U.S. Department of Transportation
Federal Highway Administration

Basics of Bridge Life Cycle Cost Analysis (LCCA)

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12 June 2023

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Bridge management software and deterioration modeling software are largely proprietary. Content pertaining to proprietary software is included only to illustrate concepts and how analyses are applied in practice. The included content shall not be construed as promotion or endorsement of specific software.

Acronyms

ADE: Agency Defined or Developed Elements

BLCCA: Bridge Life Cycle Cost Analysis

BCA: Benefit-to-Cost Analysis

BME: Bridge Management Elements

BMS: Bridge Management System

BrM: AASHTOWare Bridge Management System [Software]

BrR: AASHTOWare Bridge Rating [Software]

C: Cost

CFR: Code of Federal Regulation

CFRP: Carbon Fiber Reinforced Polymer

CRR: Corrosion Resistant Reinforcing steel

CSF: Critical Success Factor

DR: Discount Rate

ECR: Element Condition Ratings

EUAC: Equivalent Uniform Annual Cost

FV: Future Value

GCR: General Condition Rating

HI: Health Index

LCC: Life Cycle Cost

LCCA: Life Cycle Cost Analysis

LRFD: Load and Resistance Factor Design

MBEI: Manual for Bridge Element Inspection

MMFX: corrosion resistant alloy steel

NCHRP: National Cooperative Highway Research Program

NEPA: National Environmental Policy Act

NBE: National Bridge Element

NBI: National Bridge Inventory

PV: Present Value

ROW: Right-of-Way

RUC: Road User Costs

SCM: Supplemental Cementitious Materials

SCR: Special Contract Requirements

SDCL: Simple for Dead load and Continuous for Live load

SHRP: Strategic Highway Research Program

SL: Service Life

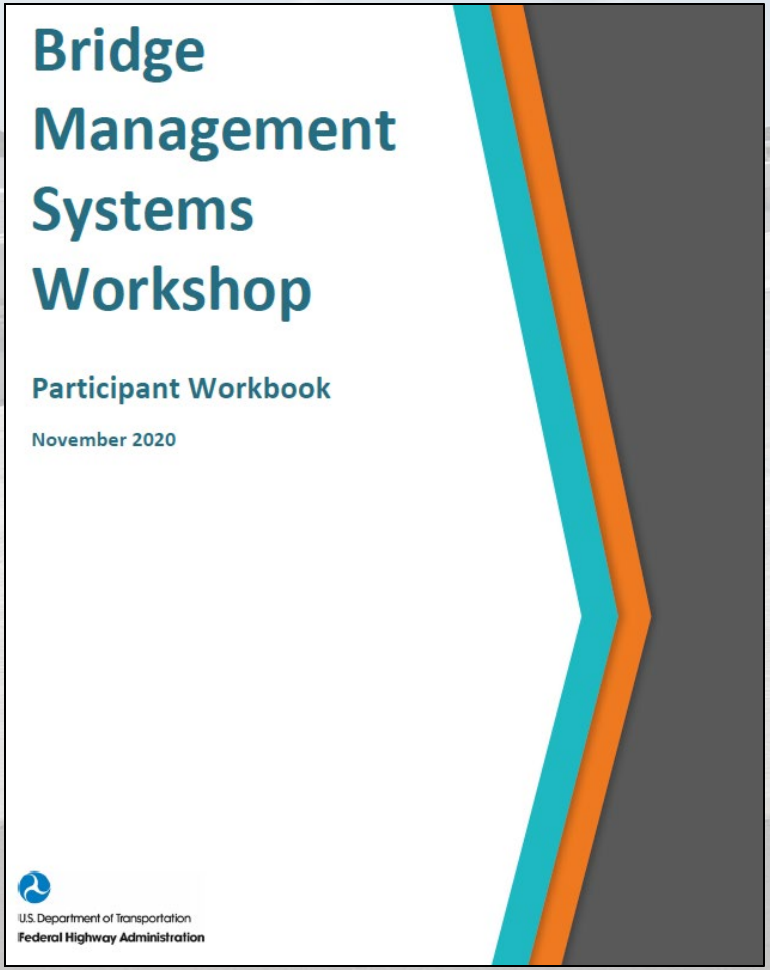
SLD: Service Life Design (durability design)

TAM: Transportation Asset Management

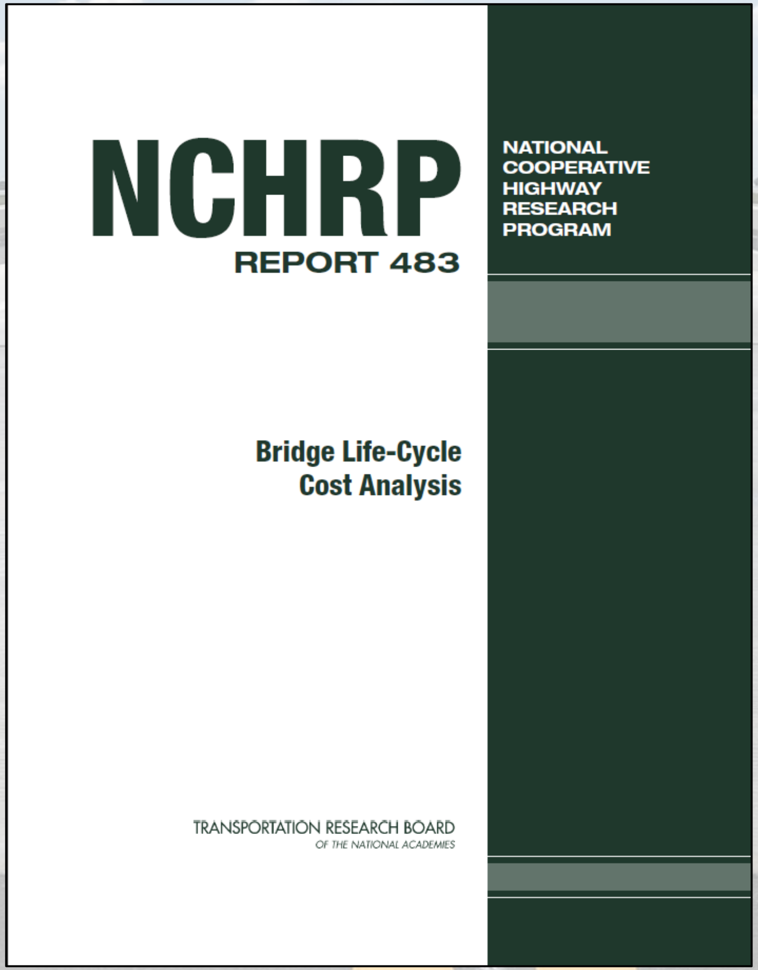
TAMP: Transportation Asset Management Plan

TPM: Transportation Performance Management

Key Resources

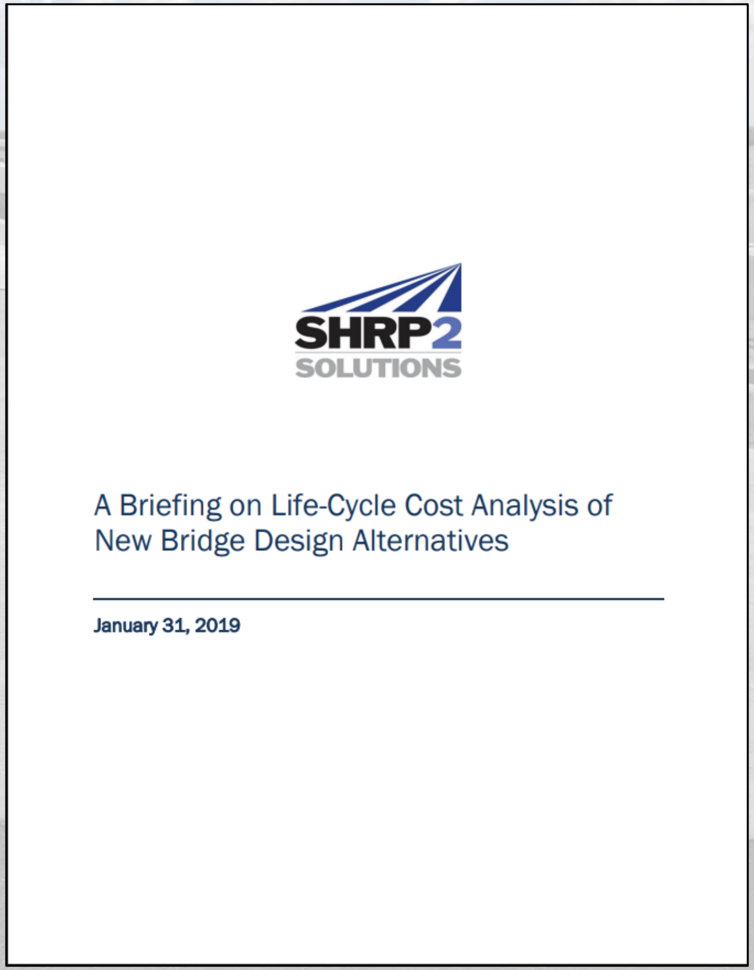


[Bridge Management Systems Workshop]



[NCHRP Report 483: Bridge Life-Cycle Cost Analysis]

[NCHRP Report 483: BLLCA Software CD]

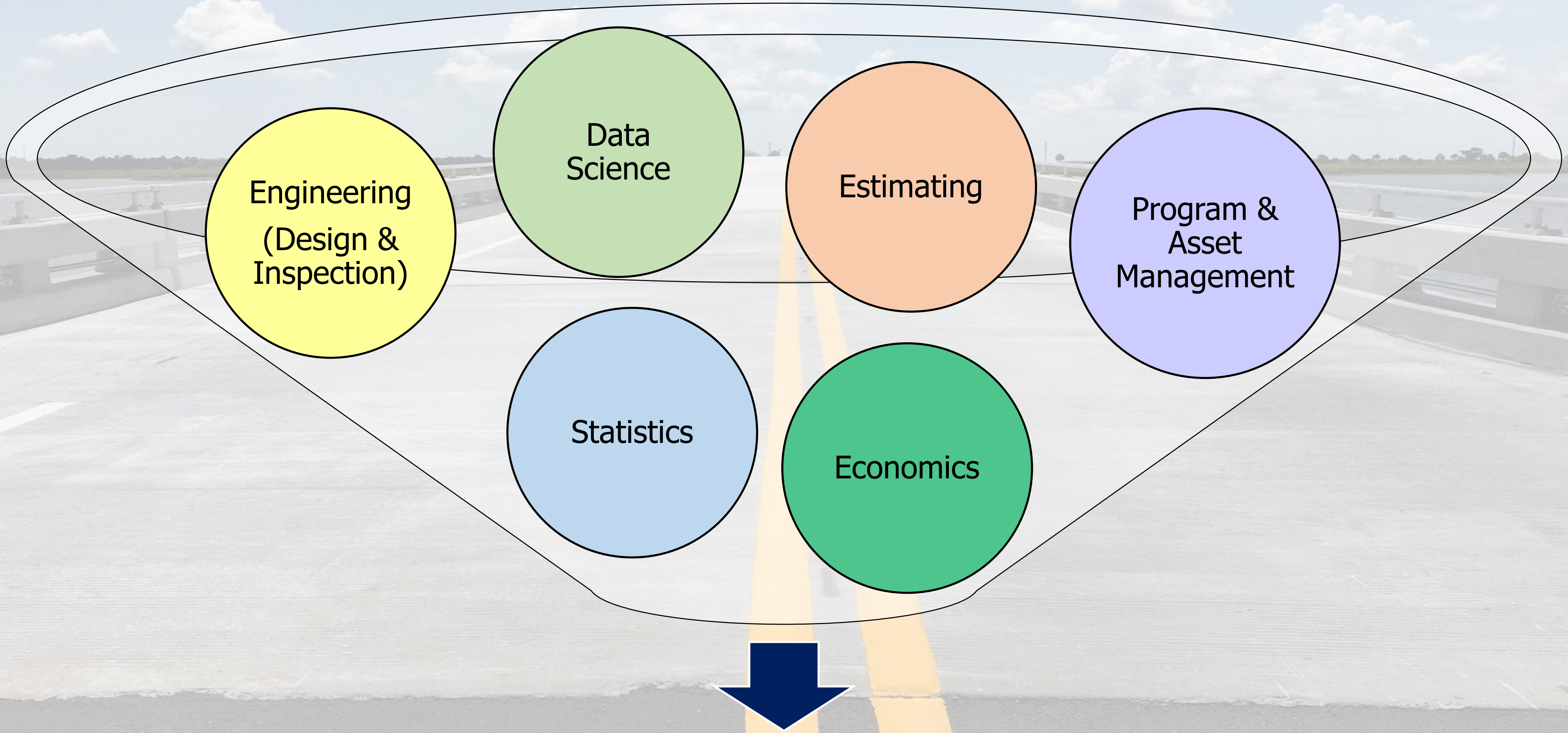


[SHRP2 R19A LCCA of New Bridge Design Alternatives]

Learning Objectives

- Understand the principles of a LCCA for bridges
- Understand the basic steps in performing a LCCA
- Understand factors & inputs into performing a bridge LCCA and why they are important
  - Design Life vs. Service Life
  - Deterioration, Exposure Zones, and Durability
  - Timing of Maintenance, Preservation, and Rehabilitation Actions
  - Cost Types and Estimates
  - Forecasting, Modeling Uncertainty, Optimization
  - Time Value of Money, Present Value, Discount Rate

LCCA is an Amalgamation of



LCCA

Life-Cycle Cost Analysis (LCCA) Basics

- Used to **compare / select the most cost-effective alternative** and **timing of activities** (design with associated preservation and maintenance strategies) **over the same time period** (e.g., 75 or 100 years).

- **Compares total costs** of competing project implementation alternatives **at the same level of service and benefits** (*these must be equal among project alternatives being considered*) by finding the **right balance** between initial costs, maintenance costs, and the desired condition of the bridge.

- Time value of money: **Money in the future is worth less than its present value so must be discounted to its present value**.

LCCA Basics, cont.

- Maintenance costs (assuming proper regular maintenance) are typically less than the costs of prematurely replacing a bridge.
- Maintenance of bridge components greatly influences the rate of their deterioration.
- Planned maintenance tasks of different bridge components are closely related to the exposure zones and level of expected deterioration of the components. Based on these factors, the necessary maintenance precautions can be planned.
- Carefully identify maintenance tasks, timing of tasks, and related unit costs since they greatly influence the outcome of LCCA.

LCCA Basics, cont.

- Since constructing and managing a bridge covers a timeframe of 75 or more years, those **costs need to be converted to a form that allows them to be compared**.
- Economists distinguish the value between a dollar today and one in the future (time value of money) through a process called **discounting**.
- **Discounting** involves calculating the range of values of a dollar over a time horizon to find their **present value**.

Basic Steps in a LCCA

1. Establish Design Alternatives
2. Determine Activity Timing
3. Estimate Costs
4. Compute Life-Cycle Costs
5. Analyze Results

Life-Cycle Cost Analysis Primer

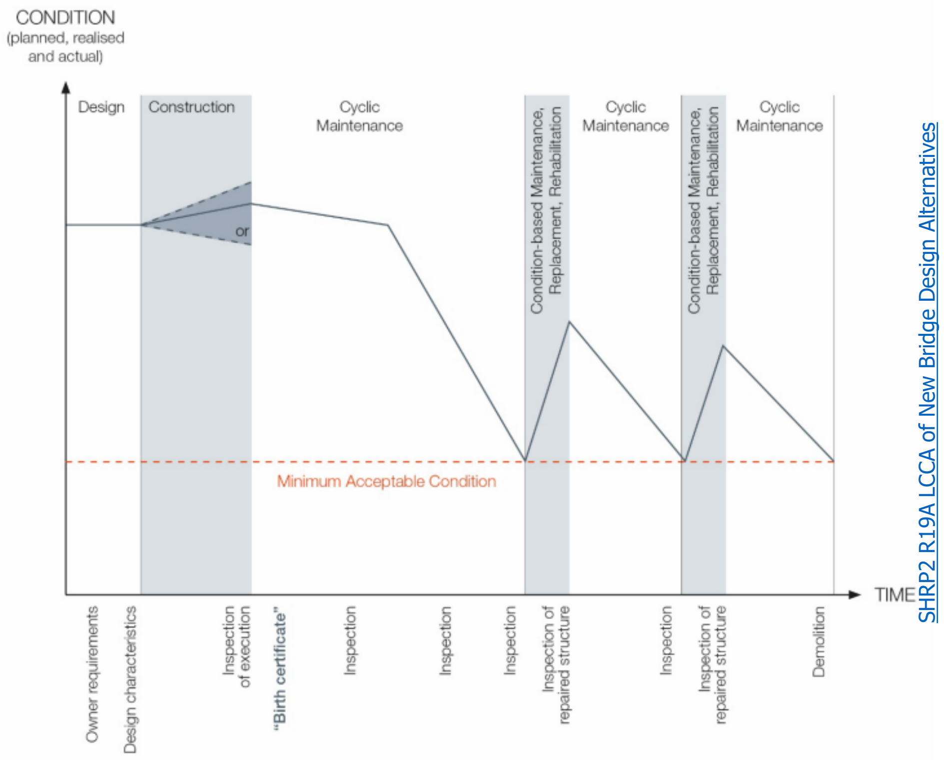
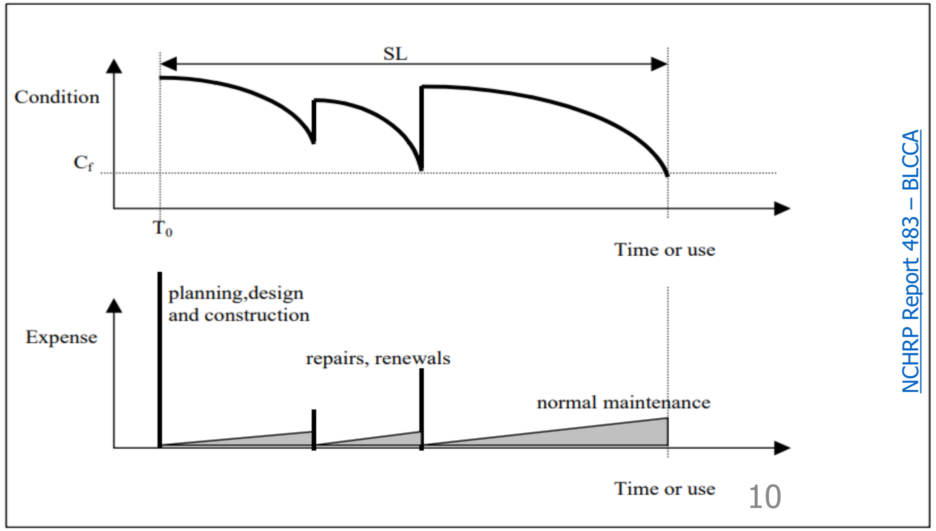


Figure 1: Complete Service Life (adapted from Gehlen, 2006, [19])

SHRP2 R19A LCCA of New Bridge Design Alternatives

Figure 2.3 Expenditure accompanying the life cycle



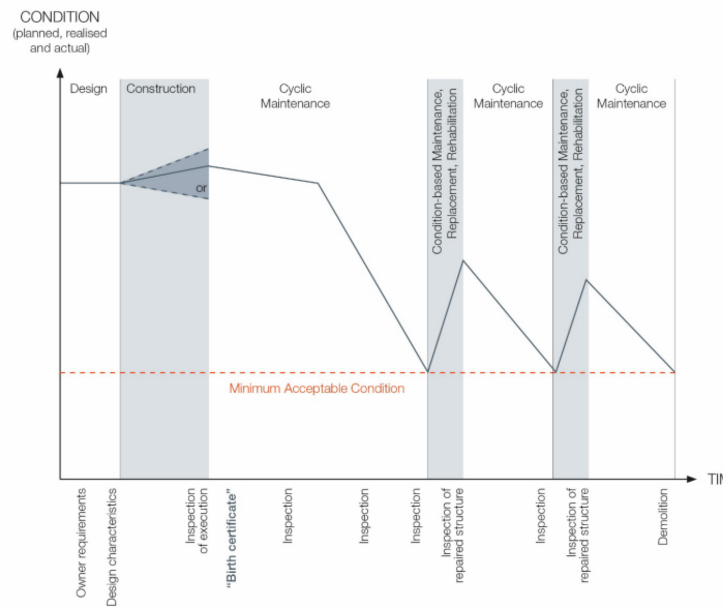
NCHRP Report 483 – BLCCA

Expanded Steps in a LCCA

1. Identify Bridge, Components, &/or Elements &/or Service Life Alternatives
2. Identify Exposure Zone(s) for Components & Elements
3. Determine Deterioration for Each Component & Element
4. Establish Maintenance* Tasks for Each Component & Element
5. Determine Frequency of Each Maintenance* Task
6. Determine Quantities of Each Component & Element
7. Determine Unit Costs of Maintenance* Tasks
8. Calculate Activity Task Cost per Time for Each Maintenance* Action (Unit Cost x Quantity)
9. Determine the Real Discount Rate & which Engineering Economics Formulas to Use
10. Calculate the Present Value Cost for Each Task Over Service Life
11. Calculate Total Present Value Cost

*The term maintenance is being used generically and refers to all activities which improve bridge conditions.

** Perform Simulations & Sensitivity Analyses to Optimize Costs, Design, & Maintenance Activities **



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SHRP2 R19A LCCA of New Bridge Design Alternatives

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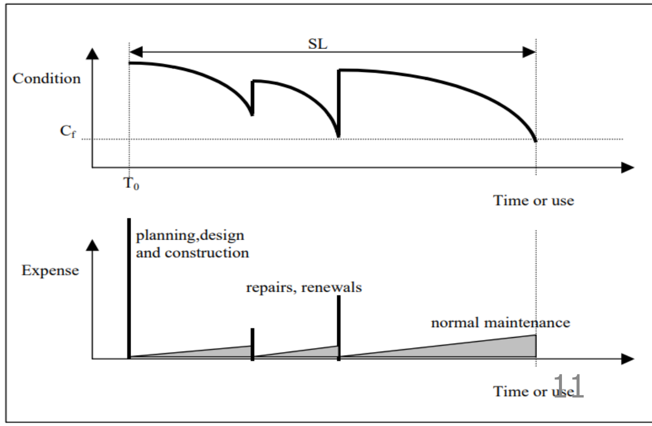


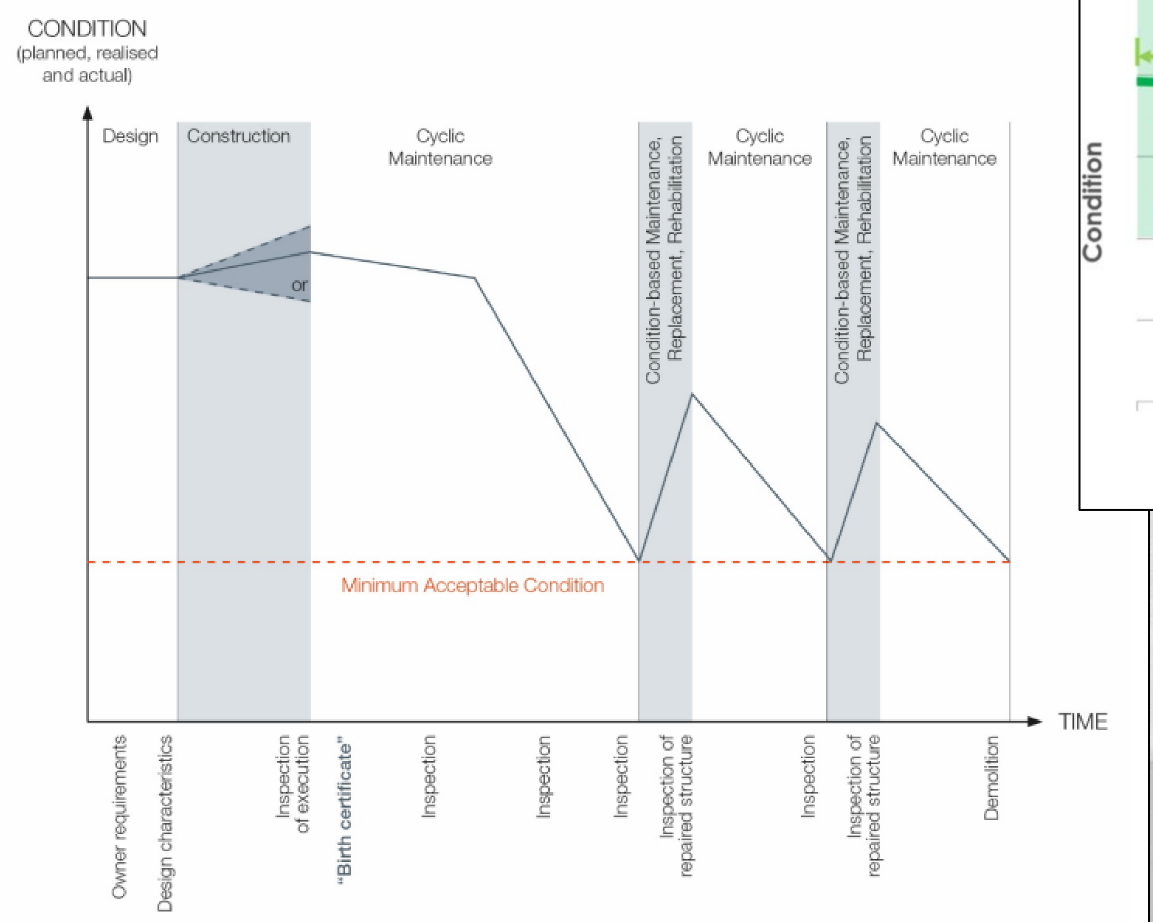
NCHRP Report 483 – BLCCA

Design Alternative Considerations

Design Life ≠ Service Life

Picture by FHWA

Activity Timing is Crucial



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SHRP2 R19A LCCA of New Bridge Design Alternatives

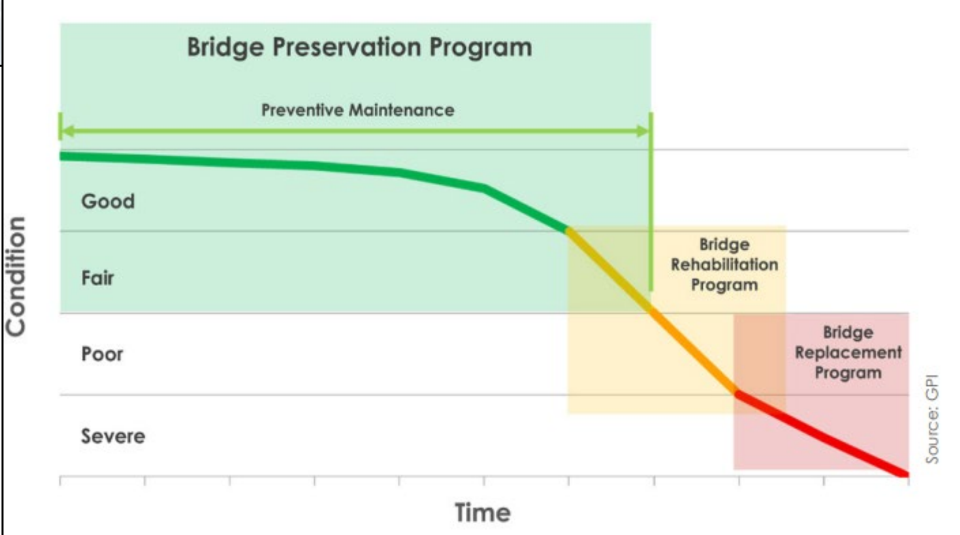


Figure 14. Bridge condition over time.

FHWA Bridge Preservation Guide

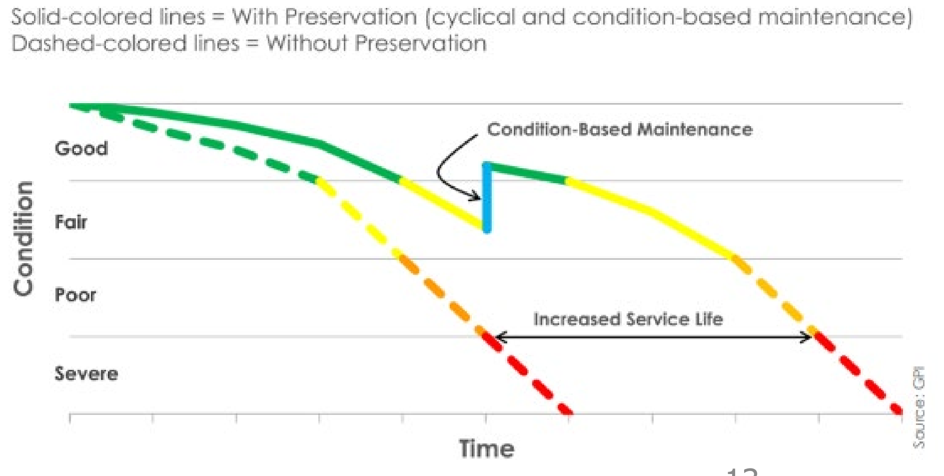


Figure 17. A comparison of bridge condition over time with and without bridge preservation.

Typical LCCA Costs

- **Agency Costs** (construction, operation (including inspections), maintenance, preservation, rehabilitation, demolition, residual value);

- **User Costs** (congestion, detours, accidents, etc.); and

- **Vulnerability Costs** (seismic, scour, floods, overloads, collisions, fires, etc.)

Computing LCCA

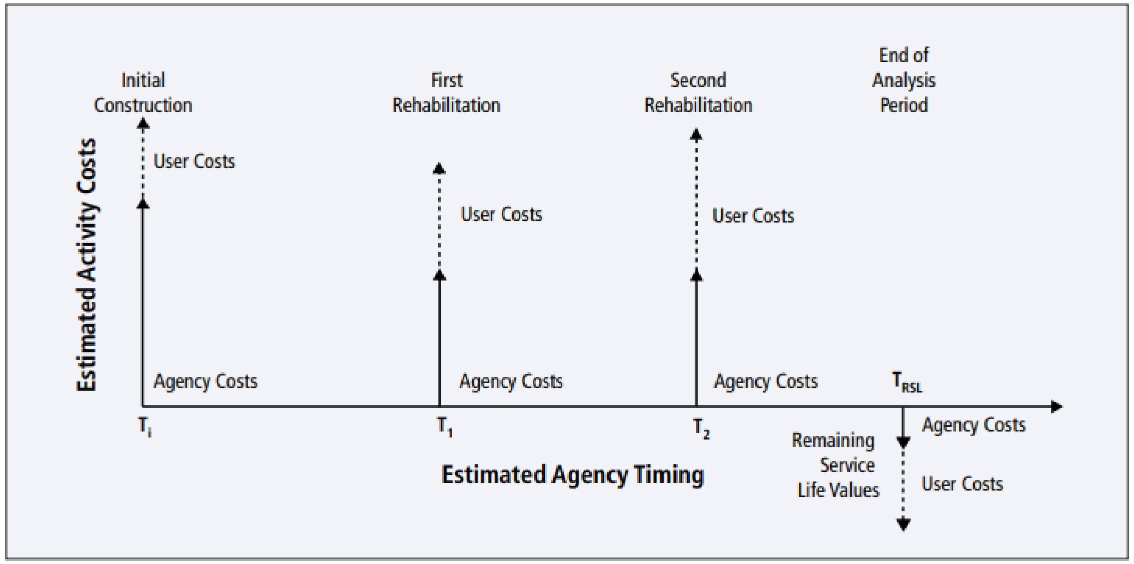


FIGURE 2. **EXPENDITURE STREAM DIAGRAM, SHOWING ACTIVITIES, COSTS, AND TIMING**

Life-Cycle Cost Analysis Primer

Money in the future is worth less than its present value so must be discounted to its present value.

SHRP2 R19A LCCA of New Bridge Design Alternatives

$$PV_{LCC} = \sum_{t=0}^{T} C_n * 1/(1+r)^n$$

One-Time Future Event

$$PV = \frac{FV_N}{(1+DR)^N}$$

Equal Annual Events

$$PV = C\,\frac{(1+DR)^N - 1}{DR(1+DR)^N}$$

NCHRP Report 483 – BLCCA

		Alternative A		Alternative B	
Year	Discount Factor	Discounted Agency Costs	Discounted User Costs	Discounted Agency Costs	Discounted User Costs
0	1.0000	$26,000,000	$11,000,000	$20,000,000	$8,000,000
12	0.6246			3,747,582	6,245,970
20	0.4564	6,845,804	13,691,608	2,738,322	7,302,191
28	0.3335			2,000,865	9,337,369
35	0.2534	(950,308)	(1,900,616)	(190,062)	(886,954)
Total Costs (PV)		**31,895,496**	**22,790,992**	**28,296,707**	**29,998,576**

Life-Cycle Cost Analysis Primer | FHWA

Analyzing Results

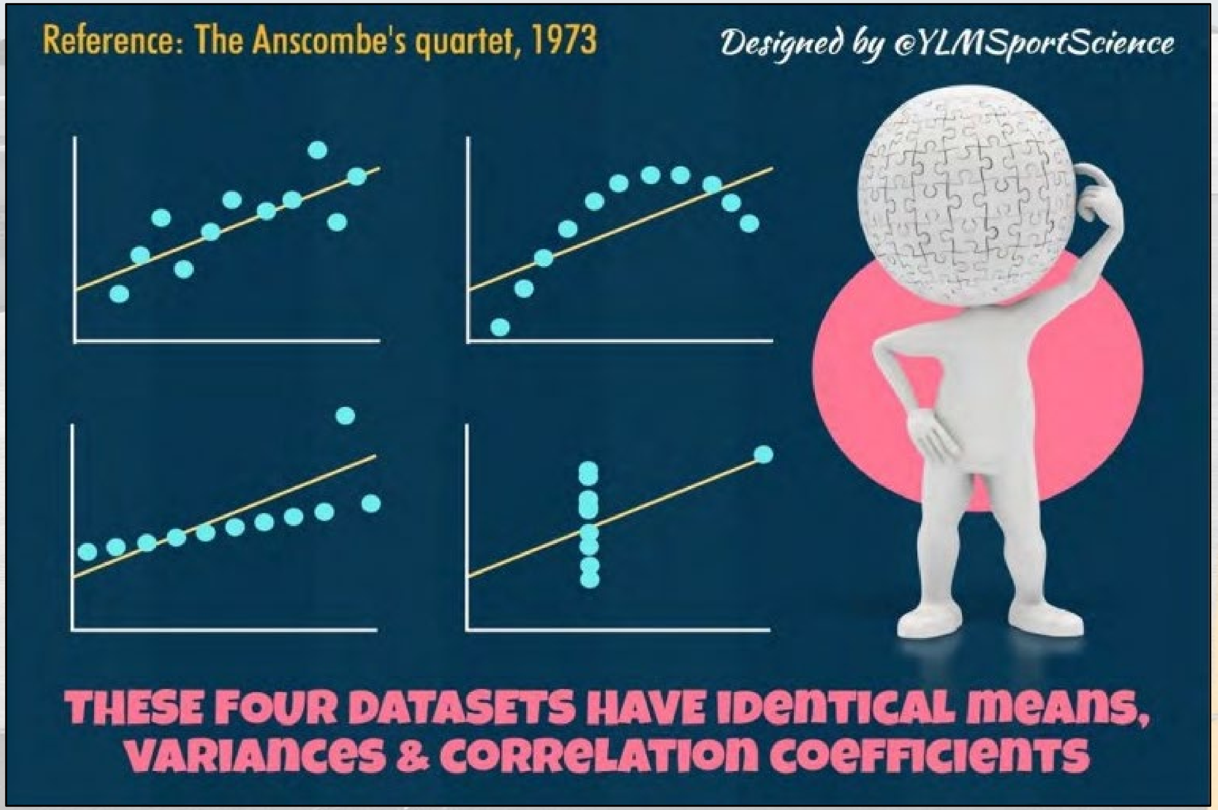
- Lowest Cost Alternative
- Sensitivity Analyses and Simulation
- Benefit-to-Cost Analysis (BCA)
  - Considers the benefits of an improvement as well as its costs
  - Use for different levels of service, utility, objectives, or duration (e.g., 75 years and 100 years)
  - Goal is to maximize benefits
    - Area-Under-the-Curve Method

COMPARISON OF ANALYSIS ELEMENTS: LIFE-CYCLE COST ANALYSIS VERSUS BENEFIT-COST ANALYSIS

Project Element	LCCA	BCA
Agency construction, rehabilitation, and maintenance expenditures	Yes	Yes
User costs during construction, rehabilitation, or maintenance	Yes	Yes
User costs during normal operations	Yes	Yes
User benefits resulting from project	No	Yes
Externalities resulting from project	No	Yes

Life-Cycle Cost Analysis Primer | FHWA

Be Aware & Beware of Your Data



Slide from: Use of IDT Testing for Asphalt Mixture Performance – Design and QC/QA (Bennett, 2019)

Garbage data image: New Course: Learn Advanced Data Cleaning in R | R-bloggers (accessed 6.08.2023)

Variability and Uncertainty

To address variability and uncertainty associated with input factors, utilize either or both computational approaches:

- **Deterministic**: (most used) uses fixed discreet values
  - Extrapolation
  - Regression
  - Curve-fitting techniques

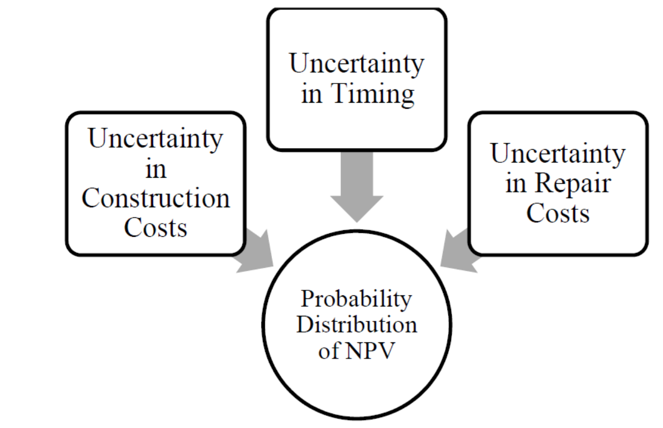


Figure 11.5. *Stochastic approach to LCCA.*

Design Guide for Bridges for Service Life

- **Stochastic (probabilistic):** defines input variables by a probability distribution
  - Markov-Chains & Markov-Chain Monte Carlo
    - Markov Transition Probability models are often used in deterioration modeling
  - Time-in-Condition Rating (TICR) for bridge deterioration models
- **Other**: Bayesian-based statistical models, neural networks, machine learning, deep learning, Artificial Intelligence

Variability and Uncertainty

Simulation and Sensitivity Analyses

- Helps reveal which variables have greater uncertainty and influence LCCA results
- Ideally, the "best" alternative will have the lowest present value in the most likely of "what-if" situations
- Determine acceptable risk levels
- Re-evaluate parameters and alternatives as needed

Remember Other Influences

- Location: urban / rural and proximity of source materials to site
- Trucking routes and bridge load ratings leading to the project
- Economy of scale
- Bidding and contract methodology and requirements
- Designer and contractor risk
- Schedule
- Work hour or noise restrictions
- Sequencing of activities
- Construction considerations, staging, hoisting
- Permitting (NEPA, oversized and superloads, etc.)
- Detours, lane closures, and traffic control
- Labor / technical expertise shortages

Bridge Parts Definitions

Bridge Element: Individual bridge member (e.g., girder, beam, bent, stem, bearing, railing, etc.).

