Long-Term
Bridge Performance
Program

TECHBRIEF

FHWA LTBP Bridge Performance Primer

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This document is a technical summary of the published Federal Highway Administration (FHWA) report FHWA-HRT-13-051, *LTBP Bridge Performance Primer*, which is available at http://www.fhwa.dot.gov/research/tfhrc/programs/infrastructure/structures/ltbp/pubs.cfm.

About LTBP

This research was conducted as part of the Federal Highway Administration's Long-Term Bridge Performance (LTBP) Program. The LTBP Program is a minimum 20-year research effort to collect scientific performance field data, from a representative sample of bridges nationwide, that will help the bridge community better understand bridge deterioration and performance. The products from this program will be a collection of data-driven tools including predictive and forecasting models that will enhance the abilities of bridge owners to optimize their management of bridges.

Objective

This TechBrief defines *bridge performance* and discusses the importance of measuring performance and current practices for doing so. It identifies key issues to improving performance measures and the role the Long-Term Bridge Performance (LTBP) Program plays in this effort.

Introduction

Under the LTBP Program, bridge performance encompasses how bridges function and behave when subjected to the complex and interrelated factors they face day in and day out—traffic volumes, loads, deicing chemicals, freeze-thaw cycles, rains, or high winds. Bridge design, construction, materials, age, and maintenance history also play roles in performance. It is the combination of these factors—unique for each individual bridge—that governs performance of that bridge.

Bridges are critical nodes in the highway infrastructure. A bridge with one or more elements in poor condition (exhibiting poor performance) has the potential to reduce the operating capacity of the highway system of which it is a part. Under typical service conditions, many bridges will eventually reach a state where some work is necessary to return one or more of its components to a satisfactory level of condition and/or operational capacity. Bridge work zones usually involve one or more conditions that result in disruption to efficient and economical traffic flow. These conditions include narrowed or closed lanes, live load restrictions, speed reductions, and lengthy detours. Consequently, poor bridge performance often leads to significant negative impacts on local and regional economies and environments.

Bridge managers have access to a vast knowledge base of inventory and condition data on bridges to support the tools they use in their decision-making activities. One such activity, periodically assessing bridge performance, is typically done by employing generally accepted formulas and criteria for evaluating bridge condition and health at some given point in time. In the bridge performance primer, some of these commonly used formulas and criteria are identified and discussed. Many of these performance measures were created and have served well when used for condition evaluation and distribution of funds. However, when used for research purposes, these measures do not address all the variables researchers need to evaluate. For research the shortcomings of these performance measures include a lack of ability to correlate changes in these measures over time with the underlying forces that govern performance, and to correlate performance measures with effective mitigation actions. Examples of additional data researchers are seeking are a detailed history of preservation and maintenance and repair activities accomplished on the bridge, all of which could potentially alter the path of performance over time. The primer examines the current knowledge base of bridge measures and data and addresses the need for improved depth and quality of data for research on bridge performance. The level of understanding of how and why bridges perform the way they do and how to improve bridge performance can be enhanced. The bridge performance primer is intended to provide a perspective on bridge performance that will point the way to approaches to improve the understanding of bridge performance. One point is of paramount importance—the need to develop performance measures that help separate and assess all of the impacts of the various forces affecting bridge performance. These performance measures can lead to improved deterioration models, more accurate life-cycle costs analysis, and other tools to identify the most effective ways (including materials and methods) to improve bridge performance.

The Highway Bridge Infrastructure

The 2008 National Bridge Inventory (NBI) database contains records for 601,411 bridges, of which 127,052 are classified as tunnels or culverts.[1] The remaining 474,359 are single or multispan bridges separating highway traffic from other traffic and/or some topographical feature, usually a stream or river. The diversity of the bridge infrastructure in terms of age and design parameters (including structural type, materials of construction, width, length, etc.) is broad. The breadth of the diversity is reflected in the many different combinations of attributes or parameters that describe those bridges. Table 1 provides an abbreviated list of these characteristics and indicates how many different types of characteristics there are in the NBI for each.

