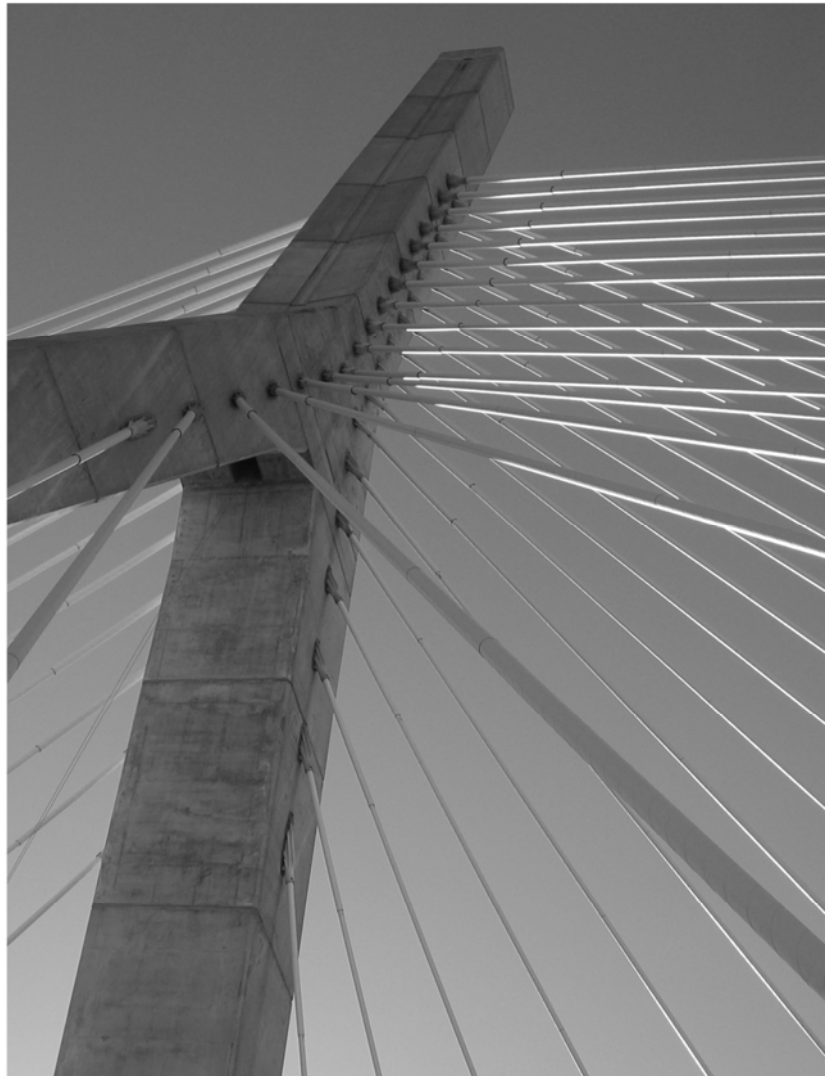


THE MANUAL FOR BRIDGE EVALUATION



THE MANUAL FOR BRIDGE EVALUATION



AMERICAN ASSOCIATION
OF STATE HIGHWAY AND
TRANSPORTATION OFFICIALS
AASHTO

3rd Edition • 2018



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FOREWORD

The Manual for Bridge Evaluation (MBE) was first adopted by the AASHTO Highways Subcommittee on Bridges and Structures in 2005. The MBE combined the *Manual for Condition Evaluation of Bridges* with the *Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges* to provide owners with a single document for evaluating and load rating bridges.

The Manual for Bridge Evaluation, Third Edition incorporates the Interim Revisions issued to the Second Edition, as well as many other improvements. In order to better address the evolving requirements and technology related to bridge management systems, Section 3: Bridge Management Systems has been completely revised and updated.

AASHTO Highways Subcommittee on Bridges and Structures

PREFACE

The Manual for Bridge Evaluation (MBE) offers assistance to Bridge Owners at all phases of bridge inspection and evaluation. An abbreviated table of contents follows this preface. Detailed tables of contents precede Sections 1 through 8.

Appendix A includes nine illustrative examples (A1 through A9), previously in the *Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges*, and two more (A10 and A11) that were added in the Interim Revisions for the Second Edition of this title. All examples are rated using the LRFR method. In addition, Examples A1 and A2 are also rated using the ASR and LFR methods, A4 is also rated using the ASR method, and A11 is also rated using the LFR method. To clarify which rating method is being illustrated, examples using multiple methods are generally divided into Parts A through C and their articles are numbered accordingly as follows:

- Part A, LRFR;
- Part B, ASR and LFR; and
- Part C, example summary.

For ease of reference, the table of contents for Appendix A includes a summary table of the bridge types, rated members, rating live loads, limit states for evaluation, and rating methods, with the starting page number for each example and, in the case of Examples A1, A2, A4, and A11, for each rating method. The typical detailed table of contents follows this summary table.

Appendix A includes numerous citations of other AASHTO bridge publications. To save space, the following shorthand has been adopted:

- “AASHTO Standard Specifications” refers to the current edition of the *AASHTO Standard Specifications for Highway Bridges*, 17th Edition, HB-17,
- “LRFD Design” refers to the current edition of the *AASHTO LRFD Bridge Design Specifications*, Eighth Edition, LRFD-8, and
- “MBE” refers to this publication, *The Manual for Bridge Evaluation*, Third Edition, MBE-3.

AASHTO Publications Staff

ABBREVIATED TABLE OF CONTENTS

SECTION 1: INTRODUCTION.....	1-i
SECTION 2: BRIDGE FILES AND DOCUMENTATION.....	2-i
SECTION 3: BRIDGE MANAGEMENT SYSTEMS	3-i
SECTION 4: INSPECTION	4-i
SECTION 5: MATERIAL TESTING.....	5-i
SECTION 6: LOAD RATING.....	6-i
SECTION 7: FATIGUE EVALUATION OF STEEL BRIDGES.....	7-i
SECTION 8: NONDESTRUCTIVE LOAD TESTING	8-i
APPENDIX A: ILLUSTRATIVE EXAMPLES.....	A-i

2019 INTERIM REVISIONS

INSTRUCTIONS AND INFORMATION

General

AASHTO has issued proposed interim revisions to the *Manual for Bridge Evaluation*, Third Edition (2018). This packet contains the revised pages. They are designed to replace the corresponding pages in the book. Please note that these changes come after the 2019 Errata for the *Manual for Bridge Evaluation*, Third Edition, also issued this month.

Affected Articles

Underlined text indicates revisions that were approved in 2018 by the AASHTO Committee on Bridges and Structures. ~~Strikethrough text~~ indicates any deletions that were likewise approved by the Committee. A list of affected articles is included below.

All interim pages are displayed on a pink background to make the changes stand out when inserted in the first edition binder. They also have a page header displaying the section number affected and the interim publication year. Please note that these pages may also contain nontechnical (i.e., editorial) changes made by AASHTO publications staff; any changes of this type will not be marked in any way so as not to distract the reader from the technical changes.

