in the inventory. The NBI includes identification information, bridge types, operational conditions, geometric data, and inspection data. States and localities submit data annually regarding the number, location, and general condition of their highway bridges.

Element-level cost data are pulled into NBIAS from other FHWA sources and incorporate a set of unit costs for various improvement and preservation actions. Replacement costs for structures are determined based on State-reported values gathered by FHWA. Improvement costs are adjusted to account for inflation.

Predicting Bridge Element Composition

Although the NBIAS uses NBI data to summarize and analyze the bridge inventory and overall conditions, it goes another level deeper in its analysis by evaluating bridges at the element level (e.g., deck, column, pier, railing). The system estimates the type, quantity, and condition of elements that exist for each bridge in the NBI by using 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 a decision tree, in which the choice of the elements for a bridge is dictated by its design (e.g., truss, arch, suspension), material (e.g., wood, steel, concrete), and several other characteristics available in the NBI. Element quantities are estimated based on the geometric dimensions of the bridge, its design, and material. The current condition of the synthesized elements is modeled in the form of a percentage-based distribution of element quantities across condition states. Such distributions are evaluated based on the structural ratings (for superstructure, substructure, and deck) of the bridge to which statistically tabulated lookup data and Monte Carlo simulation are applied.

The current version of NBIAS can accept the direct import of structural element data when such data are available, but this capability was not used in the development of this report. States are now required to collect and report such data for bridges on the National Highway System (NHS). Many collect such data for other State-owned bridges as well as part of their bridge inspection process.

Calculating Deterioration Rates

NBIAS applies deterioration algorithms to the elements and bridges in its database. NBIAS models bridge deterioration probabilistically; 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 (the same zones as in the Highway Performance Monitoring System).

Determining Maintenance, Repair, and Rehabilitation Needs

Once NBIAS has consolidated and organized data on bridge type, quantity, conditions, usage, costs for replacement or repair, and expected deterioration for elements on all the bridges in the NBI, it estimates the needs for those bridges by element. To determine maintenance, repair, and rehabilitation (MR&R) needs, NBIAS estimates the type, quantity, and condition of the elements that exist for each bridge in the NBI by statistical means and applies a set of deterioration and cost models to the estimated elements. 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.

Forming the Optimal Preservation Policy

The policy of MR&R in NBIAS is generated with the help of long- and short-term optimization models. The long-term model is formulated with the objective of keeping the elements in a condition that requires the minimum cost to maintain. The short-term model seeks to find a policy of remedial actions that minimize the cost of moving the inventory to conditions recommended by the long-term solution.

Applying the Preservation Policy

During the simulation process, the preservation policy is applied to each bridge in the NBI to determine bridge preservation work that is needed to minimize user and agency costs over time. With a set of synthesized projects developed from the maintenance and functional improvement models, NBIAS calculates a tradeoff structure showing the effect of hypothetical funding levels on each of more than 200 performance measures, including FHWA's recently adopted measures of the percentage of bridges in good, fair, and poor condition, weighted by deck area (to facilitate aggregating data between bridges).

Different Maintenance, Repair, and Rehabilitation Strategies

The modeling of a policy for maintenance, repair, and rehabilitation (MR&R) is an important input to NBIAS and can significantly influence the results due to the number of bridge replacements identified. MR&R in NBIAS is modeled using a linear optimization solved for each combination of structural element, condition state, operating environment, climate zone, and U.S. State. The output of the optimization is a specification of what action to take in each condition state to achieve the specific policy direction (minimize life-cycle costs, maximize bridge performance). User costs (for decks) are considered and a penalty function is included that varies based on condition.

Although the bridge analyses prepared for this report use a MR&R strategy directed at bringing all bridges to a good condition, described as a State of Good Repair strategy, several MR&R strategies can be used in NBIAS:

- Minimize MR&R Costs

  This strategy involves identifying and implementing a pattern of MR&R improvements that minimize long-term MR&R spending. 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. Previously, some 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 might call for a bridge to be replaced sooner than might actually be the case.

- 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 Costs strategy, but still generally results in an increase in the number of deficient bridges over time.

- Sustain Steady State

  This strategy was used for the analyses presented in the 2013 C&P Report. It involves identifying and implementing a pattern of MR&R improvements that would 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 still generally results in increases in deficient bridges over time.

- State of Good Repair

  This strategy seeks to bring all bridges to a good condition that can be sustained via ongoing investment. MR&R investment is frontloaded under this strategy, as large MR&R investments would be required in the early years of the forecast period to improve bridge conditions, whereas smaller MR&R investments would be needed in the later years to sustain bridge conditions. This strategy is the most aggressive of the four available.

The State of Good Repair strategy, although the most aggressive, generates results more consistent with agency practices and recent trends in bridge condition than do the other strategies, and has been used in the previous two C&P reports.