Bridge Component: A combination of bridge elements forming one of the three major portions of a bridge that makes up the entire structure. The three major components of a bridge system are substructure, superstructure, and deck.

Bridge Subsystem: A combination of two or more bridge elements acting together to serve a common structural purpose (e.g., such as a composite girder which could consist of girder, reinforcement, and concrete).

Bridge System: The three major components of the bridge combined to form a complete bridge.

Design Guide for Bridges for Service Life

Step 1: Establish Design Alternatives

- Establish Required Design Criteria & Factors of *Initial* Design
  - Spans, Loads, Geometric, Geotechnical, Layout, Clearances, ROW, NEPA, Economics of Design, etc.

- Determine Design Alternatives
  - Bridge type, span ranges, span configurations, materials
    - e.g., *Concrete options*: prestressed box beams, prestressed AASHTO beams, prestress bulb-tees
      Steel options: steel beams, steel plate girders, folded plate beams, SDCL

- Identify required activities throughout the structure's service life for each alternative
  - e.g., maintenance, preservation, rehabilitation, or element replacement for each element, subsystem, and/or within a system

Step 1. Cont.:

- How do / will resiliency and sustainability considerations change designs and LCCA?

- **Resiliency** considerations will likely focus on durability and high risk / vulnerability factors.
- **Sustainability** considerations will likely require additional benefit-to-cost analyses to capture benefits of sustainability.

Durability & Service Life Considerations

- Ideally design(s) incorporate durability (Service Life Design)

  ~ for each bridge element, component, subsystem, and system

- Service life design is beyond the structural load carrying capabilities and LRFD 3.4 Service Limit States I, II, and III

- All materials deteriorate with time and at unique / individual rates, even a different locations within the same element

- Typically, when a structure reaches the end of its life the cause is primarily from material deterioration due to environmental exposure conditions
  - e.g., chlorides, chemicals, wet-dry cycles, freeze-thaw cycles, temperature and humidity factors, and even abrasion

Design Guide for Bridges for Service Life

Durability & Service Life Considerations, Cont.

- Need to understand mechanisms of deterioration for each design and element, component, subsystem
- Designing for Service Life is similar to strength design to resist structural failure caused by external loads
  - External loads ↔ Environmental factors
  - Material strength ↔ Durability properties
- Ideally develop deterioration models and service life models from inspections, testing, & historical data
  - Based on environmental exposure conditions for each element
- Develop durability metrics and serviceability limit states to trigger actions (e.g., maintenance activities)

Design Guide for Bridges for Service Life

SHRP2 R19A, IBC W05: Service Life Design of Bridges (2016)

Service Life Durability Strategies

- Avoidance approach:
  - Eliminating the environmental exposure actions
    - e.g., Use of non-reactive aggregates, stainless steel, barrier systems
- Using materials with resistance well beyond the requirements needed
    - e.g., Corrosion resistant reinforcement, CCR (stainless steel, MMFX, CFRP, etc.) ~ see ASTM A1035 & AASHTO M 334
    - e.g., Concrete with increased cover and SCMs (e.g., slag, fly ash, silica fume) and / or corrosion inhibitors
  - Not always the most cost-effective solution
- Design to resist approach
  - Full probabilistic method
  - Partial safety factor method
  - Deemed-to-satisfy method
- Multiple strategies may be needed on a single bridge

Design Guide for Bridges for Service Life

SHRP2 R19A, IBC W05: Service Life Design of Bridges (2016)

Obsolescence Awareness

"Factors that can cause obsolescence:

- *Technological changes influence the scope or levels of services a bridge is to provide*
  - e.g., when heavier loads are permitted than those loads for which the bridge was initially designed
- *Regulatory changes impose new requirements on infrastructure*
  - *e.g.,* when safety requirements change the lane or shoulder widths required
- *Economic or social changes can alter the demands placed on infrastructure*
  - e.g., when development generates traffic substantially above levels envisioned in design
- *Changes in values or behavior can similarly alter demands but are more difficult to foresee"*
  - e.g., equitable community access

NCHRP Report 483

Service Life Design Resources

Design Guide for Bridges for Service Life

SHRP2: Service Life Design for Bridges, Summary Guide

SHRP2 R19A: Project Briefing

Table 1. 12 Steps to Design Bridges for Service Life

Step 1.	Identify the project requirements, particularly those that will influence the service life.
Step 2.	Identify feasible bridge systems capable of meeting the project demand.
Step 3.	Select each feasible bridge system and complete Steps 4 through 10.
Step 4.	Identify the factors that influence service life of bridge elements, components, and subsystems, such as traffic and environmental factors.
Step 5.	Identify modes of failures and consequences. For instance, the corrosion of reinforcement causing corrosion-induced cracking and loss of strength.
Step 6.	Identify suitable approaches for mitigating the failure modes or assessing risk of damage, through life-cycle cost analysis. For example, use better-performing materials for sliding surfaces in bearings.
Step 7.	Modify the element, component, or subsystem under consideration, using the selected strategy and ensure compatibility of different strategies used for various bridge elements, components, or subsystems. This step may involve the need to develop several alternatives.
Step 8.	For each modified alternative, estimate the service life of the bridge element, component, or subsystem using finite or target service life design approaches.
Step 9.	For each modified alternative, compare the service life of the bridge element, component, or subsystem to the service life of the bridge system and develop appropriate maintenance, retrofit, and/or replacement plan.
Step 10.	For each modified alternative, develop design, fabrication, construction, operation, maintenance, replacement, and management plans for achieving the specified design life for the bridge system.
Step 11.	For each modified alternative, conduct life-cycle cost analysis for each feasible bridge system meeting strength and service life requirements, and select the optimum bridge system.
Step 12.	When specified by the owner or in cases of major and complex bridges, document the entire design for service life process in a document called the Owner's Manual. Conduct an independent review of the document and provide it to the bridge owner at the time of opening the bridge to traffic.

SHRP2 R19A: Project Briefing

Service Life Design Resources

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https://shrp2.transportation.org/Pages/ServiceLifeDesignforBridges.aspx

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AASHTO SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD

SHRP 2

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- Implementation Assistance
- Products by Focus Area
- Products by Topic Area
- SHRP2 History

Need More Information?

Pamela Hutton
SHRP2 Implementation Mgr
phutton@aashto.org
303-263-1212

Service Life Design for Bridges

AASHTO > Strategic Highway Research Program 2 > Service Life Design for Bridges

Service Life Design for Bridges (R19A)

Product Overview

Comprehensive guidance to select and design durable bridge systems and components that are both easier to inspect and better-suited to their environments.

- SHRP2 Service Life Design Guide For Bridges TRB Report

Academic Toolbox

- Service Life Design for Bridges Academic Toolbox

Life Cycle Cost Analysis

- Life Cycle Cost Analysis Final Report

Service Life Design of Bridges Summary Guide

- Service Life Design for Bridges Summary Guide
- Appendix A – Request for Proposal Examples for Alternative Delivery Projects
- Appendix B – NT Build 492 Test Data
- Appendix C – Chloride Threshold for Various Reinforcement Steel Types
- Appendix D – Design Examples and Calculation Books
- Appendix E – Supplementary Concrete Specification Example
- Appendix F – Example Birth Certificate and Recommendations for Thorough-Life Management Documentation

Presentations and Webinars

- Technology Transfer Webinars
  - Service Life Design Bridges (R19A) Final Project Webinar, February 21, 2019
  - Service Life Design for Bridges (R19A) Progress Update Webinar, Dec 17, 2015
- Training Webinars
  - Walk-through Durability Design Example Webinar, March 20, 2019
  - Durability Design & Structure Birth Certificate: Implementation Plan Webinar, February 2, 2015

Regional Peer Exchanges

- Portland, OR (NW Region), July 24, 2018
  - Summary Report
- Des Moines, IA (MW Region), September 25, 2018
  - Summary Report
- Philadelphia, PA (NE Region), December 13, 2018
  - Summary Report
- Denver, CO (SW Region), March 12, 2019
  - Summary Report
- Richmond, VA (SE Region), March 27, 2019
  - Summary Report

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https://shrp2.transportation.org/Pages/ServiceLifeDesignforBridges.aspx

Tools and Technologies

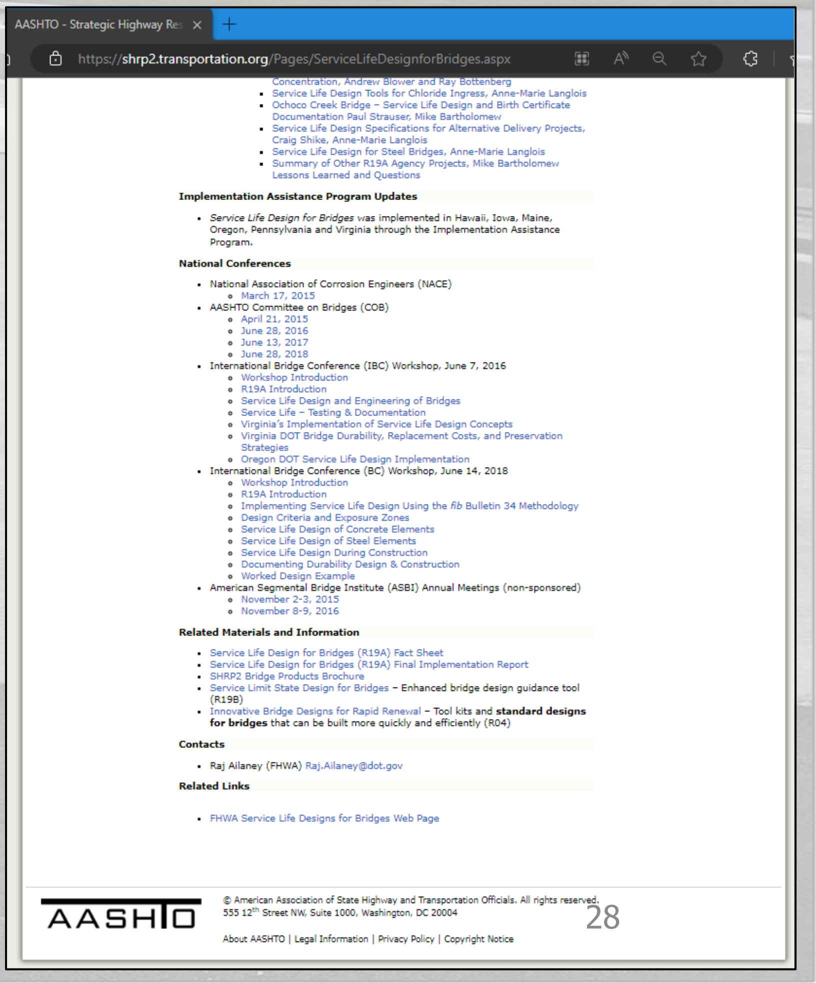
- Design Tools
  - Service Life Design – Graphical Solution
    - Chloride Migration Coefficient Charts
  - Service Life Design – Full Probabilistic Tools
- Material Testing Recommendations
  - Chloride Tests
  - Chloride Diffusion Coefficient Calculation

Final IAP State Workshops

- Virginia
  - Final Report
    - VDOT Bridge Deck Service Life Design Aid
  - Workshop Materials
    - Virginia Workshop Agenda October 4, 2017
    - Introduction to Service Life Design, Mike Bartholomew
    - Implementing Service Life Design for Concrete Structures Using the fib Bulletin 34 Methodology, Anne-Marie Langlois
    - VDOT Specifications for Corrosion Resistant Reinforcement, Prasad Nallapaneni
    - Chloride Penetration Resistance and Link to Service Life Design of Virginia Bridge Decks, Madeleine Flint
    - Service Life of Bridge Decks – Concrete Cracks, Soundar Balakumaran
    - Development of a Specification for Low Cracking Bridge Deck Concrete, Harikrishnan Nair
    - Calculation Tool for Service Life Design Developed by VDOT, Kyle Haber
    - Service Life Design on Alternative Delivery Projects, Anne-Marie Langlois
    - Overview of SHRP2 R19A and Activities Done by Other States, Mike Bartholomew
- Pennsylvania
  - Final Report
    - Penn DOT 100 Year Service Life Study Chloride Migration Coefficient Evaluation
    - Penn DOT Tutorial For Probabilistic Chloride Ingress Model ProCIM Full-Probabilistic Design Tool Report
    - PennDOT Tool
  - Workshop Materials
    - Pennsylvania Workshop Agenda August 16, 2016
    - Overview of Service Life Design for Bridges, Mike Bartholomew
    - Chloride Induced Corrosion Modeling, Anne-Marie Langlois
    - Concrete Deterioration Mechanisms, Anne-Marie Langlois
    - Implications of Cracks in Concrete on Service Life, Mike Bartholomew
    - Service Life Design Requirements for RFPs and Steel Structures, Anne-Marie Langlois
- Oregon
  - Final Report
    - Oregon Workshop Summary Report
    - Oregon Implementation of SHRP2 R19A Final Report
  - Workshop Materials
    - Oregon Workshop Agenda January 17, 2018
    - Introduction to Service Life Design, Mike Bartholomew
    - Implementing Service Life Design Using the fib Bulletin 34 Methodology, Anne-Marie Langlois
    - Overview of Material Testing for Service Life Design, Mike Bartholomew
    - Testing and Evaluation of Existing Bridge Decks for Chloride Concentration, Andrew Blower and Ray Bottenberg
    - Service Life Design Tools for Chloride Ingress, Anne-Marie Langlois
    - Ochoco Creek Bridge – Service Life Design and Birth Certificate Documentation Paul Strauser, Mike Bartholomew
    - Service Life Design Specifications for Alternative Delivery Projects, Craig Shike, Anne-Marie Langlois
    - Service Life Design for Steel Bridges, Anne-Marie Langlois
    - Summary of Other R19A Agency Projects, Mike Bartholomew Lessons Learned and Questions

Implementation Assistance Program Updates

- *Service Life Design for Bridges* was implemented in Hawaii, Iowa, Maine, Oregon, Pennsylvania and Virginia through the Implementation Assistance Program.



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https://shrp2.transportation.org/Pages/ServiceLifeDesignforBridges.aspx

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National Conferences

- National Association of Corrosion Engineers (NACE)
  - March 17, 2015
- AASHTO Committee on Bridges (COB)
  - April 21, 2015
  - June 28, 2016
  - June 13, 2017
  - June 28, 2018
- International Bridge Conference (IBC) Workshop, June 7, 2016
  - Workshop Introduction
  - R19A Introduction
  - Service Life Design and Engineering of Bridges
  - Service Life – Testing & Documentation
  - Virginia's Implementation of Service Life Design Concepts
  - Virginia DOT Bridge Durability, Replacement Costs, and Preservation Strategies
  - Oregon DOT Service Life Design Implementation
- International Bridge Conference (BC) Workshop, June 14, 2018
  - Workshop Introduction
  - R19A Introduction
  - Implementing Service Life Design Using the *fib* Bulletin 34 Methodology
  - Design Criteria and Exposure Zones
  - Service Life Design of Concrete Elements
  - Service Life Design of Steel Elements
  - Service Life Design During Construction
  - Documenting Durability Design & Construction
  - Worked Design Example
- American Segmental Bridge Institute (ASBI) Annual Meetings (non-sponsored)
  - November 2-3, 2015
  - November 8-9, 2016

Related Materials and Information

- Service Life Design for Bridges (R19A) Fact Sheet
- Service Life Design for Bridges (R19A) Final Implementation Report
- SHRP2 Bridge Products Brochure
- Service Limit State Design for Bridges – Enhanced bridge design guidance tool (R19B)
- Innovative Bridge Designs for Rapid Renewal – Tool kits and **standard designs for bridges** that can be built more quickly and efficiently (R04)

Contacts

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Related Links

- FHWA Service Life Designs for Bridges Web Page

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AASHTO SHRP2 - Service Life Design for Bridges

Service Life Design Process

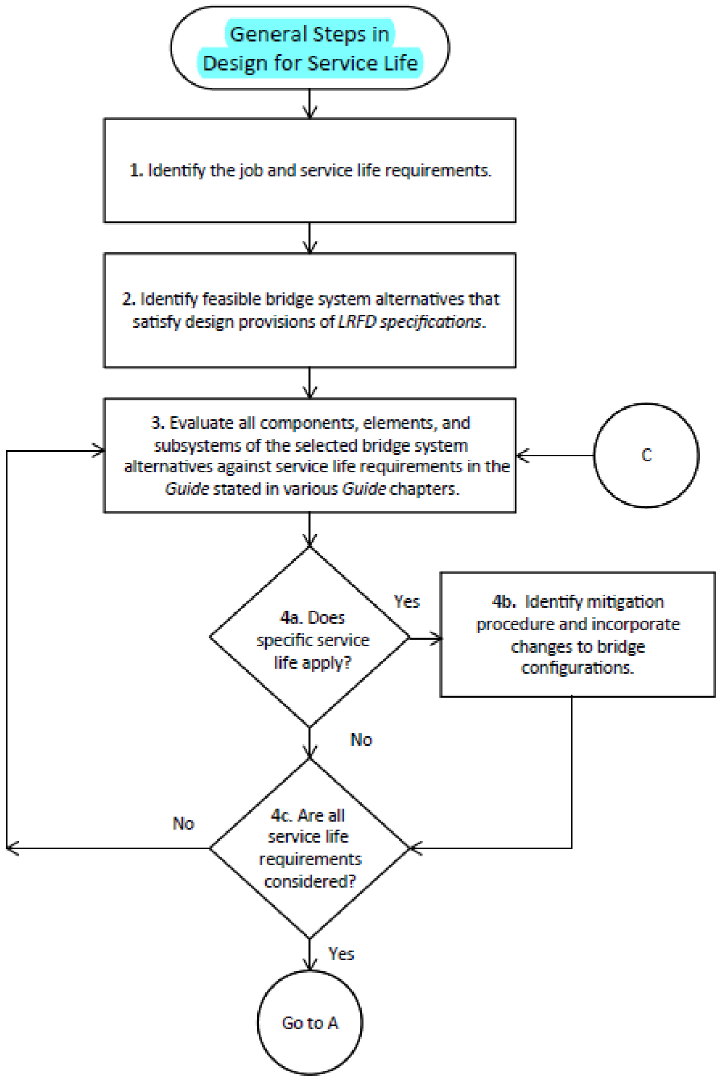


Figure 1.4. *General flowchart demonstrating the Guide's approach for service life design.*

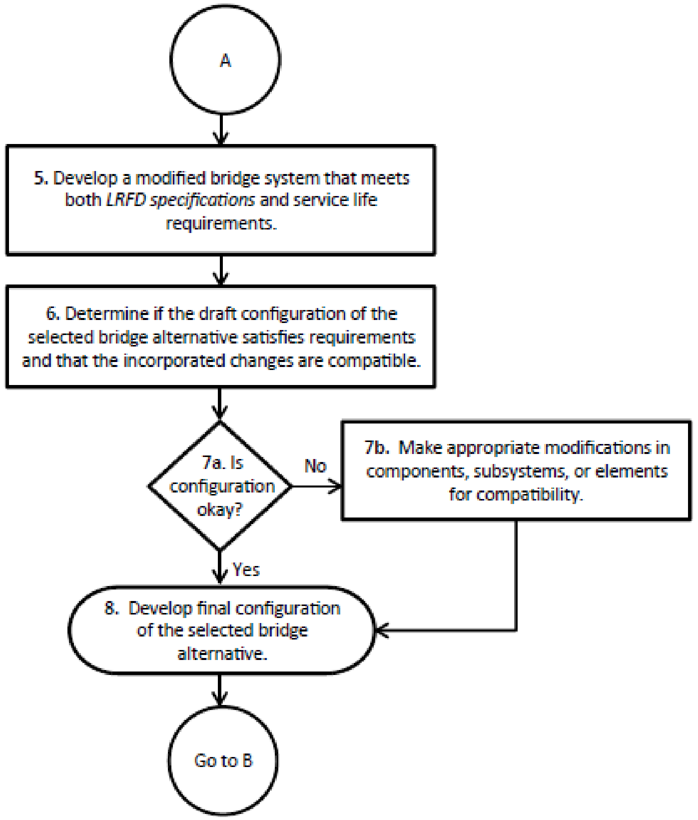


Figure 1.5. *General flowchart demonstrating the* Guide's *approach for service life design, starting with A from Figure 1.4.*

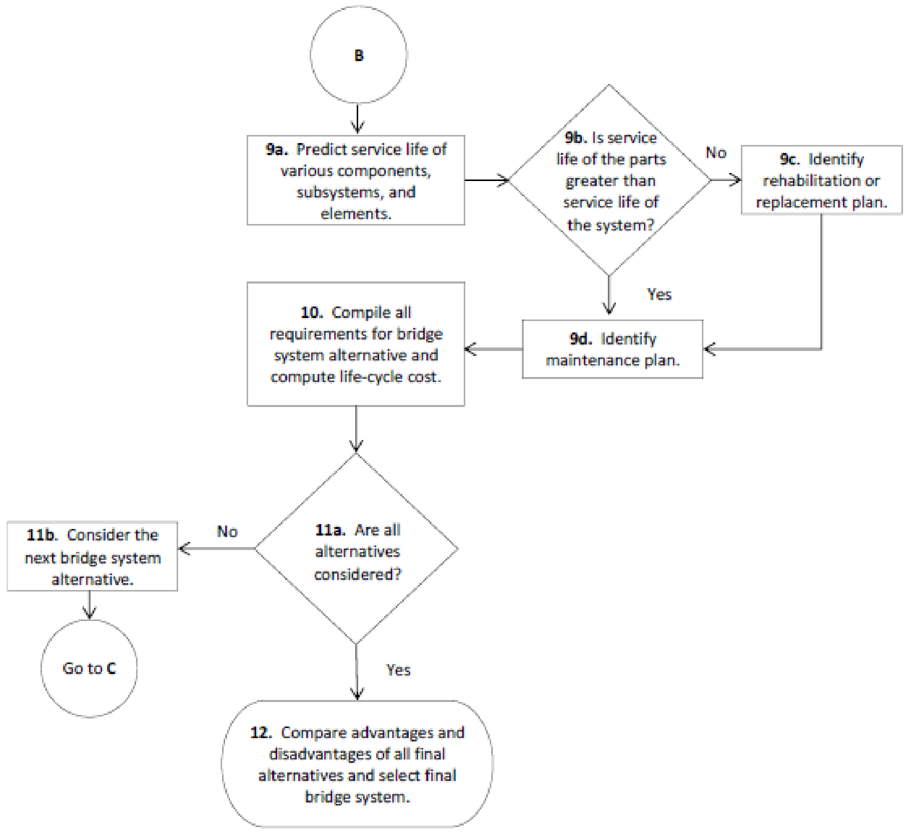


Figure 1.6. *General flowchart demonstrating the* Guide's *approach for service life design. starting with B from Figure 1.5.*

Design Guide for Bridges for Service Life

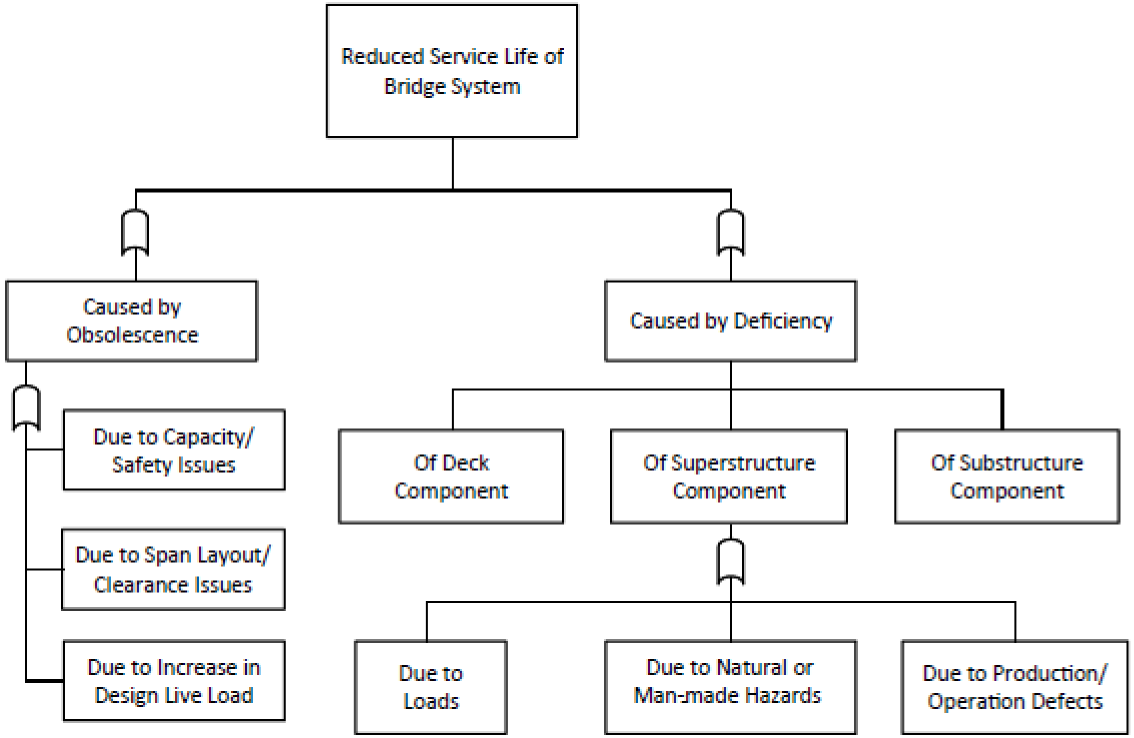


Figure 2.23. *Factors affecting service life.*

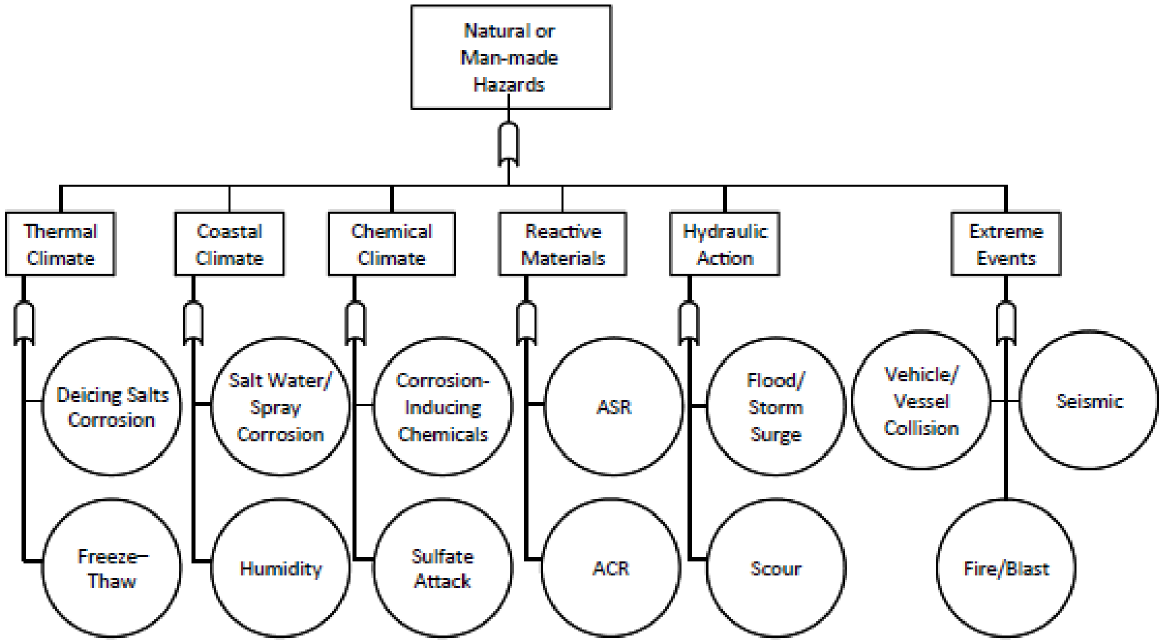


Figure 2.25. *Natural or man-made hazards.*

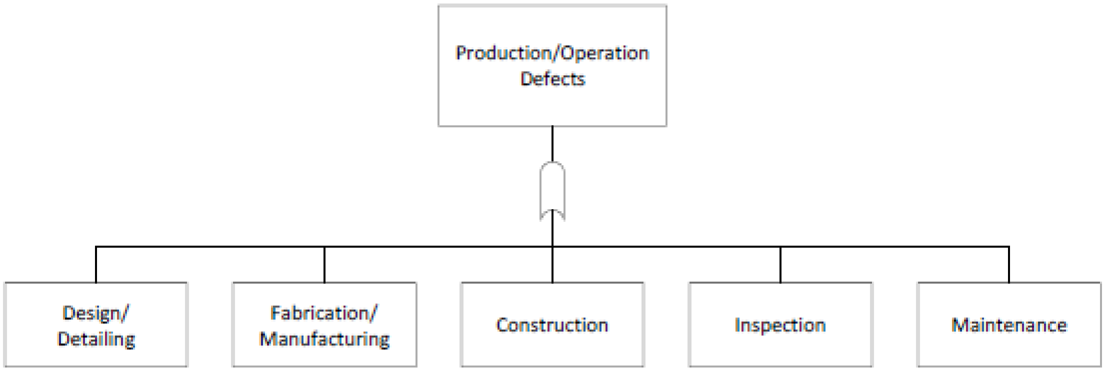


Figure 2.36. *Production or operation defects.*

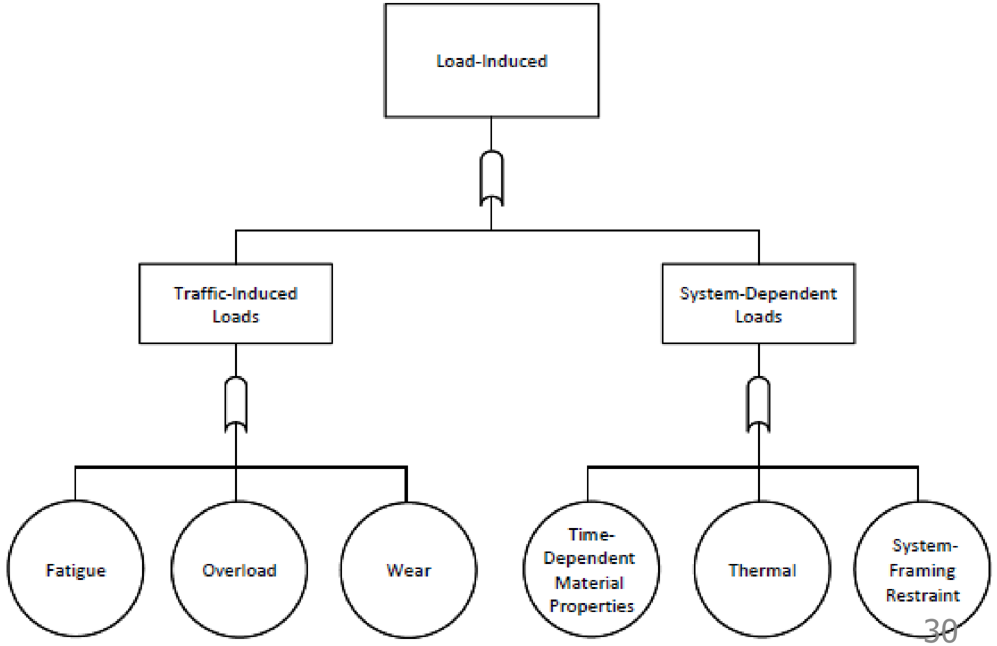


Figure 2.24. *Load-induced deficiencies.*

[Design Guide for Bridges for Service Life]

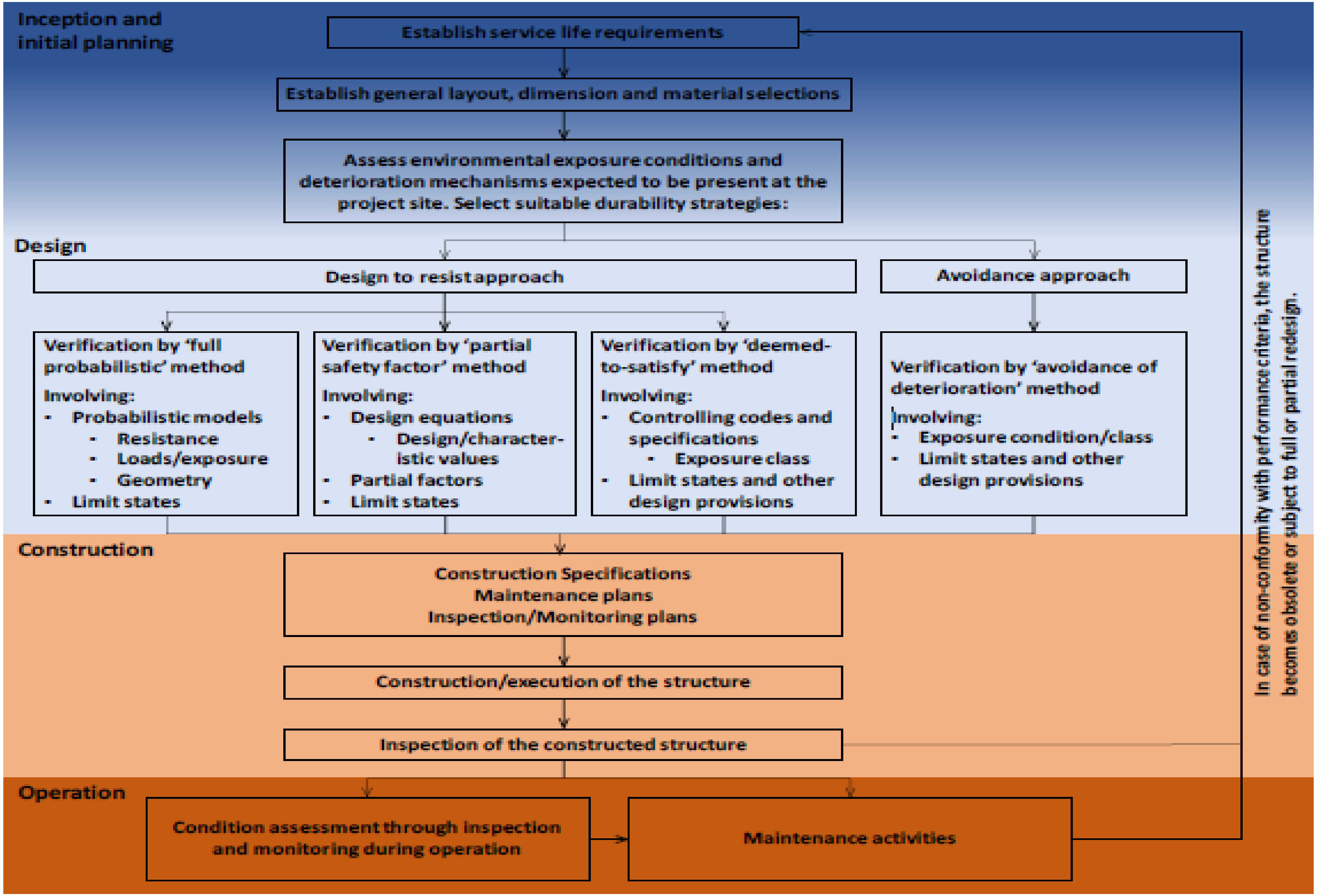
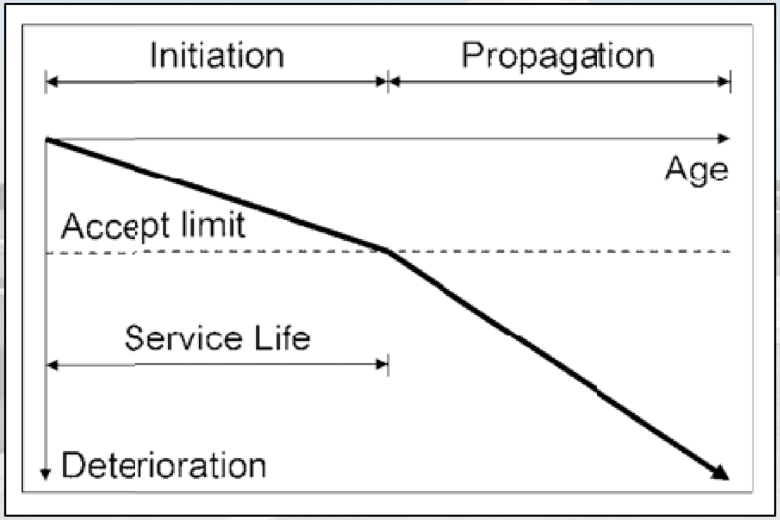


Figure 2-1: Flowchart for Service Life Design Process, after [4] and [7]

SHRP2: Service Life Design for Bridges, Summary Guide

Reinforced Concrete Corrosion

Design Guide for Bridges for Service Life



Initiation: No visible damage

Propagation: Corrosion begins and propagates

$$C_{crit} = C(x,t) = C_0 + \left(C_{S,\Delta x} - C_0\right) \cdot \left[1 - \operatorname{erf} \frac{a - \Delta x}{2 \cdot \sqrt{D_{app,C} t}}\right] \quad (1.4)$$

where

- C_{crit} = critical chloride content (wt.-%/c),
- $C(x,t)$ = content of chlorides (wt.-%/c) in the concrete at depth x (structure surface: $x = 0$ m) and time t,
- C_0 = initial chloride content (wt.-%/c) of the concrete,
- $C_{S,\Delta x}$ = chloride content (wt.-%/c) at depth Δx and certain point of time t,
- x = depth (mm) with a corresponding content of chlorides [$C(x,t)$],
- a = concrete cover (mm),
- Δx = depth of convection zone (concrete layer, up to which the process of chloride penetration differs from Fick's second law of diffusion) (mm),
- $D_{app,C}$ = apparent coefficient of chloride diffusion through concrete (mm^2/years),
- t = time (years), and
- erf = error function.