2019 Changed Articles

SECTION 6: LOAD RATING

6B.5.3.1

SECTION 7: FATIGUE EVALUATION OF STEEL BRIDGES

7.2.5.1

7.2.7.2.3

APPENDIX A

A1A.1.1

A1A.1.8.3

A1A.1.8.3a

A1A.1.8.3b

SECTION 1: INTRODUCTION

TABLE OF CONTENTS

1.1—PURPOSE.....	1-2
1.2—SCOPE.....	1-2
1.3—APPLICABILITY.....	1-2
1.4—QUALITY.....	1-2
1.4.1—Provisions to Support the NBIS Requirements.....	1-3
1.4.2—QC/QA Procedures.....	1-3
1.5—DEFINITIONS AND TERMINOLOGY.....	1-4
1.6—REFERENCES.....	1-6

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INTRODUCTION

1.1—PURPOSE

The purpose of *The Manual for Bridge Evaluation* (MBE) is to serve as a resource for use in developing specific policy and procedures for the inspection and evaluation of existing in-service highway bridges. The MBE also includes the nationally recognized guidance for the load rating of highway bridges.

The National Bridge Inspection Standards (NBIS), as found in the Code of Federal Regulations (23 CFR 650 Subpart C), define the regulations for the inspection and evaluation of the nation's bridges.

The MBE is incorporated by reference in the CFR (23 CFR 650 Subpart C) to be used along with other reference documents such as the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Bridge Element Inspection*, the Federal Highway Administration's (FHWA) *Bridge Inspector's Reference Manual* (BIRM), and the latest National Bridge Inventory (NBI) coding guidance document for the inspection and evaluation of the nation's bridges.

The NBIS have evolved and been improved over the years since their creation in the early 1970s.

The MBE has also evolved and been revised and improved to reflect best practices as determined by research, state departments of transportation (DOTs), and others. In the future as improved practices and research are developed, the MBE will reflect those improvements.

Throughout this Manual there are subsections titled in part "Provisions to Support the NBIS Requirements." These subsections were developed to provide specific guidance and best practices that are considered to be required under the regulations.

1.2—SCOPE

The Manual has been divided into eight Sections, with each Section representing a distinct phase of an overall bridge inspection and evaluation program.

- Section 1—Purpose, scope, applicability, inspection and evaluation quality measures, and definition of general interest terms.
- Section 2—Provisions for proper documentation to be included in a bridge file. The bridge file associated with each bridge provides the foundation against which changes in physical condition can be compared.

- Section 3—Overview of bridge management systems and their key elements.
- Section 4—Types and frequency of field inspections, as well as specific inspection techniques and procedures.
- Section 5—Various inspection and evaluation testing methods. Conditions at a bridge site or the absence of information from original construction may warrant more elaborate material tests to determine properties for evaluation.
- Section 6—Nationally recognized specification for the load rating of bridges. Includes the Load and Resistance Factor method, the Load Factor method, and the Allowable Stress method.
- Section 7—Provisions for the evaluation of existing bridges for fatigue.
- Section 8—Field-performed load test procedures. Field load testing is a means of supplementing analytical procedures in determining the live-load capacity of a bridge and for improving the confidence in the assumptions.

The successful application of this Manual is directly related to the DOT organizational structure. Such a structure should be both effective and responsive so that the unique characteristics and special problems of individual bridges are considered in developing an appropriate inspection plan and load capacity determination.

1.3—APPLICABILITY

The provisions of this Manual apply to all highway structures that qualify as bridges in accordance with the AASHTO definition of a bridge (see Article 1.5). These provisions may be applied to smaller structures which do not qualify as bridges at the discretion of the DOT.

The NBIS establish minimum requirements for inspection programs and minimum qualifications for bridge inspection personnel. The NBIS apply to all highway bridges that are more than 20 ft in length and located on public roads.

Where conflicts or inconsistencies exist between this Manual and the federal requirements specified in the NBIS, the FHWA coding guidance, or BIRM, the federal requirements shall govern.

1.4—QUALITY

To maintain the accuracy and consistency of inspections and load ratings, bridge inspection programs need to have appropriate quality control (QC) and quality assurance (QA) measures in place. QC procedures are intended to maintain the quality of the bridge inspections, bridge data, scour evaluations, and load ratings, and are usually performed continuously

within the bridge inspection teams or units performing these functions. QC procedures can vary depending on the structural and scour conditions of a bridge with increased level of review commensurate with increased deterioration of bridge conditions. QA procedures are used to verify the adequacy of the quality control procedures to meet or exceed the standards established by the program manager. QA procedures are usually performed independently of the bridge inspection and load rating teams on a sample of their work.

1.4.1—Provisions to Support the NBIS Requirements

A quality control and quality assurance (QC/QA) program is to include periodic field review of inspection teams, periodic bridge inspection refresher training for program managers and team leaders, QC/QA measures for inventory data, and independent review of inspection reports and computations. The program manager is responsible for developing a QC/QA program that generally conforms to the provisions of Article 1.4. Specific details are to be determined by the program manager.

1.4.2—QC/QA Procedures

Typical quality procedures may include the use of checklists to ensure uniformity and completeness, the review of reports and computations by a person other than the originating individual, and the periodic field review of inspection teams and their work. The documented quality control plan may include:

- Defined QC roles and responsibilities;
- Qualifications for the program manager, bridge inspection personnel, and load rating personnel, including:
 - Education,
 - Certification or registration,
 - Training, and
 - Years and type of experience;
- Procedures for review and validation of inspection reports and data;
- Procedures for documenting important bridge inspection information;
- Procedures for review validation of load rating and scour calculations and data; and
- Procedures for identification and resolution of data issues including errors, omissions, compatibility between items, changes, or any combination thereof.

QA measures include the overall review of the inspection and rating program to ascertain that the

results meet or exceed the standards established by the program manager. The documented QA plan may include:

- Defined quality assurance roles and responsibilities;
- Frequency parameters for review of districts or units and bridges; and
- Procedures and sampling parameters for selecting bridges to conduct independent review and check of results, including:
 - Condition rating of elements or change in condition rating,
 - Load rating and scour evaluations,
 - Posting status,
 - Deficiency status,
 - Critical findings and the status of any follow-up action, and
 - Location of bridge.

QA measures provide a validation that QC practices are resulting in accurate and thorough inspections, complete bridge files, accurate and complete load ratings and scour evaluations, and qualified inspectors and load raters. Results from QA reviews are used by the program manager to maintain the quality of the program and make improvements where needed.

1.5—DEFINITIONS AND TERMINOLOGY

AASHTO—American Association of State Highway and Transportation Officials.

As-Built Plans—Plans that show the state of the bridge at the end of construction; usually prepared by the Contractor or the resident Engineer.

ASR—Allowable Stress Rating.

Bias—The ratio of mean to nominal value of a random variable.

Bridge—A structure including supports erected over a depression or an obstruction such as water, highway, or railway; having a track or passageway for carrying traffic or other moving loads; and having an opening measured along the center of the roadway of more than 20 ft between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes. It may also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening.

Bridge Management System (BMS)—A system designed to optimize the use of available resources for the inspection, maintenance, rehabilitation, and replacement of bridges.

Calibration—A process of adjusting the parameters in a new standard to achieve approximately the same reliability as exists in a current standard or specification or to achieve a target reliability index.

Coefficient of Variation—The ratio of the standard deviation to the mean of a random variable.

Collapse—A major change in the geometry of the bridge rendering it unfit for use.

Complex Bridges—Movable, suspension, cable stayed, and other bridges with unusual characteristics.

Condition Rating—The result of the assessment of the functional capability and the physical condition of bridge components by considering the extent of deterioration and other defects.

Evaluation—An assessment of the performance of an existing bridge.

Exclusion Vehicle—Grandfather provisions in the federal statutes which allow states to retain higher limits than the federal weight limits if such limits were in effect when the applicable federal statutes were enacted. Exclusion vehicles are vehicles routinely permitted on highways of various states under grandfather exclusions to weight laws.