(*Please note that, despite the similarity in names, the NBIAS State of Good Repair strategy and the state of good repair benchmark presented in Chapter 7 (Capital Investment Scenarios) are not the same. The state of good repair benchmark includes all investments identified as cost‑beneficial by NBIAS and includes both MR&R investments and functional* improvements.)

Determining Functional Improvement Needs

NBIAS also assesses what functional improvements would be needed for bridges in the inventory. Functional improvement needs are determined by applying user-specified standards to the existing bridge inventory, subject to benefit-cost considerations. NBIAS also includes a set of standards by functional class that are derived from sufficiency rating calculations, standards prescribed by the Florida Department of Transportation models, and previous bridge investment analysis systems. For example, raising a bridge will be identified as a bridge improvement option if the vertical clearance under the bridge fails to meet the specified standard and if the costs associated with diverting traffic around the bridge exceed the cost of improving the bridge.

NBIAS estimates needs for the following types of bridge functional improvements:

- Widening existing bridge lanes,
- Raising bridges to increase vertical clearances,
- Strengthening bridges to increase load-carrying capacity, and
- Replacement.

When other functional improvements are determined to be infeasible, a replacement need is generated. NBIAS also compares the cost of performing preservation work with the cost of completely replacing a bridge to identify situations in which replacement would be more cost effective. If the physical condition of the bridge has deteriorated to minimal tolerable conditions (the system user specifies the threshold for such a determination), the system might consider bridge replacement to be the only feasible alternative. Replacement need might also be identified if a user-specified replacement rule is triggered. For example, one or more replacement rules can be introduced in NBIAS based on the threshold values for age, sufficiency rating, and health index.

When NBIAS selects a structure for replacement, it replaces it with one of the same type and capacity, irrespective of whether added capacity is needed. Thus, the cost of adding lanes to satisfy increased capacity demands is not included in the cost to construct the replacement structure, and the benefits of added capacity are considered as a separate project—even if there would be additional benefits (or cost savings) of combining the two.

When evaluating and prioritizing various functional improvement projects, the improvement benefits increase with the projected traffic. Therefore, whether a functional improvement is justified in NBIAS depends greatly on predicted traffic. In the current version of NBIAS, traffic predictions are made for each year in an analysis period based on NBI data and national level vehicle miles traveled forecasts prepared by the Volpe National Transportation Systems Center (see Chapter 10 for details).

Future NBIAS Enhancements Currently Underway

Several enhancements are being introduced for future versions of NBIAS. Two of these enhancements relate to refining the use of budget parameters in scenario analyses. One improvement is to enable the user to assign individual budgets for specific work categories, such as maintenance, rehabilitation, and replacement of bridges in poor condition, instead of providing a single budget for all actions. This capability will enable users to consider a broader array of potential alternative future investment strategies. The second improvement will modify NBIAS to improve its ability to determine budget levels required to meet user-defined performance measures. This feature will enable users to quickly determine the annual level of funding required over a specified period to change the current value of a performance measure to a user-specified target value.

Another set of important enhancements relate to updating element specifications and refining element performance algorithms. NBIAS was developed using the AASHTO Commonly Recognized Elements specification. This standard was recently superseded by the AASHTO Manual for Bridge Element Inspection. FHWA has incorporated this specification in its requirements for submission for bridge element data for NHS bridges detailed in the Specification for National Bridge Inventory Bridge Elements (SNBIBE), and States are in the process of changing their bridge inspection practices to use the new element specifications. NBIAS is being updated to use data reported according to the SNBIBE, allowing for better incorporation of available State data and to support future use of the system. At the same time, the NBIAS element performance algorithms are being recalibrated to improve the model's prediction of various bridge condition measures. These algorithms, which were last fully recalibrated in 2006, are no longer fully consistent with current bridge management practices.

Additionally, functionality is being added to NBIAS to enable analysis of culverts. Upcoming versions of NBIAS will incorporate projections of culvert deterioration, future overall culvert conditions, and estimation of the costs of culvert maintenance and replacement.

Culverts in the NBI and NBIAS

Culverts are structures that allow water to flow under another structure such as a roadway or bridge. When multiple pipes or box culverts placed side by side below a public roadway span a total length greater than 20 feet, they are considered structures and are subject to NBI reporting requirements. Currently, data for approximately 125,000 culverts are included in the NBI.

The current NBIAS model does not contain the algorithms needed to conduct a full analysis of culverts because, unlike typical bridges, culverts do not have a deck, superstructure, or substructure. Instead, they are self-contained units located under roadway fill and typically are constructed of concrete or corrugated steel pipes. Future versions of NBIAS currently under development will incorporate the necessary algorithms and data to include culverts.