Design Guide for Bridges for Service Life

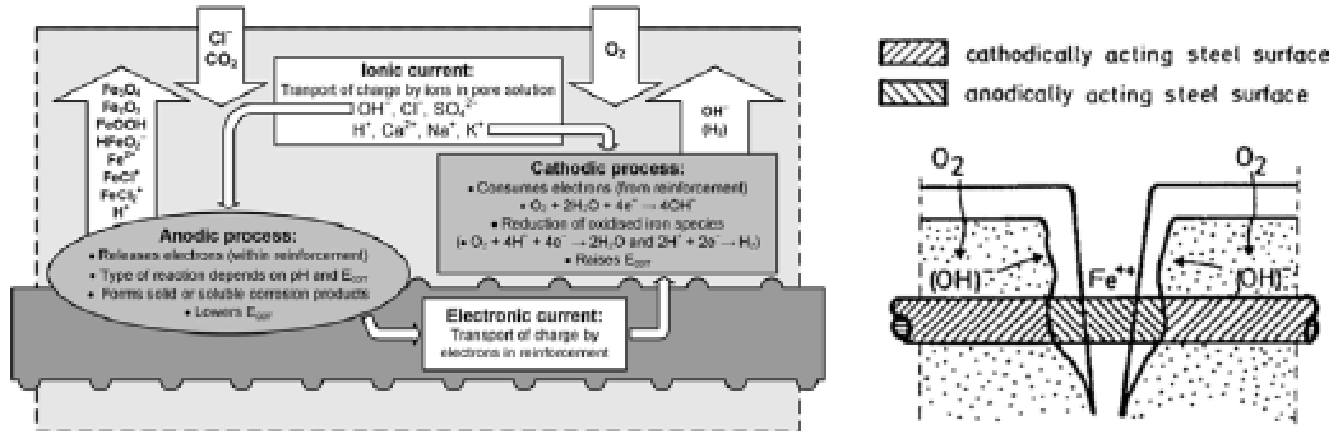


Figure 4-9: (Left) Illustration of electrochemical and physical processes occurring in reinforcement corrosion process, from [41], and (Right) illustration of the basic impact concrete cracks have on reinforcement corrosion with the white cover zone indicating a layer of carbonated concrete, from [42].

SHRP2: Service Life Design for Bridges, Summary Guide

$$D_{app,C} = k_e \cdot D_{RCM,0} \cdot k_t \cdot A(t)$$

$$k_e = \exp\left(b_e \left(\frac{1}{T_{ref}} - \frac{1}{T_{real}}\right)\right)$$

$$A(t) = \left(\frac{t_0}{t}\right)^a$$

SHRP2 R19A: Service Life Design for Bridges, Academic Toolbox

$D_{RCM,0}$ is the chloride migration coefficient;

k_t is a transfer parameter;

b_e is a regression variable;

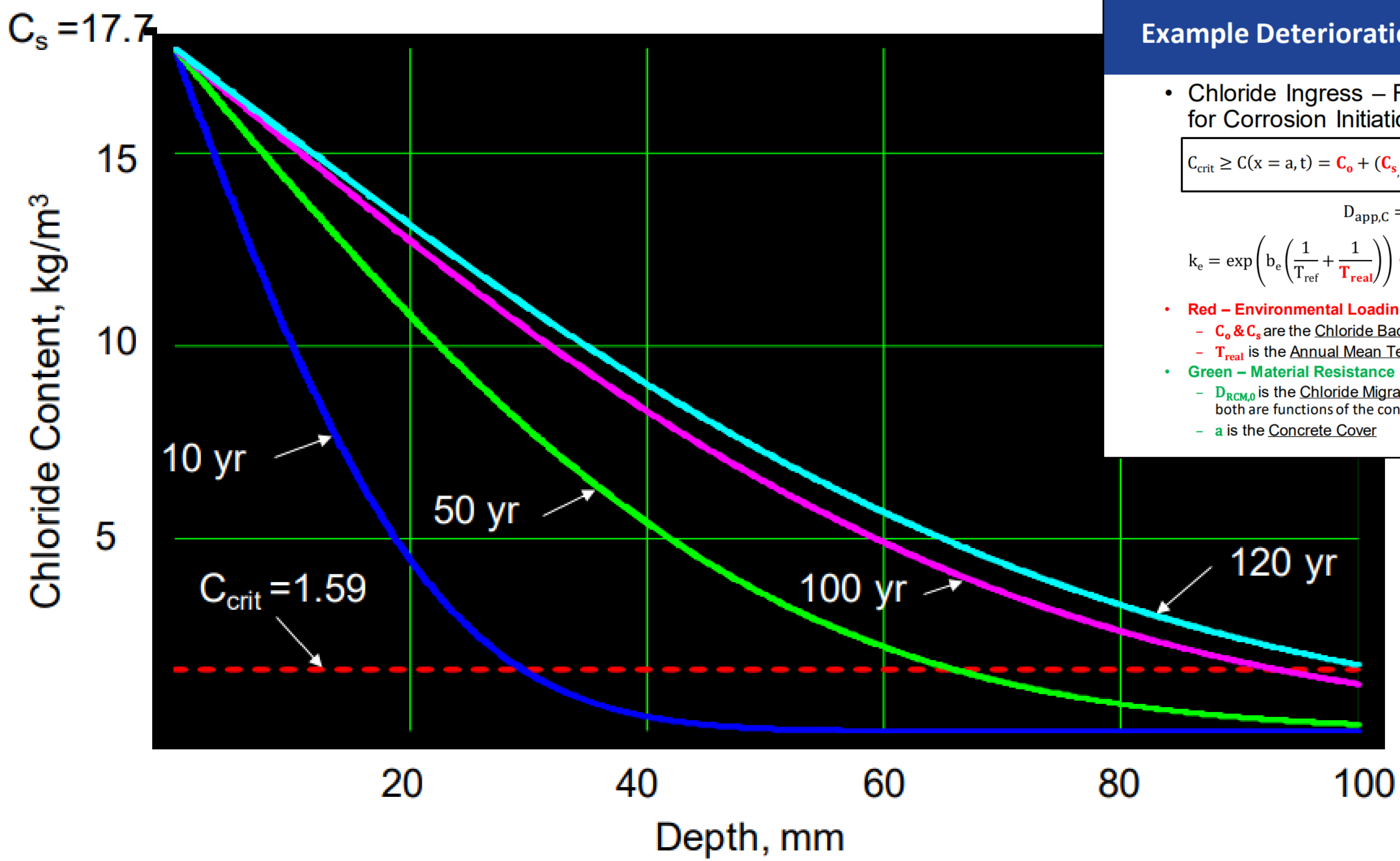
T_{ref} is the standard test temperature;

T_{real} is the temperature of the structural element or the ambient air; and,

t_0 is the reference point of time and a is the age factor.

Chloride Profiles vs. Age

constant $D_{app,c}$ = 15.1 mm^2/yr



Example Deterioration Model

- Chloride Ingress – Fick's 2nd Law of Diffusion for Corrosion Initiation

$$C_{crit} \geq C(x=a,t) = C_o + (C_{s,\Delta x} - C_o) \cdot \left[1 - \operatorname{erf}\left(\frac{a - \Delta x}{2\sqrt{D_{app,C} \cdot t}}\right)\right]$$

$$D_{app,C} = k_e \cdot D_{RCM,0} \cdot k_t \cdot A(t)$$

$$k_e = \exp\left(b_e\left(\frac{1}{T_{ref}} + \frac{1}{T_{real}}\right)\right) \qquad A(t) = \left(\frac{t_o}{t}\right)^{\alpha}$$

- **Red – Environmental Loading**
  - C_o & C_s are the Chloride Background and Surface Concentrations
  - T_{real} is the Annual Mean Temperature at the project site
- **Green – Material Resistance**
  - $D_{RCM,0}$ is the Chloride Migration Coefficient, α is the Aging Exponent, both are functions of the concrete mix (*W/C* ratio, SCMs)
  - a is the Concrete Cover

SHRP2 R19A, IBC W05: Service Life Design of Bridges (2016)

Typical Exposure Zones

- **Atmospheric**: Exposed to airborne chlorides. Temperature and humidity variations, including freeze-thaw
- **Direct de-icing salts**: Exposed to alternating wetting and drying, freeze/thaw with direct exposure to de-icing salts, and temperature variations
- **Indirect de-icing salts**: Exposed to alternating wetting and drying, freeze/thaw with indirect exposure to de-icing salts, leakage from deck joints, and temperature variations
- **Water level or tidal zone**: Exposed to atmospheric conditions and alternating wetting and drying from a body of water (could be fresh water or salted water), temperature variations, possibly ice abrasion
- **Submerged**: Permanently submerged in water
- **Buried**: Permanently buried in soil

SHRP2 R19A LCCA of New Bridge Design Alternatives

Example Exposure Zones

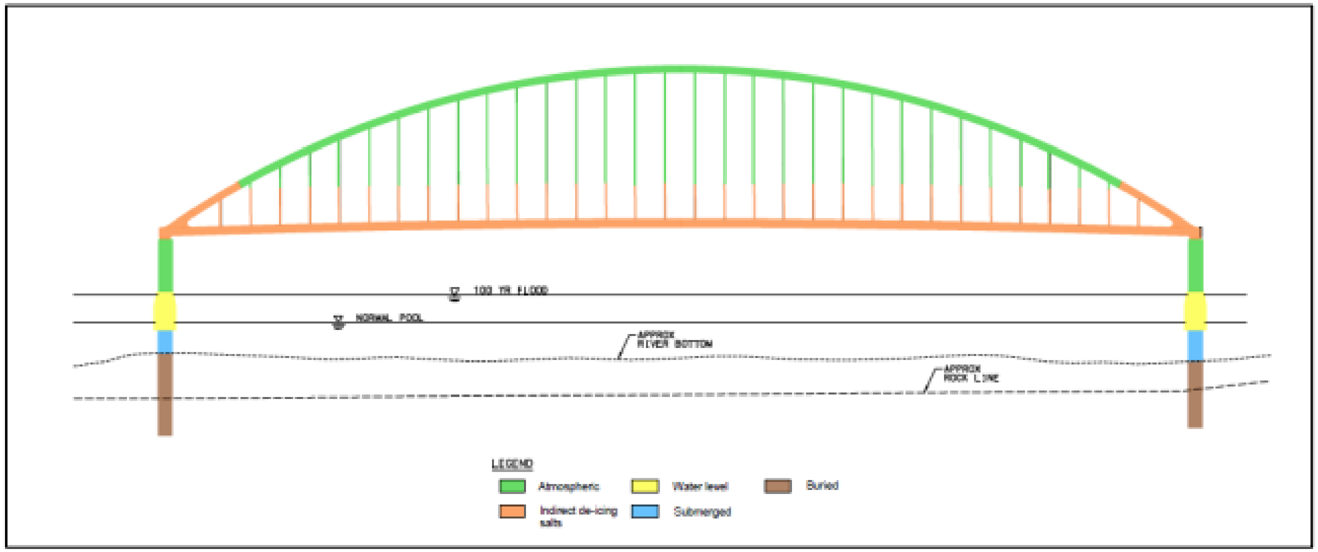


Figure 4: Color code used to visualize exposure zones for main span of the Bridge

[SHRP2 R19A LCCA of New Bridge Design Alternatives]

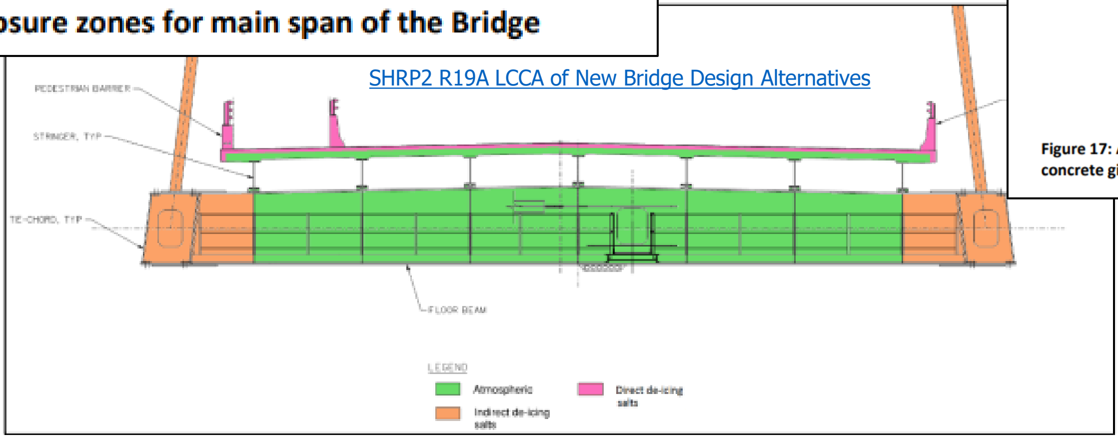


Figure 5: Color code used to visualize exposure zones for main span cross section of the Bridge

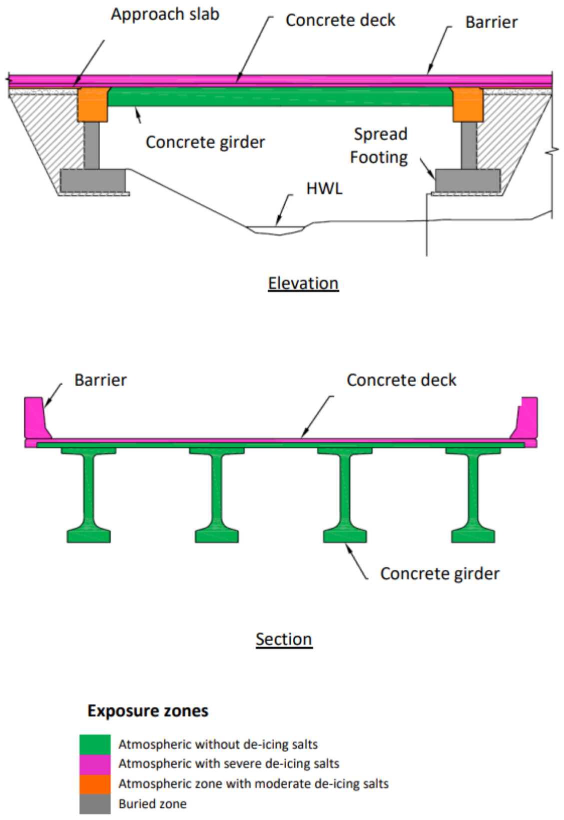


Figure 17: A color code is used to define the different exposure zones of the pre-stressed bulb-tee concrete girder bridge with a concrete deck.

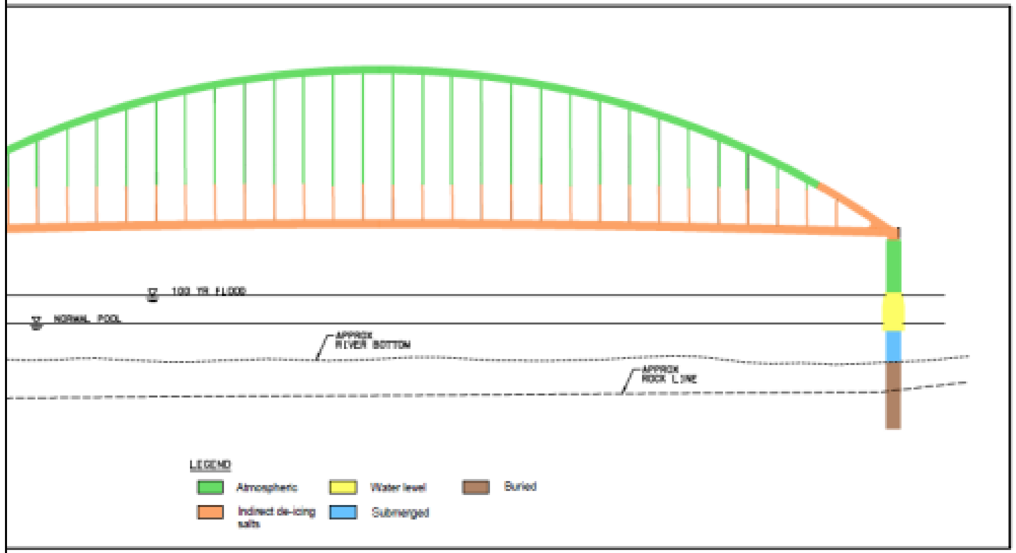
[SHRP2 R19A: Service Life Design for Bridges, Academic Toolbox]

Example Service Life by Component

Table 2: Summary of Minimum Service Life Requirements of Bridge Components

Non-Replaceable Components	Minimum Service Life (years)
Foundations, abutments, piers, structural steel, and deck	100
Replaceable Components	**Minimum Service Life (years)**
Bridge bearings	50
Expansion joints	30
Bridge barriers	60
Drainage system	75
Access: access ladders, platforms, and lifts	60
Painting	25
Cables and hangers	60

SHRP2 R19A LCCA of New Bridge Design Alternatives



code used to visualize exposure zones for main span of the Bridge

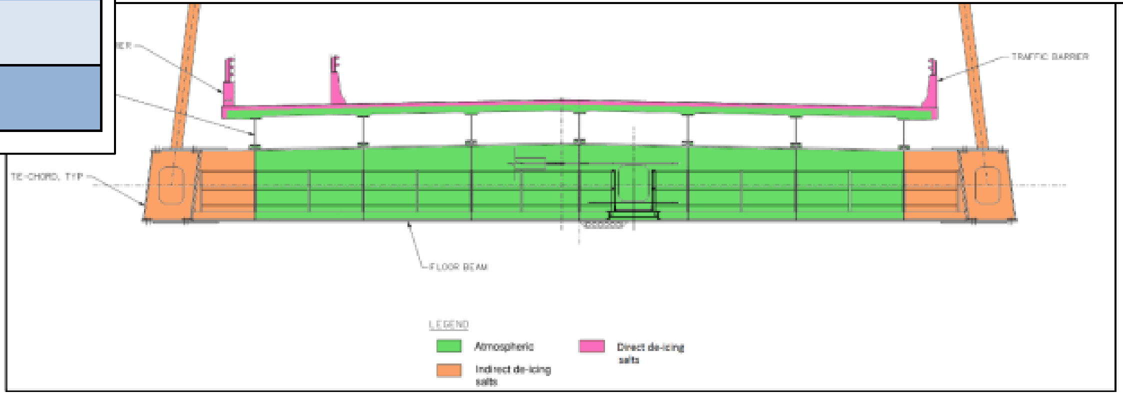
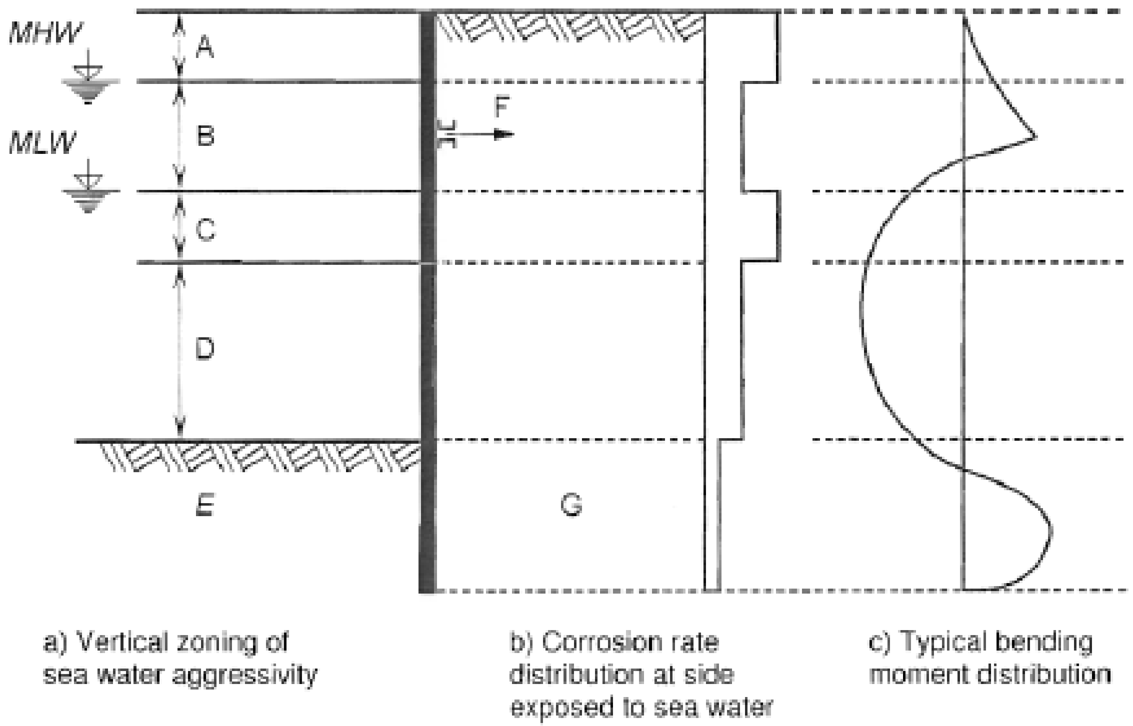


Figure 5: Color code used to visualize exposure zones for main span cross section of the Bridge

Example of Steel Exposure in Marine Zone:



A	Zone of high attack (splash zone);	B	Intertidal zone;
C	Zone of high attack (Low water zone);	D	Permanent immersion zone;
E	Buried zone (Water side);	F	Anchor;
G	Buried zone (Soil side)		
MHW	Mean high water;	MLW	Mean low water

Figure 4-8: Example of Exposure Zones for Structural Steel in a Marine Environment, from EN 1993-5 [17].

SHRP2: Service Life Design for Bridges, Summary Guide

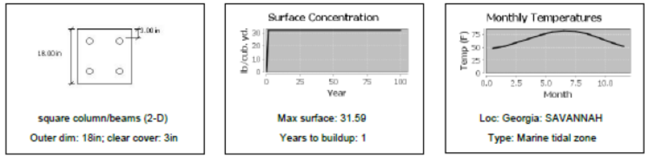
Service Life Example (using Life-365)

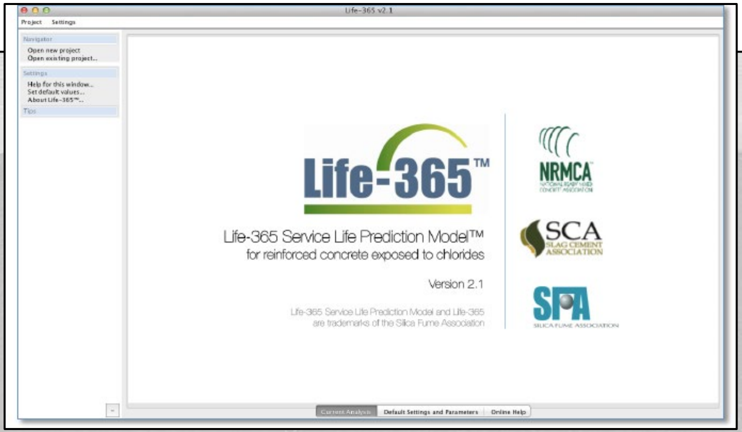
Innovations to Meet 100 Year Service Life Requirement

- LIFE 365 Software Modelled Service Life of Concrete Elements
  - Develop Contract Requirements for Various Structural Elements (Constructible , Economical)

Example of Process – Design Prestress Pile With 3" of Cover for 100 Year Service Life

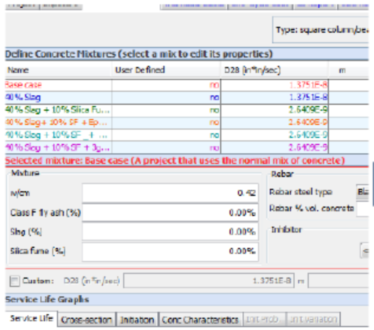
Worse Chloride Loading is The Marine Splash Zone – Maximum Surface Concentration of 31.6 pcy of Chloride After 1 Year





DESIGN PRESTRESS PILE FOR 100 YEAR SERVICE LIFE

1- INPUT MIX DESIGN PARAMETERS and STEEL TYPE



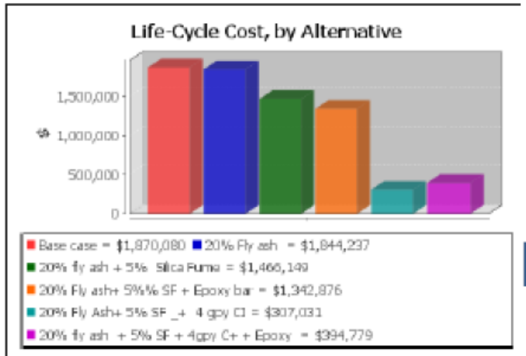
2- Calculate Service Life

Diffusion Properties and Service Lives

Alt name	D28	m	Ct	Init.	Prop.	Service life
Base case	1.38E-8 in*in/sec	0.2	1.97 lb/cub. yd.	4.8 yrs	6 yrs	**10.8 yrs**
20% Fly ash	1.38E-8 in*in/sec	0.36	1.97 lb/cub. yd.	8.9 yrs	6 yrs	**14.9 yrs**
20% fly ash + 5% Silica Fume	6.03E-9 in*in/sec	0.36	1.97 lb/cub. yd.	28.1 yrs	6 yrs	**34.1 yrs**
20% Fly ash+ 5%% SF + Epoxy bar	6.03E-9 in*in/sec	0.36	1.97 lb/cub. yd.	28.1 yrs	20 yrs	**48.1 yrs**
20% Fly Ash+ 5% SF _+ 4 gpy CI	6.03E-9 in*in/sec	0.36	12.64 lb/cub. yd.	100.1+ yrs	6 yrs	**106.1+ yrs**
20% fly ash + 5% SF + 4gpy C+ + Epoxy	6.03E-9 in*in/sec	0.36	12.64 lb/cub. yd.	100.1+ yrs	20 yrs	**120.1+ yrs**

"->" indicates that the user has directly specified this value; "+" indicates the service life exceeds the study period.

3- Input Materials and Repair Costs – Determine Life Cycle Costs



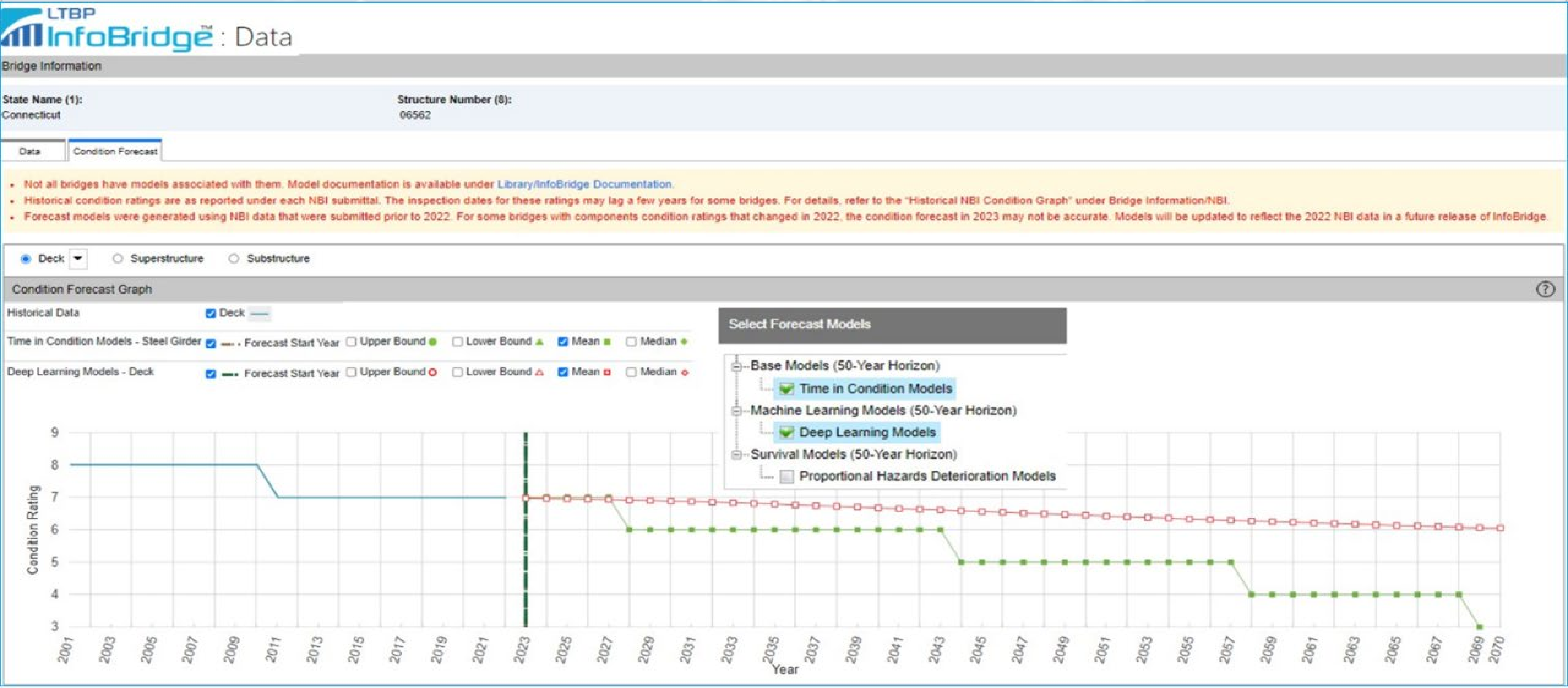
4- Develop SCR Tables For Contract

Table 552-1
Composition Requirements of Concrete for 75-Year Service Life
3 inches of Concrete Cover
Type F Fly Ash

Microsilica Percentage	Minimum Type F Fly Ash %	Maximum Type F Fly Ash %	Corrosion Inhibitor (gal/ yd³) minimum	Maximum w/cm ratio
0% Microsilica	25	25	5.0	0.35
5 % Microsilica	15	25	3.0	0.38
7.5% Microsilica	15	25	2.0	0.38
10% Microsilica	15	25	0	0.38

Slides from Mike Dallaire's Fort Pulaski Project Innovations' 2018 presentation for EFL-FHWA

Condition Forecasting (using InfoBridge)



Step 2: Determine Activity Timing

The **degree and timing of maintenance and preservation activities** of bridge components has a **large influence on the rate of deterioration** and thus the **service life** of the structure **and total LCCA results**

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NBIS Metrics 6 to 10 provides requirements for bridge inspection frequencies

Step 2: Cont.

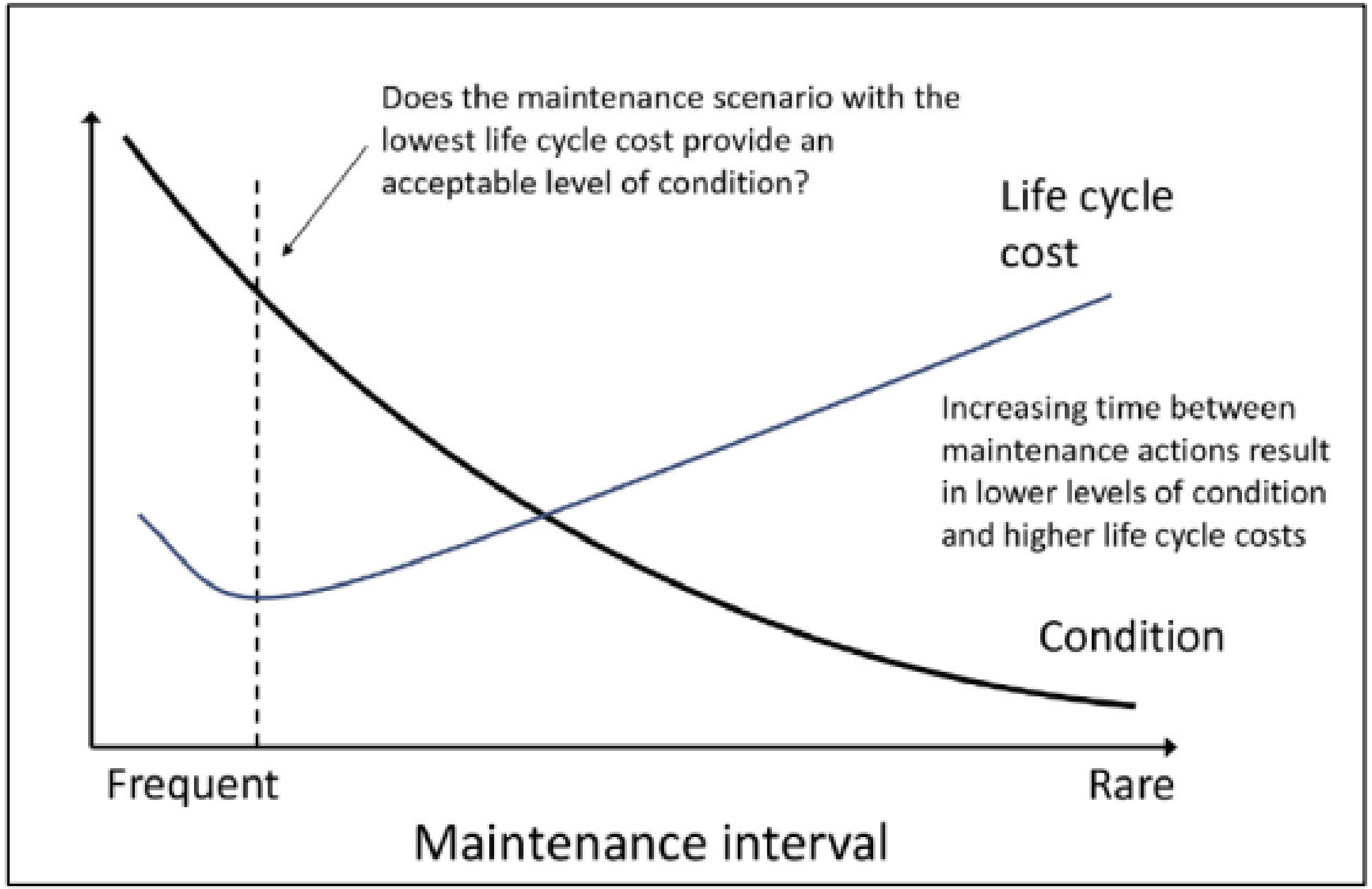

Figure 2: Life Cycle Cost and condition of bridge as a function of maintenance interval [7]

[SHRP2 R19A LCCA of New Bridge Design Alternatives]

Step 2: Determine Activity Timing

Determine analysis period (<u>must</u> be the same for all alternatives)

- Use BCA for non-similar duration and other factor comparisons
- The analysis period should include the total duration of cost differences between the alternatives
- Alternatives do not need to have same number of activities during the analysis period

Determine activities and timing / frequency of activities

  - e.g., annual, bi-annual, every x years, etc. for each element, component, and/or subsystem
- Ideally base some of the timing of the work from deterioration models, inspections, and experience
- Determine approximate degree of condition improvement

Discuss with timing with other program areas (is it realistic?):

- Maintenance, Estimating, Program Management, Materials, Bridge Inspection, Construction, Asset Management, District / local offices, Economic and Infrastructure Development, Environmental, etc.

Optimal interval between maintenance tasks is found by repeating the LCCA for different maintenance schedules (sensitivity analysis and/ or simulation) and predicting the lowest cost-scenario

Step 2: Cont.

Typical LCCA Activity Phases:

- Design
- Construction
- Maintenance Activities (seasonal routine and preventive, cyclical and condition-based)
- Preservation Activities (every x years)
- Rehabilitation / Replacement Activities (every n years)
- Demolition / Replacement

Maintenance & Preservation Timing

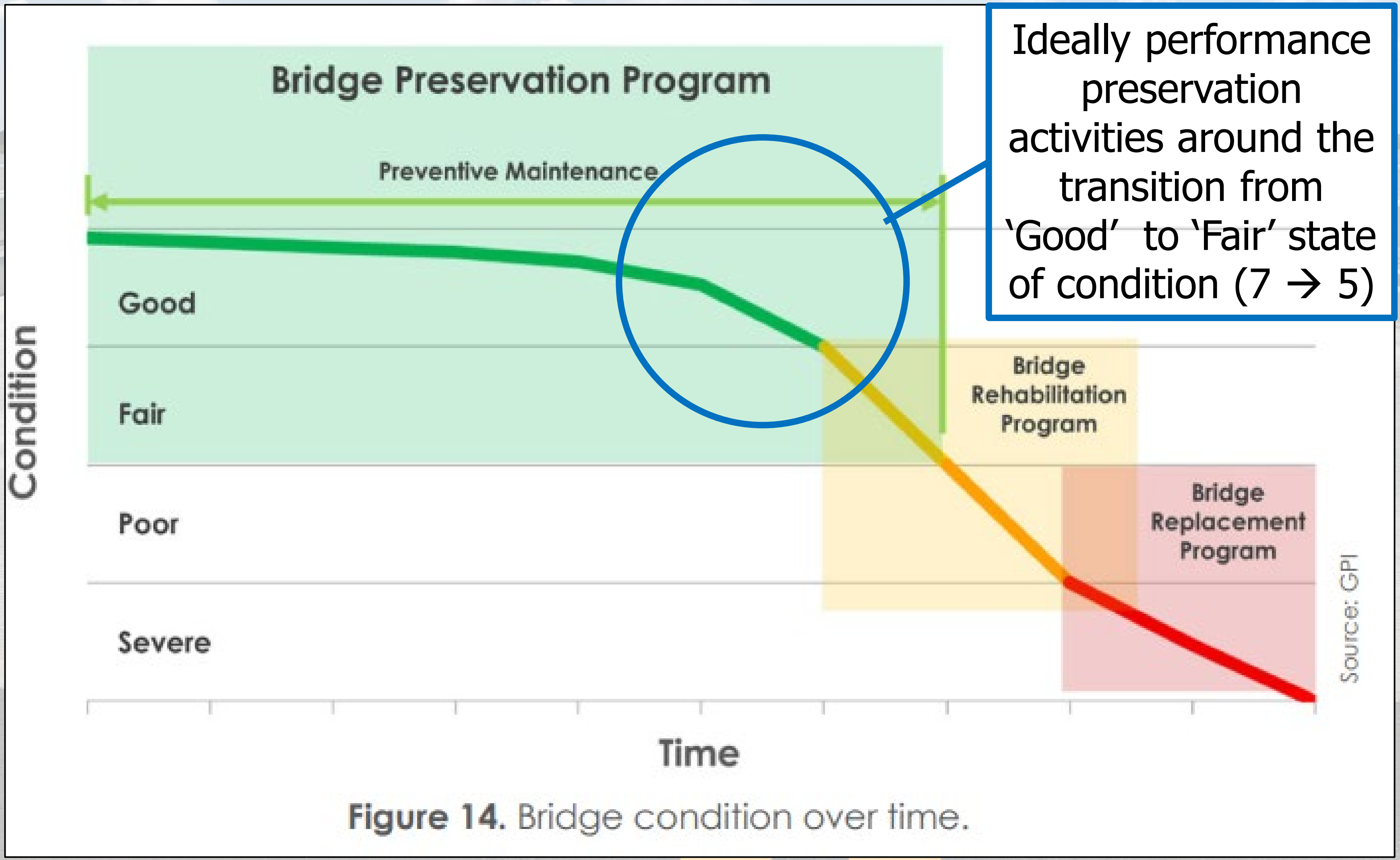

Figure 14. Bridge condition over time.