Failure—A condition where a limit state is reached or exceeded. This may or may not involve collapse or other catastrophic occurrences.

FHWA—Federal Highway Administration, U.S. Department of Transportation.

Inventory Rating—Load ratings based on the inventory level allow comparisons with the capacity for new structures and, therefore, results in a live load, which can safely utilize an existing structure for an indefinite period of time.

Inventory Level Rating (LRFR)—Generally corresponds to the rating at the design level of reliability for new bridges in the *AASHTO LRFD Bridge Design Specifications*, but reflects the existing bridge and material conditions with regard to deterioration and loss of section.

LFR—Load Factor Rating.

Limit State—A condition beyond which the bridge or component ceases to satisfy the criteria for which it was designed.

Load Effect—The response (axial force, shear force, bending moment, torque) in a member or an element due to the loading.

Load Factor—A load multiplier accounting for the variability of loads, the lack of accuracy in analysis, and the probability of simultaneous occurrence of different loads.

Load Rating—The determination of the live-load carrying capacity of an existing bridge.

LRFD—Load and Resistance Factor Design.

LRFD Exclusion Limits—Weight and length limits of trucks operating under grandfather exclusions to federal weight laws.

LRFR—Load and Resistance Factor Rating.

Margin of Safety—Defined as R/S , where S is the maximum loading and R is the corresponding resistance (R and S are assumed to be independent random variables).

MUTCD—*Manual on Uniform Traffic Control Devices*.

National Bridge Inventory (NBI)—The aggregation of structure inventory and appraisal data collected to fulfill the requirements of the National Bridge Inspection Standards.

National Bridge Inspection Standards (NBIS)—Federal regulations establishing requirements for inspection procedures, frequency of inspections, a bridge inspection organization, qualifications of personnel, inspection reports, and preparation and maintenance of bridge inventory records. The NBIS apply to all structures defined as highway bridges located on or over all public roads.

NICET—National Institute for Certification in Engineering Technologies.

Nominal Resistance—Resistance of a component or connection to load effects, based on its geometry, permissible stresses, or specified strength of materials.

Operating Rating (ASR, LFR)—Load ratings based on the operating rating level generally describe the maximum permissible live load to which the structure may be subjected. Allowing unlimited numbers of vehicles to use the bridge at operating level may shorten the life of the bridge.

Operating Level Rating (LRFR)—Maximum load level to which a structure may be subjected. Generally corresponds to the rating at the operating level of reliability in past load rating practice.

Owner—Agency having jurisdiction over the bridge.

Posting—Signing a bridge for load restriction.

Quality Assurance—The use of sampling and other measures to assure the adequacy of quality control procedures in order to verify or measure the quality level of the entire bridge inspection and load rating program.

Quality Control—Procedures that are intended to maintain the quality of a bridge inspection and load rating at or above a specified level.

RF—Rating Factor.

Reliability Index—A computed quantity defining the relative safety of a structural element or structure expressed as the number of standard deviations that the mean of the margin of safety falls on the safe side.

Resistance Factor—A resistance multiplier accounting for the variability of material properties, structural dimensions and workmanship, and the uncertainty in the prediction of resistance.

Safe Load Capacity—A live load that can safely utilize a bridge repeatedly over the duration of a specified inspection cycle.

Scour Critical Bridge—A bridge whose foundation (or foundations) has been determined to be unstable for the predicted scour conditions.

Service Limit State—Limit state relating to stress, deformation, and cracking.

Serviceability—A term that denotes restrictions on stress, deformation, and crack opening under regular service conditions.

Serviceability Limit States—Collective term for service and fatigue limit states.

Specialized Hauling Vehicle (SHV)—Short wheelbase multi-axle trucks used in the construction, waste management, bulk cargo and commodities hauling industries.

Strength Limit State—Safety limit state relating to strength and stability.

Structure Inventory and Appraisal Sheet (SI&A)—A summary sheet of bridge data required by NBIS.

Target Reliability—A desired level of reliability (safety) in a proposed evaluation.

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SECTION 2: BRIDGE FILES AND DOCUMENTATION

TABLE OF CONTENTS

2.1—INTRODUCTION	2-1
2.2—PROVISIONS TO SUPPORT THE NBIS REQUIREMENTS.....	2-1
2.2.1—General File Information.....	2-2
2.2.2—Field Inspection Information.....	2-3
2.2.3—Critical Findings and Actions Taken	2-3
2.2.4—Waterway Information.....	2-3
2.2.5—Significant Correspondence	2-4
2.2.6—Other Inspection Procedures or Requirements.....	2-4
2.2.7—Load Rating Documentation	2-4
2.2.8—Posting Documentation.....	2-5
2.2.9—Scour Assessment	2-5
2.2.10—Scour Plan of Action.....	2-5
2.3—SUPPLEMENTAL DOCUMENTATION IN BRIDGE FILE	2-5
2.3.1—General.....	2-5
2.3.2—Plans and Drawings	2-5
2.3.3—Construction Documentation	2-6
2.3.4—Original Design Documentation	2-6
2.3.5—Unique Considerations.....	2-6
2.3.6—Utilities and Ancillary Attachments.....	2-7
2.3.7—Maintenance and Repair History	2-7
2.3.8—Additional Waterway Documentation	2-7
2.3.9—Traffic Data.....	2-7

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BRIDGE FILES AND DOCUMENTATION

2.1—INTRODUCTION

Maintaining bridges safe for public travel is of utmost importance to transportation officials. In order to ensure public safety, management of in-service highway bridges requires the collection and maintenance of accurate, up-to-date, and comprehensive information for each bridge. The information includes 1) data that does not typically change over the life of a bridge, 2) data that is updated by field inspections, and 3) data that is derived or calculated to assess specific attributes such as scour, vulnerability to extreme events, and safe load-carrying capacity.

Data that does not typically change includes information such as the length and width of the structure and the structure type. Data that is updated as a result of field inspections includes condition information on the structural components and elements, clearances and changes to dead load, and the identification of conditions that introduce a potential risk to the bridge, such as debris accumulation around substructure units and scour or erosion.

Information is organized in a file for each bridge. The bridge file includes a description of the characteristics and conditions of the structure; calculations for determining scour vulnerability (if over water); a determination of the load-carrying capacity, including computations substantiating reduced load limits; and details of any damage and alterations or repairs to the structure.

The information in a bridge file provides a cumulative history of the structure that is useful to review prior to conducting a bridge inspection, rating, or evaluation.

The information in a bridge file may exist electronically, on paper, or in external documents that are appropriately referenced within each bridge file or manual. The external documents may apply to multiple bridges and exist in various locations.

The bridge file provides information that directly relates to requirements of the National Bridge Inspection Standards (Article 2.2) and other supplemental information that bridge owners may find useful in managing bridges (Article 2.3).

2.2—PROVISIONS TO SUPPORT THE NBIS REQUIREMENTS

An inventory of all bridges is to be maintained as required by the National Bridge Inspection Standards (NBIS), in accordance with coding guidance issued by the Federal Highway Administration (FHWA). Certain data is defined by the FHWA that must be collected and retained. This data is typically retained within a computer database. Summaries of the inventory and evaluation data

may be included in bridge files. The data accurately captures specific, key information including bridge identification, location, structural attributes, dimensions, clearances, condition, and load-carrying capacity.