Table 1. Diversity of bridge characteristics.[2]

NBI Item	# of Types
Kind of material, main span, and/or approach span	10
Structure type, main span, and/or approach span	23
Design load	10
Bridge posting	6
Deck structure type	9
Wearing surface	9
Membrane	5
Protective system	9

The appendix of the primer provides additional detail on the diversity in the condition and status of bridges. These features are important factors that govern performance of each bridge. Other factors that can significantly impact performance and can vary considerably from bridge to bridge include the following:

- Service conditions—traffic volumes carried; truck loadings (including overweight permit loads); level of vulnerability to the forces of natural events such as floods, ice, waterborne debris, wind, and seismic loadings; and susceptibility to longer-term effects of climate and the service environment (e.g., material deterioration that increases over time).
- The types, frequency, and effectiveness of bridge preservation, preventive maintenance, rehabilitation, and/or replacement actions.[1,2]

This broad diversity in the nature and the individual service conditions of different bridges presents a challenge to any research effort to more clearly understand bridge performance. It can be difficult to obtain and/or effectively analyze all of the necessary types and details of data on service conditions, conditions of bridge materials and elements, and the actions taken on bridges by the owners. In order to create a better understanding of bridge performance, FHWA has initiated the LTBP Program. The overall objective of the LTBP Program is to inspect, evaluate, and periodically monitor representative samples of bridges nationwide in order to collect, document, maintain, and manage high-quality, quantitative performance data over an extended period of time. These data then become the basis for research tools to better manage assets, understand bridge performance, and create data-driven approaches to improving performance.

Measuring Bridge Performance

There are different ways to measure bridge performance, and these usually involve comparison of performance against some set of established standards. Some measures of performance are in the form of an index value calculated for each bridge from a defined formula using input data such as NBI condition ratings, traffic volumes, etc. The Federal sufficiency rating (SR) is one example of this type; several State transportation departments use a "health index" to measure bridge condition. Similar indices have been developed by transportation agencies in other countries. Another type of measurement is based on whether a bridge meets some defined criteria. This type of measurement includes approaches that classify bridges as "structurally deficient" or as "functionally obsolete." Still others reflect a compliance with a desirable level of operational capacity or service. These include posted load, load rating, limitations on deflections under live load, rideability of the bridge-wearing surface, traffic congestion near or on the bridge, number of accidents on the bridge, percentage of rain events and floods that overtop the bridge, etc.

The bridge performance primer provides some insight into some of the measures commonly used today. It is important to note these measures usually reflect a "snapshot" of performance at a given point in time. The primer discusses what additional research data and information is needed to better understand and develop solutions to improving bridge performance.

Experience has shown the performance of any specific bridge is dependent on complex interactions of multiple factors, many of which are closely linked and include the following:

- Original design parameters and specifications, such as bridge type, materials of construction, geometry, and load capacity.

[1] Replacement actions may or may not be performed by the owner; they may be performed by others on behalf of the owner.

[2] The definition of *bridge preservation* is actions or strategies that prevent, delay or reduce deterioration of bridges or bridge elements, restore the function of existing bridges, keep bridges in good condition and extend their life. Preservation actions may be preventive or condition-driven. The definition of *preventive maintenance* is a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the function condition of the system (without substantially increasing structural capacity).[(3)]

- Initial quality of materials and of the as-built construction.
- Varying environmental conditions of climate and air quality, marine environment, or even surrounding soil.
- Incidence of corrosion or other deterioration processes.
- Traffic volumes and frequency and weight of truck traffic carried by the structure.
- Types, frequency, and effectiveness of bridge preservation, preventive maintenance, rehabilitation, and/or replacement actions.

All of these factors combine to affect the condition and operational capacities of the bridge and its various structural elements at any given point in the life of the bridge. Measures such as those mentioned above can be used to evaluate the overall performance of a bridge or a group of bridges under different service conditions. Researchers hope to show the qualitative or quantitative impact of a parameter or set of parameters on some specific aspect of bridge performance.

Why Measure Bridge Performance?

Bridge performance measures have different uses depending on the perspective and the responsibilities of those persons using the performance measures. Bridge performance measures are useful for the following reasons:

- Identifying clear links between specific policies (such as the type and quantity of anti-icing materials), actions, and the resulting change in performance level of a bridge element.
- Improving knowledge of how and why bridges deteriorate.
- Gaining a better understanding of the effectiveness of various design, construction, inspection, and preservation strategies, as well as management practices.
- Gaining a better understanding of the effectiveness of durability strategies for new bridge construction, including material selection.
- Improving bridge management practice using qualitative and quantitative data.
- Evaluating serviceability and durability.
- Setting priorities for resource allocations and evaluating organization-wide policies and programs such as the split between maintenance and capital funds.
- Establishing risk-based evaluations of bridges that are vulnerable to failure.