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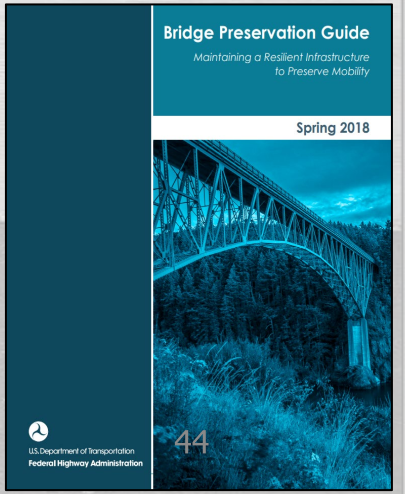


Maintenance & Preservation Timing

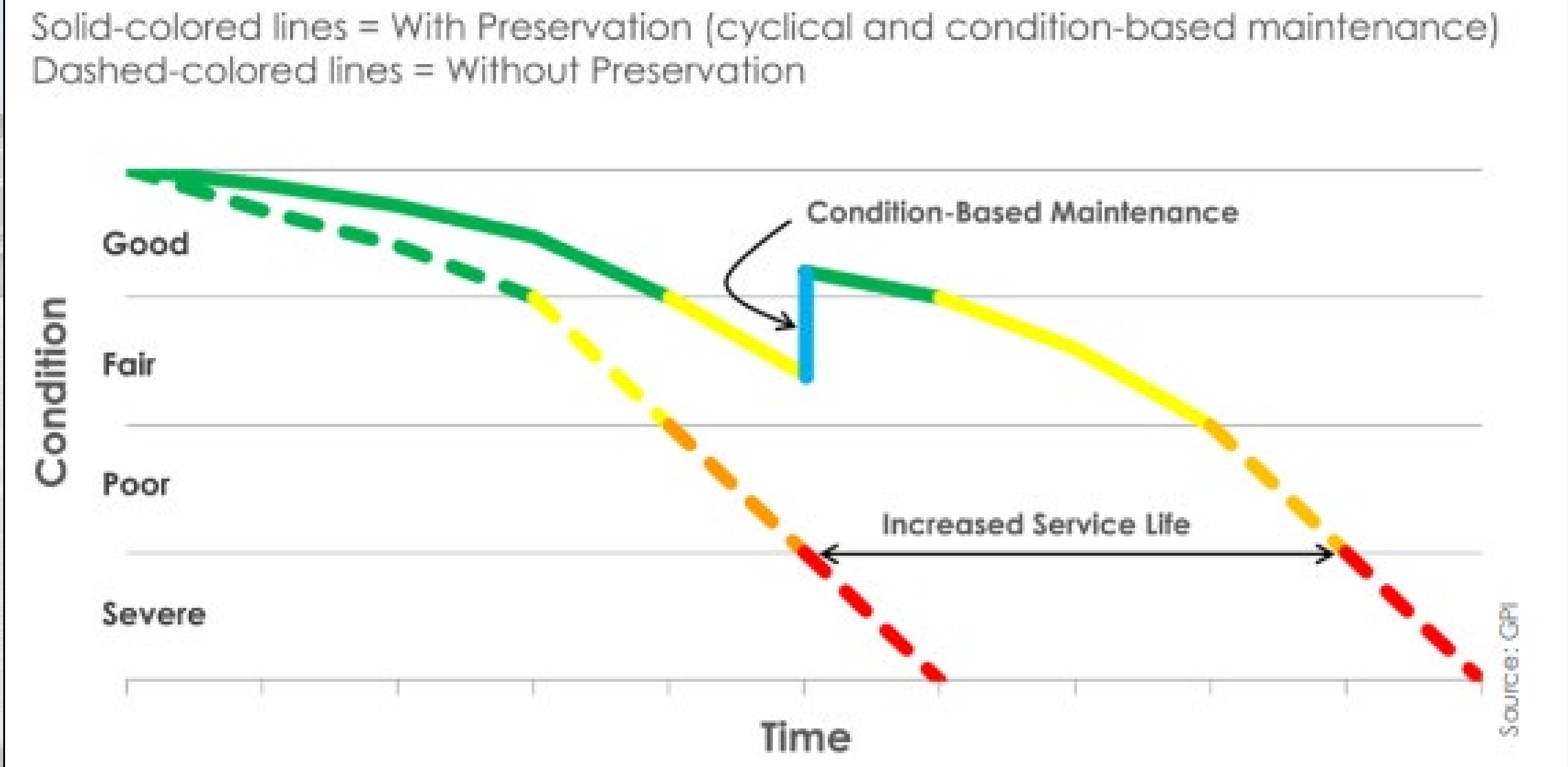
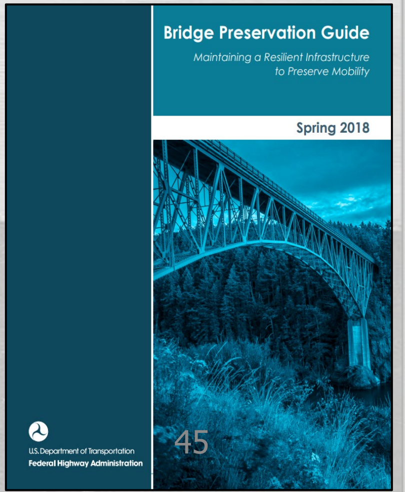


Figure 17. A comparison of bridge condition over time with and without bridge preservation.



FHWA Bridge Preservation Guide

FHWA Activity Definitions*

Routine Maintenance: encompasses work that is performed in reaction to an event, season, or activities that are done for short-term operational need that do not have preservation value. This work requires regular reoccurring attention.

Bridge Preservation: actions or strategies that prevent, delay, or reduce deterioration of bridges or bridge elements; restore the function of existing bridges; keep bridges in good or fair condition; and extend their service life. Preservation actions may be cyclic or condition-driven.

Preventive Maintenance: a cost-effective means of extending the service life of highway bridges by applying cost-effective treatments to bridge elements, including both cyclical and condition-based activities.

> **Cyclical maintenance activities**: performed on pre-determined intervals that aim to preserve and delay deterioration of bridge elements or component conditions.
>
> **Condition-based maintenance activities**: performed on bridge components or elements in response to known defects identified through an inspection process. Improves the condition of that portion of the element, but may or may not result in an increase in the component condition rating.

Rehabilitation: involves major work required to restore the structural integrity of a bridge, as well as work necessary to correct major safety defects. Provides complete or nearly complete restoration of bridge elements or components and require significant engineering resources for design, a lengthy completion schedule, and considerable costs.

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* Important for FHWA Funding Eligibility

Maintenance Activity Examples

Table 2. Examples of cyclical maintenance activities.

Cyclical Maintenance Activity	Bridge Component
Clean/Wash Bridge	Deck and/or Super/Substructure
Clean and Flush Drains	Deck
Clean Joints	Deck
Deck/Parapet/Rail Sealing and Crack Sealing	Deck
Seal Concrete	Super/Substructure

Photo courtesy of Washington State DOT

Figure 3. Bridge washing.

Table 3: Examples of condition-based maintenance activities

Examples of Condition-Based Maintenance Activity	Bridge Component
Drains, Repair/Replace	Deck
Joint Seal Replacement	Deck
Joint Repair/Replace/Elimination	Deck
Electrochemical Extraction (ECE)/Cathodic Protection (CP)	Deck
Concrete Deck Repair (see halo effect below) in Conjunction with Overlays, CP Systems or ECE Treatment	Deck
Deck Overlays (thin polymer epoxy, asphalt with waterproof membrane, rigid overlays)	Deck
Repair/Replace Approach Slabs	Approach
Seal/Patch/Repair Superstructure Concrete	Superstructure
Protective Coat Concrete/Steel Elements	Superstructure
Spot/Zone/Full Painting Steel Elements	Superstructure
Steel Member Repair	Superstructure
Fatigue Crack Mitigation (pin-and-hanger replacement, retrofit fracture critical members)	Superstructure
Bearing Restoration (cleaning, lubrication, resetting, replacement)	Superstructure
Movable Bridge Machinery Cleaning/Lubrication/Repair	Superstructure
Patch/Repair Substructure Concrete	Substructure/Culvert
Protective Coat/Concrete/Steel Substructure	Substructure/Culvert
ECE/CP	Substructure/Culvert
Spot/Zone/Full Painting Steel Substructure	Substructure
Pile Preservation (jackets/wraps/CP)	Substructure
Channel Cleaning / Debris Removal	Channel
Scour Countermeasure (installation/repair)	Channel

FHWA Bridge Preservation Guide

Example Activity Rules

Table 5. Examples of cyclical agency rule.

NBI Item 58	Preservation Activity	Interval Years
≥ 7	Deck Sweeping/Washing	1 to 2
	Crack Sealing	3 to 5
	Deck Sealing	3 to 5
	Polymer Overlay	8 to 12
	Polymer-Modified Asphalt Overlay	12 to 15

Table 6. Example of a condition-based agency rule.

Deck GCR, Before				Repair Option	Deck GCR, After		Service Life Years
Top Surface		Bottom Surface			Top Surface	Bottom Surface	
BSIR #58a	Defect Area	BSIR #58b	Defect Area		BSIR #58a	BSIR #58b	
≥ 5	≤ 5%	> 5	≤ 2%	Epoxy Overlay	8, 9	No Change	10 to 15
N/A	≤ 10%	N/A	≤ 25%	Deck Patch	+ 1	No Change	3 to 10

Rules do not account for relative priority and benefit of different action types, or relative priority of bridges, **which need to be considered when there are budget constraints.**

Other Factors of Consideration:

- Net benefit of an action
- Duration of extension of service life
- Availability of specialty contractors
- Coordination of work along route segments or bridge bundling contracts
- Consideration of traffic operations

FHWA Bridge Preservation Guide

Bridge Preservation Best Practices

- A needs identification method that is uniform, specific, and repeatable.
  - Can be based on National Bridge Inventory (NBI) major component condition ratings, detailed inspections and scopes, or element-level condition data.
- A commitment by agency management to asset preservation.
- Resource allocation determined by agency network goals and a bridge management system directed to preservation actions.
- A process for categorization and/or prioritization that integrates agency objectives.
- Verification and feedback on work completed.

FHWA Bridge Preservation Guide

Establishing a Bridge Preservation Program

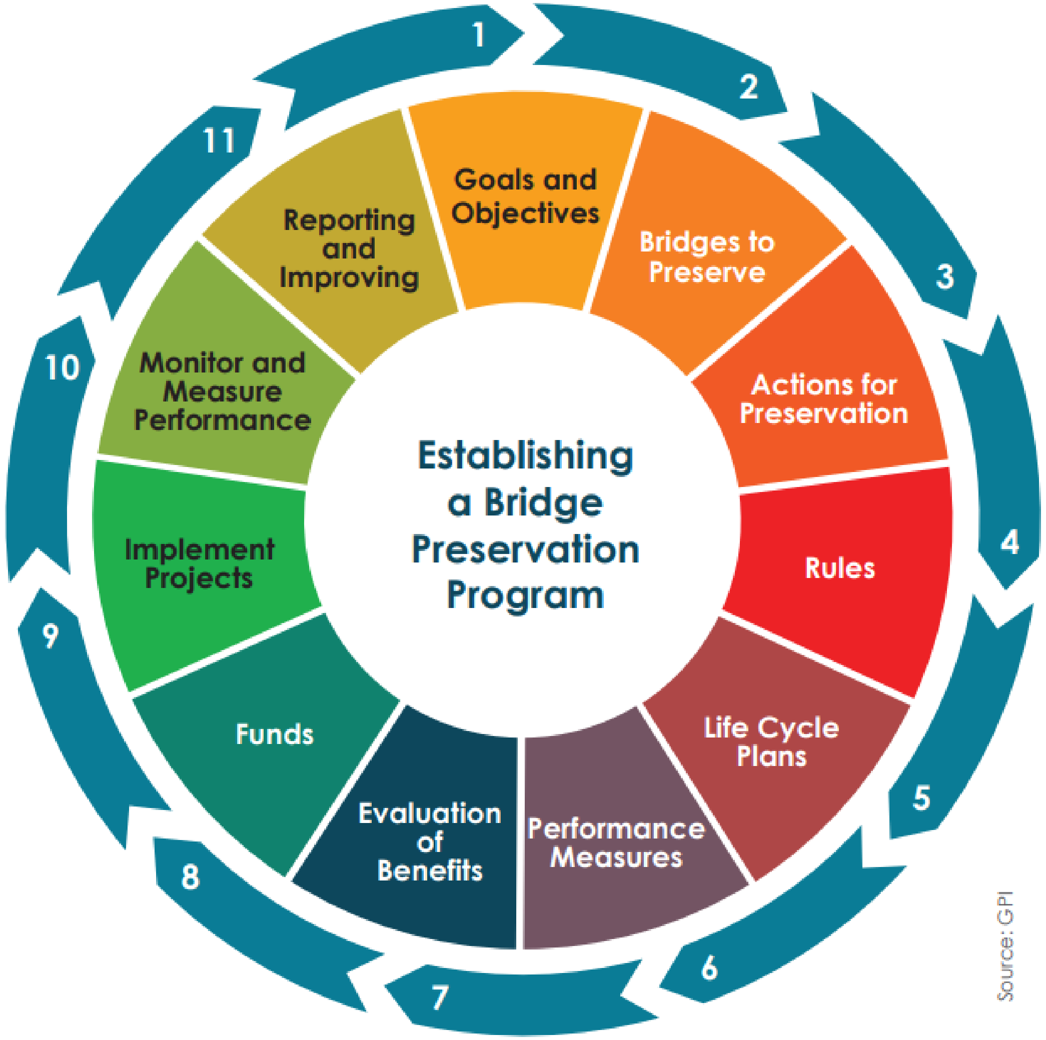

Figure 15. Steps for establishing a bridge preservation program.

Owner agency steps toward establishing a bridge preservation program:

- Identify agency goals and objectives.
- Identify bridges to preserve.
- Develop a list of actions for preservation (a list of cyclical and condition-based PM activities are provided in this guide).
- Establish rules for the actions, a combination of either cyclical or condition-based.
- Use the actions to develop life cycle plans.
- Develop performance measures for the effectiveness of the actions, projects, and programs of projects to satisfy agency's goals.
- Develop methods to evaluate benefits of the actions.
- Dedicate funds for preservation actions.
- Implement and evaluate projects.
- Monitor and measure performance of preservation program.
- Report and improve preservation program.

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Step 3: Estimating Costs

3 General Cost Types:

1. Agency Costs
2. User Costs
3. Vulnerability Costs

Step 3: Cont.

1. For simplified LCCA work and analysis, include only the costs that are different between the alternatives
   ~ LCCA does not require that all costs associated with each alternative be calculated
2. Determine residual value of components with remaining service life at the end of the bridge's service Life
3. Perform quantity take-offs

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SHRP2 R19A LCCA of New Bridge Design Alternatives

Step 3: Cont.

4. Determine cost estimates and calculate unit costs for each activity

   ~ Unit costs have a great influence on the outcome of LCCA and should be decided carefully

   ~ A LCCA can include a cost contingency, added as a separate cost item, if the uncertainty on the different unit costs is deemed too high

   ~ Alternatively, in case of high uncertainty for a specific unit cost, a sensitivity analysis may be completed using minimum, average, and maximum expected unit cost values so that this uncertainty is considered in deciding which solution is most cost-effective

   ~ Don't forget traffic control costs, especially if the alternatives require different traffic control

5. From Step 2, for each task frequency time combine costs for each task(s) for that time

6. Remember to address variability and uncertainty of inputs

[Design Guide for Bridges for Service Life]

[SHRP2 R19A LCCA of New Bridge Design Alternatives]

Life-Cycle Cost Mathematical Models

General Models

A generalized life-cycle cost model can be expressed as the following (*12*):

$$LCC = C_1 + C_2 \quad (1)$$

where

LCC = life-cycle cost,
C_1 = nonrecurring costs, and
C_2 = recurring costs.

It may be noted that the salvage value or terminal value may be regarded as a nonrecurring cost if the analysis period equals the life of the project.

The risk and vulnerability of a system can be included in a life-cycle cost model, as follows:

$$LCC = IC + OP + FC \quad (2)$$

where

LCC = life-cycle cost,
IC = initial cost,
OP = operating cost, and
FC = failure cost.

Bridge Models. Bridges are unique structures in transportation systems, and they require frequent and substantial maintenance, rehabilitation, and replacement. Consequently, maintenance and rehabilitation costs are a significant part of the total costs in BLCCAs. Similar to the pavement model presented in Equation 3, a bridge life-cycle cost model can be expressed as follows:

$$LCC = DC + CC + MC + RC + UC + SV \quad (6)$$

where

LCC = life-cycle cost,
DC = design cost,
CC = construction cost,
MC = maintenance cost,
RC = rehabilitation cost,
UC = user cost, and
SV = salvage value.

DC & UC is often ignored

NCHRP Report 483 – BLCCA

Step 3: Cont.

Agency Costs

General Activities:

- Design (? - depends)
- Construction
- Maintenance Activities (seasonal routine and preventive, cyclical and condition-based)
- Preservation Activities (every x years)
- Rehabilitation / Replacement Activities (every n years)
- Demolition / Replacement

Step 3: Cont.

User Costs

- Associated with reduced traffic capacity in work zones to the User
  - Delays (lost time), increased vehicle operating costs, and accidents / crash costs
  - Timing, duration, scope, and number of construction, preservation, and replacement work zones should be included in each project alternative
- Very challenging to estimate precisely, but a greater focus on User Costs in recent years
- When calculated, user costs are often so large that they may substantially exceed agency costs, particularly for transportation investments being considered for high-traffic areas

Design Guide for Bridges for Service Life

Step 3: Cont.

User Costs, cont.

- Many agencies have been reluctant to incorporate user costs into LCCA because of the difficulty and uncertainty in assigning value to user delay time, or because user costs are not factored into agency budgets, and there's a lack of time-travel market value (for non-business travel)
- See Section 11.3.3 in the Design Guide for Bridges for Service Life for additional approaches for estimating user costs based on traffic volumes and user delays.

Design Guide for Bridges for Service Life

Step 3: Cont.

Vulnerability Costs

Vulnerability costs are **associated with extraordinary circumstances and risks**, and **often are not included in an LCCA for comparison of service life strategies**. They are useful, however, in evaluating vulnerability of existing bridges that might have a high probability for one or more of these extreme events.

Vulnerability costs often very difficult to quantity due ranges of severity and magnitude of impacts

Step 3: Cont.

Vulnerability Costs

Typical Vulnerability Considerations:

- Condition-related reduction in load capacity, service life, or both (due to deterioration if not addressed or conditions change)
- Seismic vulnerability
- Scour
- Floods
- Overloads
- Collisions
- Blasts
- Fires
- Safety: substandard bridge railing, guiderails, transitions, end treatments
- Legislative and Regulatory

Design Guide for Bridges for Service Life

Partial NCHRP 483 Vulnerability Example

Table 3.7 Annual hazard-vulnerability risk

Event	Risk measure (1 year)	Estimated risk			
Load-related structural failure	Probability of event Cost, per event	0.95 $0	0.03 $200,000	0.01 $1,000,000	0.01 $3,000,000
Severe traffic accident attributable to deck condition	Probability of event Cost, per event	0.989 $0	0.010 $40,000	0.001 $1,000,000	
Seismic damage	Probability of event Cost, per event	0.91 $0	0.05 $400,000	0.03 $1,500,000	0.01 $5,000,000

Table 3.8 Expected annual vulnerability cost computation

Event	Expected cost calculation	Expected cost
Load-related structural failure	0.97x$0 + 002x$200,000 + 0.005x$1,000,000 + 0.001x$3,000,000	$12,000
Severe traffic accident attributable to deck condition	0.989x$0 + 0.010x$40,000 + 0.001x$1,600,000	2,000
Seismic damage	0.91x$0 + 0.05x$400,000 + 0.03x$1,500,000 + 0.01x$5,000,000	105,000
	Expected annual vulnerability cost, base case	$119,000

Table 3.9 Best estimates of costs of deck reconstruction

Cost	Annual costs			
	Year 1	Year 2	Years 1-25	Years 3-25
Agency	270,000	630,000		4,000
User		1,452,000		
Vulnerability			119,000	

NCHRP Report 483 – BLCCA

NCHRP 483 Example Input Variables

TABLE 11.1. LCCA INPUT VARIABLES

LCCA Component	Input Variable	Source
Initial and future agency costs	Preliminary engineering	Estimate
	Construction management	Estimate
	Construction	Estimate
	Maintenance	Assumption
Timing of costs	Bridge deterioration	Projection
User costs	Current traffic	Estimate
	Future traffic	Projection
	Hourly demand	Estimate
	Vehicle distributions	Estimate
	Value of delay time	Assumption
	Work zone configuration	Assumption
	Work zone hours of operation	Assumption
	Work zone duration	Assumption
	Work zone activity years	Projection
	Crash rates	Estimate
	Crash cost rates	Assumption
Vulnerability costs	Flood probability	Estimate
	Flood damage distribution	Estimate
	Earthquake probability	Estimate
	Earthquake damage	Estimate
	Load distribution probability	Estimate
	Load-related structural damage	Estimate
Other parameters	Discount rate	Assumption

Design Guide for Bridges for Service Life

Historical ODOT Bid Data

Pages - Bid Histories

https://www.dot.state.oh.us/Divisions/ConstructionMgt/Estimating/Pages/...

An Official Site of Ohio.gov

ODOT / Working / Contracts / Estimating

Bid Data

Item Search

- Search for ODOT items and cost history.
- Refreshed regularly with the latest letting information.

Bid Tabs

- Published after projects are awarded, typically within two weeks after a letting.
- Only published for awarded projects, never published for rejected projects.

Summary of Contracts Awarded

- Compiled and published by the end of January of the following year.

Issues Opening Files

If you experience issues opening files, please try the following:
1. Hover your mouse cursor over the file you wish to view.
2. Click on the arrow to the right of the file.
3. Select "Download a Copy" and note where the file is downloaded locally. You should now be able to open the file on your computer. Excel macros must be enabled for the files to function.

Type	Name
Category : 1. Item Search (4)	
	Bid Data Item Search 2019-2023
	Bid Data Item Search 2015-2019
	Bid Data Item Search 2014-2018
	Bid Data Item Search 2010-2013
Category : 2. Bid Tabs (24)	
	Bids Summary 2015Q2-2022Q4
	Bid Tabs 2023
	Bid Tabs 2022
	Bid Tabs 2021

Bid Histories | ODOT (ohio.gov)

Reminder

The total LCCA of a specific bridge component (and of the entire bridge) depends on the chosen maintenance schedule particularly considering that maintenance may require partial closures and incurrence agency costs due to mobilization and maintenance of traffic, and user costs due to delay.

Step 4. Compute Life-Cycle Costs

Money in the future is worth less than its present value so must be discounted to its present value

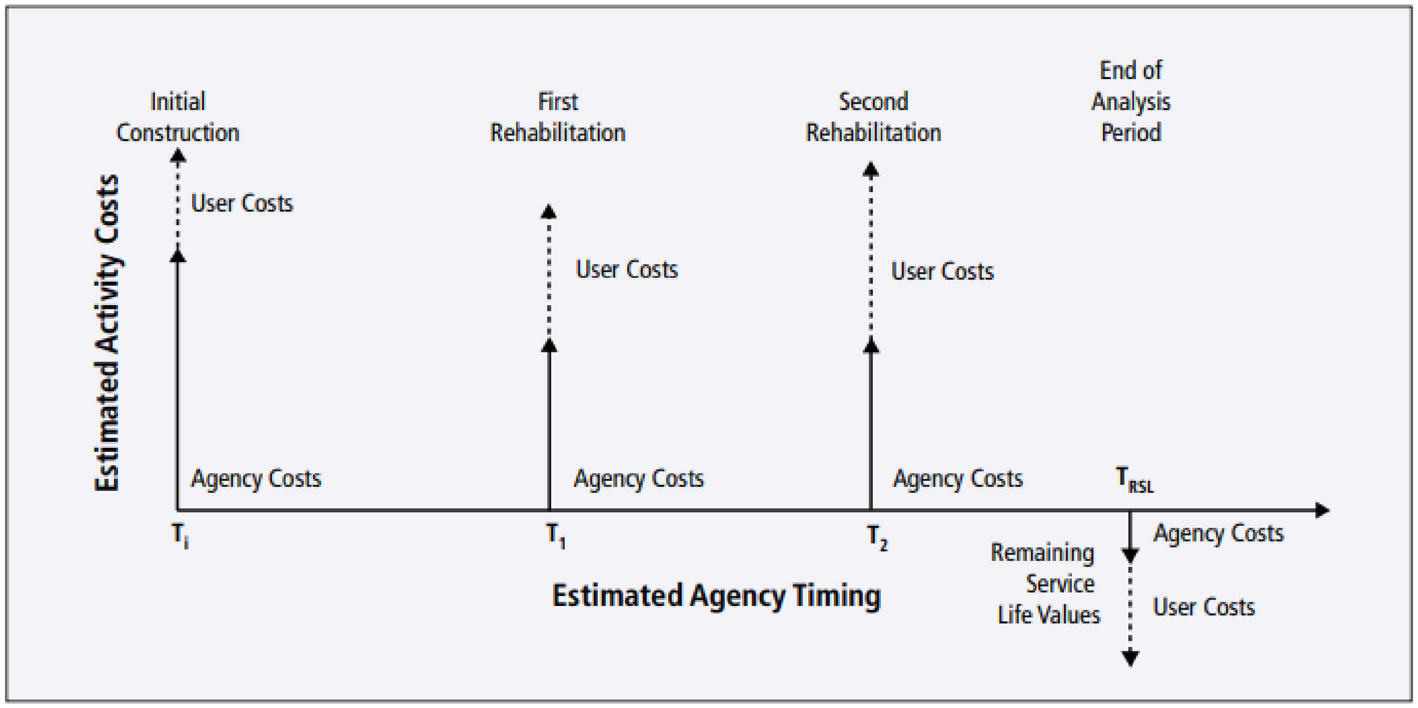
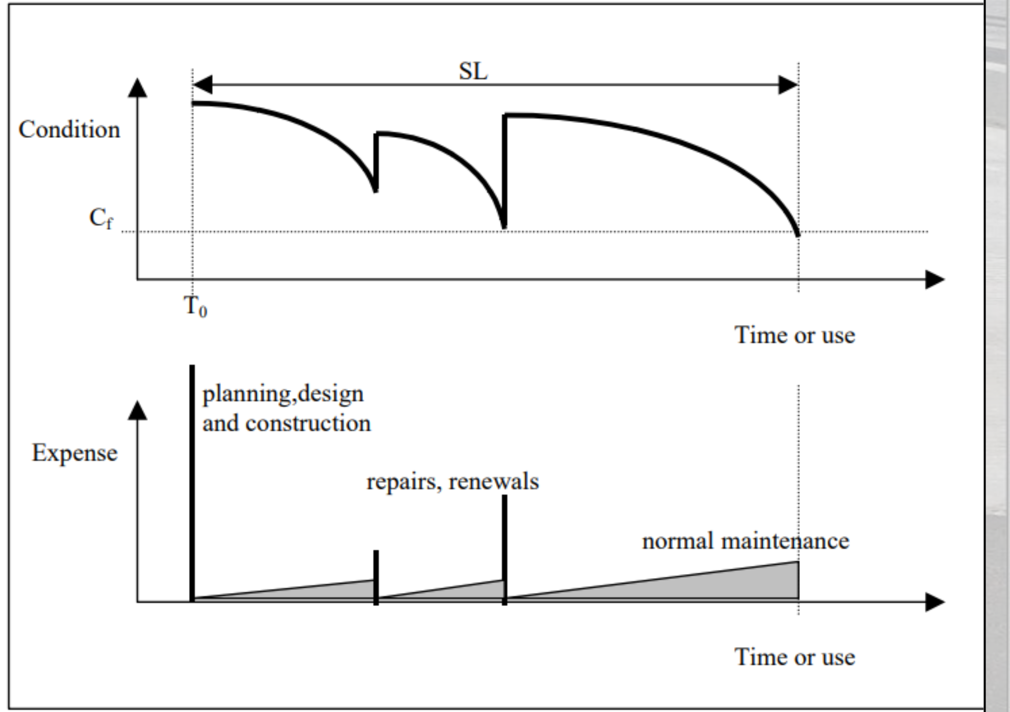


FIGURE 2. EXPENDITURE STREAM DIAGRAM, SHOWING ACTIVITIES, COSTS, AND TIMING

Life-Cycle Cost Analysis Primer

Figure 2.3 Expenditure accompanying the life cycle



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Step 4. Compute Life-Cycle Costs

1. Determine real discount rate
   ~ For LCCA of bridges, typically a real discount rate of 2% to 4% per year is used

2. Determine formulas and calculate present value for each cost for each alternative
   ~ Process translates cashflows over time into common units
   ~ Analysis period must be the same for all alternatives (ideally its optimal service life)
   ~ Beginning of first year is traditionally defined as "Time 0"
   ~ Use BCA for non-similar analysis periods and benefits or other factor comparisons

3. Remember to address variability and uncertainty of inputs

Effect of Discount Rate on Present Value

$$i^* = \frac{(1+i)(1+q)}{(1+f)} \quad (14)$$

where

i^* = "true" discount rate that incorporates the effect of inflation,
i = prevailing discount rate,
q = rate of increase in funding, and
f = expected rate of inflation.

If the rate of increase in funding is expected to keep pace with the rate of inflation, the discount rate can be taken equal to the prevailing discount rate.

NCHRP Report 483 – BLCCA

Note as the discount rate increases the present value decreases, i.e., your funds are worth less

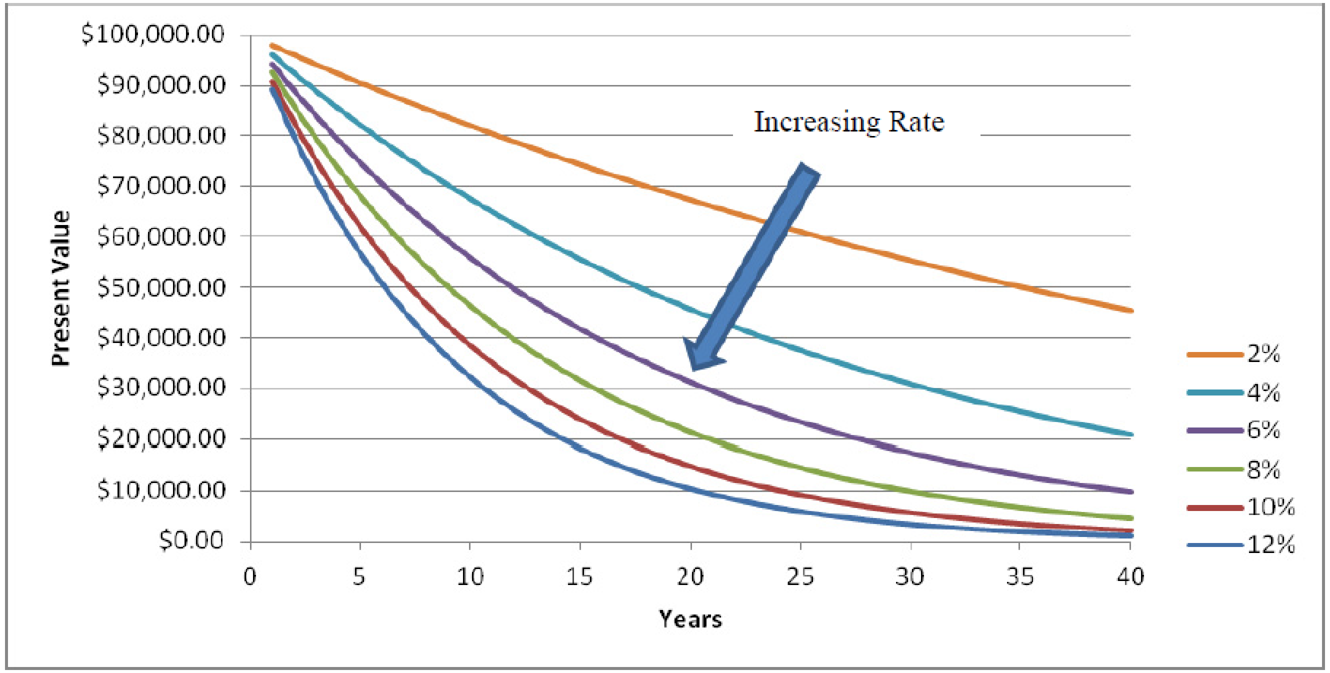

Figure 11.1. *Effect of discount rates on present value.*

Design Guide for Bridges for Service Life

- Carefully choice the real discount rate since it has a significant influence on the outcome of the LCCA
- Sometimes it is necessary to carry out LCCAs with different real discount rates to assess the sensitivity of the analysis
- Low real discount rates favor current expenditures whereas high rates reduce the present value of future costs and consequently tend to favor options with low capital cost, short life and high recurring cost.

Step 4. Cont.

Basic Net Present Value (NPV, PV) Formulas

The formula to convert the sum of the initial cost and the present value of future repair and renewal costs into NPV is given by Equation 11.1:

$$\text{NPV} = \text{initial cost} + \sum_{k=1}^{N} \text{rehab cost}_k \left[\frac{1}{(1+r)^{n}\, k} \right]$$

where

- r = real discount rate,
- k = order number of a rehabilitation activity undertaken in the future,
- N = total number of rehabilitation activities, and
- n_k = year in the future when the cost will be incurred.

Design Guide for Bridges for Service Life

The term $\left[\frac{1}{(1+r)^{n}\, k} \right]$ is called the discount factor.

always ≤ 1

Each year (period) will have a different discount factor

The relationship between the amount of a future expenditure and its equivalent present value, (PV) is calculated from the following expression using a real discount rate (r) [10].

$$PV = C_n * 1/(1+r)^n \qquad (1)$$

where:

- C_n = Cost of expenditure at year n, (in today's dollars)
- r = real discount rate
- n = year in the future when cost will be incurred

Additional discussion of discounting and the above equation can be found in the Primer [10].

The LCC is then calculated as the sum of the PVs of accumulated costs (C_n) incurred at time t, over a period of time (T) as given by the following formula:

$$PV_{LCC} = \sum_{t=0}^{T} C_n * 1/(1+r)^n \qquad (2)$$

wherein each time-step considers costs associated for that year.

Step 4. Cont.: Formulas

* Some formulas for the same variable in other sources have different terms within the formula

$$SPPWF_{i,n} = \frac{1}{(1+i)^n} \quad (9)$$

One-Time Future Event

$$PV = \frac{FV_N}{(1+DR)^N}$$

$$USPWF_{i,n} = \frac{(1+i)^n - 1}{i(1+i)^n} \quad (10)$$

Equal Annual Events

$$PV = C\,\frac{(1+DR)^N - 1}{DR(1+DR)^N}$$

$$GSPWF_{i,n} = \frac{1}{i(1+i)^n}\left[\frac{(1+i)^n - 1}{i} - n\right] \quad (11)$$

$$CRF_{i,n} = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (12)$$

$$PSPWF_{i,n} = \frac{(1+i)^n}{(1+i)^n - 1} \quad (13)$$

where

$SPPWF_{i,n}$ = single-payment present worth factor at discount rate i (in decimals), for a single payment in year n;
$USPWF_{i,n}$ = uniform series present worth factor at discount rate i, over a period of n years;
$GSPWF_{i,n}$ = gradient series present worth factor at discount rate i, over a period of n years;
$CRF_{i,n}$ = capital recovery factor at discount rate i, over an analysis period of n years; and
$PSPWF_{i,n}$ = perpetual series present worth factor at discount rate i, with n equal payment intervals.

$$i^* = \frac{(1+i)(1+q)}{(1+f)} \quad (14)$$

where

i^* = "true" discount rate that incorporates the effect of inflation,
i = prevailing discount rate,
q = rate of increase in funding, and
f = expected rate of inflation.

If the rate of increase in funding is expected to keep pace with the rate of inflation, the discount rate can be taken equal to the prevailing discount rate.