A bridge file is to be prepared as required by the NBIS and described in this Manual. Specifically:

- Maintain reports on the results of bridge inspections and note any actions taken to address the findings of the inspections,
- Maintain relevant maintenance and inspection data and use it to assist with the assessment of current bridge conditions,
- Document observations and measurements needed to determine the physical and functional condition of the bridge, and
- Identify any changes from initial or previously recorded conditions and other actions needed to ensure that the structure continues to satisfy present structural service requirements.

The format used to document the information in bridge files may vary significantly. If the information is not available in a consolidated inspection report, look for it elsewhere in the inspection file or as referenced to another location. Bridge Owners may make generalized reference to the location of the digital information within their own manuals or other files rather than individually in each bridge file.

Include the following specific bridge information. The level of documentation will vary depending on the complexity, condition, and situation of a structure; however, always include the information that is common to all bridges.

2.2.1—General File Information

Include the following general file information:

- General plan and elevation drawing or a sketch depicting the layout of the bridge, if available;
- Clear and understandable approach to labeling members and elements that enables an assessment of the inspection process and its completeness;
- Inspection and inventory data as defined by the FHWA for reporting to the National Bridge Inventory. This data is often referred to as Structure Inventory and Appraisal information (SI&A);
- Photographs showing a top view of the roadway across the bridge, a side elevation view, and an under view of the main or typical span superstructure configuration. Photographs necessary to show major defects, posting restrictions, and other important features should be included; and
- History of any structural damage.

2.2.2—Field Inspection Information

Inspection reports provide a chronological record of the date and type of all inspections performed on the bridge. Document each inspection conducted for a bridge and retain in the bridge file. Document the observations and findings from each inspection. Identify the Team Leader responsible for the inspection and report, and the date the inspection was conducted. Observations include a description of conditions of bridge members and the identification of factors that require further review, close monitoring, or additional attention during inspections:

- Brief narrative descriptions of general and component/element conditions with detail to justify a condition rating of 5 or less for NBI items and Condition State 3 or more for elements.
- Sketches or photographs, as appropriate, of elements or members showing typical and deteriorated conditions.
- Sketches documenting remaining section of components with sufficient detail to facilitate determination of the load capacity. These sketches may be part of the load rating documentation.
- Notations of actions taken to address previous inspection findings.

2.2.3—Critical Findings and Actions Taken

Provide a detailed description and photographs of the specific critical finding(s) sufficient to document safety or structural concerns. Identify appropriate immediate actions or follow-up inspections. Include a record of the actions taken to resolve or monitor the critical finding(s).

2.2.4—Waterway Information

Provide channel cross-sections or sketches, soundings, and stream profiles as needed to provide adequate information on the stability of the waterway and allow for adequate assessment of the risk to the structure. Update channel information periodically and when otherwise necessary. Perform a historical comparison to determine the extent of any scour, channel shifting, degradation, or aggradation of the channel. Determine and document a frequency for obtaining and updating these measurements, depending on an assessment of the bridge and stream characteristics. Consider the potential for lateral migration of the stream channel or head-cutting in determining the extent of channel documentation. A single cross-section or sketch at one face may be appropriate for historically stable channels and embankments. Evaluate the need for obtaining cross-sections for pipes and box culverts and structures with small drainage areas on a case-by-case

basis. The Bridge Inspector's Reference Manual (BIRM) provides additional information on inspecting channels.

2.2.5—Significant Correspondence

Provide correspondence and agreements regarding inspection responsibility, ownership, maintenance responsibilities with other agencies, or other issues that have an impact on the ability to ensure that thorough and timely inspections are completed.

2.2.6—Other Inspection Procedures or Requirements

Provide procedures for specific types of inspections (fracture-critical, underwater, and complex bridges). Address those items that need to be communicated to an inspection team leader to ensure a successful bridge inspection.

Provide procedures to document special access needs, inspection equipment, structural details, inspection methods, and any special qualifications required of inspecting personnel. Overall inspection procedures may exist in a bridge inspection manual that address common aspects of these more complex inspections; however, if there are items unique to that structure that are not covered in the overall inspection procedures, provide written procedures specific to that fracture critical, underwater, and complex bridge inspection.

Document the following items, either in bridge-specific inspection procedures or by referring to general inspection procedures:

1. Identify each of the fracture-critical, complex features, and underwater members, and any elements that need special attention during those inspections, preferably on plan sheets, drawings, or sketches.
2. Describe the inspection method(s), special access needs (under bridge inspection truck, climbing, etc.), special inspection equipment (non-destructive evaluation, a.k.a. NDE), and frequency to be used for the elements.
3. Provide information regarding proximity necessary to details, such as “arm’s length” or “hands-on.”
4. Provide special qualifications required of inspection personnel by the Program Manager, if any. Section 4 provides additional information on inspection plans for bridges.

2.2.7—Load Rating Documentation

Provide dated load rating results along with the identification of the analyst to determine the safe load-carrying capacity of the bridge and, where necessary, the load limits for posting. Include the load rating results which clearly identify the loads and methodology used in the analysis, a general statement of the results of the

analysis, identification of members that were found to control the load rating, and any other modifying factors that were assumed in the analysis. Include updates to the calculations as needed to reflect changes in the condition of structural members; changes to the structural configuration, strength of members, or dead load; and changes to the legal live load that may alter the load rating result. If calculations cannot be provided due to a lack of information (missing plans, unknown materials, etc.), provide documentation for justification of determined load rating. If a field load test is used to establish the load-carrying capacity of the bridge, provide reports that describe and document the testing process and results.

2.2.8—Posting Documentation

Provide a summary of posting recommendations and actions taken for the bridge and date of posting.

2.2.9—Scour Assessment

Document the assessment conducted to determine the scour vulnerability of the bridge. Provide a clear reference to an alternate location if documentation is available outside of the inspection file.

2.2.10—Scour Plan of Action

For scour-critical bridges, provide a copy of a plan of action, or a clear reference to the plan of action if the documentation is available in a location other than the inspection file. The plan of action is used to monitor known and potential deficiencies and address or monitor critical scour related findings.

2.3—SUPPLEMENTAL DOCUMENTATION IN BRIDGE FILE

2.3.1—General

Retain the supplemental documentation described in Articles 2.3.2 through 2.3.9 in the bridge file at the discretion of the Program Manager and subject to availability, especially for older bridges. Additional information not listed in this section may be included in the file and may contain information Bridge Owners believe is necessary to operate their Bridge Management Systems. Some of this information may be referenced in the bridge file or references may be provided to outside source locations.

2.3.2—Plans and Drawings

Include one set of final drawings showing the “as-built” condition of the bridge. Construction shop drawings may be included.

2.3.3—Construction Documentation

Include construction documentation of relevant as-built information regarding the structure, including reference to material certifications and tests performed during construction activities such as pile driving, concrete placement, and prestressing operations.

Retain all pertinent certificates for the type, grade, and quality of materials incorporated in the construction of the bridge, such as steel mill certificates, concrete delivery slips, and other manufacturers' certifications, in accordance with applicable policies and the appropriate statute of limitations.

Reference in the file any reports of nondestructive and laboratory tests of materials incorporated in the bridge during construction.

Retain one complete copy or reference to the special technical specifications under which the bridge was built. Reference the edition and date of the general technical specification in the bridge file.

2.3.4—Original Design Documentation

Retain the original design calculations and documentation for the bridge. Record the AASHTO Bridge Design Specifications version and any project-specific assumptions and criteria.

2.3.5—Unique Considerations

Provide information as necessary on other items that may need to be addressed depending on each unique situation. If appropriate, include special planning considerations such as the following:

- *Special Coordination Procedures*—Coast Guard, security, operations, or other agencies;
- *Natural Safety Concerns*—rattlesnakes, bats, or other wildlife; and
- *Optimum Inspection Periods of the Year*—lake draw down, canal dry time, snow, ice, bird nesting seasons, or other considerations.