Current Approaches to Measuring Bridge Performance

Understanding bridge performance is a challenging task. The primer describes some current approaches to measuring bridge performance and provides some discussion of the data upon which the calculations of these measures are based. The value of performance measures commonly used today lies in their relative simplicity, their familiar nature, and the long-standing and broad-based acceptance of them. The data used as a basis for many of the current performance measures come from NBI, which includes condition and appraisal ratings on a scale of 0 (failed condition—out of service—beyond corrective action) through 9 (excellent condition). In practice, ratings in the range of 4 to 7 are most common for bridges in service. Condition ratings are assessed for the deck, superstructure, and substructure of the bridge, and appraisal ratings assess key functional characteristics of the bridge.

One type of commonly used bridge performance measure uses a single criterion as the basis for evaluation of performance. An example of this type is the determination if a bridge is structurally deficient (SD). A bridge is classified as SD if items 58 (deck), 59 (superstructure), and 60 (substructure) or 62 (culvert) are rated in "poor" condition or worse (4, 3, 2, 1, or 0 on the NBI rating scale). A bridge can also be classified as structurally deficient if its load-carrying capacity is significantly below current design standards (i.e., if item 67—structural evaluation appraisal—is coded 2, 1, or 0) or if the waterway adequacy for the feature below the bridge is coded 2 or below, meaning basically intolerable and requiring high priority for replacement. In a similar manner, bridges can be classified as functionally obsolete because their design is outdated—they may have lower load-carrying capacity, narrower shoulders, or less clearance than bridges built to the current standard. These types of measures provide bridge managers with a consistent basis for identifying bridges as candidates for future improvement actions.

A more complex type of performance measure is represented by the Federal SR, an index devised and used in the past by FHWA to evaluate the eligibility of bridges for Federal highway bridge rehabilitation and replacement funds. The SR formula is a method of evaluating highway bridge data by calculating and summing four separate factors to obtain a numeric value that is indicative of bridge sufficiency to remain in service. On the resulting rating scale, 100 would represent an entirely sufficient bridge, and 0 would represent an entirely insufficient or deficient bridge. No bridge is given an SR of below 0.

The SR is calculated using a complex formula wherein weighting factors are assigned to several different bridge parameters and attributes in order to arrive at the numerical index for each bridge. The basic formula follows:

Figure 1. Equation. Federal SR.[2]

$$SR = S1 + S2 + S3 - S4$$

These four factors provide consideration and weight as follows:

- S1: structural adequacy and safety (condition ratings for deck, superstructure, and substructure plus the inventory (load) rating). Maximum value = 55 percent.
- S2: serviceability and functional obsolescence (traffic lanes, average daily traffic, structure type, structural evaluation, waterway adequacy, Strategic Highway Network (STRAHNET) designation, and several key geometric parameters). Maximum value = 30 percent.
- S3: essentiality for public use (detour length, average daily traffic, and STRAHNET designation). Maximum value = 15 percent.
- S4: special reductions (detour length, traffic safety features, and structure type). Maximum value = 6 percent.

While these performance measures have served well when used for condition evaluation and apportionment of funds, these measures do not cover all of the variables researchers are seeking.

Additional data needed for research come in three forms. First, condition information for not only bridge components such as the deck, superstructure, substructure, but also for the condition of the individual elements of a bridge, such as individual beams, pier columns, and abutments. Second, additional condition information to accurately distinguish what is happening to the bridge components over time. Third, measures that relate directly to the causes of symptoms of deterioration (such as rates of corrosion of the reinforcing bars).

The implementation of a more detailed "element level" inspection system by many states has provided more bridge inspection data to use in evaluating bridge performance. Condition data is recorded on individual elements of the bridge rather than on the general elements of deck, superstructure, and substructure. Thus, severity of any deterioration is better defined and the extent is estimated and recorded.