The equivalent uniform annual cost of an option in perpetuity may be expressed as follows:

$$EUAC_{OC} = \left[\left\{\begin{array}{l} I - E(SPPWF_{i,N}) \\ + G(GSPWF_{i,h+1}) \\ (SPPWF_{i,g-1}) \\ + F(SPPWF_{i,n_1}) \\ + (A(USPWF)_{i,N} \end{array}\right\}(PSPWF_{i,N})\right] i \quad (15)$$

where

I = initial cost,
F = future rehabilitation cost,
A = annual maintenance cost,
G = gradient series of maintenance cost increase,
E = salvage value of existing structure,
g = time passed before the beginning of uniform gradient series of maintenance cost increase,
h = duration of uniform gradient series maintenance cost increase,
n_1 = time passed before the future rehabilitation,
N = service life of the option, and
i = discount rate.

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Component: Real Discount Rate:						
Year	Condition-based Maintenance		Cyclical Maintenance		Replacement	
	Unit Cost (2018$)	PV (2018$)	Unit Cost (2018$)	PV (2018$)	Unit Cost (2018$)	PV (2018$)
1						
2						
3						
4						
5						
6						
7						
:						
:						
:						
:						
99						
100 (service life of bridge)						
Total						

SHRP2 R19A LCCA of New Bridge Design Alternatives

Step 5. Analyze Results

- Compare initial and life-cycle costs associated with each alternative
- Determine lowest cost or optimal cost-effective solution
  - Consider anticipated funding and staffing levels
- Reanalyze LCCA alternatives by perform sensitivity analyses and simulation
- If the alternatives provide different levels of service, then the alternative that provides the best overall long-term benefit can also be compared using Benefit-to-Cost Analysis (BCA)
  - Considers the benefits of an improvement as well as its costs
  - Use for different levels of service, utility, objectives, or duration (e.g., 75 years and 100 years)
  - Goal is to maximize benefits

Example LCCA

Alternative A:
- Fewer construction and rehab activities
- More extensive work and work zones per activity
- Higher cost per activity

Alternative B:
- Requires more frequent activities and use of work zones
- Shorter work zone durations
- Lower cost per activity

Note smaller discount factors as time increase.

Life-Cycle Cost Analysis Primer

LIFE-CYCLE COST ANALYSIS (LCCA) EXAMPLE: DETERMINISTIC APPROACH

Presented here is an example of a deterministic LCCA comparing two alternative project strategies. Each alternative will supply the same level of performance or benefit, so application of LCCA is appropriate. Costs that are equal between alternatives have been removed from the analysis. The discount rate is 4 percent, and a 35-year analysis period is used.

Step One: Establish Design Alternatives

Alternative A is characterized by fewer construction and rehabilitation activities than is Alternative B, but the activities it requires are more extensive and cost more, per activity, than those of Alternative B. Alternative B requires more frequent use of work zones to maintain level of service, but these work zones last less time, per activity, than those of Alternative A.

Step Two: Determine Activity Timing

Year	Alternative A Activities	Alternative B Activities
0	Initial construction	Initial construction
12		Rehabilitation one (8-year service life)
20	Rehabilitation one (20-year service life)	Rehabilitation two (8-year service life)
28		Rehabilitation three (8-year service life)
35	End of analysis period—residual service life value if applicable.	

Step Three: Estimate Costs (Agency and User)

Agency and user costs for each activity are in constant, base year dollars. User costs are based upon user vehicle operating costs and traveler delay associated with work zone activities. User costs increase for similar work due to the increase in traffic over time. Costs for year 35 reflect the value of remaining service life for each alternative in year 35.

	Alternative A Activities		Alternative B Activities	
Year	Constant Dollar Agency Costs	Constant Dollar User Costs	Constant Dollar Agency Costs	Constant Dollar User Costs
0	$26,000,000	$11,000,000	$20,000,000	$8,000,000
12			6,000,000	10,000,000
20	15,000,000	30,000,000	6,000,000	16,000,000
28			6,000,000	28,000,000
35	(3,750,000)	(7,500,000)	(750,000)	(3,500,000)

Step Four: Compute Life-Cycle Costs

Using the discount factor, the present value (PV) is calculated for each of the agency and user costs (see the Inflation and Discounting box on page 16).

		Alternative A		Alternative B	
Year	Discount Factor	Discounted Agency Costs	Discounted User Costs	Discounted Agency Costs	Discounted User Costs
0	1.0000	$26,000,000	$11,000,000	$20,000,000	$8,000,000
12	0.6246			3,747,582	6,245,970
20	0.4564	6,845,804	13,691,608	2,738,322	7,302,191
28	0.3335			2,000,865	9,337,369
35	0.2534	(950,308)	(1,900,616)	(190,062)	(886,954)
Total Costs (PV)		**31,895,496**	**22,790,992**	**28,296,707**	**29,998,576**

Step Five: Analyze the Results

Example LCCA

Life-Cycle Cost Analysis Primer

Step Four: Compute Life-Cycle Costs

Using the discount factor, the present value (PV) is calculated for each of the agency and user costs (see the Inflation and Discounting box on page 16).

		Alternative A		Alternative B	
Year	Discount Factor	Discounted Agency Costs	Discounted User Costs	Discounted Agency Costs	Discounted User Costs
0	1.0000	$26,000,000	$11,000,000	$20,000,000	$8,000,000
12	0.6246			3,747,582	6,245,970
20	0.4564	6,845,804	13,691,608	2,738,322	7,302,191
28	0.3335			2,000,865	9,337,369
35	0.2534	(950,308)	(1,900,616)	(190,062)	(886,954)
Total Costs (PV)		**31,895,496**	**22,790,992**	**28,296,707**	**29,998,576**

Alternative A:

- Lowest *combined* agency *and* user costs

Alternative B:

- Lowest *initial* construction and *total agency* costs

"Based on this information alone, the decision-maker could lean toward either Alternative A (based on overall cost) or Alternative B (due to its lower initial and total agency costs).

However, more analysis might prove beneficial.

… Alternative B might be revised to see if user costs could be reduced through improved traffic management during construction and rehabilitation.

Sensitivity analysis could be performed based on discount rates or key assumptions concerning construction and rehabilitation costs.

Finally, probabilistic analysis could help to capture the effects of uncertainty in estimates of timing or magnitude of costs developed for either alternative." Life-Cycle Cost Analysis Primer

Simple SHRP2 Example #1

Table 3: Total Quantities for Different Components of the Bridge for the Different Exposure Zones

Component	Buried / Submerged	Water Level	Interior	Atm.	Indirect De-icing	Direct De-icing
Land structures (Pier 1 and abutments)* (ft^2)	Not calculated	5,703				
Pier 2+3+4+5* (ft^2)	Not calculated	40,846				
Top deck roadway and pedestrian surface main and approach spans (ft^2)						104,063
Structural steel to be painted (ft^2)			103,782	62,795	50,037	
Total barrier length (ft)						5,550
Cables and hangers (ea)				64		
Elastomeric bearings on appr. span (ea)				42		
Elastomeric bearings on stringers (ea)				231		
Arch disc bearings (ea)				4		
Modular expansion joints (ea)					2	
Strip seal expansion joints (ea)					2	
Scuppers (ea)				90		

* The exposure zones 'water level, interior', 'atmospheric', 'indirect de-icing salts', and 'direct de-icing salts' are considered under one for land structures and piers because the maintenance tasks defined for these exposure zones are assumed to be the same. There is uncertainty related to the amount of maintenance specific to each zone, instead one maintenance regime is assumed for these structures. No maintenance tasks are considered for the buried exposure zone and therefore areas are not calculated.

SHRP2 R19A LCCA of New Bridge Design Alternatives

Simple SHRP2 Example #1, cont.

Table 5: Calculations of Maintenance Cost for Cables and Hangers.

Maintenance	Calculation	Activity Cost per Time (2018$)
Condition-based Maintenance	1 x $6,500	$6,500
Cyclical Maintenance	64 x $1,560	$99,840
Replacement	64 x $156,000	$9,984,000

Table 4: Unit Costs for Maintenance Tasks for Cables and Hangers

Maintenance	Unit	Unit Cost (2018$)
Condition-based Maintenance	Lump sum	$6,500
Cyclical Maintenance	ea	$1,560
Replacement	ea	$156,000

Table 6: Calculations of Present Value for Cables and Hangers at Year 40.

Maintenance	Calculation	Present Value (2018$)
Condition-based Maintenance	$\$6,500 \times (1+0.029)^{-40}$	$2,072
Cyclical Maintenance	$\$99,840 \times (1+0.029)^{-40}$	$31,819

SHRP2 R19A LCCA of New Bridge Design Alternatives

Simple SHRP2 Example #1, cont.

Component: Cables and hangers

Condition-based maintenance:

Description: Cleaning and minor adjustment, based on outcome of routine inspection (every two years).	
Duration of cycle (years):	2
Cycle starting at year:	2
Quantity:	1 (lump sum)
Unit cost (2018$):	6,500
Activity cost per time (2018$):	6,500
Total PV (2018$):	**103,760**

Cyclical maintenance:

Description: Minor repair of sealing, grease, drainage, HDPE tube, bolts, and coating.	
Duration of cycle (years):	5
Cycle starting at year:	25
Quantity:	64 (ea)
Unit cost (2018$):	1,560
Activity cost per time (2018$):	99,840
Total PV (2018$):	**323,830**

Replacement:

Description: Replacement of cables.	
Duration of cycle (years):	60+
Cycle starting at year:	60
Quantity:	64 (ea)
Unit cost (2018$):	156,000
Activity cost per time (2018$):	9,984,000
Total PV (2018$):	**1,796,313**

TOTAL LCC for cables and hangers in PV 2018$: 2,223,903

SHRP2 R19A LCCA of New Bridge Design Alternatives

Simple SHRP2 Example #1, cont.

Table 7: Calculation of Present Value at Each Year for Maintenance and Replacement of Cables and Hangers.

Component: Cables and hangers Real Discount Rate: 2.9%						
Year	Condition-based Maintenance		Cyclical Maintenance		Replacement	
	Unit Cost (2018$)	PV (2018$)	Unit Cost (2018$)	PV (2018$)	Unit Cost (2018$)	PV (2018$)
1						
2	6,500	6,139				
3						
4	6,500	5,798				
5						
6	6,500	5,475				
7						
8	6,500	5,171				
9						
10	6,500	4,884				
:	:	:				
25			99,840	48,856		
26	6,500	3,091				
27						

SHRP2 R19A LCCA of New Bridge Design Alternatives

Simple SHRP2 Example #1, cont.

Table 7: Calculation of Present Value at Each Year for Maintenance and Replacement of Cables and Hangers.

Component: Cables and hangers Real Discount Rate: 2.9%						
Year	Condition-based Maintenance		Cyclical Maintenance		Replacement	
	Unit Cost (2018$)	PV (2018$)	Unit Cost (2018$)	PV (2018$)	Unit Cost (2018$)	PV (2018$)
28	6,500	2,919				
29						
30	6,500	2,757	99,840	42,349		
31						
:	:	:				
60	6,500	1,169	99,840	17,963	9,984,000	1,796,313
61						
62	6,500	1,104				
:	:	:				
:	:	:				
100	-	-	-	-		
Sub-Total	318,500	103,760	1,497,600	323,830	9,984,000	1,796,313
Grand Total	103,760 + 323,830 + 1,796,313 = 2,223,903					

SHRP2 R19A LCCA of New Bridge Design Alternatives

Simple SHRP2 Example #1, cont.

Condition-based and Routine Maintenance *(the latter is marked with * below)*

Concrete

Component: Bridge deck (main + approach spans)
Description: Condition-based maintenance is not anticipated or very minor. Ignored for this example.

Component: Concrete barriers*
Description: Repair of damaged sections as needed (for example due to impacts).

Duration of cycle:	1
Cycle starting at year:	1
Quantity:	1 (lump sum)
Unit cost (2018$):	750
Activity cost (2018$):	750
Total PV (2018$):	**24,336**

Component: Land structures (Pier 1 and abutments)
Description: Condition-based maintenance is not anticipated or very minor. Ignored for this example.

Component: Piers 2-3-4-5
Description: Condition-based maintenance is not anticipated or very minor. Ignored for this example.

Structural Steel

Component: Cables and hangers
Description: Cleaning and minor adjustments.

Duration of cycle:	2
Cycle starting at year:	2
Quantity:	1 (lump sum)
Unit cost (2018$):	6,500
Activity cost (2018$):	6,500
Total PV (2018$):	**103,760**

Component: Painting, interior
Description: Touch-ups of paint (5%), overcoat (100%), and repaint (100%, last year of replacement: 48).

Duration of cycle:	48
Cycle starting at year:	26 (touch-up) / 35 (overcoat) / 48 (repaint)
Quantity:	5,189 ft2 / 103,782 ft2 / 103,782 ft2
Unit cost (2018$):	9.6 / 16.8 / 32.4
Activity cost (2018$):	49,815 / 1,743,530 / 3,362,521
Total PV (2018$):	**29,696 / 803,586 / 852,564**

Component: Painting, atmospheric
Description: Touch-ups of paint (5%), overcoat (100%), and repaint (100%, last year of replacement: 76).

Duration of cycle:	38
Cycle starting at year	21 (touch-up) / 28 (overcoat) / 76 (repaint)
Quantity:	4,396 ft2 / 62,795 ft2 / 62,795 ft2
Unit cost (2018$):	9.6 / 16.8 / 32.4
Activity cost (2018$):	42,198 / 1,054,953 / 2,034,552
Total PV (2018$):	**30,963 / 633,697 / 918,256**

Component: Painting, indirect de-icing salts
Description: Touch-ups of paint (5%), overcoat (100%), and repaint (100%, last year of replacement: 66).

Duration of cycle:	33
Cycle starting at year:	18 (touch-up) / 24 (overcoat) / 33 (repaint)
Quantity:	5,004 ft2 / 50,037 ft2 / 50,037 ft2
Unit cost (2018$):	9.6 / 16.8 / 32.4
Activity cost (2018$):	48,035 / 840,614 / 1,621,183
Total PV (2018$):	**44,243 / 652,218 / 876,846**

Other Components

Component: Bearings (disc)
Description: Maint. of sliding material, repair of coating.

Duration of cycle:	25
Cycle starting at year:	25
Quantity:	4 (ea)
Unit cost (2018$):	13,600
Activity cost (2018$):	54,400
Total PV (2018$):	**46,021**

Component: Drainage
Description: Overhaul, spot coating repair, tighten loose fasteners.

Duration of cycle:	10
Cycle starting at year:	10
Quantity:	90 (ea)
Unit cost (2018$):	200
Activity cost (2018$):	18,000
Total PV (2018$):	**50,242**

Component: Expansion joints (modular/strip seal)
Description: Maint. of moving parts (incl. springs), repair of strip seal, and repair of coating.

Duration of cycle:	10
Cycle starting at year:	10
Quantity:	2 (ea) / 2 (ea)
Unit cost (2018$):	28,600 / 14,300
Activity cost (2018$):	57,200 / 28,600
Total PV (2018$):	**159,657 / 79,829**

Component: Access systems
Description: Touch-ups of coatings and minor repair.

Duration of cycle:	5
Cycle starting at year:	5
Quantity:	1 (lump sum)
Unit cost (2018$):	15,000
Activity cost (2018$):	15,000
Total PV (2018$):	**89,323**

SHRP2 R19A LCCA of New Bridge Design Alternatives

Simple SHRP2 Example #1, cont.

Cyclical maintenance

Concrete

Component: Bridge deck (main + approach spans)
Description: Repair of concrete surface spalls and other concrete deterioration and any localized reinforcement deter.

Duration of cycle:	30
Cycle starting at year:	30
Quantity:	51,839 ft^2 (50% of total)
Unit cost (2018$):	60
Activity cost (2018$):	3,121,875

Component: Concrete barriers
Description: Repair due to scaling, corrosion etc.

Duration of cycle:	15
Cycle starting at year:	15
Quantity:	555 ft (10% of total)
Unit cost (2018$):	100
Activity cost (2018$):	55,500
Total PV (2018$):	**85,759**

Component: Land structures (Pier 1 and abutments)
Description: Repair of concrete deterioration.

Duration of cycle:	1
Cycle starting at year:	1
Quantity:	5.7 ft^2 (0.1% of total)
Unit cost (2018$):	100
Activity cost (2018$):	570
Total PV (2018$):	**18,505**

Component: Piers 2-3-4-5
Description: Repair of concrete deterioration.

Duration of cycle:	1
Cycle starting at year:	1
Quantity:	40.8 ft^2 (0.1% of total)
Unit cost (2018$):	100
Activity cost (2018$):	4,085
Total PV (2018$):	**132,541**

Structural Steel

Component: Cables and hangers
Description: Minor repair of sealing, grease, drainage, HDPE tube, bolts and coating.

Duration of cycle:	5
Cycle starting at year:	25
Quantity:	64 (ea)
Unit cost (2018$):	1,560
Activity cost (2018$):	99,840
Total PV (2018$):	**323,830**

Component: Painting, interior
Description: N/A (Per definitions in Section 3.0, maintenance of paint is condition-based in all cases)

Component: Painting, atmospheric
Description: N/A (Per definitions in Section 3.0, maintenance of paint is condition-based in all cases)

Component: Painting, indirect de-icing salts
Description: N/A (Per definitions in Section 3.0, maintenance of paint is condition-based in all cases)

Other Components

Component: Bearings
Description: Cleaning, spot repair of coating.

Duration of cycle:	1
Cycle starting at year:	1
Quantity:	1 (lump sum)
Unit cost (2018$):	17,500
Activity cost (2018$):	17,500
Total PV (2018$):	**568,846**

Component: Drainage
Description: Cleaning and small repair work.

Duration of cycle:	1
Cycle starting at year:	1
Quantity:	1 (lump sum)
Unit cost (2018$):	4,600
Activity cost (2018$):	4,600
Total PV (2018$):	**149,262**

Component: Expansion joints
Description: Cleaning and spot repair of coating.

Duration of cycle:	1
Cycle starting at year:	1
Quantity:	1 (lump sum)
Unit cost (2018$):	1,000
Activity cost (2018$):	1,000
Total PV (2018$):	**64,896**

Component: Access systems
Description: Ad hoc minor repair.

Duration of cycle:	1
Cycle starting at year:	1
Quantity:	1 (lump sum)
Unit cost (2018$):	5,000
Activity cost (2018$):	5,000
Total PV (2018$):	**162,241**

SHRP2 R19A LCCA of New Bridge Design Alternatives

Simple SHRP2 Example #1, cont.

Replacement

Concrete

<u>Component: Bridge deck (main + approach spans)</u>
Description: No replacement anticipated.

<u>Component: Concrete barriers</u>
Description: Replacement of 100% of the barriers.

Duration of cycle:	60
Cycle starting at year:	60
Quantity:	5,550 ft
Unit cost (2018$):	313
Activity cost (2018$):	1,737,150
Total PV (2018$):	**312,547**

<u>Component: Land structures (Pier 1 and abutments)</u>
Description: No replacement anticipated.

<u>Component: Piers 2-3-4-5</u>
Description: No replacement anticipated.

Structural Steel

<u>Component: Cables and hangers</u>
Description: Replacement of all cables and hangers.

Duration of cycle:	60
Cycle starting at year:	60
Quantity:	64 (ea)
Unit cost (2018$):	156,000
Activity cost (2018$):	9,984,000
Total PV (2018$):	**1,796,313**

<u>Component: Painting, interior</u>
Description: N/A (Per definitions in Section 3.0, maintenance of paint is condition-based in all cases)

<u>Component: Painting, atmospheric</u>
Description: N/A (Per definitions in Section 3.0, maintenance of paint is condition-based in all cases)

<u>Component: Painting, indirect de-icing salts</u>
Description: N/A (Per definitions in Section 3.0, maintenance of paint is condition-based in all cases)

Other Components

<u>Component: Bearings (disc/elastomeric)</u>
Description: Replacement of bearings.

Duration of cycle:	50
Cycle starting at year:	50
Quantity:	4 (ea) / 273 (ea)
Unit cost (2018$):	20,000 / 3,000
Activity cost (2018$):	80,000 / 819,000
Total PV (2018$):	**19,157 / 196,117**

<u>Component: Drainage</u>
Description: Replacement of scuppers.

Duration of cycle:	75
Cycle starting at year:	75
Quantity:	90 (ea)
Unit cost (2018$):	4,100
Activity cost (2018$):	369,000
Total PV (2018$):	**43,239**

<u>Component: Expansion joints (modular / strip seal)</u>
Description: Replacement of expansion joints.

Duration of cycle:	30
Cycle starting at year:	30
Quantity:	2 (ea)/ 2 (ea)
Unit cost (2018$):	53,900 / 41,800
Activity cost (2018$):	107,800 / 83,600
Total PV (2018$):	**73,348 / 56,882**

<u>Component: Access systems</u>
Description: Replacement of ladders, platforms etc.

Duration of cycle:	60
Cycle starting at year:	60
Quantity:	1 (lump sum)
Unit cost (2018$):	100,000
Activity cost (2018$):	100,000
Total PV (2018$):	**17,992**

SHRP2 R19A LCCA of New Bridge Design Alternatives

Simple SHRP2 Example #1, cont.

6.2.12 Total Present Value Cost for Entire Bridge (Step 10)

Finally, the total PV cost for the entire bridge structure is determined by summation of all total PV costs for each component. In the present example, the total PV cost to be expected for maintenance tasks during the 100-year service life of the bridge structure is approximately $11.5M. It is noted that user cost is not included in this example.

SHRP2 R19A LCCA of New Bridge Design Alternatives

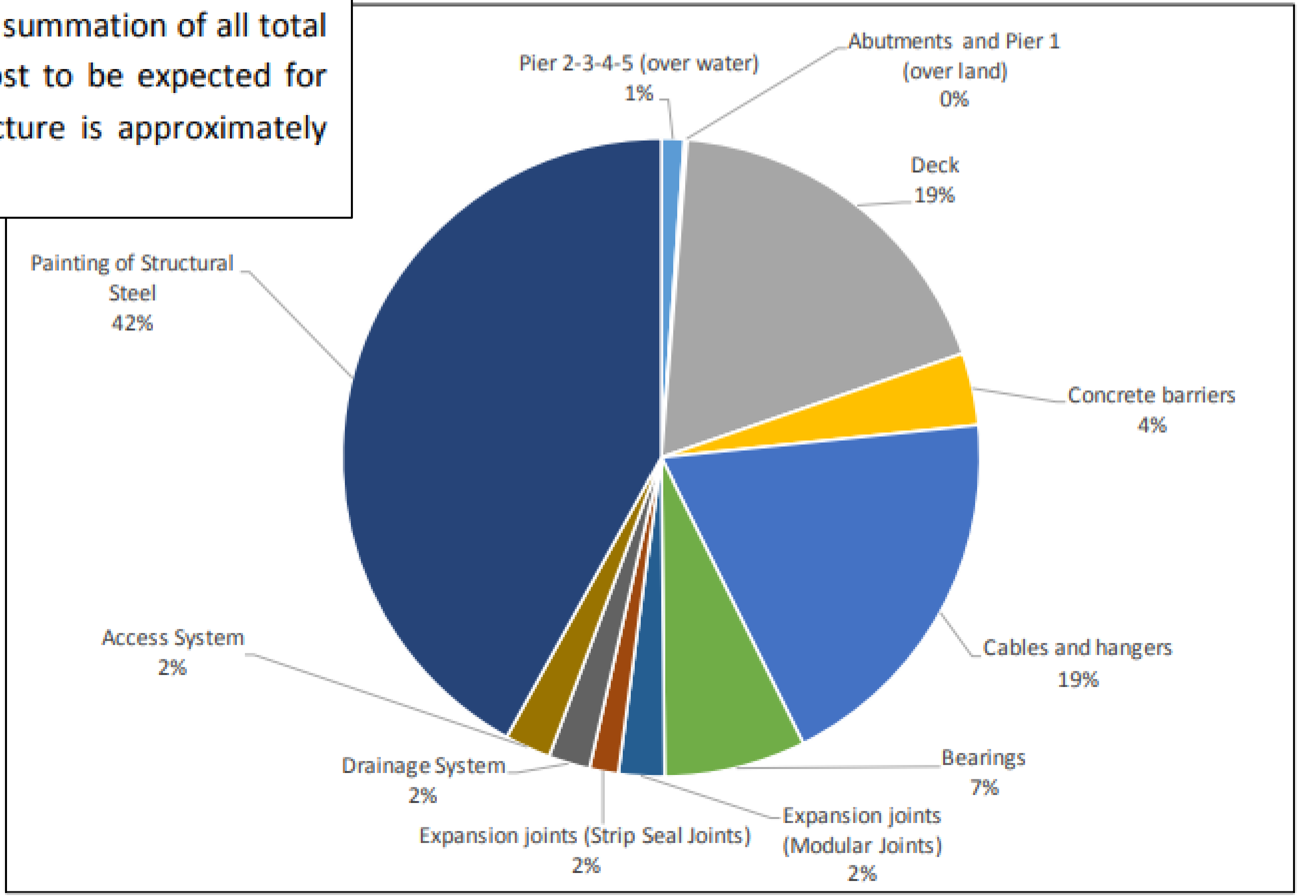

Figure 6. Pie chart visualization of the finalized LCCA

Simple SHRP2 Example #1, cont.

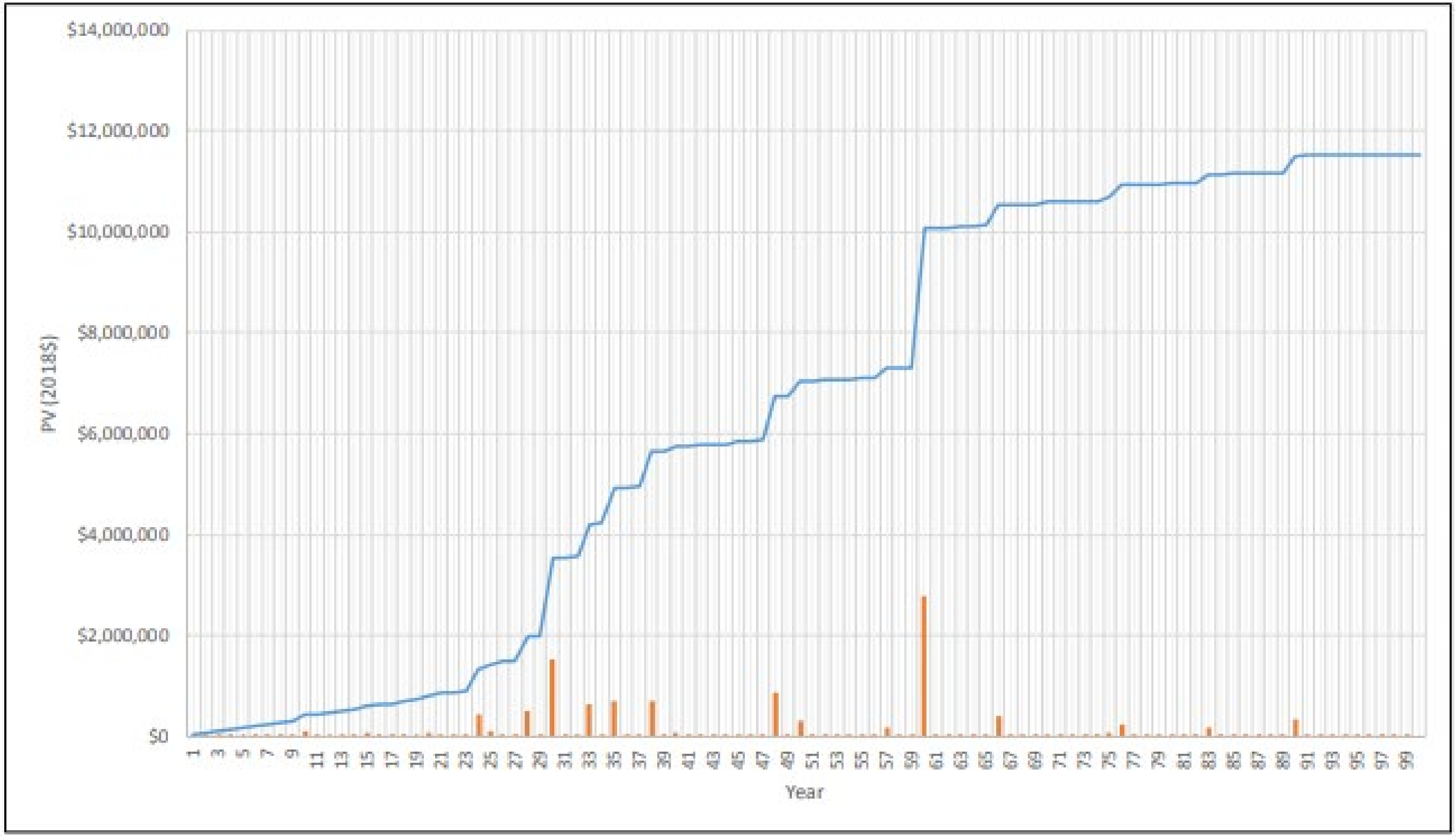

Figure 7. Life Cycle Costs per year and accumulated costs. Values are shown as present values

[SHRP2 R19A LCCA of New Bridge Design Alternatives]

Simple SHRP2 Example #2

Option 1: Waterproofing and asphalt overlay

Option 2: Concrete overlay (2.5 inches)

SHRP2 R19A LCCA of New Bridge Design Alternatives

Table 8. Maintenance Schedule by Option.

Year	Option 1 - Waterproofing and Asphalt Overlay	Option 2 - Concrete Overlay
15	Replacement of asphalt	-
25	Replacement of waterproofing and asphalt	Roughening of the surface (milling)
40	Replacement of asphalt	-
50	Replacement of waterproofing and asphalt	Replacement of concrete overlay
65	Replacement of asphalt	-
75	Replacement of waterproofing and asphalt	Replacement of concrete overlay
90	Replacement of asphalt	-

Table 9. Detailed Procedure for Maintenance Tasks.

	Option 1 - Waterproofing and Asphalt Overlay	Option 2 - Concrete Overlay
Maintenance task	Replacement of waterproofing and asphalt	Replacement of concrete overlay
Detailed maintenance procedure	1. Surface removal 2. Partial depth repairs 3. Deck surface preparation 4. Deck waterproofing 5. Asphalt supply, application	1. Concrete removal 2. Partial depth repairs 3. Supply high performance concrete (HPC) deck overlay 4. Placement of HPC deck overlay

Simple SHRP2 Example #2, cont.

Description: Surface removal (Option 1)

Duration of cycle (years):	See Table 8
Cycle starting at year:	See Table 8
Quantity:	92 ft x 131 ft = 12,052 ft²
Unit cost (2018$):	6.5$/ft²
Activity cost per time (2018$):	12,052 ft² x 6.5$/ft² = 78,338$
Total PV (2018$):	**160,455**

SHRP2 R19A LCCA of New Bridge Design Alternatives

Table 10. Calculation of Present Value at Each Year for Maintenance and Replacement of Overlay.

Component: Overlay Real Discount Rate: 2.9%		
Year	Surface removal (option 1)	
	Unit Cost (2018$)	PV (2018$)
1	-	-
:	-	-
15	78,338	51,020
:	-	-
25	78,338	38,334
:	-	-
40	78,338	24,966
:	-	-
50	78,338	18,759
:	-	-
65	78,338	12,217
:	-	-
75	78,338	9,180
:	-	-
90	78,338	5,978
:		
100	-	-

Component: Overlay Real Discount Rate: 2.9%		
Year	Surface removal (option 1)	
	Unit Cost (2018$)	PV (2018$)
Total	548,366	160,455

Simple SHRP2 Example #2, cont.

Table 11. Total Present Value Cost for Option 1 – Waterproofing and Overlay and Option 2 – Concrete Overlay for the Highway Bridge.

Option 1 - Waterproofing and Asphalt Overlay		Option 2 - Concrete Overlay	
Maintenance task	Total PV (2018$)	Maintenance task	Total PV (2018$)
Surface removal (See Table 8)	160,455	Deck surface roughening (Year 25)	10,961
Partial depth repairs (every 25 years)	94,749	Concrete removal (Years 50 and 75)	79,887
Deck surface preparation (every 25 years)	18,950	Partial depth repairs (Years 50 and 75)	101,803
Deck waterproofing (every 25 years)	71,063	Supply HPC deck overlay (2.5 inch) (Years 50 and 75)	3,355
Asphalt supply+application (every 10 to 15 years)	70,376	Placement of HPC deck overlay (Years 50 and 75)	3,195
TOTAL	**415,573**	**TOTAL**	**199,202**

SHRP2 R19A LCCA of New Bridge Design Alternatives

Simple SHRP2 Example #2, cont.

SHRP2 R19A LCCA of New Bridge Design Alternatives

Table 12. Road User Costs Per Hour for Cars and Trucks According to Ohio DOT [14]. The Values From 2008 are Extrapolated to Future Years by Use of the Consumer Price Index.

Year	Car	Truck
2018	$23.09	$62.33

Table 13. Duration of Closure for Either Complete or Partial Closure of the Highway Bridge by Option.

Option 1 – Waterproofing and Asphalt Overlay			Option 2 – Concrete Overlay		
Task	Traffic Control	Duration (days)	Task	Traffic Control	Duration (days)
Replacement of asphalt (every 10 to 15 years)	Complete closure (detour)	3	Roughening of the surface (milling) (Year 25)	Complete closure (detour)	1
	Partial closure (lane restrictions)	6		Partial closure (lane restrictions)	2
Replacement of waterproofing, asphalt and asphalt (every 25 years)	Complete closure (detour)	14	Replacement of concrete overlay (Years 50 and 75)	Complete closure (detour)	16
	Partial closure (lane restrictions)	20		Partial closure (lane restrictions)	38

Simple SHRP2 Example #2, cont.

SHRP2 R19A LCCA of New Bridge Design Alternatives

Table 14. Calculation of RUC for Surface Roughening at Year 2045 with Full Bridge Closure for Option 2 – Concrete Overlay by Use of Calculation Tool found at Ohio DOT's Website [15].

Work Zone User Cost Calculations (Year 2018)		
Detour (Using Distance & Speed)		
User Input:		
Construction Calendar Year:	2045	
	Car	B/C Truck
ADT of Detoured Section:	22,727	2,273
Length of Normal Route (Miles):	1.1	
Length of Detour Route (Miles):	2.6	
Avg Posted Speed on Normal Route (MPH):	55	
Avg Posted Speed on Detour Route (MPH):	40	
Duration of Closure (Days):	1	
Calculated Values:		
Cost per Hour:	$23.09	$62.33
Travel Time Along Normal Route (Secs):	72	72
Travel Time Along Detour Route (Secs):	234	234
Delay (Secs):	162	162
Delay (Hours):	0.045	0.045
Delay Cost per Vehicle:	$1.04	$2.81
Delay Cost per Day:	$23,617.50	$6,375.85
Delay Cost for Closure Duration:	$23,617	$6,376
Total Delay Cost for Closure Duration:	**$29,993**	
Average Delay Cost per Day:	**$29,993**	

Simple SHRP2 Example #2, cont.

SHRP2 R19A LCCA of New Bridge Design Alternatives

Table 15. Calculation of RUC for Replacement of Asphalt at Year 2035 with Partial Bridge Closure for Option 1 – Waterproof and Asphalt Overlay by Use of Calculation Tool found at Ohio DOT's Website [15].

Work Zone User Cost Calculations (Year 2018)		
No Lanes Closed		
User Input:		
Construction Calendar Year:	2035	
	Car	B/C Truck
ADT of Section:	22,727	2,273
Length of Work Zone (Miles):	1.1	
Original Posted Speed (MPH):	55	
Work Zone Posted Speed (MPH):	30	
Duration of Work Zone (Days):	6	
Calculated Values:		
Cost per Hour:	$23.09	$62.33
Travel Time Pre-Work Zone (Secs):	72	72
Travel Time During Work Zone (Secs):	132	132
Delay (Secs):	60	60
Delay (Hours):	0.017	0.017
Delay Cost per Vehicle:	$0.38	$1.04
Delay Cost per Day:	$8,747.22	$2,361.42
Delay Cost for Work Zone Duration:	$52,483	$14,169
Total Delay Cost for Work Zone Duration:	$66,652	
Average Delay Cost per Day:	$11,109	

Simple SHRP2 Example #2, cont.

Table 16. Calculations of Present Value for Total Delay Costs in Table 14 and Table 15.

Total Delay Cost Example For	Calculation	Present Value (2018$)
Option 2, surface roughening, year 2045, partial closure (Table 14)	$29,993 x (1+0.029)$^{-25}$	$14,677
Option 1, replacement of asphalt, year 2035, full closure (Table 15)	$66,652 x (1+0.029)$^{-15}$	$43,409

SHRP2 R19A LCCA of New Bridge Design Alternatives

Simple SHRP2 Example #2, cont.

SHRP2 R19A LCCA of New Bridge Design Alternatives

Table 17. Comparison of RUC for Complete or Partial Closure of the Highway Bridge for Option 1 - Waterproofing and Asphalt Overlay. RUC are shown as Present Value Costs.

Year	Task	Complete Closure (Detour)		Partial Closure (Lane Restrictions)	
		Duration (days)	Total RUC (PV 2018$)	Duration (days)	Total RUC (PV 2018$)
2020	Bridge constructed				
2035	Replacement of asphalt	3	$58,602	6	$43,409
2045	Replacement of waterproofing and asphalt	14	$205,480	20	$108,719
2060	Replacement of asphalt	3	$28,677	6	$21,242
2070	Replacement of waterproofing and asphalt	14	$100,551	20	$53,201
2085	Replacement of asphalt	3	$14,033	6	$10,395
2095	Replacement of waterproofing and asphalt	14	$49,204	20	$26,034
2110	Replacement of asphalt	3	$6,867	6	$5,087
TOTAL COST			**$463,413**		**$268,087**

RUC: Road User Costs

Simple SHRP2 Example #2, cont.

SHRP2 R19A LCCA of New Bridge Design Alternatives

Table 18. Comparison of RUC for Complete or Partial Closure of the Highway Bridge for Option 2 - Concrete Overlay. RUC are shown as Present Value Costs.

Year	Task	Complete Closure (Detour)		Partial Closure (Lane Restrictions)	
		Duration (days)	Total RUC (PV 2018$)	Duration (days)	Total RUC (PV 2018$)
2020	Bridge constructed				
2045	Replacement of asphalt	1	$14,677	2	$10,872
2060	Replacement of waterproofing and asphalt	16	$93,368	38	$85,122
2095	Replacement of asphalt	16	$45,689	38	$41,654
TOTAL COST			**$153,734**		**$137,648**

Table 19. Comparison of Total Costs in Present Value (PV 2018$) for Option 1 – Waterproofing and Asphalt Overlay and Option 2 – Concrete Overlay for the Highway Bridge.