Identify special access issues or equipment required to inspect the features (traveler system, climbing, equipment for confined spaces, or remote access camera technology).

Emphasize and highlight special structural details or situations, such as fatigue-prone details, pins and hangers in nonredundant systems, cathodic protection, and weathering or brittle steels.

Document any unusual environmental conditions that may have an effect on the structure, such as salt spray and industrial gases.

2.3.6—Utilities and Ancillary Attachments

Include information on utilities or ancillary attachments that either 1) are attached to the structure or 2) otherwise affect access to portions of the bridge. The type of connection should be noted. Note a utility in the immediate area, though not fastened to the bridge, e.g., a sewer line crossing the right-of-way and buried in the channel beneath the bridge.

2.3.7—Maintenance and Repair History

Include a chronological record documenting the maintenance and repairs to the bridge since its initial construction. Include details such as significant dates, description of project, contractor, cost, and contract number.

Document the surface protective coatings used, including surface preparation, application methods, and dry-film thickness as well as types of paint, concrete and timber sealants, and other protective membranes. This information may be in the referenced original design file.

2.3.8—Additional Waterway Documentation

For structures over waterways, when available, include a chronological history of major hydraulic events, high-water marks, and scour activity in the bridge file. Channel profiles, mean high-water levels, debris accumulation, and storm surge data are useful information for effectively managing bridges over waterways.

2.3.9—Traffic Data

When the information is available, include the frequency and type of vehicles using the bridge and their historical variations in the bridge file. Vehicle weight data, such as weigh-in-motion (WIM) data, can aid in the determination of bridge-specific load factors when refining LRFR load capacity calculations.

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TABLE OF CONTENTS

3.1—INTRODUCTION	3-1
3.2—OBJECTIVES OF BRIDGE MANAGEMENT SYSTEMS	3-2
3.3—COMPONENTS OF A BRIDGE MANAGEMENT SYSTEM	3-2
3.3.1—Information Management	3-2
3.3.1.1—Bridge Inventory, General Condition Ratings, and Bridge Element Ratings	3-3
3.3.1.1.1—Bridge Inventory.....	3-3
3.3.1.1.2—General Condition Ratings	3-3
3.3.1.1.3—Bridge Element Ratings.....	3-3
3.3.1.2—Agency Performance Measures	3-4
3.3.1.3—Preservation and Improvement Action Data.....	3-7
3.3.1.4—Cost Data and Financial Plans	3-7
3.3.2—Data Integration	3-8
3.3.2.1—Data Analysis.....	3-8
3.3.2.2—Risk Assessment.....	3-9
3.3.2.3—Agency Rules.....	3-11
3.3.2.4—Cost/Benefit Analysis	3-12
3.3.2.4.1—Condition Driven Cost/Benefit Analysis	3-12
3.3.2.4.2—Improvement Cost/Benefit Analysis.....	3-12
3.3.2.4.3—Lifecycle Cost/Benefit Analysis.....	3-13
3.3.2.5—Prioritization and Optimization	3-14
3.3.2.5.1—Multi-Objective Optimization	3-15
3.3.3—Decision Support	3-16
3.4—REFERENCES	3-16

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BRIDGE MANAGEMENT SYSTEMS

3.1—INTRODUCTION

As defined by the AASHTO Standing Committee on Highways, Planning Subcommittee on Asset Management, “Transportation asset management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well defined objectives.”

NCHRP Report 551, *Performance Measures and Targets for Transportation Asset Management*, provides a list of core principles of asset management as follows:

- **Policy-Driven**—Resource allocation decisions are based on a well-defined set of policy goals and objectives. These objectives reflect desired system condition, level of service, and safety provided to customers and are typically tied to economic, community, and environmental goals.
- **Performance-Based**—Policy objectives are translated into system performance measures that are used for both day-to-day and strategic management.
- **Analysis of Options and Tradeoffs**—Decisions on how to allocate resources within and across different assets, programs, and types of investments are based on understanding how different allocations will affect the achievement of policy objectives and what the best options to consider are. The limitations posed by realistic funding constraints also must be reflected in the range of options and tradeoffs considered.
- **Decisions Based on Quality Information**—The merits of different options with respect to an agency's policy goals are evaluated using credible and current data. Decision support tools are applied to help in accessing, analyzing, and tracking these data.
- **Monitoring Provides Clear Accountability and Feedback**—Performance results are monitored and reported for both impacts and effectiveness. Feedback on actual performance may influence agency goals and objectives, as well as future resource allocation and use decisions.

Transportation agencies must balance limited resources when evaluating individual bridge needs and considering the overall infrastructure needs of an aging highway system. The best action for an individual bridge may not be the best action for an agency's network of bridges when facing funding constraints. Additionally, competing needs from other transportation assets may require adjusting bridge performance targets based on an overall transportation management plan. The goal of asset management is to determine and implement an infrastructure preservation and improvement strategy that best integrates capital and maintenance activities to maximize the net benefit to society.

3.2—OBJECTIVES OF BRIDGE MANAGEMENT SYSTEMS

A bridge management system (BMS) is a tool or collection of tools integrated through a process whose goal is to assist an agency to meet strategic objectives by connecting inventory management and project selection to agency strategic goals through a data driven process. A BMS should meet the needs of both upper management, where it is a strategic planning tool, and technical decision makers, where it is an engineering tool. A BMS helps engineers and decision-makers determine the best fiscally constrained action to take on maintenance programs and short-, medium-, and long-term capital improvement programs. Its purpose is to determine the optimum use of funding by enabling decision-makers to understand the consequences of their actions and strategies. A BMS assists the bridge owner in expending the appropriate level of resources in order to maintain the inventory in an acceptable state of good repair. It also provides essential information to help transportation agencies enhance safety, perform risk assessments, extend the service life of bridges, and serve commerce and the motoring public.

3.3—COMPONENTS OF A BRIDGE MANAGEMENT SYSTEM

A BMS provides three components to support bridge asset management:

- Information Management
- Data Analysis
- Decision Support

3.3.1—Information Management

A BMS requires comprehensive, connected, and well organized relational databases that are capable of

supporting the various analyses involved in bridge management and reporting this information in a way that can be readily understood by various stakeholders. There are four major types of data required by a BMS:

1. Bridge inventory, general condition ratings, and bridge element ratings;
2. Agency performance measures;
3. Preservation and improvement activity data;
4. Cost data and financial plans.

3.3.1.1—Bridge Inventory, General Condition Ratings, and Bridge Element Ratings

3.3.1.1.1—Bridge Inventory

The National Bridge Inventory (NBI) is data collected by each state Department of Transportation (DOT) and reported to the Federal Highway Administration (FHWA). The data includes inventory, appraisal, and condition information for the nation's highway bridges. NBI data includes component and element level condition data. Bridge owners may also have agency specific bridge inventory data that they use in their BMS.

3.3.1.1.2—General Condition Ratings

In a component level inspection, General Condition Ratings (GCRs) are collected for the deck, superstructure, and substructure for bridge type structures, and a culvert rating for culvert type structures. The GCRs are determined in accordance with the National Bridge Inspection Standards (NBIS) using the 0 (failed condition) to 9 (excellent condition) NBI rating scale to provide an overall assessment of the structure's major components and ensure structural safety of the bridge. NBI appraisal items and condition ratings are often used by state DOTs and the FHWA as bridge performance measures. Bridge owners may also have their own GCRs. For example some state DOTs collect GCRs for each span of the structure. GCRs can be used to categorize bridges into major categories of condition and general need, such as good, fair, and poor, which can be used to do network level bridge management and report on performance measures to stakeholders.