The Keys to Improving Bridge Performance

The need for additional, useful, reliable bridge performance measures is clear. Those studying bridge performance will be able to evaluate the impact of different maintenance practices and priorities, design methodologies, and new technologies on future bridge performance. The keys to improving bridge performance measures are as follows:

1. Establishing clear, objective research measures targeted to the causes of bridge deterioration.
2. Identifying the elements and characteristics that most seriously impact bridge performance.
3. Identifying critically needed data for experimental studies to improve the knowledge of the multivariable cause-and-effect relationships that govern performance.
4. Collecting data to fill the gaps identified in the previous three points and to create valid models that describe deterioration mechanisms, address the effectiveness of mitigation actions, predict future deterioration, and support more realistic life-cycle cost calculations.

The large amount of "legacy data" currently available for bridges provides a solid foundation upon which to build a better knowledge base of data. The NBI and the State transportation department bridge element level databases can be used as important and fundamental resources in furthering the understanding of bridge performance. The past, current, and future data contained in these two resources is very helpful in identifying trends in bridge performance and in identifying general parameters that govern performance. Bridge owners also possess other useful data such as the following:

- Design drawings and specifications.
- Analytical models.
- Construction records.
- Inspection reports.
- Photographic documentation.
- History of maintenance and preservation actions and timing, including costs.

Beyond these current resources, the additional research data needed to properly evaluate bridge performance can be quite extensive. Table 2 illustrates the breadth of data that may be necessary to better understand bridge performance.

The primer describes a recommended breakdown of bridge performance issues into four categories of performance: structural condition (for durability and serviceability), functionality (for safety and traffic capacity), structural integrity (for safety and stability), and risk and costs (to the user and to the agency). This definition helps isolate the most critical aspects of bridge performance and provides the basis for long-term research studies to improve the understanding of these issues.

Table 2. Possible durability and serviceability performance data.

Category	Data
Design and construction	Design plans and specifications
	Critical design details
	Change orders
	Inspection notes
	Construction QA/QC
	Corrosion protection measures
Operating conditions	Local climate
	Snow and ice removal practices
	Freeze-thaw cycles
	Rainfall and runoff; drainage control
	Marine environment
	Industrial pollutants
Dynamic loadings	Traffic volume
	Truck volumes and weights
	Weigh-in-motion data
	Overload permits
	Debris, ice
	Impact loads
	Flexibility, vibrations
Corrosion protection measures	Concrete cover over reinforcement
	Corrosion resistant reinforcement
	Deck overlays, membranes, and sealers
	Other concrete sealers
	Steel coatings—including weathering steel
	Concrete characteristics—including high-performance concrete
Material conditions	Concrete
	Steel
	Reinforcing bars
	Prestressing steel
	Deck
	Concrete superstructure
	Steel superstructure
	Concrete substructure
Geometric data	Deflections
	Rotations
	Settlements
	Loss of camber
	Horizontal alignment and skew
Condition of components	Bearings
	Joints
	Approach slabs
	Details requiring NDE evaluation

QA/QC = Quality Assurance/Quality Control
NDE = Nondestructive Evaluation

Conclusions

Nearly everyone in the United States, from bridge maintenance engineers to the everyday road user, has a stake in ensuring the performance of bridges in the nation is good or even excellent in terms of durability, operational capacity, roadway safety, resistance against failure, and life-cycle costs. For example, for commercial interests, shippers, drivers, etc., a simple measure of bridges with posted weight limits or geometrical dimensions may suffice.

On the other hand, members of the bridge community—designers, construction engineers, inspectors, maintenance engineers, and bridge management personnel—responsible for maintaining performance must be able to properly and effectively evaluate bridge performance in precise and targeted manners. Toward this end, we must better understand bridge performance, which must be broken down into very specific issues that can be evaluated in terms of cause and effect. This will allow actions or programs to be identified to ensure a high level of performance at a reasonable cost. Understanding bridge performance can be a formidable task given the many factors that can govern performance under different circumstances. The LTBP Program is being implemented to identify the most critical aspects of bridge performance and conduct studies to provide the high-quality data necessary to better understand how multiple, variable factors affect aspects of performance. This should ultimately improve performance and extend the life of bridges at a minimum cost.

References

1. National Bridge Inventory Data, FHWA, 2008 Data, http://www.fhwa.dot.gov/bridge/nbi.htm.

2. *FHWA Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges,* FHWA, U.S. Department of Transportation, Report No. FHWA-PD-96-001, McLean, VA, 2005.

3. *Bridge Preservation Guide,* FHWA, U.S. Department of Transportation, Report No. FHWA-HIF-11042, McLean, VA, August 2011.

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