	Option 1 – Waterproofing and Asphalt Overlay	Option 2 – Concrete Overlay
Initial construction costs	$120,000	$40,000
Maintenance costs	$415,573	$199,202
SUM	**$535,573**	**$239,202**
Road user costs	$268,087	$137,648
Total PV cost (2018$)	**$803,660**	**$376,850**

RUC: Road User Costs

U.S. Department of Transportation
Federal Highway Administration
Office of Infrastructure

Bridge Management Systems Workshop


Source: Adobe Stock


Source: Adobe Stock

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Bridge Management System (BMS)

Examples:

- AASHTOWare™ Bridge Management (BrM)

- AgileAssets® Structures Analyst™

- Deighton dTIMS©

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D1M2-S11

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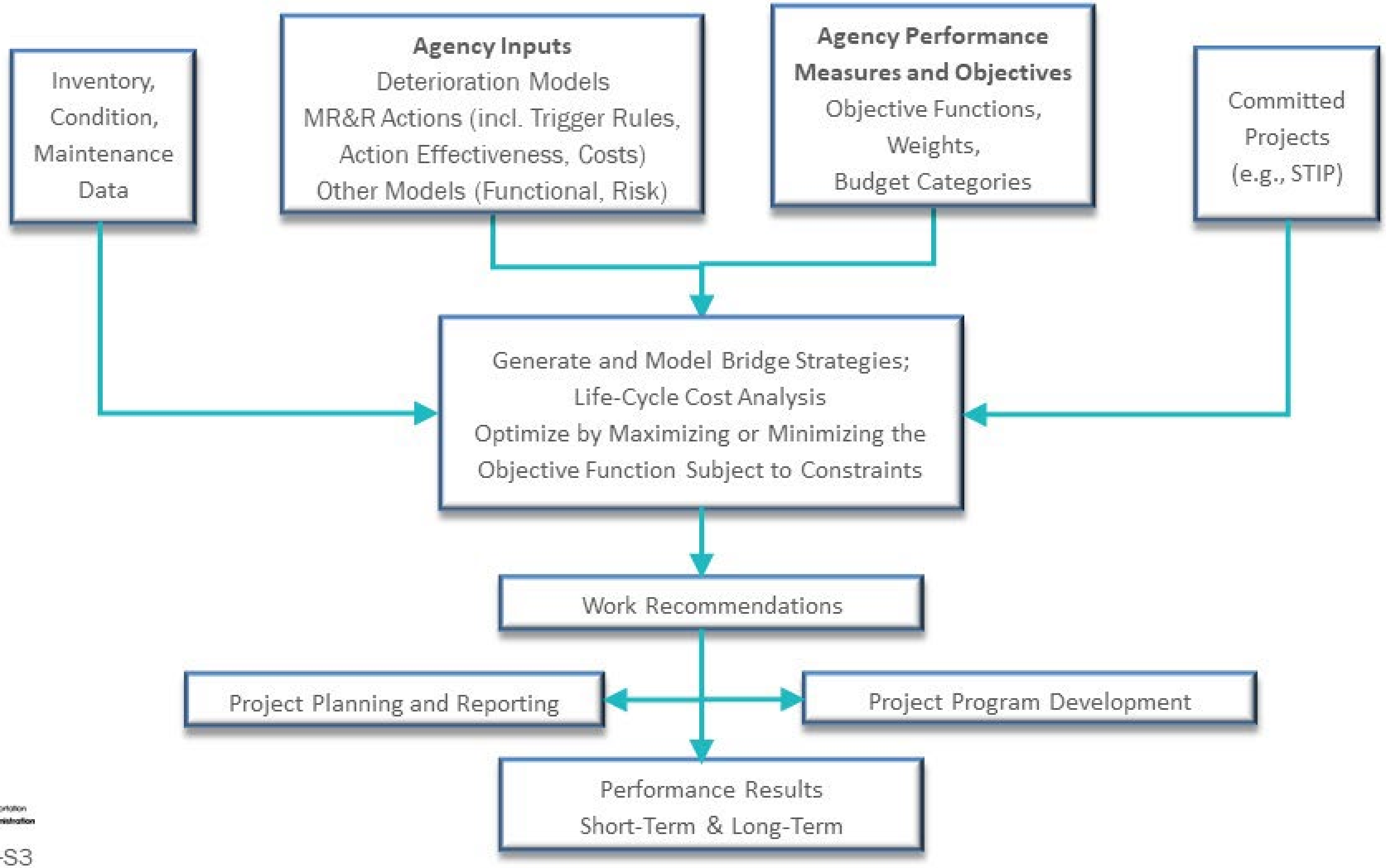
BMS Workflow Steps



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U.S. Department of Transportation Federal Highway Administration

Inventory and Condition Data

Source: Adobe Stock

Structure Details Actions ▾

* 043A - Structure Type, Main (spans) Material	1-Concrete
* 043B - Structure Type, Main (spans) Design/Const	02-Stringer/Multi-Beam or Girder
* 052 - Deck Width, Out to Out	31.168
* 035 - Structure Flared?	No
* 032 - Approach Roadway Width	36
050A - Curb or Sidewalk Width (Left)	0
* 033 - Bridge Median	0-None
* 031 - Design Load	6- HS 20 + Mod (2-24,000# Axles @ 4ft Ctrs., when they g...

Courtesy of AgileAssets® Structures Analyst™

Element Conditions

Hide Elem Inspection Details | Arrow Key Grid Navigation Help

Element: Elem # or Elem Desc | Struct. Unit: All | Env.: All | Clear Filters | ◉ Quantity ○ Percent | Add Element

Elem.	Str. Unit.	Env.	Element Description	Tot. Qty.	Units	Qty1	Qty2	Qty3	Qty4
12	101	Mod. (3)	Re Concrete Deck	23844.796	sq.ft	4,768.961	11922.398	6676.541	476.895
107	101	Low (2)	Steel Opn Girder/Beam	3345.098	ft	1,672.549	1505.295	167.254	0
161	101	Low (2)	Stl Pin Pin/Han both	18	each	0.000	18	0	0
205	101	Low (2)	Re Conc Column	18	each	18.000	0	0	0

Courtesy of AASHTOWare™ Bridge Management (BrM)

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D1M3-S4

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Condition Data in the BMS – Example Bridge Element Inspection

Element Conditions

Hide Elem Inspection Details

Arrow Key Grid Navigation Help

Element: Elem # or Elem Desc | Struct. Unit.: All | Env.: All | Clear Filters | Quantity / Percent | Add Element

Elem.	Str. Unit.	Env.	Element Description	Tot. Qty.	Units	Qty1	Qty2	Qty3	Qty4
12	101	Mod. (3)	Re Concrete Deck	23844.796	sq.ft	4,768.961	11922.398	6676.541	476.895
107	101	Low (2)	Steel Opn Girder/Beam	3345.098	ft	1,672.549	1505.295	167.254	0
161	101	Low (2)	Stl Pin Pin/Han both	18	each	0.000	18	0	0
205	101	Low (2)	Re Conc Column	18	each	18.000	0	0	0
215	101	Mod. (3)	Re Conc Abutment	327.799	ft	278.629	49.17	0	0
234	101	Low (2)	Re Conc Pier Cap	315.098	ft	308.796	6.302	0	0
300	101	Sev. (4)	Strip Seal Exp Joint	327.799	ft	0.000	327.799	0	0
311	101	Low (2)	Moveable Bearing	18	each	0.000	18	0	0
313	101	Low (2)	Fixed Bearing	18	each	0.000	18	0	0
321	101	Sev. (4)	Re Conc Approach Slab	4137.496	sq.ft	4,137.496	0	0	0
331	101	Sev. (4)	Re Conc Bridge Railing	812.001	ft	0.000	812.001	0	0

Courtesy of AASHTOWare™ Bridge Management (BrM)

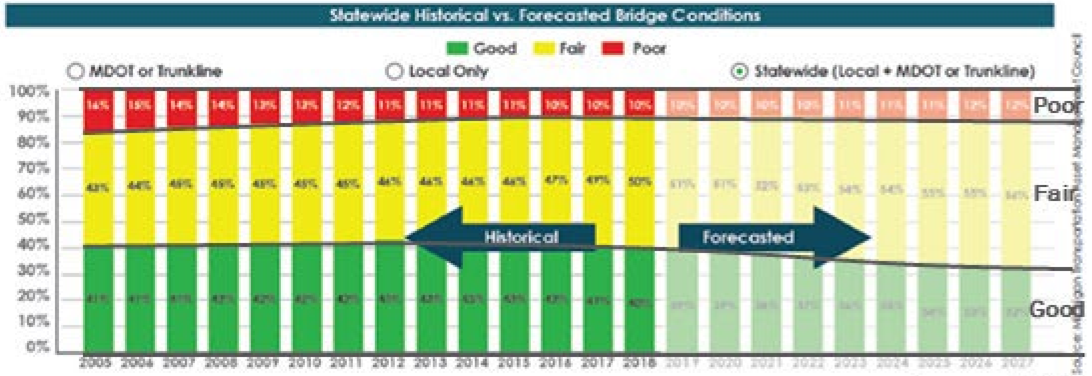
Feeds into LCCA

Goals, Objectives, and Performance Measures

CS1 Coef.	CS2 Coef.	CS3 Coef.
1	0.75	0.5

Element Number	Element Name	Total Quantity	Units	CS1	CS2	CS3	CS4	ω_e	Element Health Index	$q_e\omega_e HI_e$	$q_e\omega_e$
12	Concrete Deck	300	SFT	0		300		600	50.00%	180000	90000
107	Steel Girder/Beam	100	LFT	61	34	5		3500	89.00%	350000	311500
215	Concrete Abutment	24	LFT	24				7700	100.00%	184800	184800
300	Strip Seal Expansion Joint	24	LFT	0			24	560	0.00%	13440	0
205	Reinforced Concrete Columns	4	Each	4				9000	100.00%	36000	36000
									Total	764240	622300

Bridge Health Index
81.4%



Source: FHWA

- Goal: Maintain bridges in a state of good repair
- Objective: Maintain asset value at 80% (HI)
- Performance Measure: Health Index

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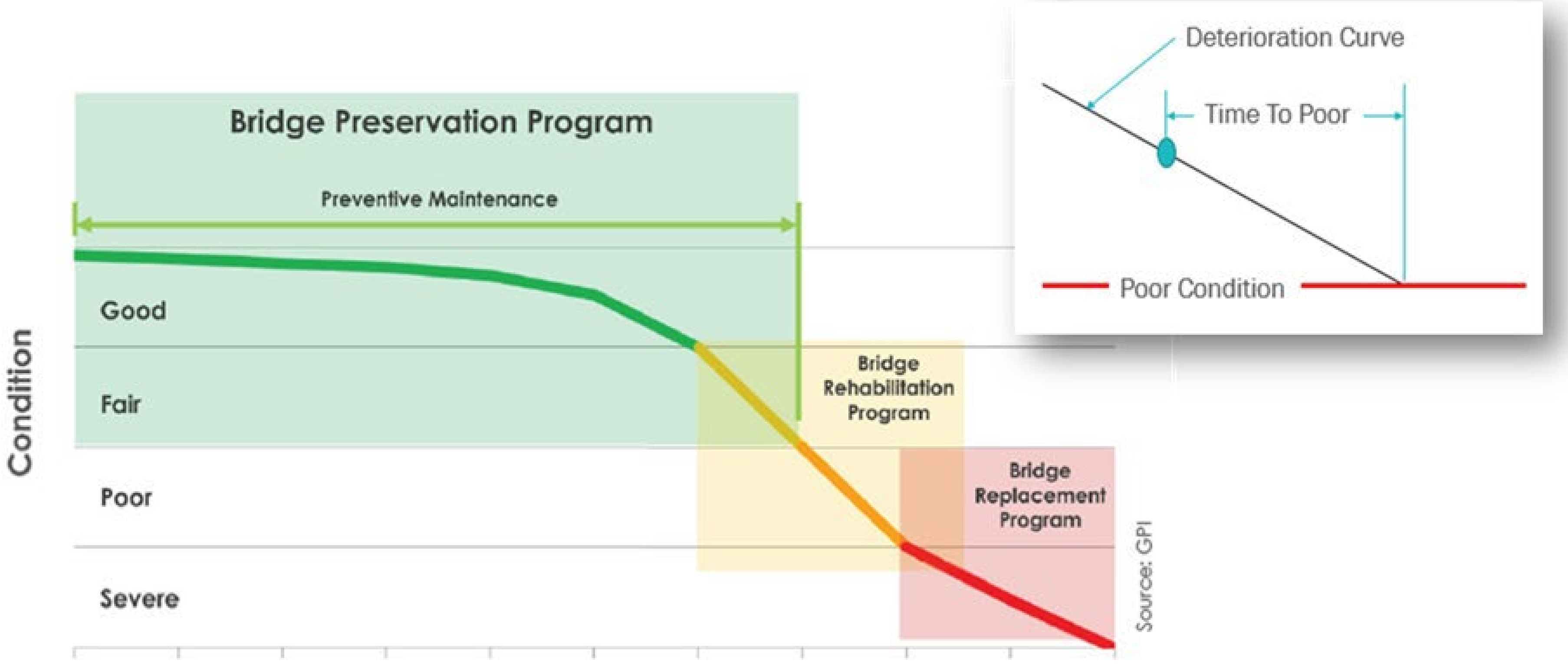
U.S. Department of Transportation Federal Highway Administration

Deterioration Modeling and Project Selection



Bridge condition over time.

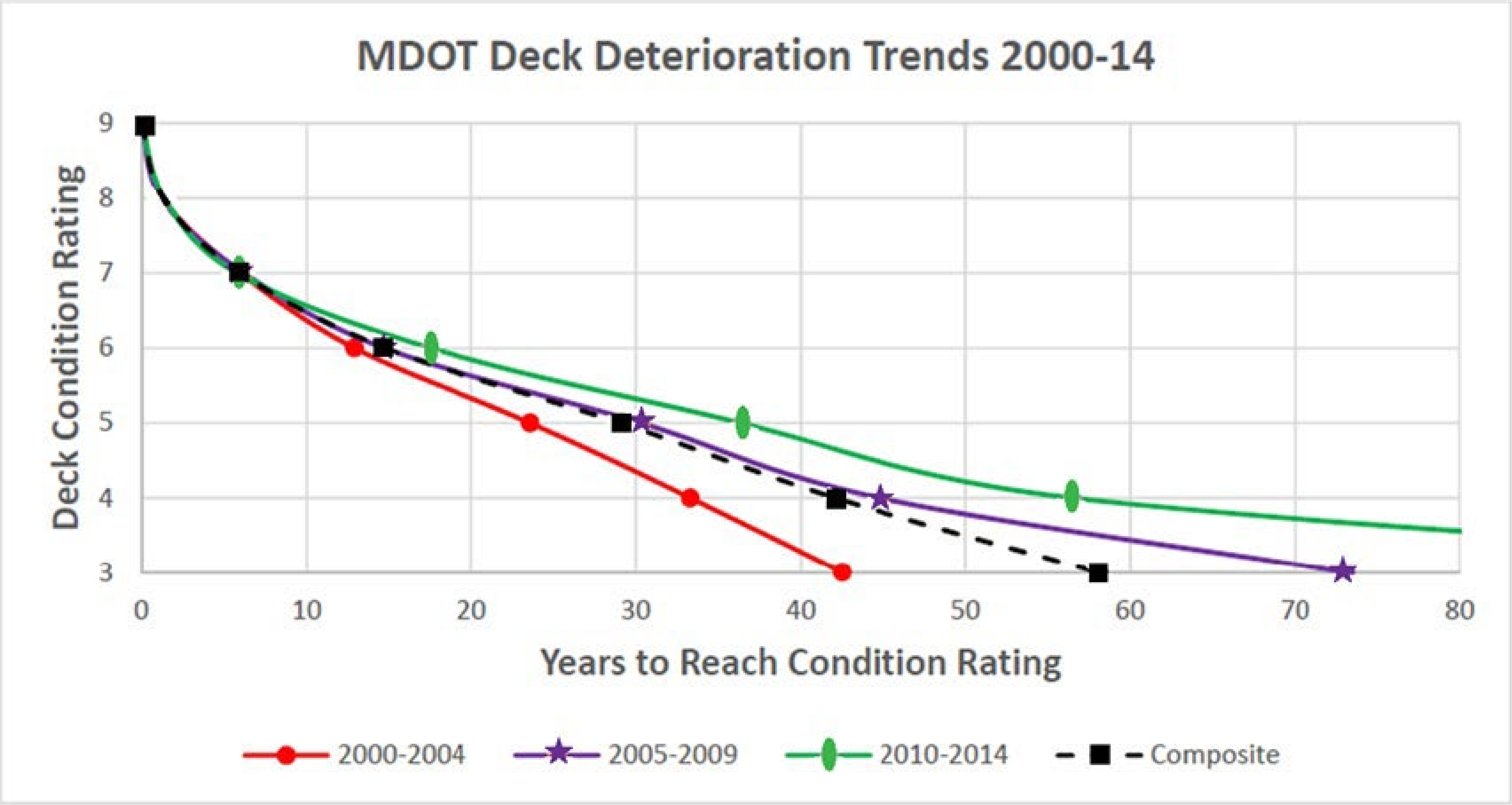
[Bridge Management Systems Workshop Participant Workbook | FHWA (dot.gov)]

U.S. Department of Transportation Federal Highway Administration

D1M5-S7

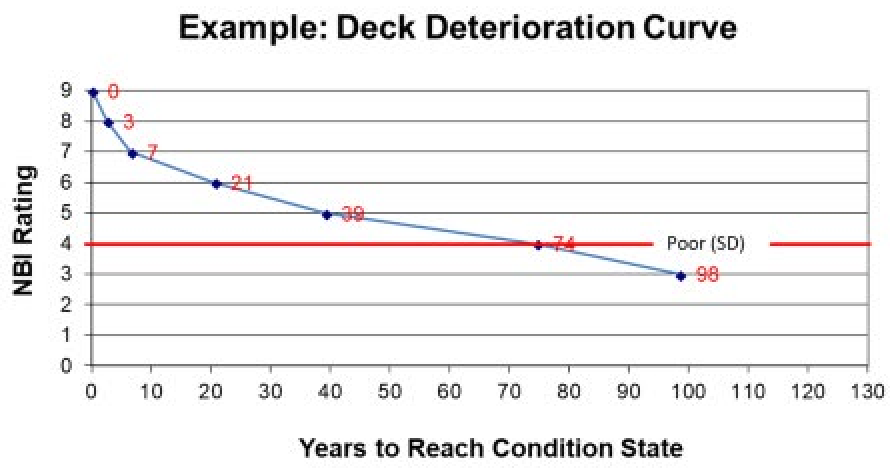
★ Deterioration Rates Can Change Over Time ★

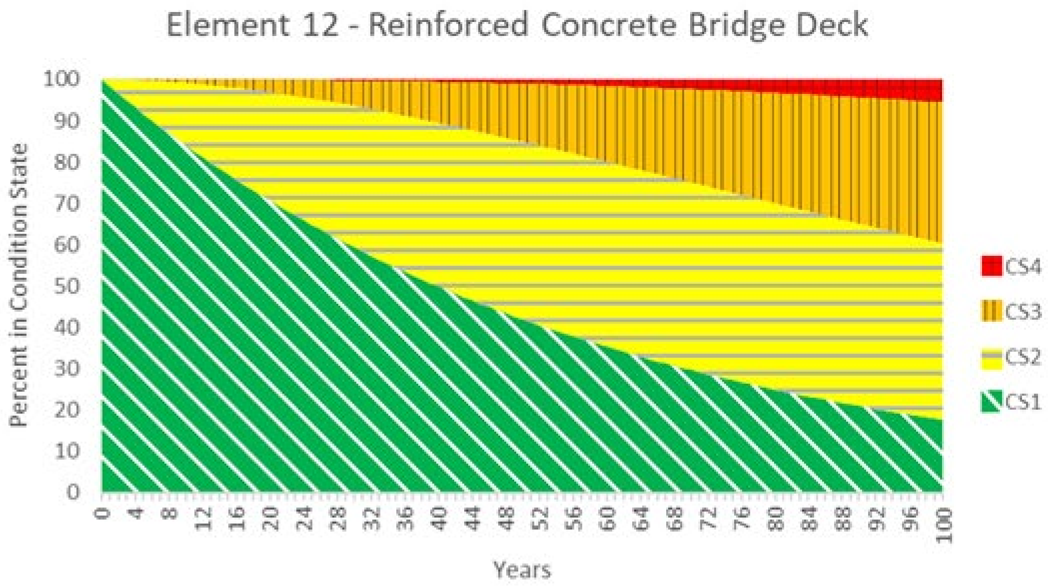
Will



[Bridge Management Systems Workshop Participant Workbook | FHWA (dot.gov)](#)

Deterioration Modeling





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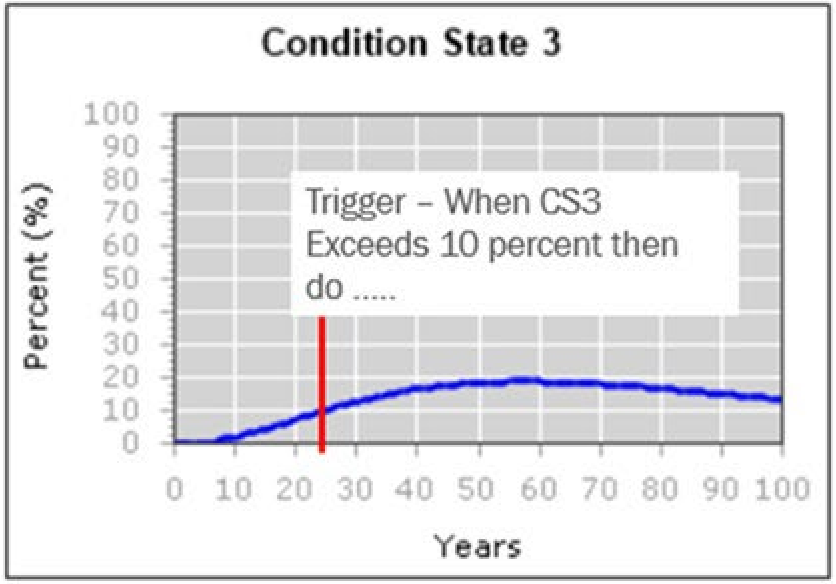
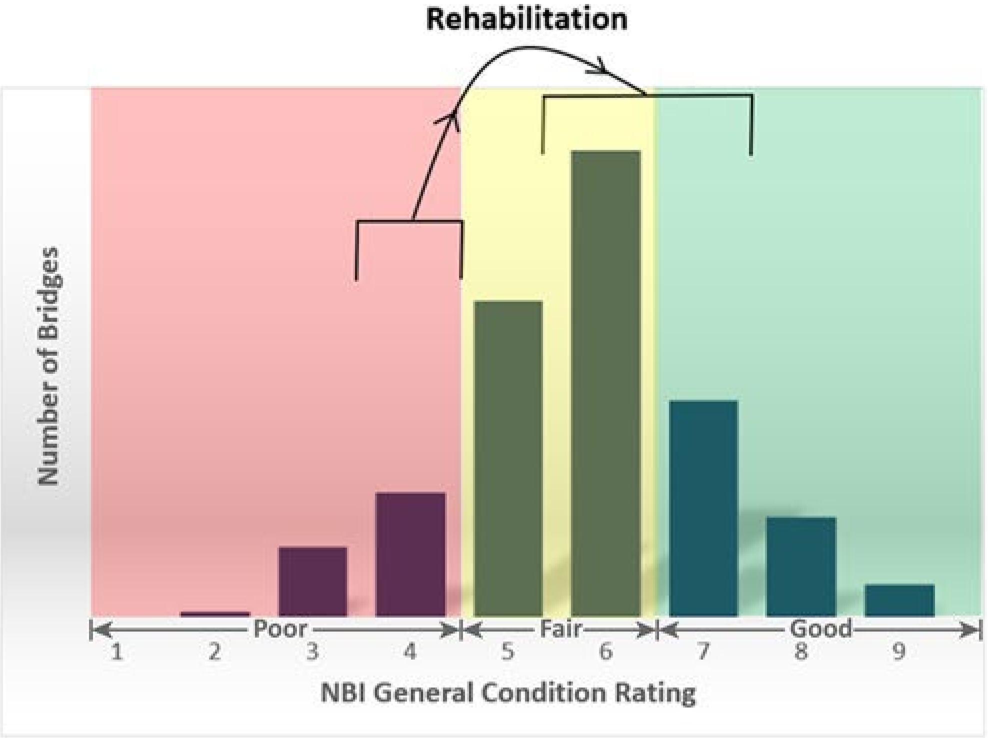
Actions, Triggers, Costs and Effects



Courtesy of AASHTOWare™ Bridge Management (BrM)



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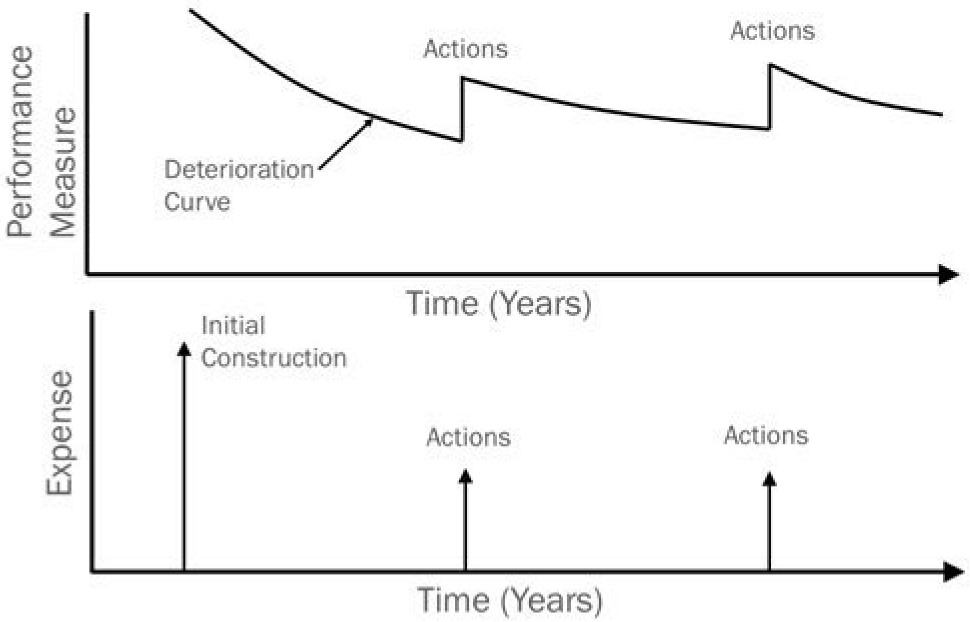
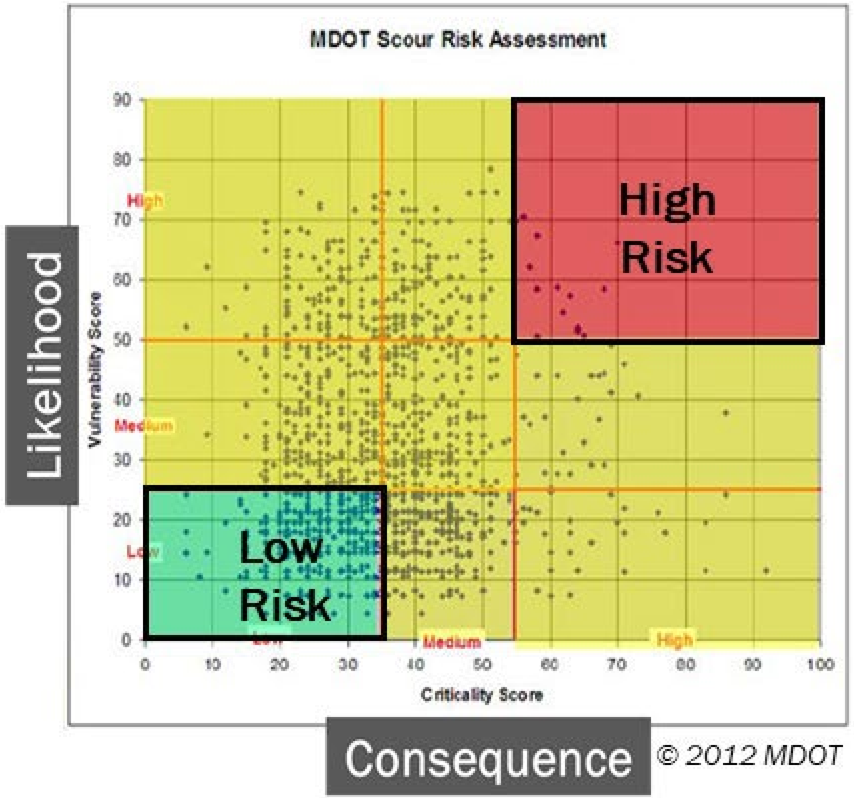
D1M3-S7

Life-Cycle Modeling, User Costs, and Risk Assessment





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U.S. Department of Transportation
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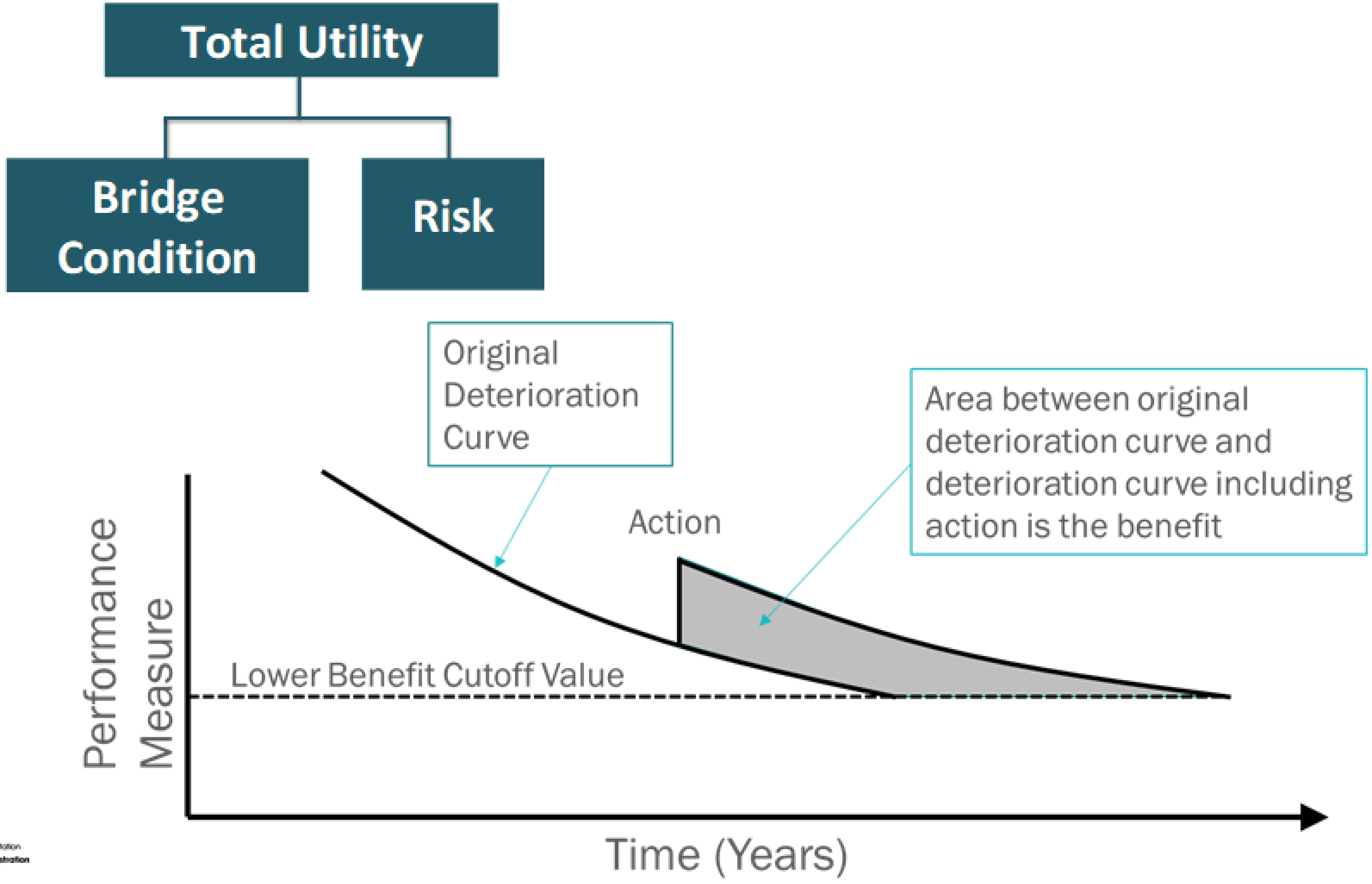
D1M3-S8

Benefit/Cost Analysis



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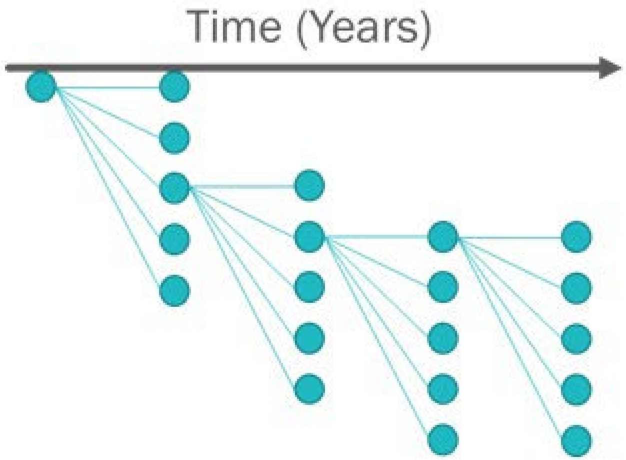
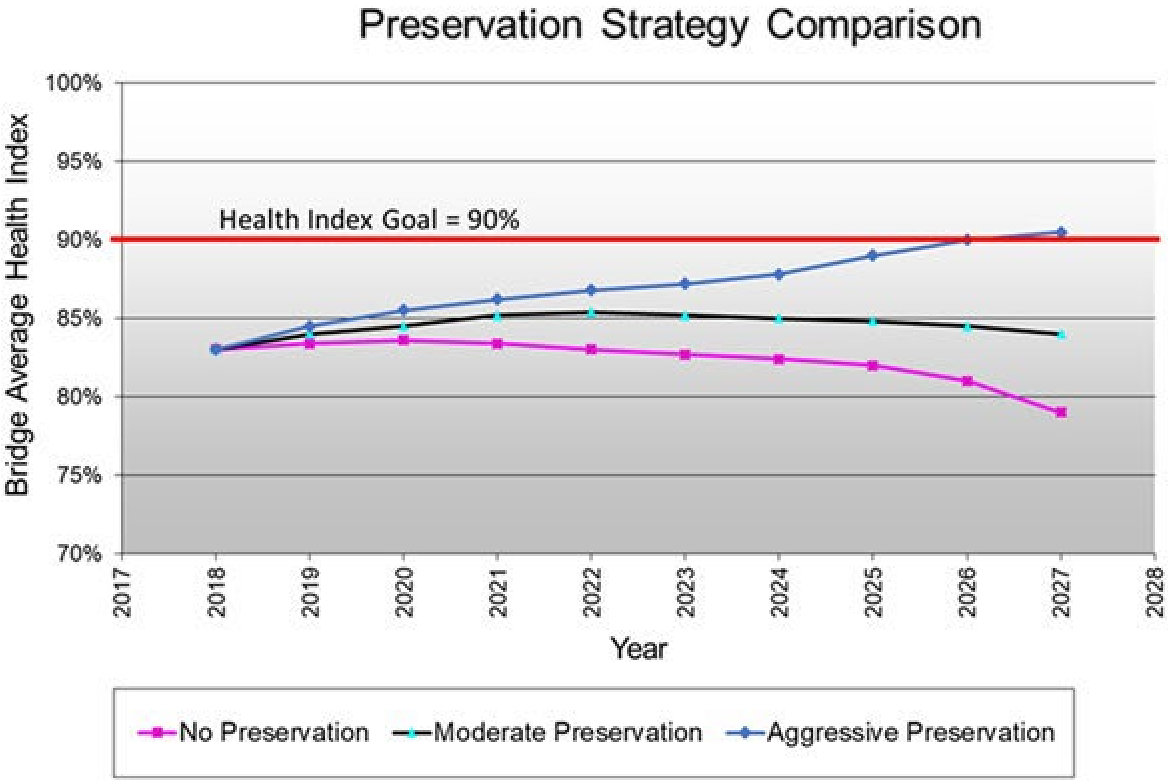
Strategy Generation and Scenario Modeling





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Federal Highway Administration

D1M3-S10

TRANSPORTATION ASSET MANAGEMENT PLAN

December 2022

Ohio Department of Transportation

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Transportation Asset Management Plan (TAMP) | Ohio Department of Transportation

1.4 Asset Management at ODOT

Asset Management at ODOT is guided by several initiatives and involves nearly every employee at the agency. The overall ODOT TAM program is guided by the following Federal programs and department criteria. While each program provides a specific focus related to TAM objectives, the targets and implementation of each often overlap.

Figure 3 - ODOT Asset Management

1.4.3 TPM Performance Measures and Federal Targets

MAP-21 and the FAST Act require States to set 2- and 4-year performance targets for Pavements and Bridges on the NHS[4]. While the legislation establishes these requirements, rules were established by FHWA that define the performance measures and the process for setting the State targets. In addition, the legislation and rules established minimum condition levels for NHS Bridges and Interstate Pavement that are evaluated based on Federal performance measures.

Preserve Our Assets

Metric	Description	Goal
Bridge Condition	Percent of bridge deck area in good or fair condition, meaning that both the deck and general appraisal ratings are at least 5 on a scale of 0-9.	97%

Please note the Bridge Condition CSF accounts for non-major state bridges (10' and greater, carrying a state route or over a state route) and excludes major bridges (structures greater than 81,000 square feet or crossing the Ohio River). Major bridges are not included in the CSF because funding decisions for major bridges are made separately from the remaining non-major state bridges. A separate CSF for Major Bridges does not exist, with these assets managed on an individual structure need basis.