3.3.1.1.3—Bridge Element Ratings

GCRs provide a general assessment of the overall condition of each major component of a bridge, but

provide limited detail on the type and quantity of deficiencies that may be present. Advanced BMS analyses requires a more detailed condition assessment to predict and prioritize bridge repair, preservation, or replacement actions. To meet the data needs of a modern BMS, AASHTO developed an element level condition assessment system. Bridge elements comprised of National Bridge Elements (NBEs), Bridge Management Elements (BMEs), and Agency-Defined Elements (ADEs) are defined in the *AASHTO Manual for Bridge Element Inspection* (MBEI). The goal of bridge element data is to completely capture the condition of bridges in a simple and effective way that can be standardized across the nation while providing the flexibility to be adapted to both large and small agency settings. Element descriptions consider material composition and where applicable, the presence of protective systems. The condition of each element is reported according to the quantity or percentage of the element rated in four Condition States (CS): CS 1—Good, CS 2—Fair, CS 3—Poor, and CS 4—Severe. The MBEI defines the condition states in objective engineering terms that are intended to provide consistent ratings nationwide. All National Bridge Elements and a select number of Bridge Management Elements on the National Highway System (NHS) are reported to the FHWA to develop bridge condition reports to the United States Congress. Using element level data, DOTs and local bridge owners can better evaluate individual components of a structure, determine and prioritize preservation needs, and estimate cost for projects.

3.3.1.2—Agency Performance Measures

Performance measures are tools used to connect asset management decisions to strategic goals set for the transportation network as well as to communicate the need for and value of investment in the asset. Performance goals are the ideal targets that are set as the high level goal tied directly to the strategic plan and are often set at the executive or legislative level. Performance goals are used to identify funding needs to reach desired levels of service. Performance targets are the predicted value of the measure at a given point in time based upon funding constraints. By comparing performance targets to performance goals, an agency is able to identify performance gaps and can then reevaluate resource allocation.

Performance measures are used by the FHWA to monitor condition trends of the nation's bridges, to provide reports to Congress, and to administer the Federal Aid to Highways Program. Various groups and national publications use performance measures to communicate bridge network conditions and need

on a uniform national basis. Most state DOTs have their own performance measures that reflect the specific conditions and needs of the state. These are used to communicate program issues to upper management, their state transportation commission, and to their legislature. State specific performance measures are of great importance to owner agencies because they are tailored to the unique needs of that state. Often bridge performance measures use GCRs to categorize bridges as being in good, fair, or poor condition. Bridge owners may use combinations of GCRs and bridge inventory items to set performance measures relevant to their state.

Performance measures using element condition ratings are becoming more prevalent. Bridge elements can be looked at individually, such as the quantity of steel beams in good, fair, poor, or severe condition, or they can be aggregated to provide an overall bridge assessment, such as categorizing the bridges in terms of need (cyclic maintenance, preventive maintenance, rehabilitation, or replacement).

The AASHTOWare BrM software provides a bridge “Health Index” which is a single-number assessment (0–100 scale) of a bridge’s condition based on an amalgamation of the individual element health indexes.

The “Health Index” of an element is a single-number assessment of an element’s condition based on the weighted, fractional distribution of the quantities across the range of condition states. Index values range from 0 (the worst possible or a completely failed condition) to 100 (the best possible condition).

$$HI_e = C_{e1}y_{e1} + C_{e2}y_{e2} + C_{e3}y_{e3} + C_{e4}y_{e4} \quad (\text{Eq. 3.3.1.3-1})$$

where:

C_{ei} is the health index coefficient, or weighted value of Condition State i for element e .

y_{ei} is the percentage of element e in Condition State i .

Quantities of an element in CS1 are in good condition and are generally taken to contribute fully to the health index ($C_{e1} = 1$). Quantities of an element in CS4 are in a severe or failed condition and are generally assumed to contribute nothing to the index ($C_{e4} = 0$). Allowing for variable weights in the CS2 and CS3 categories (Fair to Poor) allows the owner to customize the health index into a useable value for that element. For instance, the portions of a protective system in fair condition (CS2) are “substantially effective” while the quantities in poor condition (CS3) have “limited effectiveness.” The fair condition (CS2) quantities may

be given an index value close to that of the “fully effective” portions in good condition because the underlying element is still protected. The quantity in poor condition (CS3), however, may be given a much lower index value to represent the risk of deterioration of the underlying element. By allowing this flexibility, the agency is able to create element level health indexes that correspond to the practices within the agency, and can then be used to develop meaningful performance measures and trigger actions to correct deficiencies at the appropriate times.

The impact of an element on the bridge health index is related to its condition, total quantity, and the weight or importance factor of that element.

$$HI = \frac{\sum_e q_e w_e HI_e}{\sum_e q_e w_e} \quad (\text{Eq. 3.3.1.3-2})$$

where:

HI_e is the health index of the element e .

q_e is total quantity of the element e .

w_e is the weight of element e .

Bridge performance measures can also include measures of other variables such as seismic vulnerability, potential scour, substandard load capacity, and functional deficiencies such as low vertical clearance and narrow deck width. Where possible, it is desirable that national and state specific performance measures be related, but there may be good reasons for the measures to be different as long as the differences and the purpose of the measures are communicated clearly.

Best practices in performance measurement include:

- if general condition rating data is used due to limited element history, the measure should be adaptable and meaningful when sufficient data is available to transition to the National Bridge Elements;
- communication should be considered in naming the performance measure;
- the goals should follow the SMART philosophy—Specific, Measurable, Attainable, Realistic, and Timely;
- the measure should be short and simple;
- the measure should be reliable, transparent, and understandable;
- a high priority should be set on preservation and maintenance;

- the units selected for the performance measure should be carefully considered. For example, creating a condition performance measure using deck area can result in different project prioritization and outcomes than the projects selected if the measure was based upon number of structures;
- the measures should have a direct linkage to the deterioration and the improvement of bridge elements or components to perform the tradeoff analysis or cost/benefit analysis.

3.3.1.3—Preservation and Improvement Action Data

In order to analyze bridges for project selection, the BMS requires information on the action—whether it is preservation or improvement driven—that should be considered in a network and the benefit the action has on a structure. The benefits may vary depending upon the type and condition of the structure that is having the action applied to it, and this complexity must be included in the action data for it to be considered in the analysis. To report bridge needs at both the bridge and network level, an overall category of work type (such as preventative maintenance, rehabilitation, replacement, or mitigation) should be assigned to each action. In addition to maintaining information on possible work activities, historical preservation and improvement data should be stored within the BMS. This information can then be used to evaluate the efficacy of actions, verify assumed benefit information, and influence the timing of future work according to agency policy.

3.3.1.4—Cost Data and Financial Plans

The evaluation of alternative actions and strategies requires knowledge of the costs to perform the work and a knowledge of the available finances. Costs to be considered include the direct cost of the action and the indirect costs associated with a project, such as mobilization and traffic control. Inflation should be included when analyzing the effectiveness of the work performed in future years.

Financial planning information is required to apply fiscal constraints to the analysis. The amount of funds available in the short term and predicted for the long term, the source of the funding, and any other restrictions should be included in the BMS so that it can be incorporated in the analysis. A bridge program does not exist by itself. Financial planning often needs to consider the challenge of planning for prioritization of projects that involve multiple assets and should be

coordinated with other programs such as pavement, safety, and modernization.

3.3.2—Data Integration

Data integration identifies data driven actions and strategies to optimize the use of limited resources. The optimal decision is the one that minimizes cost and risk over the long term while providing the desired level of service. Because decisions made today on bridge preservation or improvement affect the condition of the bridge system in the future, a BMS should include mechanisms for predicting the effects of today's decisions. Two major prediction tools that are important for BMS operation are bridge deterioration models and bridge-related cost models. The deterioration and cost models provide engineering and economic data to the optimization module, where these inputs, along with agency rules, budgets, and policy data, are analyzed to develop, categorize, and prioritize a selection of projects for maximum benefit within financial constraints.

Data integration is composed of five main components:

1. data analysis;
2. risk assessment;
3. agency rules;
4. cost/benefit analysis; and
5. prioritization and optimization.

3.3.2.1—Data Analysis

A BMS uses data to identify the current and future bridge needs and evaluates system performance. This analysis may involve inventory information, general condition ratings, bridge element ratings, and inspector work recommendations. The BMS should be able to optimize work activities to address the deficiencies and categorize the work types into major categories such as preventive maintenance, rehabilitation, or replacement to report to stakeholders.

Strategic planning requires DOTs to make decisions that are cost-effective over the long term. Assessing future needs based on current condition data is an essential component of BMS data analysis. Bridge deterioration models forecast the probability of element condition states or bridge condition ratings at future points in time, under the assumption that no programmed major preservation, repair, or replacement activity is undertaken. These are typically accompanied by action effectiveness models, which

forecast bridge condition following completion of preservation activity. Together, these models can be used to predict the rate at which new needs arise, and the effects of alternative policies and funding levels for preservation. When implementing a new bridge management system, deterioration models are typically developed using a process of expert judgment elicitation. Once a few cycles of inspections are completed on a sufficiently large inventory, it becomes possible to develop cross-sectional models, using statistical analysis methods that make year-to-year forecasts of the probabilities of each possible change in condition that might be observed. Such forecasts can be chained year after year to produce an estimate of new needs that are likely to arise each year in a long-range plan. Some deterioration models can consider variables such as climate, traffic volume, and interaction among bridge elements (for example, the effect of paint condition on the underlying steel) to refine the predicted rates of change in condition. Quantifying the uncertain rate of deterioration is important because even long-lived assets can produce near-term preservation needs on a fraction of bridges in the inventory. Methods for developing deterioration models can be found in NCHRP Report 713, *Estimating Life Expectancies of Highway Assets*.

3.3.2.2—Risk Assessment

Risk may be understood as the potential for unplanned adverse events to impact one or more transportation facilities in a way that causes unacceptable transportation system performance according to any or all of the agency's performance objectives. In bridge management, the primary concern is disruption of expected or designed service levels, which may cause injuries or property damage, loss of mobility, and immediate expenditures or long-term excess costs.

The adverse events which may cause these service disruptions may include natural hazards such as earthquakes, landslides, storm surge, high winds, floods, scour, and wildfires; man-made hazards such as overloads and vehicle or vessel collisions, including vehicles containing flammable cargo; and advanced deterioration related to corrosion, section loss, displacement, or fatigue cracking.

Risk assessment evaluates the likelihood and consequence of adverse events. The likelihood of the event includes the probability of the event occurring and may include the vulnerability of the structure to the event. The consequence of the adverse event would quantify the damage to the structure, the impact on the flow of people and goods in the transportation network, and the importance (criticality) of the structure. NCHRP Report 20-07/Task 378 provides a

risk assessment methodology with worksheets that were developed to assist in estimating likelihood and consequences of service disruption for various types of hazards.

A transportation system is best prepared to reduce the consequence of an extreme event when the system includes redundancy, robustness, and resiliency.

Redundancy is excess capacity in times of emergency. Bridge engineers are familiar with load path redundancy in bridges; however, sound management of the assets on detour and emergency evacuation routes increases a highway system's redundancy.

Robustness is the capacity to cope with stress or uncertainty. Well-maintained assets are generally better able to withstand the stresses of storm events and other disasters than weakened and poorly maintained ones.

Resiliency has been defined in several ways; one definition is "the ability to prepare for, plan for, absorb, recover from, and more successfully adapt to adverse events." Another definition is "the capability of a system to maintain its functions and structure in the face of internal and external change and to degrade gracefully when it must" (Allenby and Fink 2005).

A risk-based BMS should contribute to all three attributes.

A BMS supports risk assessment and strives for risk reduction. A BMS should provide an accurate inventory of bridges with their condition and unit-cost data; identify those bridges at risk for given types of events such as floods, hurricanes, or earthquakes; and prioritize the level of risk. A BMS may have mapping and geographic information system (GIS) capabilities to assist with identifying bridges and prioritizing their coordination with evacuation planning or detour routing. As not all structures have the same criticality or vulnerability, the prioritization can allocate resources—both in terms of dollars and personnel—which may be the limiting factor during an event. A BMS should prioritize critical bridges for mitigation prior to an event, for inspection during critical events, and for repair following an event. A BMS should prioritize bridges for data collection realizing that not all structures have the same criticality or may not have the same level of risk. Sound maintenance practices recommended and tracked by a BMS "harden" assets. For example, bridges with well-maintained wing walls, bank protection, and scour protection are more robust during high water events. Conversely, a BMS can identify bridges where deferring maintenance can allow an undesired condition and lead to an unacceptable vulnerability and risk.

Risk assessment within a BMS can be used to modify and optimize inspection and data collection practices. Bridge inspection and condition data collection can perform two purposes; identify safety

issues on bridges, and report condition for asset management decisions. NCHRP Report 782, *Proposed Guideline for Reliability-Based Bridge Inspection Practices*, outlines a methodology to develop a risk-based approach for determining the bridge inspection interval. The goal of the methodology is to improve the safety and reliability of bridges by focusing inspection efforts where needed most and optimizing the use of resources.

3.3.2.3—Agency Rules

In order for a BMS to make bridge level decisions consistent with agency practice, agency rules need to be developed. The intent of the rules is to translate agency practices and their effects on bridge, program, and network level recommendations into the system's modeling approach. These rules should be intuitive and reflect agency business practice and policy. Rules may be cyclic or conditional. A cyclic rule is set out as an action and an interval. For example, "Wash every bridge once each year." Conditional rules are set out as action taken as the result of the condition of an element or component. For example, "Replace seals in strip seal expansion joints when quantity in Condition State 2 (Fair) exceeds 20 percent, or quantity in Condition State 3 is greater than 0 percent" is a conditional rule. Conditional rules most often need to be considered concurrently with related elements that could impact how the rules should be applied. For example, a concrete bridge deck may be protected by a wearing surface, or steel beams may be protected by a paint system, or feasible actions such as rehabilitating a deck surface or replacing deck expansion joints may be "constrained" by the poor condition of the bridge's superstructure, which needs to be replaced. Agency rules within the BMS need to provide the recognition of these interdependencies.

Agency rules may provide thresholds for performing work on the entirety of an element when a certain percentage is deteriorated, or there may be rules to address multiple deficiencies at once whenever possible or to defer work for a certain number of years following a project to minimize the impact on the traveling public. Agency rules can be an important tool to reduce computational time by eliminating unrealistic work candidates during network analysis.

Rules may be applied at the bridge, program, or network level. Bridge level rules might reflect different preservation policies for steel versus concrete structures, or prevent replacement recommendations for historic structures. Program level rules may reflect varying performance measure goals or funding constraints, while network rules cover standard agency practice.