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Technology and Management Systems

ODOT's management strategies depend on the availability of analysis models and computerized tools to effectively evaluate the long-term impacts of investment options. ODOT currently uses a state-of-the-art Pavement management system (dTIMS) for managing its Pavement investments and is in the process of linking its new maintenance management processes, which include maintenance work planning, and reporting, to its Asset Management program.

ODOT has fully implemented AssetWise for the inventory and inspection data collection process for Ohio's Bridges. A project was initiated to implement the AASHTOWare Bridge Management System (BrM), however, it is currently postponed due to a lack of resources. ODOT has an implementation schedule defined to deliver BrM in 2023 for use by the district's 2024 work plans.

ODOT Tier 1 Assets

Asset	Regulatory	Inspection Frequency	Performance Target	Replacement Strategy
Bridges	FHWA/State	1, 2-yr	97% GA>=5	Life Cycle

Minimum Bridge Conditions:

State DOTs are required to maintain bridges so that the percentage of the deck area of bridges classified as in poor condition does not exceed 10.0 percent. This minimum condition level applies to bridges carrying the NHS, which includes on- and off-ramps connecting to the NHS within a State, and bridges carrying the NHS that cross a State border. A bridge will be classified as in poor condition when one of its NBI Items, 58—Deck, 59—Superstructure, 60—Substructure, or 62—Conduits, is 4 or less.

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Transportation Asset Management Plan (TAMP) | ODOT

2.3 Bridge Inventory and Condition

Ohio has over 44,000 Bridges. ODOT is responsible for maintaining over 10,000 of these Bridges on the Priority and General systems. The Ohio Turnpike maintains 531 additional Bridges. The Bridge inventory includes all structures with a span greater than or equal to 10 feet.

2.3.1 ODOT Bridge Inventory and Condition

ODOT inspects bridges on a 1 or 2-year cycle depending on the most recent condition rating, based on Ohio Revised Code Section 5501.47. Each inspection provides a rating for the major elements of the Bridge (superstructure, substructure, deck, and conduit) on a 0 to 9 scale, with 9 representing an element in *Excellent* condition and 0 representing a *Failed* element. Any element rated below 5 is considered *Poor*. To provide an overall assessment of the Bridge condition that takes all major components into account, the lowest rating from these primary elements is reported as General Appraisal (GA). In addition to these primary condition ratings, some Bridges require more detailed inspections if they have fracture-critical members, underwater components, or are complex structures. On a Statewide basis, more than 98.3 percent of the Bridges maintained by ODOT are in *Fair* or better condition (GA of 5 or more).

Overall Bridge Condition Ratings

In the below table, Bridge conditions are reported based on the lowest component rating. The lowest rating for the three major elements of the Bridge (superstructure, substructure, and conduit) is calculated. Below are the levels to identify when a Bridge is in Good, Fair, or Poor Condition.

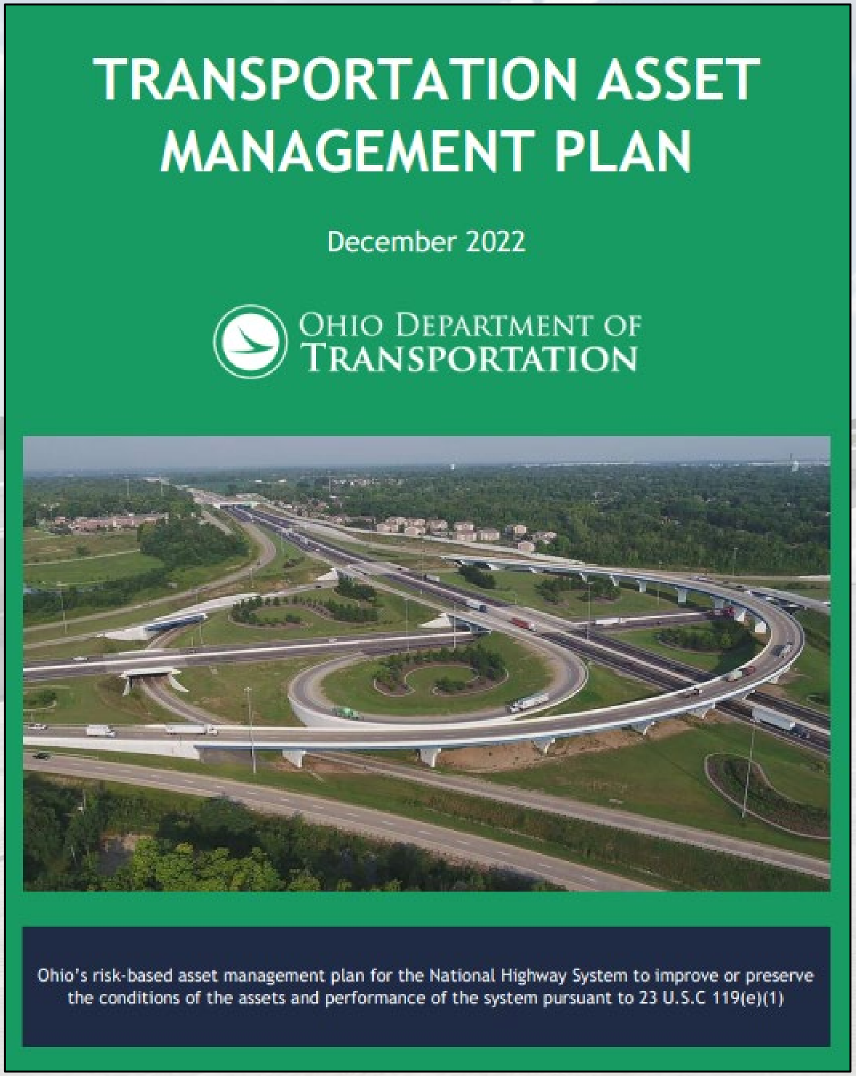
- Good (7-9)
- Fair (5-6)
- Poor (0-4)

BRIDGE INVENTORY AND CONDITION[5]

	Count	Deck Area (sq. ft)	Good	Fair	Poor
NHS					
Interstate	2,157	34,999,520	69.22%	29.25%	1.53%
U.S. Route	1,895	16,687,849	66.65%	32.19%	1.16%
State Route	1,468	16,175,499	61.78%	36.38%	1.84%
Turnpike	380	5,178,028	57.63%	41.84%	0.53%
Local	185	1,700,059	51.35%	43.78%	4.86%
TOTAL	**6,085**	**74,740,955**	**65.29%**	**33.21%**	**1.50%**
NON-NHS					
U.S. Route	978	4,692,639	62.88%	35.58%	1.53%
State Route	6,457	21,236,103	62.95%	34.77%	2.28%
Turnpike	151	1,094,554	61.59%	37.09%	1.32%
Local	29,826	54,942,785	57.44%	35.70%	6.87%
TOTAL	**37,412**	**81,966,081**	**58.50%**	**35.53%**	**5.93%**
GRAND TOTAL	**43,497**	**156,707,036**	**59.44%**	**35.27%**	**5.29%**

Table 15 - Bridge Inventory and Condition

[5] The analysis was run in March 2022, which would include all condition information approved at that time.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2.5.6 Bridge Data Quality Management

Data Quality

ODOT follows the below processes and methodology in ensuring that the bridges and structure's data quality is of the highest order:

1. The Office of Structural Engineering (OSE) performs the following data checks and balances:
   a. Monthly Data checks: NBI Data Checks (dot.gov).
   b. OSE performs Quarterly Element Data checks (adhering to the granularity required on NHS NBIS bridges): Element Data Errors and Flags (dot.gov).
   c. Data quality checks are also performed using the Base Transportation Referencing System (BTRS). BTRS is an ODOT-developed database workflow process that perpetuates the LRS and Roadway information changes to other ODOT enterprise systems. This process is designed to discover and detail data anomalies, if they exist, so that appropriate action can be taken based on the result of the completed process.

2. ODOT staff perform a significant percentage of the inventory and inspection of Ohio's bridges and rely on numerous local partner agencies to complete this work on their respective structures.
   a. OSE evaluates bridge inspection frequencies as compared to Federal regulatory requirements outlined in the NBIS Metrics 6 -10. Data is then gathered and analyzed from approved inspection reports.
   b. Monthly Frequency Checks are performed for Routine, Dive, and Fracture Critical inspections. This is to ensure inspections occur at timely intervals.
   c. OSE utilizes the AssetWise application for bridge inspection notes, details, and reference guidelines for inspection reporting. AssetWise Inspection.

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NHS Bridge Performance Targets (Performance Period 2022 - 2026)

	Previous Target (2018 - 2022)	Current Performance	2 Yr. Target (2024)	4 Yr. Target (2026)
Percentage of NHS Bridges by deck area in Good Condition	50%	63.3%	>55%	>55%
Percentage of NHS Bridges by deck area in Poor Condition	5%	1.7%	<3%	<3%

Table 23 - NHS Bridge Targets

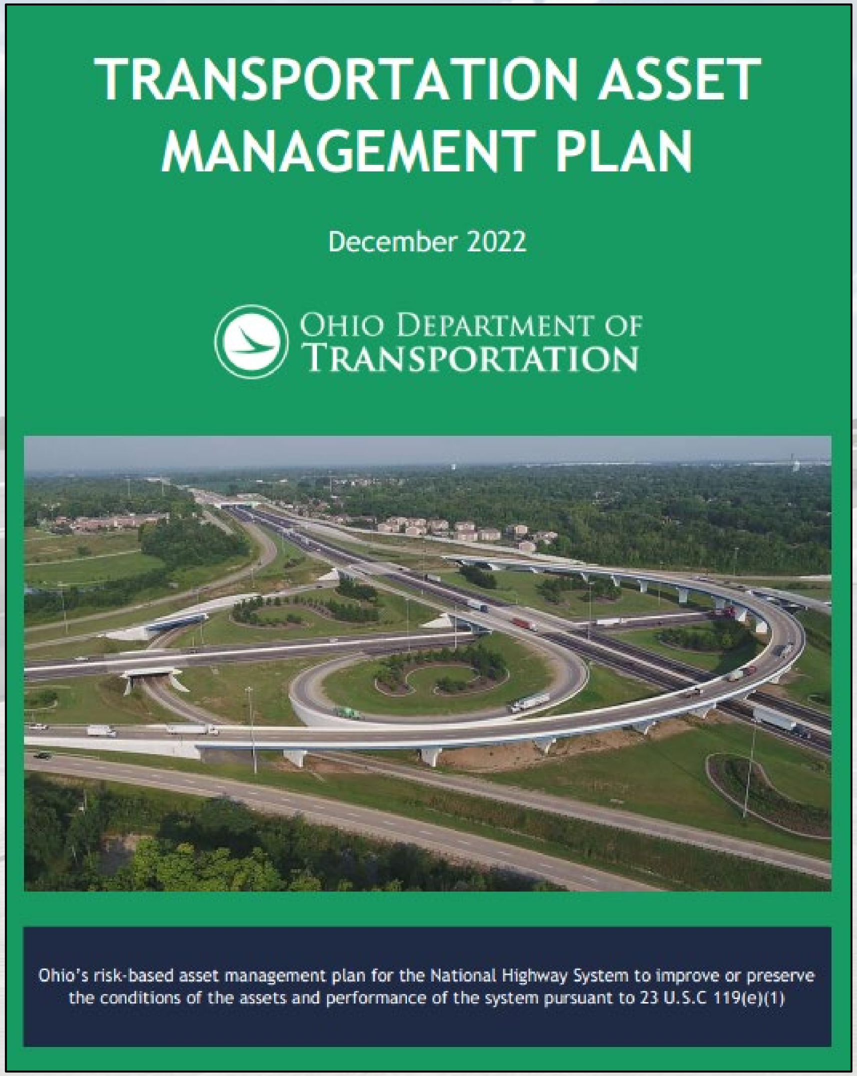
The above bridge (Both NHS and Non-NHS) performance targets were compared against the 4-year targets documented in the 2021 -2024 STIP. The results were that the performance targets listed in the TAMP met and exceeded the targets listed in the STIP.

The Federal Requirements for LCP Analysis (23 CFR 515.7(b)) include:

- Incorporating the State DOT targets for asset conditions for each asset class or asset sub-group into the analysis.
- Modeling deterioration for NHS bridges and pavements for each asset class or asset sub-group.
- Analyzing potential work types across the whole life of each asset class or asset sub-group with the general unit costs identified.
- Identifying management strategies for each asset class or asset subgroup to minimize the life cycle costs while achieving the 23 U.S.C. 150(d) performance targets for asset conditions.
- Identifying any subgroups that have been excluded, with justification for their exclusion.

Additionally, the new Bipartisan Infrastructure Law (BIL) updates, State DOTs are required to:

- Consider extreme weather and resilience as part of the life cycle cost and risk management analyses within a State TAMP (23 U.S.C. 119(e)(4)(D)).



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4.5 Life Cycle Planning for Bridge

ODOT currently utilizes a spreadsheet analysis tool to conduct the life cycle analysis required for the bridge network. This analysis leverages representative rates of deterioration for bridge conditions, and various treatment cycles with a comparison of a traditional rehabilitation approach (which predominately includes deck replacement and bridge replacement in a worst-first prioritization) with a strategy that increased the amount of preservation work, with each strategy aiming to maintain current condition levels.

4.5.1 The Trade-off of Funding and Condition

Note for the below graphics, "Long-term" is based on a 200-year analysis period of computing life cycle costs. Because of discounting, future costs are given less weight, which increases the benefit of delaying big costs by utilizing preservation work. Since replacement costs are considerable, this calculation ensures we account for the future cost of keeping each transportation network link in operation by replacing bridges at the end of their economic life, even though it is far in the future. This long-term calculation ensures we capture those future costs in the calculation.

Below is the general appraisal information for the NBI NHS, Non-NBI NHS, Non-NHS, and Turnpike NHS. Additionally, the Deck, Wearing Surface, and Protective Coating information are shown for NBI NHS. To see this information for the other networks, please refer to Appendix C.

Ohio Bridge NBI NHS (All Owners) Analysis:

General Appraisal:

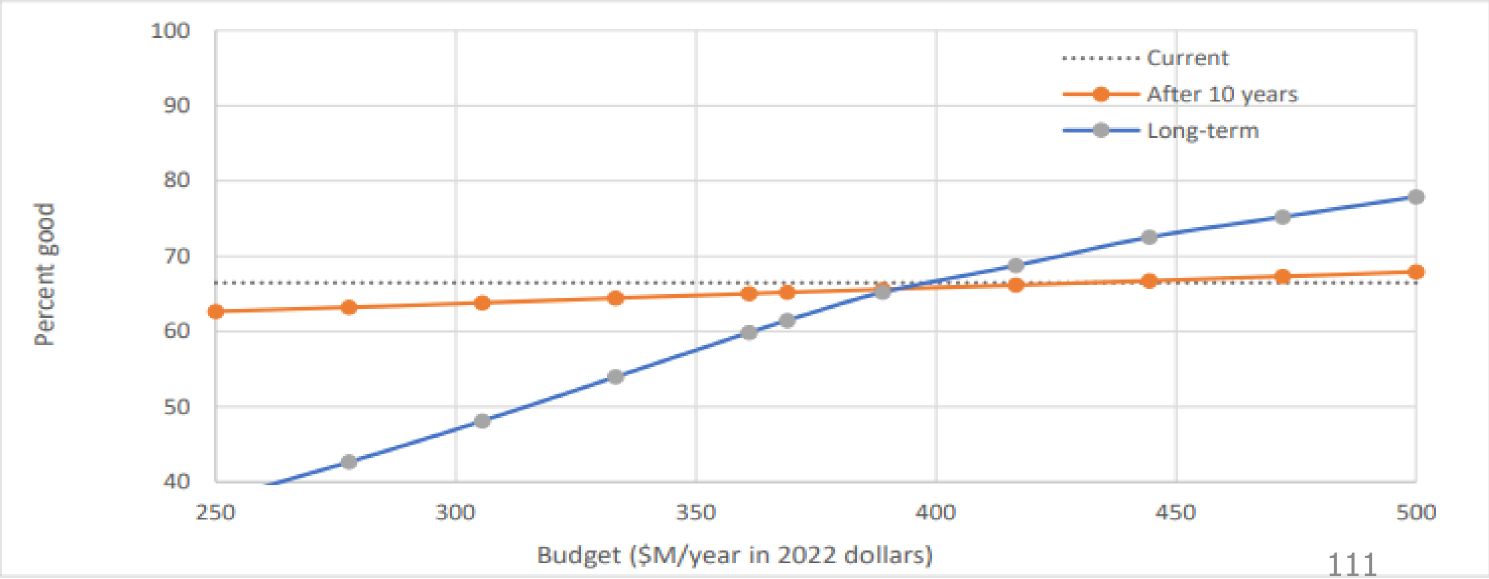

Table 29 - Ohio Bridge NBI NHS All Owners Analysis General Appraisal

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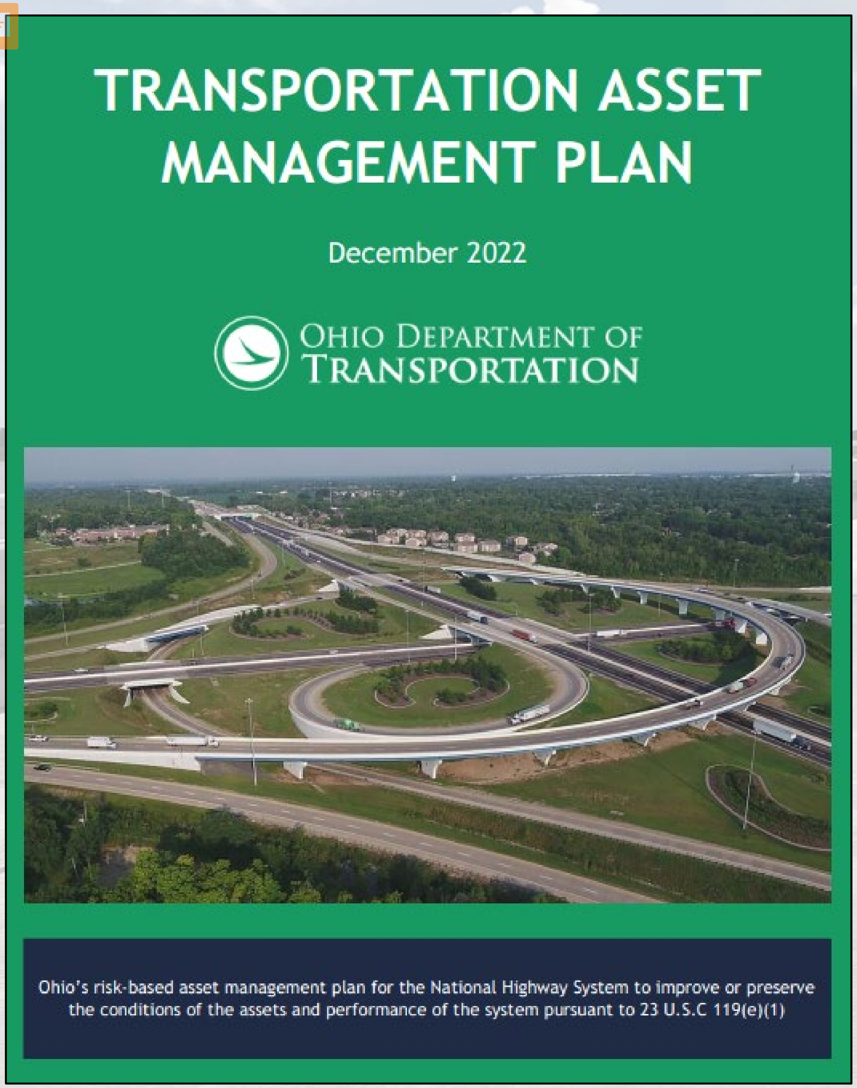
4.5.2 Return on Investment

These LCP analysis results were analyzed in their current conditions to assess the return on investment that ODOT achieves from this preservation strategy. The analysis assumed that roughly the same conditions from year to year would be maintained over the long term. The preservation model was calibrated to keep conditions roughly constant. The findings were that ODOT's preservation strategy yields a 47 percent return on investment for the NBI NHS. The non-NHS result showed a 69 percent return on investment.

4.7 Life Cycle Costs for Extreme Weather and Resilience

The BIL amendments which took effect on October 1, 2021, instruct State DOTs to consider extreme weather and resilience as part of the life cycle analysis. ODOT's current processes for project selection through the Annual District Work Plan Process and Risk Management strategies provide ODOT planners and engineers the ability to factor in these risks to the agency's strategies.

Conducting a sound life cycle analysis accounting for future extreme weather scenarios requires an understanding of several factors potentially including specific potential impacts, impacts on materials performance, impacts on funding, and impacts on ODOT's project selection processes among others. In Chapter 5, ODOT details a variety of initiatives related to extreme weather and resilience already complete, as well as a proposed project to develop a comprehensive Resiliency Improvement Plan. This plan will enable ODOT to develop a holistic approach for continuing to achieve the SOGR while accounting for these additional risk factors.



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"Each type of treatment serves a different function in keeping an asset operational and the costs vary as the magnitude of the treatment increases. Life cycle strategies that promote the timely application of maintenance and preservation treatments, such as the strategies we have adopted, are cost-effective because they defer the need for more costly rehabilitation and reconstruction activities."

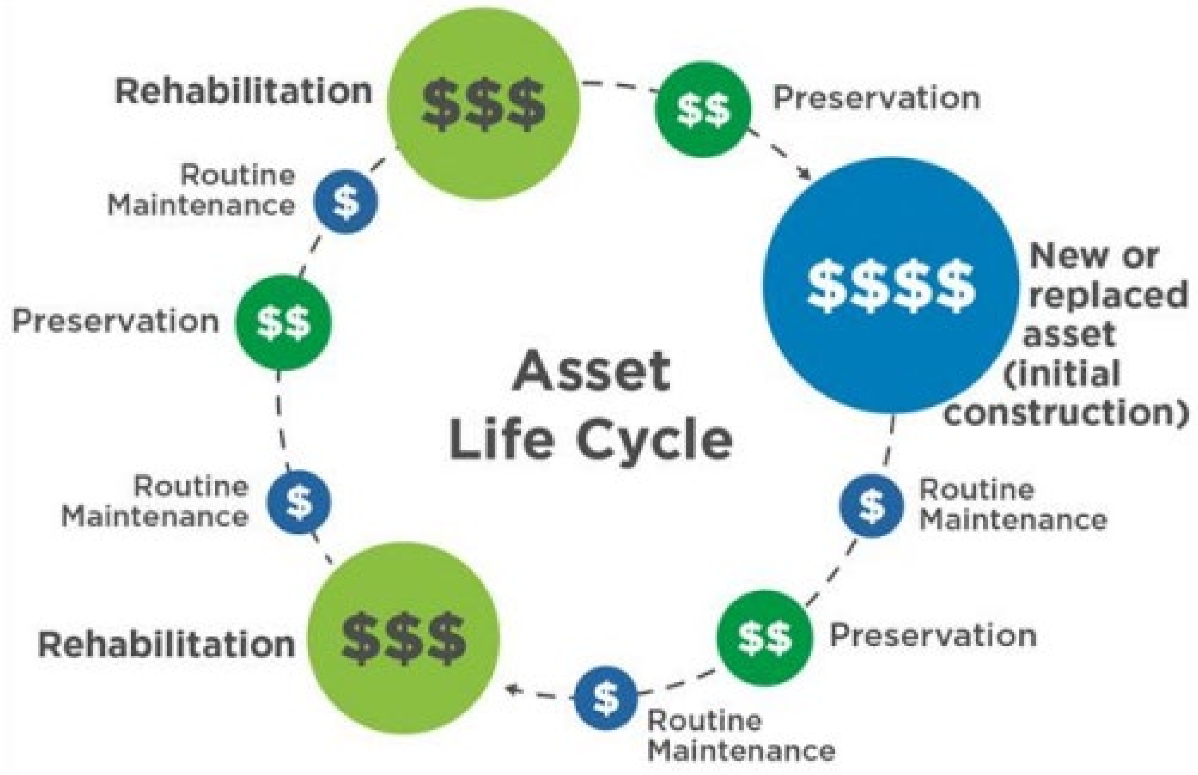

Figure 16 - Asset Life Cycle

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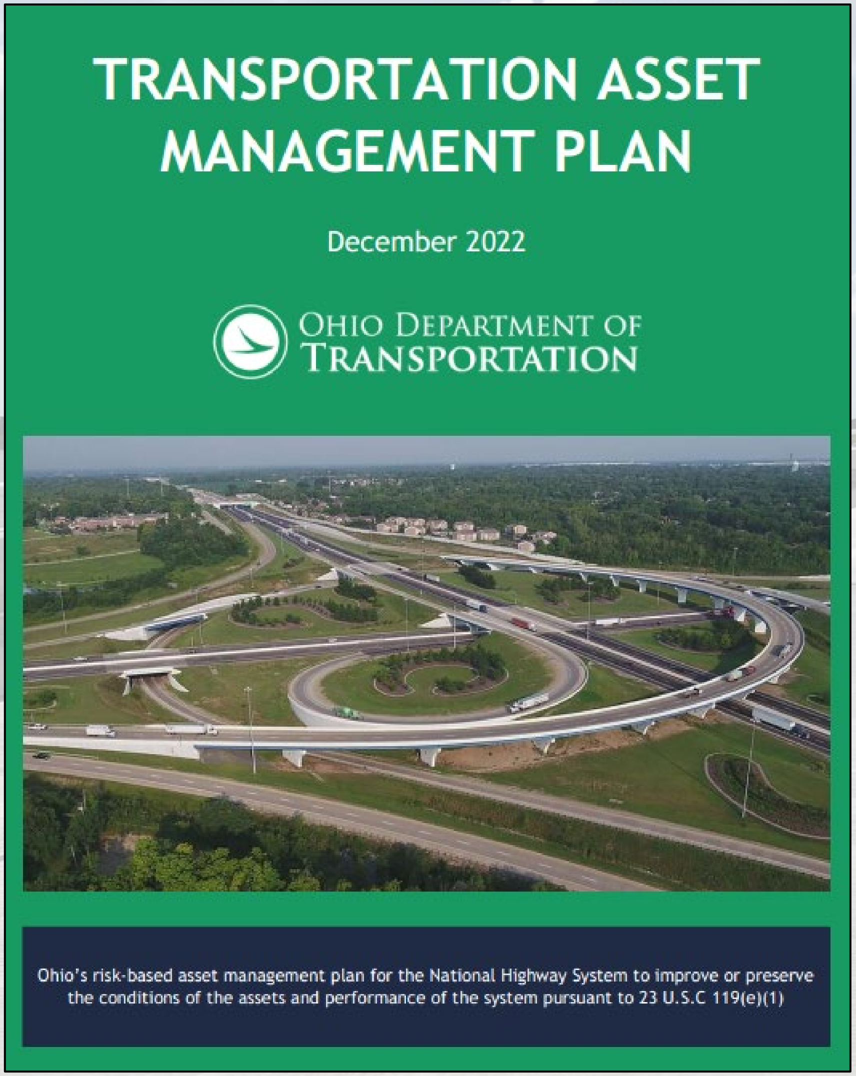
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Asset Life Cycle

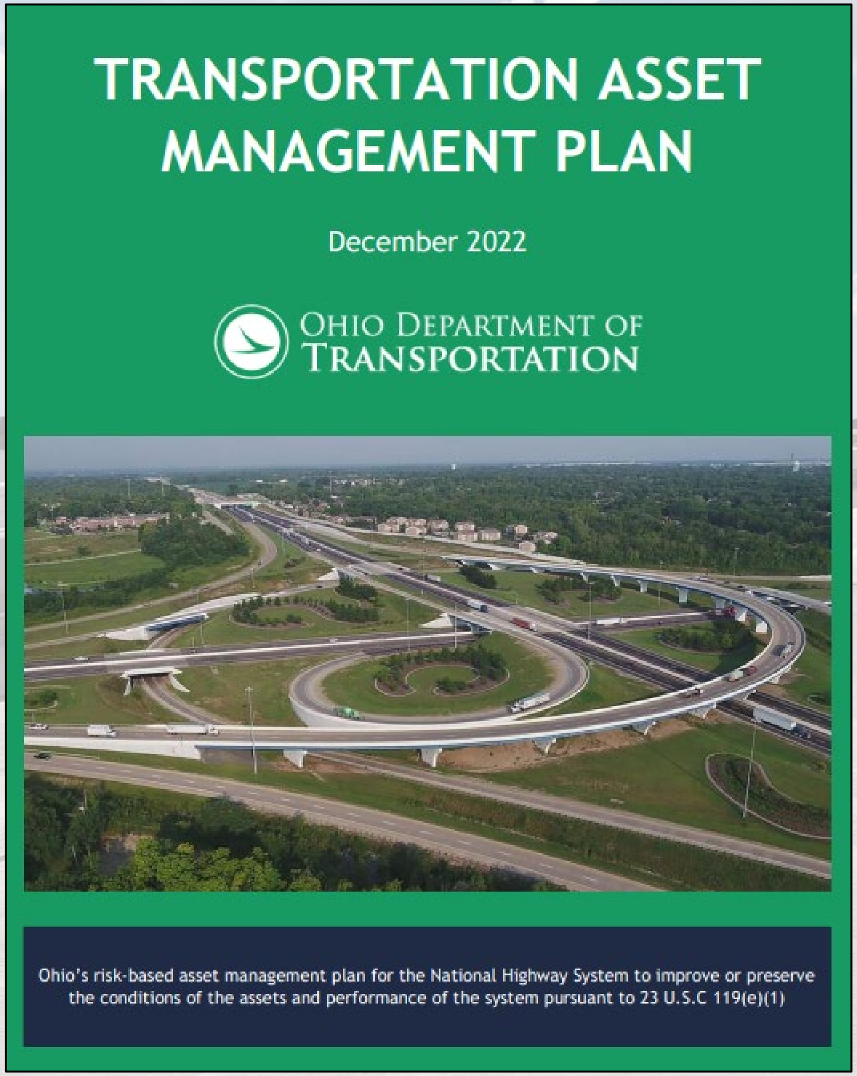
Initial Construction – This category refers to the construction of new assets, including Pavements or Bridges, on new alignments.

Reconstruction – Work activities in this category involve the complete replacement of an existing asset to serve the same alignment once the asset reaches the end of its service life. ... For a Bridge or Conduit, it involves the complete replacement of the Bridge or an open-cut replacement of a Conduit.

Rehabilitation – This category involves major work to restore the structural integrity of an asset as well as work that may be necessary to correct major safety defects. ... For Bridges, repairs to, or replacement of, one or more major Bridge elements, such as deck replacement or substructure rehabilitation may be included.

Preservation – This category includes low-cost treatments applied to assets in relatively good condition to slow the rating of deterioration or address minor repairs. ... For Bridges, it includes Bridge and joint sealing, Bridge deck resealing, and painting of steel elements.

Routine Maintenance – Maintenance activities may include cyclic activities, such as joint sealing or crack filling, to prevent damage to underlying layers. Routine maintenance may also include repairs to address safety-related issues to keep the asset operational.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Bridge Work Type Summary

FHWA Work Category	Treatment Type	Average Low	Average Medium	Average High
Preservation	Bridge Preservation	$470,476	$996,527	$6,107,366
Preservation	Patching concrete structures	$722	$8,305	$16,858
Preservation	Slope and channel scour protection	$772	$4,324	$12,725
Preservation	Special - Patching Concrete Bridge Decks	$4,613	$10,659	$19,669
Preservation	Treating concrete	$1,123	$2,152	$3,715
Reconstruction	Add Through Lane(s)	$33,701,824	$49,728,377	$110,433,343
Rehabilitation	Approach slabs	$1,582	$3,328	$5,039
Rehabilitation	Joint Repair	$643	$2,395	$5,110
Rehabilitation	Railings	$1,138	$1,954	$2,983
Routine Maintenance	Bridge cleaning	$117	$337	$1,388
Routine Maintenance	Bridge Maintenance	$301,541	$671,129	$2,805,538
Routine Maintenance	Bridge Repair per Force Account	$1,212	$2,406	$4,238
Routine Maintenance	Bridge Sweeping	$69	$150	$404

Table 41 - Bridge Work Type Summary

ODOT Risk Likelihood Ratings

Risk Ranking	Likelihood	Frequency	Risk Score
Very High or Almost Certain	Near Certainty (90%)	Within 1 Year	5
High or Likely	Highly Likely (70%)	Within 2 Years	4
Moderate	Likely (50%)	Within 3-5 Years	3
Low or Unlikely	Unlikely (20-30%)	Within 6-10 Years	2
Very Low or Rare	Remote (10%)	Within More Than 10 Years	1

Table 43 - Risk Likelihood Ratings

ODOT Risk Impact Ratings

Factor	Impact on System Performance Score				
	Insignificant/ Little	Low/Some	Moderate/ Noticeable	High/ Large	Catastrophic
	1	2	3	4	5
Asset Valuation/ Economic Impact	< $50M	$50M-$100M	$100M-$500M	$500M-$2.2B	> $2.2B
Legal Compliance	In Compliance	Agrees to Compliance Schedule	Adopts Corrective Action	Expects to Comply Within 1 Year	No Viable Plan to Comply
Public Expectations	Minor complaints	Unplanned Disruption < 1 Day	Multiple Unplanned Disruptions 1-4 Days	Large Number of Unplanned Disruptions 5-29 Days	Unplanned Disruption to Essential Services > 30 Days
Safety	None	Minor	Serious	Single Fatality	Multiple Fatalities
Reputation	None	Some Minor Issues	Regional Issues	Larger System Issues	System Highly Impacted
Environmental Damage	Short-Term	Limited	Major	Heavy	Permanent

Table 44 - Risk Impact Ratings

Transportation Asset Management Plan (TAMP) | ODOT

Risk Likelihood Ratings and Levels

Impact Ratings		Rare (1)	Unlikely (2)	Moderate (3)	Likely (4)	Almost Certain (5)
	Catastrophic (5)	Low	Medium	High	Extreme	Extreme
	High (4)	Low	Medium	High	High	Extreme
	Moderate (3)	Low	Low	Medium	High	High
	Low (2)	Very Low	Low	Low	Medium	Medium
	Insignificant (1)	Very Low	Very Low	Low	Low	Low

Table 45 - Risk Likelihood Ratings and Levels

The highest priority risks are addressed using one of the following strategies:

Strategy	Description
Terminating	Eliminating the threat posed by an adverse risk or avoiding the risk by clarifying requirements, obtaining information, improving communications, or acquiring expertise.
Transferring	Shifting the negative impact of a threat, along with the ownership of the response, to a third party (e.g., insurance or transfer responsibility to a private or other public entity). This action does not eliminate the risk.
Treating	Reducing the probability and/or impact of an adverse risk event to an acceptable threshold.
Tolerating	Retaining the risk, which may indicate a decision to accept a risk or an inability to identify any other suitable response strategy.
Take Advantage	Benefitting from an opportunity (e.g., new external funding) that helps attain strategic goals.

Table 46 - Risk Strategies

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Bridge & Conduit Work Activities - Funding Investment Categories

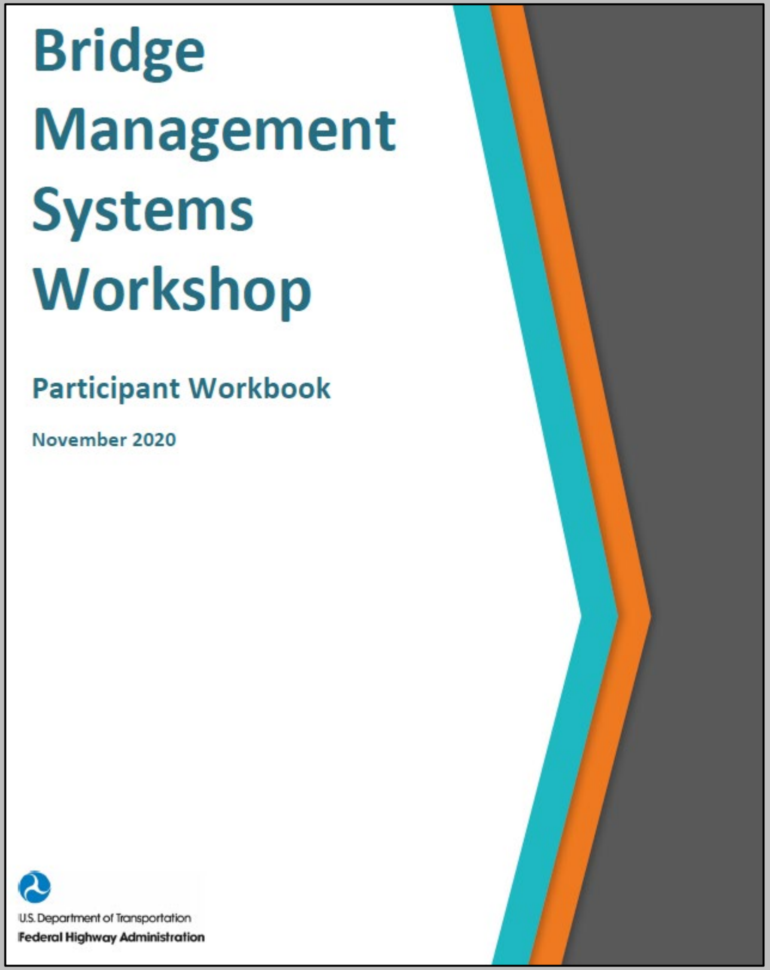
Category	Definition/Detail
Bridge/Conduit Maintenance	OTC Bridge Maintenance is Operating Expenses spent on Bridges and Maintenance Misc. CIP.
Preservation	OTC Bridge Preservation is Bridge Painting and Weatherproofing.
Bridge/Conduit Rehabilitation	OTC Bridge Rehabilitation is 60 percent of Bridge Deck Replacements, Bridge Deck Overlays, and Misc. Bridge Repairs. The conduit allocation is as follows: 50 percent goes to maintenance and 50 percent goes to Rehabilitation of OpEx and Capex.
Reconstruction	OTC Bridge Reconstruction is 40 percent of Bridge Deck Replacements, Bridge Deck Overlays, and Misc. Bridge Repairs and accounts for replacement structures.