Agency rules may also be used to apply the connection between bridge asset management and the needs and performance measures of the other assets within the transportation system. For example, bridge specific agency rules can time actions to correspond with pavement preservation activities.

3.3.2.4—Cost/Benefit Analysis

With limited resources and competing system needs, cost/benefit analyses are required to determine effective work activities. Cost/benefit analyses can be condition, improvement, or lifecycle driven. Optimization approaches to a BMS recognize that preservation activities including cyclic maintenance, preventive maintenance, repair, and rehabilitation are done to deter deterioration (condition driven benefits) while improvements such as widening, strengthening or mitigation actions respond to user demands or reduce risk. The choice of preservation actions should be predicated on maintaining safety, meeting performance measures, and minimizing agency lifecycle costs while improvements should be based on the benefit to road users or eliminating bridge deficiencies.

3.3.2.4.1—Condition Driven Cost/Benefit Analysis

The most basic asset management program takes condition data, identifies the work activities that could address any deficiencies in condition, and then calculates the cost of the activity based on the quantity to be repaired. In order to compare possible activities, the condition improvement (benefit) is shown as a ratio to the cost. The activity or combination of activities with the highest benefit to cost ratio would be the preferred condition driven action for that structure. The bridge manager needs to take caution when developing a strategy based solely upon condition driven cost/benefit analysis because if condition benefits and costs alone are considered, the alternatives could tend to favor maintenance only to extend life until permanent closure.

3.3.2.4.2—Improvement Cost/Benefit Analysis

Improvement benefits reduce risk or user costs by eliminating, mitigating, or reducing bridge deficiencies. Bridges with low vertical clearance or insufficient load capacity will force a certain volume of truck traffic to be detoured to alternate routes, resulting in increased vehicle operating costs. Bridges having narrow deck width, low vertical clearance, or poor alignment may have a higher occurrence of

accidents than bridges without these deficiencies. Scour critical bridges or bridges with poor seismic details are at risk during extreme events. Reducing these deficiencies through replacement, widening, strengthening, or mitigation actions provides a benefit to the user. Consideration of improvement benefits is essential in a BMS if functional deficiencies are to be eliminated and risk is to be reduced. AASHTO provides *User and Non-User Benefit Analysis for Highways* (2010) for agencies to help analyze the benefits and costs of highway projects.

3.3.2.4.3—Lifecycle Cost/Benefit Analysis

The direct cost to a highway agency for owning a bridge is not a one-time initial construction cost. Rather, agency costs are a long-term, multi-year investment of a series of expenditures for maintenance, rehabilitation, and replacement. Therefore, a BMS should take a long-term view of the lifecycle of a bridge, reflecting the highway agency's long-term responsibility.

Lifecycle Cost Analysis (LCCA) is an economic evaluation used in the selection of the least cost design and management strategies that impact initial construction and lifecycle agency costs. It compares the differential costs of initial design and lifecycle management alternatives over a specified analysis period to identify the least cost alternative. Design features and management practices similar between the alternatives are not typically included in the analysis. The analysis period should cover a time span that includes at least one major rehabilitation for each alternative being considered. Lifecycle costs can be shown as the discounted present value of the total initial and future agency costs that occur over the analysis period. To perform network level analyses, the assumptions and analysis process of lifecycle costs should be comparable from one structure to another. If lifecycle costs are calculated over a design service life that varies with each type of structure, it is convenient to convert lifecycle costs to equivalent uniform annual costs. If lifecycle costs are calculated over a set period of time for each structure, the remaining value of the structure at the end of the evaluation period should be normalized. LCCA can include user costs attributable to the functional deficiency of a bridge such as a load posting or clearance restriction. It can also include impact to the user resulting from bridge closure or work zone restrictions during construction. Agency costs should not be combined with user costs, since agency costs represent direct impacts to budgets and influence resource allocation decisions. User costs help identify initial construction, preservation, maintenance, and procurement strategies that have the least impact to

users. The specific elements of agency and user costs considered in a bridge LCCA will depend on the bridge under consideration and the purpose for which the analysis is being made.

When doing LCCA, the use of deterioration models, estimated service life durations for activities, and costs associated with them are needed. BMS software such as AASHTOWare BrM provide deterioration modeling developed from regional and national data and expert elicitation. State agencies typically have historic data that can be used to develop deterioration modeling for bridges in their networks. In addition, construction and maintenance costs from previous projects or studies can be used for developing costs for fix types. There are several resources for doing bridge lifecycle cost analysis, including NCHRP Report 483, *Bridge Lifecycle Cost Analysis*, The National Institute of Standards Technology, Bridge Lifecycle Tool (BLCC) and user's manual, and FHWA's National Bridge Investment Analysis System (NBIAS) and documentation.

3.3.2.5—Prioritization and Optimization

Optimization has become the preferred method for bridge network management. The purpose of optimization at the network level is to select a set of bridge projects in such a way that the total benefit derived from the implementation of the selected projects is maximized (costs and risks are minimized). The ability to establish project priorities and optimally allocate limited funds over a predefined planning horizon, both short- and long-run, is a fundamental part of a BMS.

The system should consider unconstrained, constrained, and required budget cases. If unlimited budgets are available, it is possible to determine the optimum period in which selected alternatives should be scheduled. Where adequate funding is not available to maintain a desired level-of-service, the BMS may calculate the economic consequences of a lower level-of-service and provide an objective means of setting priorities for bridges so that risks are minimized. When a project must be delayed, the BMS can use the deterioration models and cost models to quantify the bridge level effect and the impact on road users, and to determine the new optimal set of actions for the bridge at a later period. By exploring period-by-period project deferrals, multi-year programs can be generated. The system should also be able to indicate the funding required to reach performance goals to identify the financial performance gap.

Modern optimization approaches can take several forms. The differences in optimization approaches tend to be in the specific techniques used and in the

way that network-level considerations are reflected in the analysis. Two common approaches are:

- **Top-Down Approach**, where network-level performance measures are addressed first and the results are then used to guide project selection, resource allocation, and scheduling. For the top-down approach, an agency may deteriorate the entire network over the programming time frame, and try to balance the best option for each bridge with the best option for the whole network, increasing or decreasing work on any one bridge to make the most progress toward the agency's performance measures.
- **Bottom-Up Approach**, where the most cost effective option is identified for each bridge by using condition information and inspector recommendations. The BMS accomplishes this by providing near- and long-term side-by-side comparisons of alternative work candidates and alternate timing of the projects. After bridge level decisions of scope and timing of work are made, the results of the analysis are summarized back up to the network level to determine the level of funding required to address network deficiencies for a given period of time and the optimum projects to schedule subject to budget and other network level constraints.

Agencies will often use a combination of these two methods for optimization.

3.3.2.5.1—Multi-Objective Optimization

Bridge owners often need to consider multiple performance criteria and constraints, such as bridge condition, lifecycle costs, safety, traffic flow disruption, and vulnerability when making decisions and prioritizing projects. They may need to analyze tradeoffs between these performance criteria. NCHRP Report 590, *Multi-Objective Optimization for Bridge Management Systems*, provides a methodology for this decision-making predicated on utility theory. Utility theory is based on the premise that the decision maker's preference structure can be represented by a utility function. Construction of the utility function generally involves three major steps:

- **Weighting:** This assigns relative weights to each of the multiple criteria based on their relative importance.
- **Scaling:** This provides a common scale of measurement for performance criteria that have different units. This involves developing a single-