Table 55 - Bridge and Conduit Work Activities - Funding Investment Categories

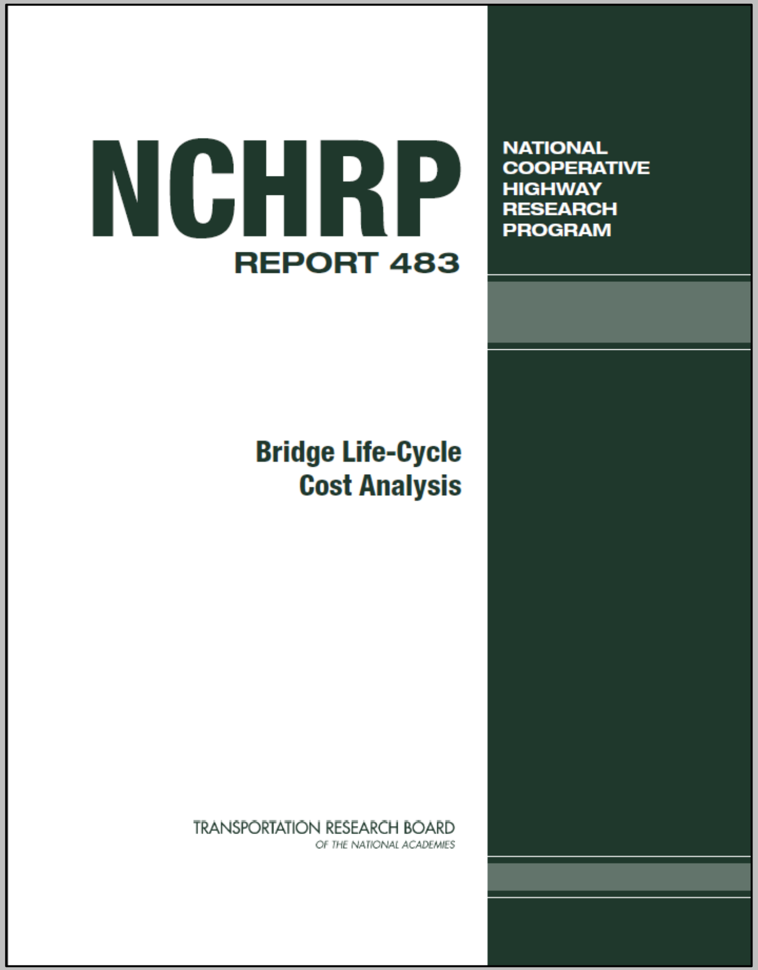
APPENDIX B: FEDERAL IMPROVEMENT REFERENCE TABLE

Federal Improvement Code	Federal Improvement Definition	TAMP Category
Bridge - New Construction	Construction of a new bridge that does not replace or relocate an existing bridge.	New Construction
Bridge Replacement - Added Capacity	Total replacement of a structurally inadequate or functionally obsolete bridge with a new structure constructed with additional lanes in the same general traffic corridor to current geometric construction standards. Incidental roadway approach work is included. The use of this code requires the reporting of the National Bridge Inventory (NBI) structure number in the data field identified Bridge Numbers.	Reconstruction
Bridge Replacement - No Added Capacity	Total replacement of a structurally inadequate or functionally obsolete bridge with a new structure constructed without additional lanes in the same general traffic to current geometric construction standards. A bridge removed and not replaced or replaced with a lesser facility is considered a bridge replacement. Incidental roadway approach work is included. Widening the lanes and/or shoulders of an existing structure without adding through lanes. The use of this code requires the reporting of the National Bridge Inventory (NBI) structure number in the data field identified Bridge Numbers.	Reconstruction
Bridge Rehabilitation - Added capacity	The major work required to restore the structural integrity of a bridge as well as work necessary to correct major safety defects. Bridge deck replacement (both partial and complete) and widening of bridges including the addition of through lanes to specified standards are included. Construction of a dual structure to alleviate a capacity deficiency is also included. Work required to correct minor structure and safety defects or deficiencies, such as deck patching, resurfacing, protective systems, upgrading railings, curbs and gutters, and other minor bridgework. If HBRRP funds are involved, the use of this code requires the reporting of the National Bridge Inventory (NBI) structure number in the data fields identified as Bridge Numbers.	Rehabilitation
Bridge Rehabilitation - No Added Capacity	The major work required to restore the structural integrity of a bridge as well as work necessary to correct major safety defects. Bridge deck replacement (both partial and complete) and widening of bridges without adding through lanes to specified standards are included. Work required to correct minor structure and safety defects or deficiencies, such as deck patching, resurfacing, protective systems, upgrading railings, curbs and gutters, and other minor bridge work. If HBRRP funds are involved, the use of this code requires the reporting of the National Bridge Inventory (NBI) structure number in the data fields identified as Bridge Numbers.	Rehabilitation
Bridge Preventive Maintenance		Maintenance

Resources

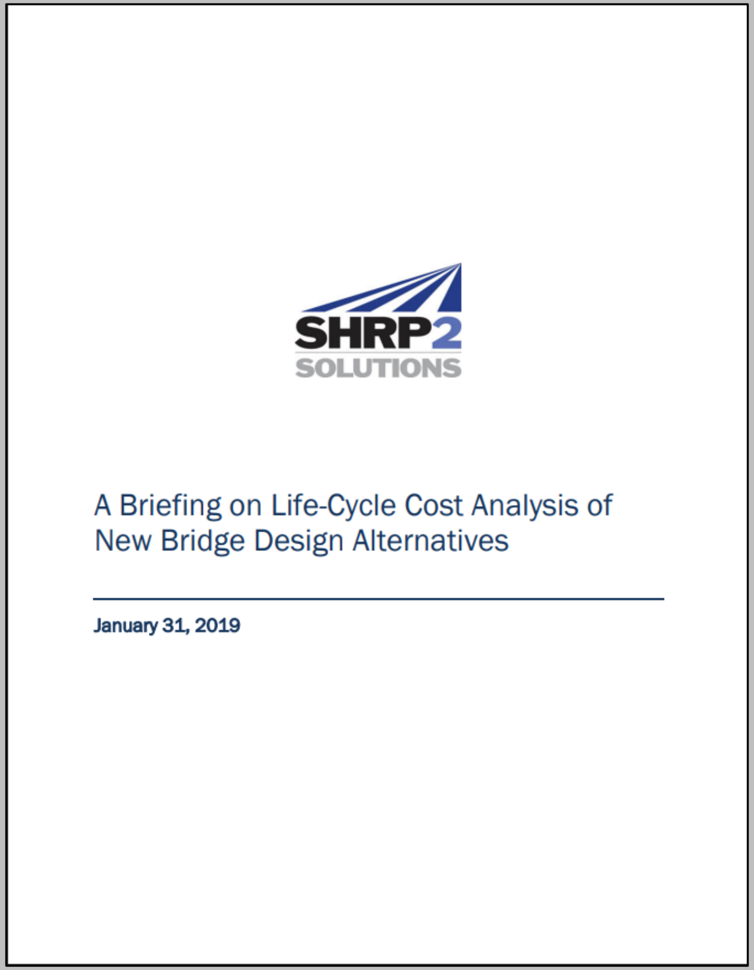


Bridge Management Systems Workshop (2020) | FHWA (dot.gov)



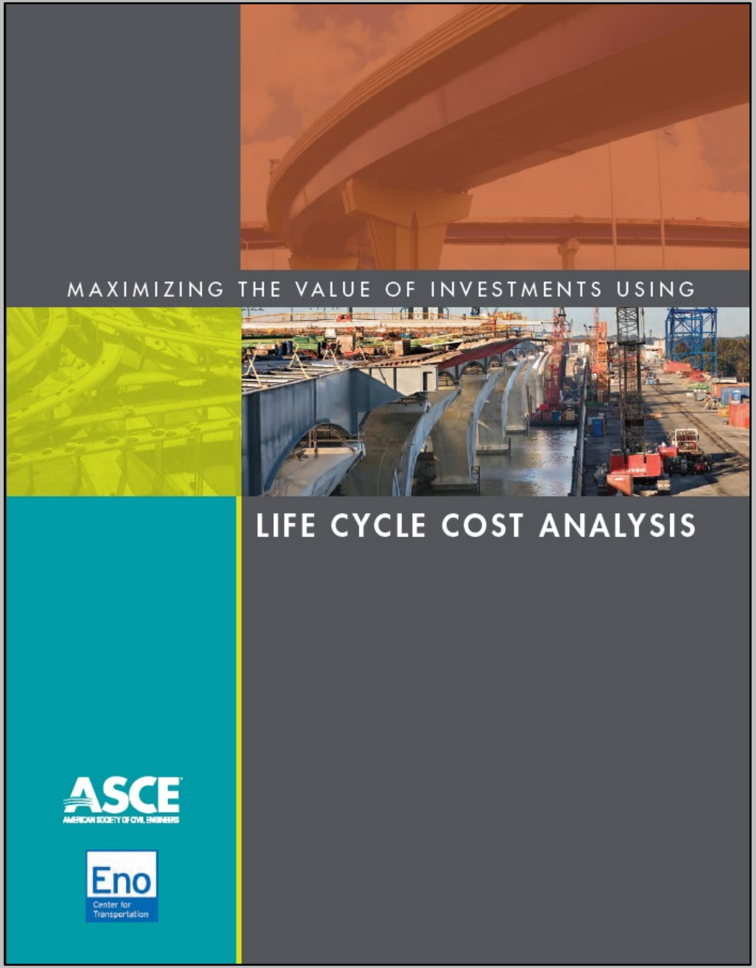
NCHRP Report 483 – Bridge Life-Cycle Cost Analysis (trb.org)

NCHRP Rpt 483 -- BLLCA Software CD



SHRP2_R19A_LCCA_Final_2-6-2019.pdf (transportation.org)

Resources



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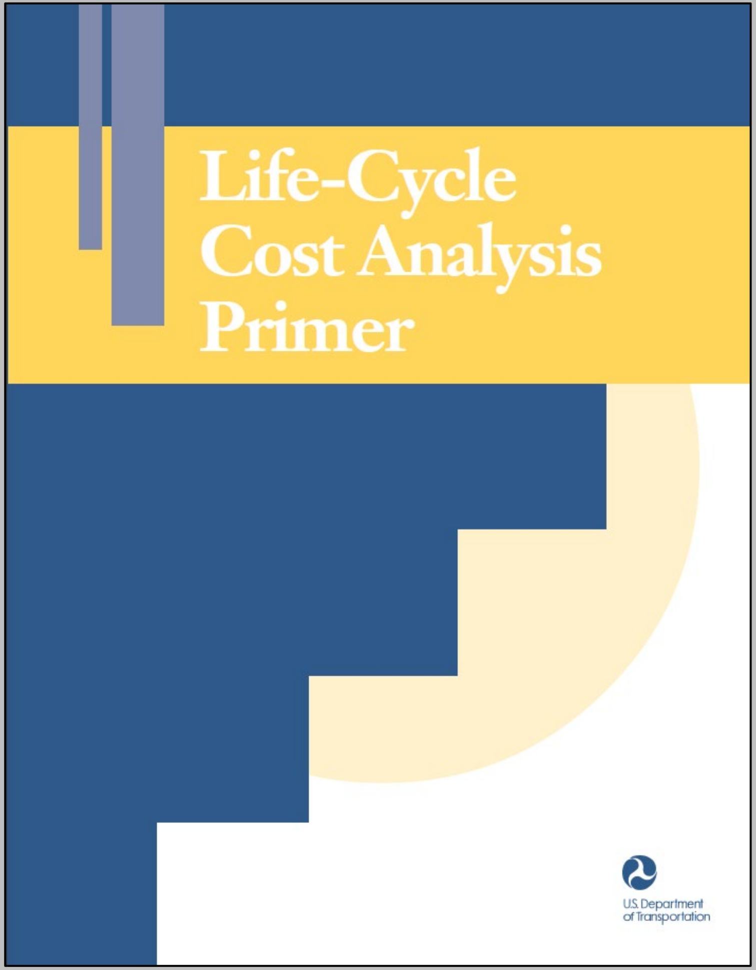

Life-Cycle Cost Analysis Primer | FHWA

Comparison of Software Packages for Life Cycle Cost and Benefit Analysis of Highway Projects

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ABSTRACT

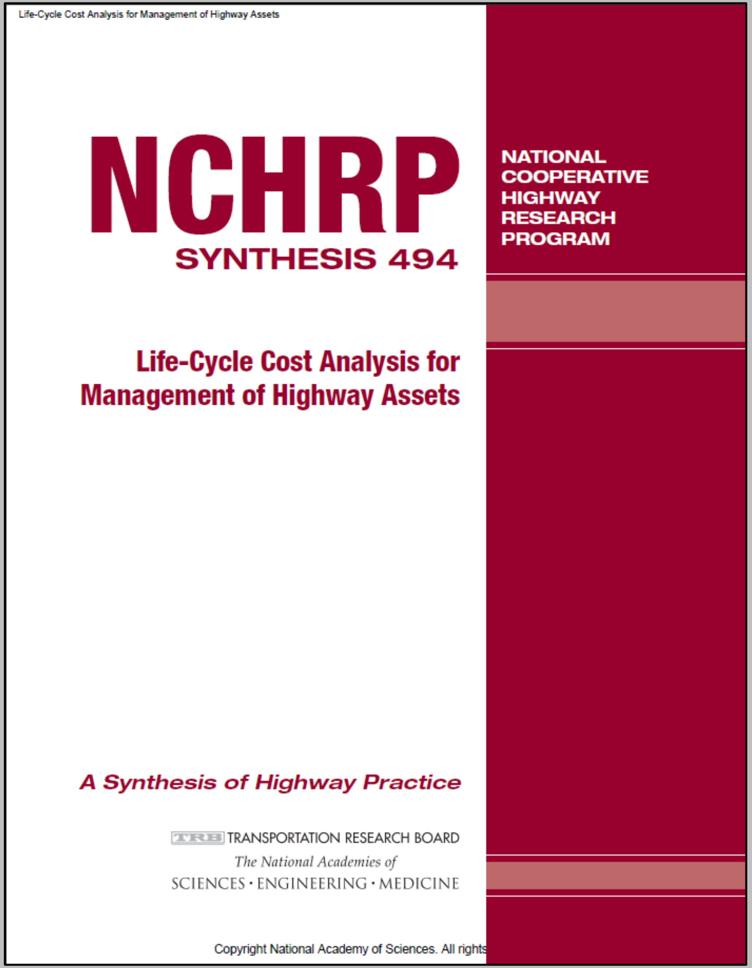
As part of the effort to develop an economic analysis methodology for evaluating highway projects, the commonly utilized software packages for highway life cycle cost analysis (LCCA) were examined and evaluated. The software packages include MicroBENCOST, California Life-Cycle Benefit/Cost Analysis Model (Cal-B/C), and the Redbook Wizard. Through this study, the methodologies applied by these packages were examined. The similarities and differences among the methodologies were identified and compared. Cost and benefit data from real highway projects were applied using the software packages to evaluate and compare the economic analysis results. It was found that even though the general frameworks of economic analyses are similar in these packages, there exist many differences in the specific processes and parameter values. This paper presents the results of the comparisons and evaluations. The evaluation procedures are illustrated. The similarities and differences of the methods are outlined. The impact of the differences on the results of highway economic analysis is discussed. It is believed that the results of this study will be helpful for highway engineers and planners to understand the capacities and limitations of the software packages.

INTRODUCTION

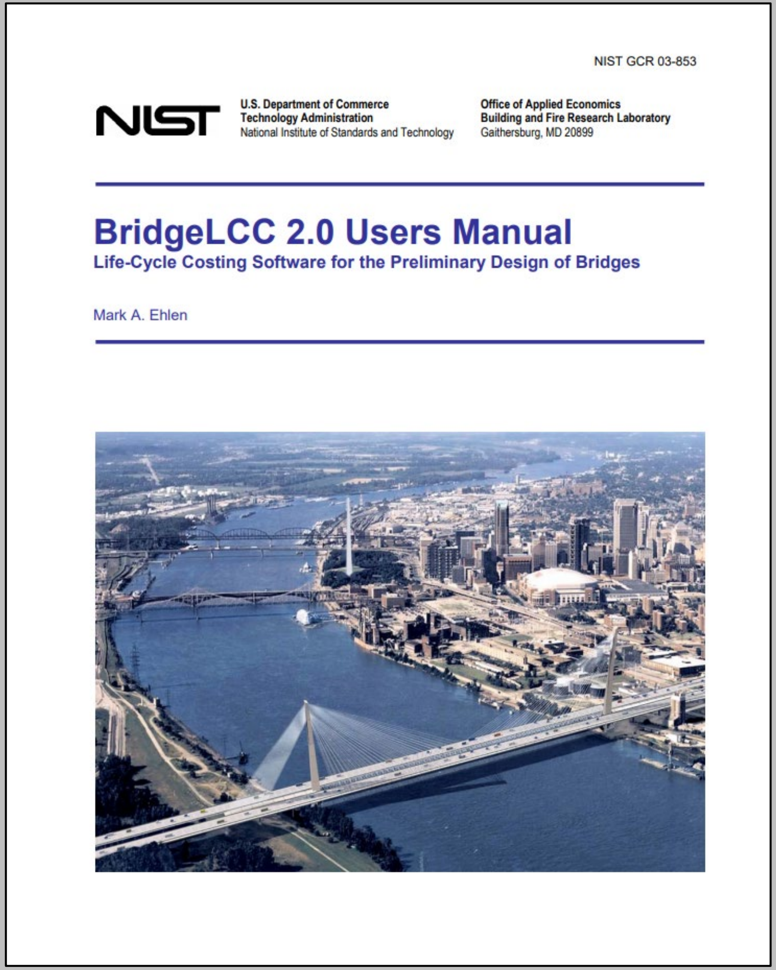
Economic analysis is a critical component of a comprehensive project or program evaluation methodology that considers all key quantitative and qualitative impacts of highway investments. It allows highway agencies to identify, quantify, and value the economic benefits and costs of highway projects and programs over a multiyear timeframe. With this information, highway agencies are better able to

Comparison of Software Packages for Life Cycle Cost & Benefit Analysis of Highway Projects

Resources

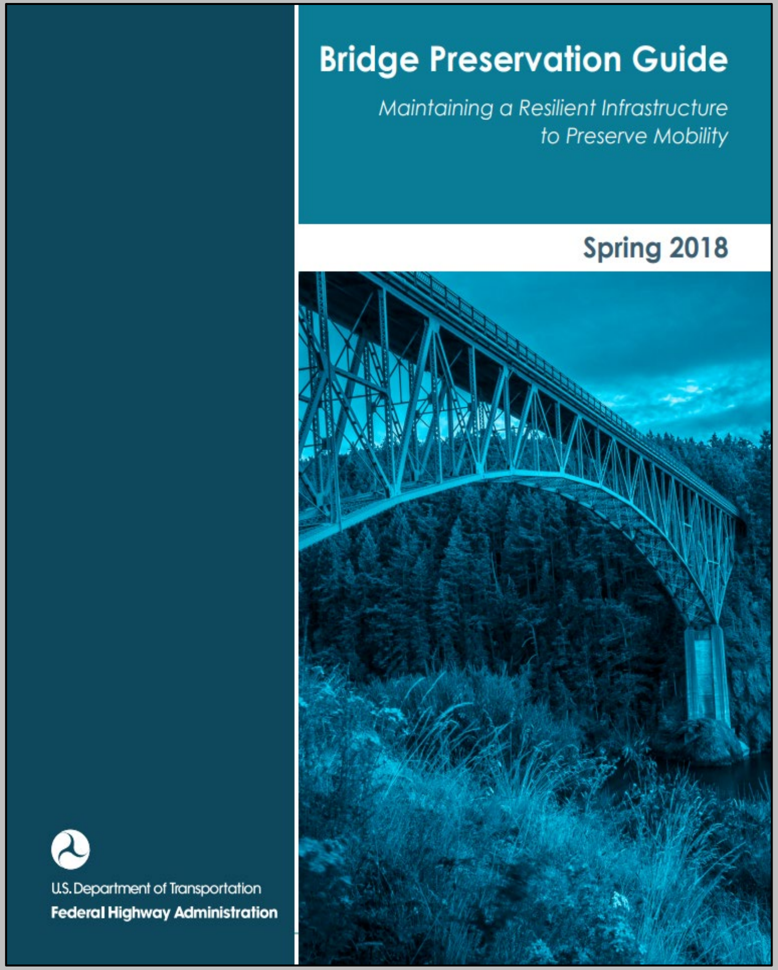


[NCHRP 494 LCCA for Management of Highway Assets | TRB]



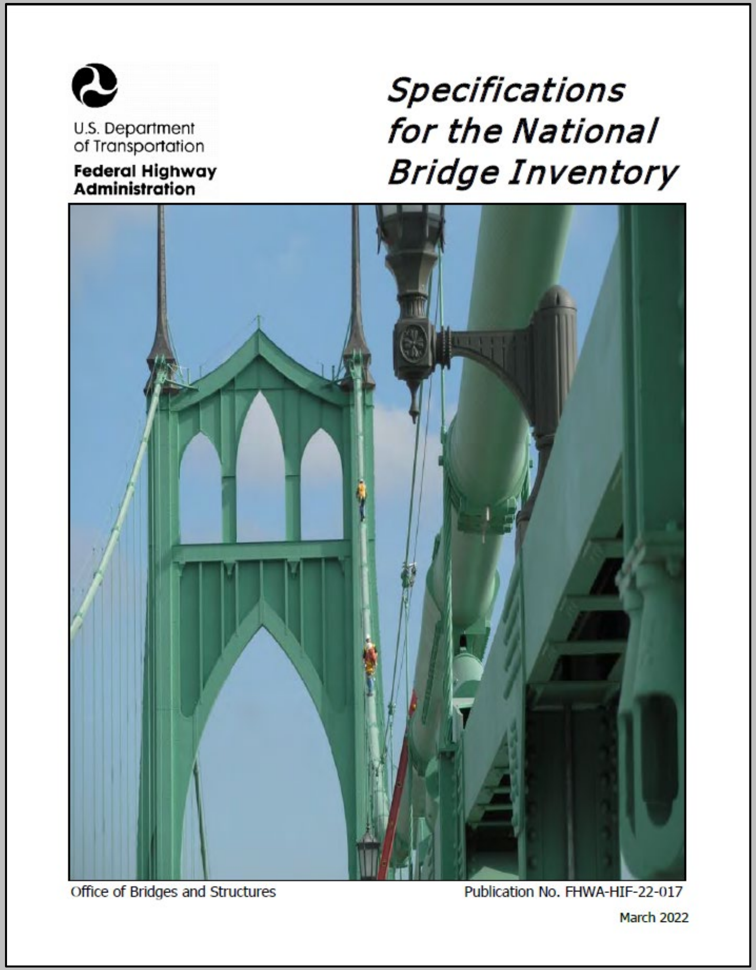
[BridgeLCC 2.0 Users Manual (nist.gov)]

[BridgeLCC | NIST]

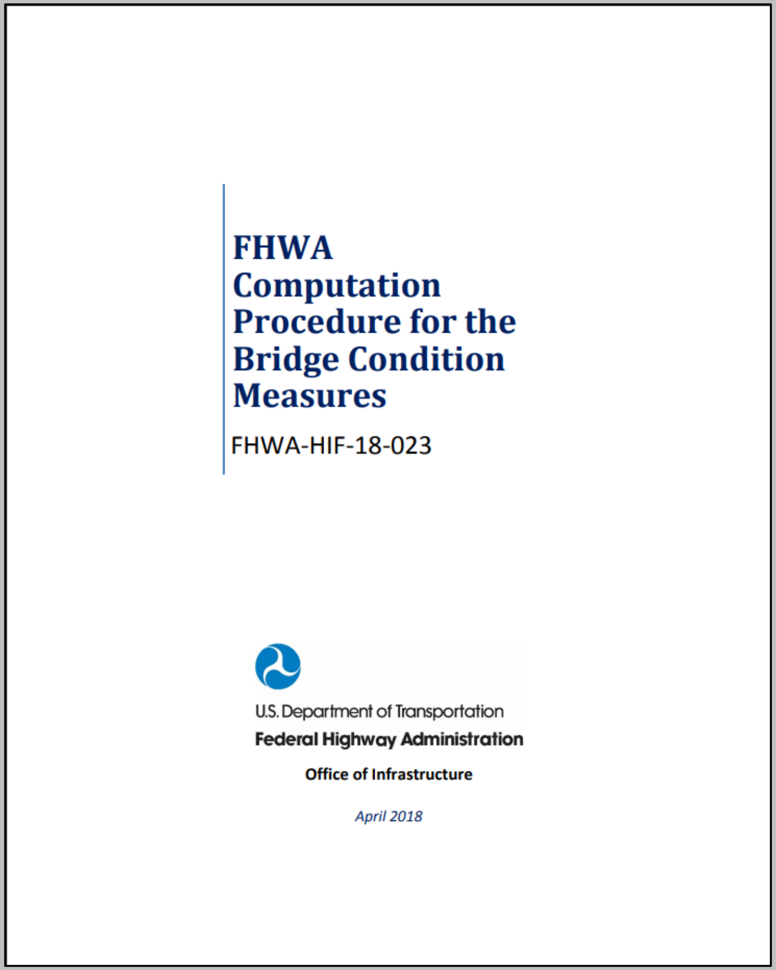


[FHWA Bridge Preservation Guide (dot.gov)]

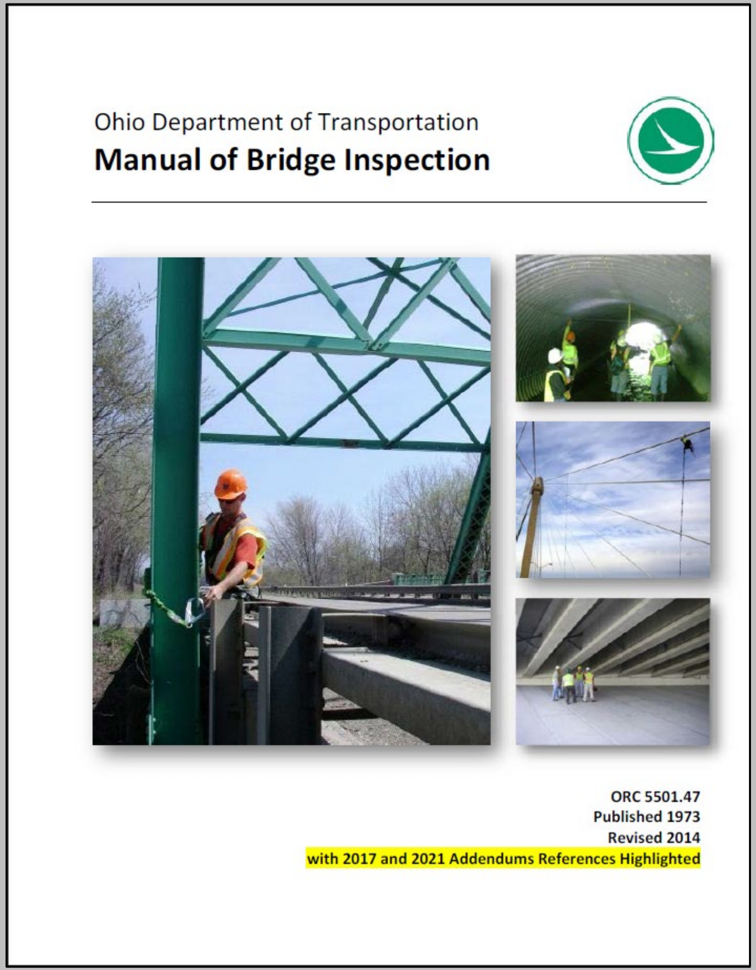
Resources



[Specifications for the National Bridge Inventory (dot.gov)]

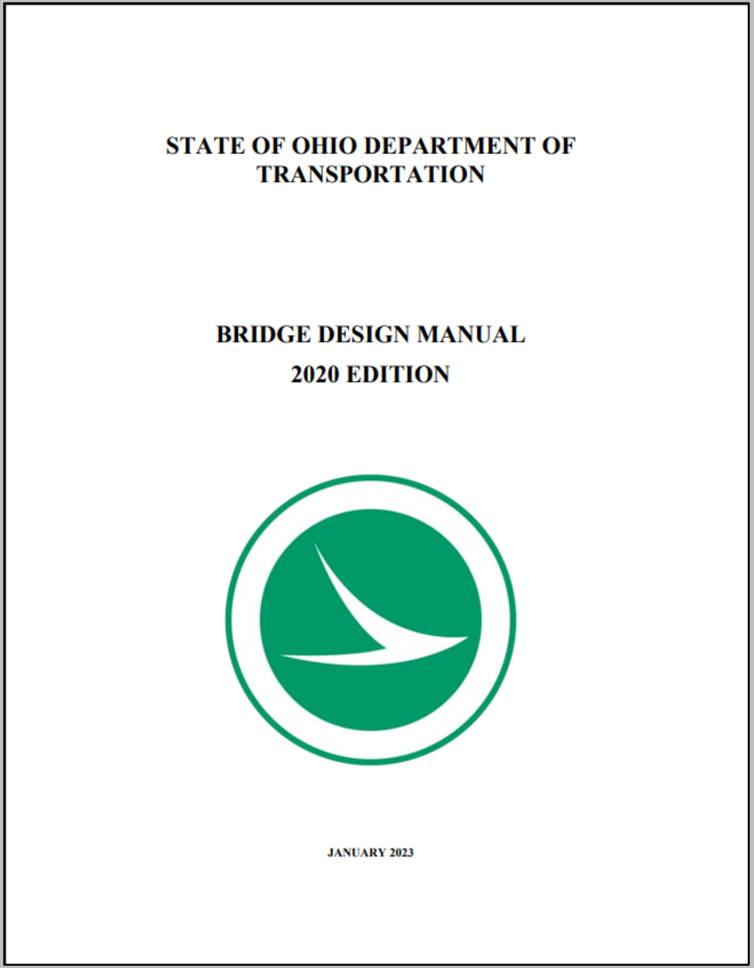


[FHWA Computation Procedure for the Bridge Condition Measures | FHWA (dot.gov)]



[Manual of Bridge Inspection (2014) | ODOT (ohio.gov)]

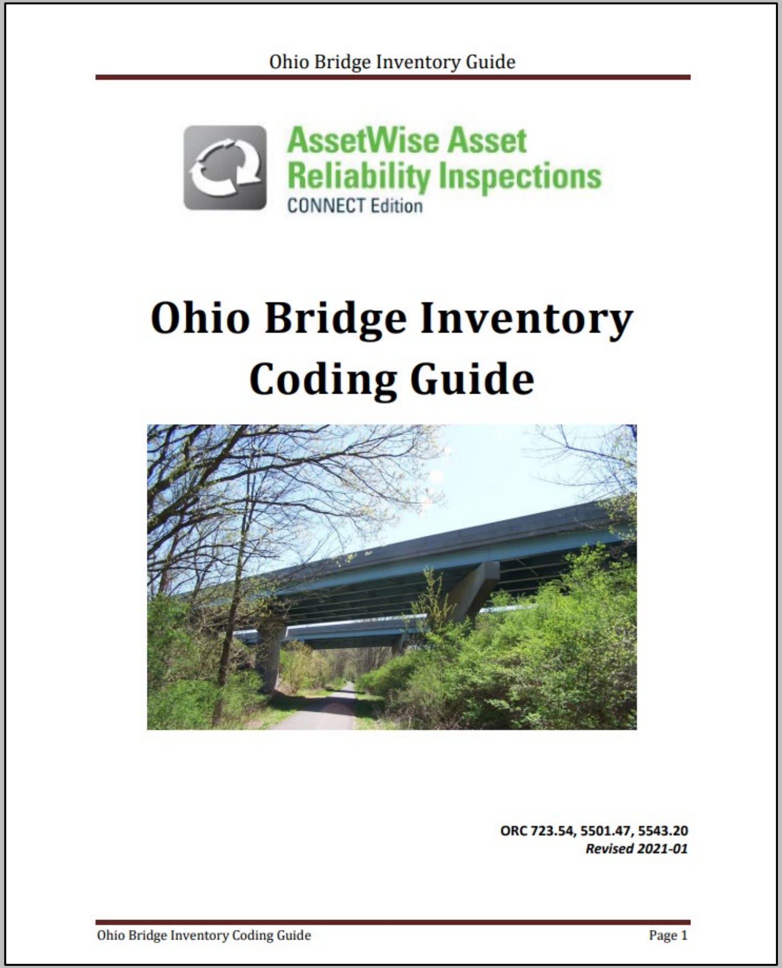
Resources


STATE OF OHIO DEPARTMENT OF TRANSPORTATION

BRIDGE DESIGN MANUAL
2020 EDITION

JANUARY 2023

[Bridge Design Manual (2020) | ODOT (ohio.gov)](#)


Ohio Bridge Inventory Guide

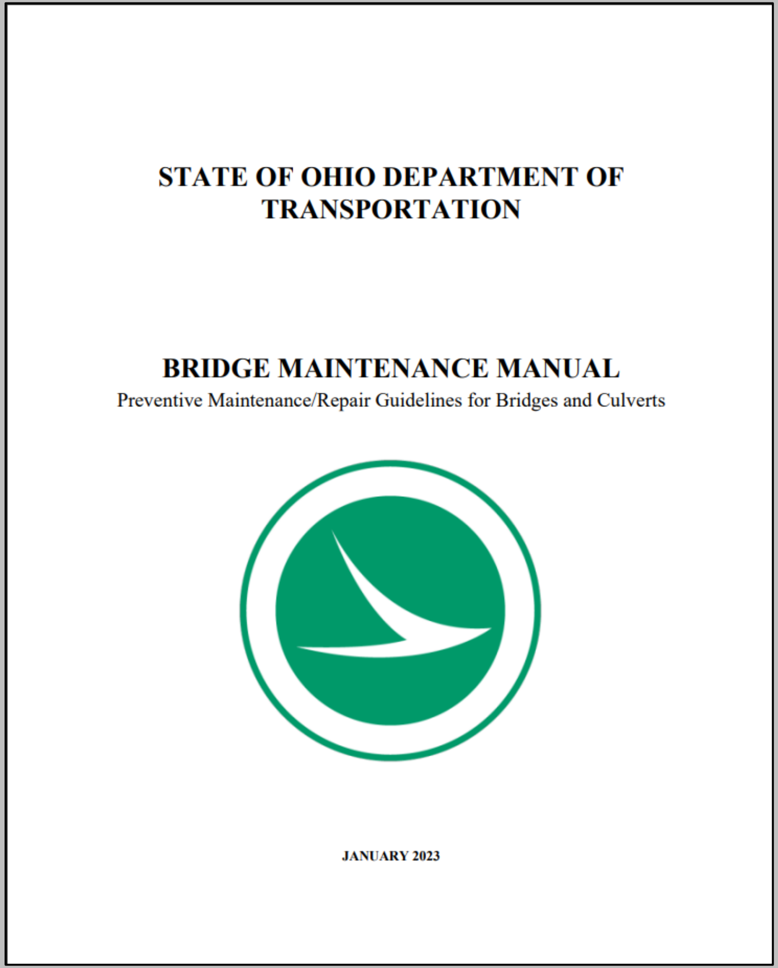
AssetWise Asset Reliability Inspections
CONNECT Edition

Ohio Bridge Inventory Coding Guide

ORC 723.54, 5501.47, 5543.20
Revised 2021-01

Ohio Bridge Inventory Coding Guide Page 1

[Ohio Bridge Inventory Guide | ODOT (ohio.gov)](#)

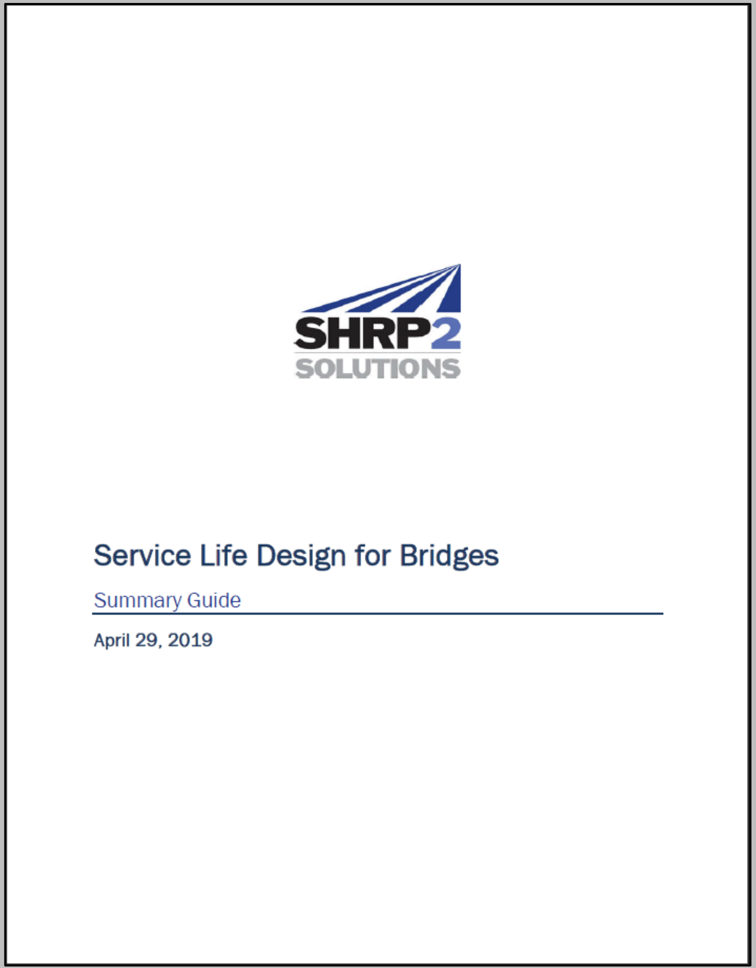

STATE OF OHIO DEPARTMENT OF TRANSPORTATION

BRIDGE MAINTENANCE MANUAL
Preventive Maintenance/Repair Guidelines for Bridges and Culverts

JANUARY 2023

[Bridge Maintenance Manual | ODOT (ohio.gov)](#)

Resources

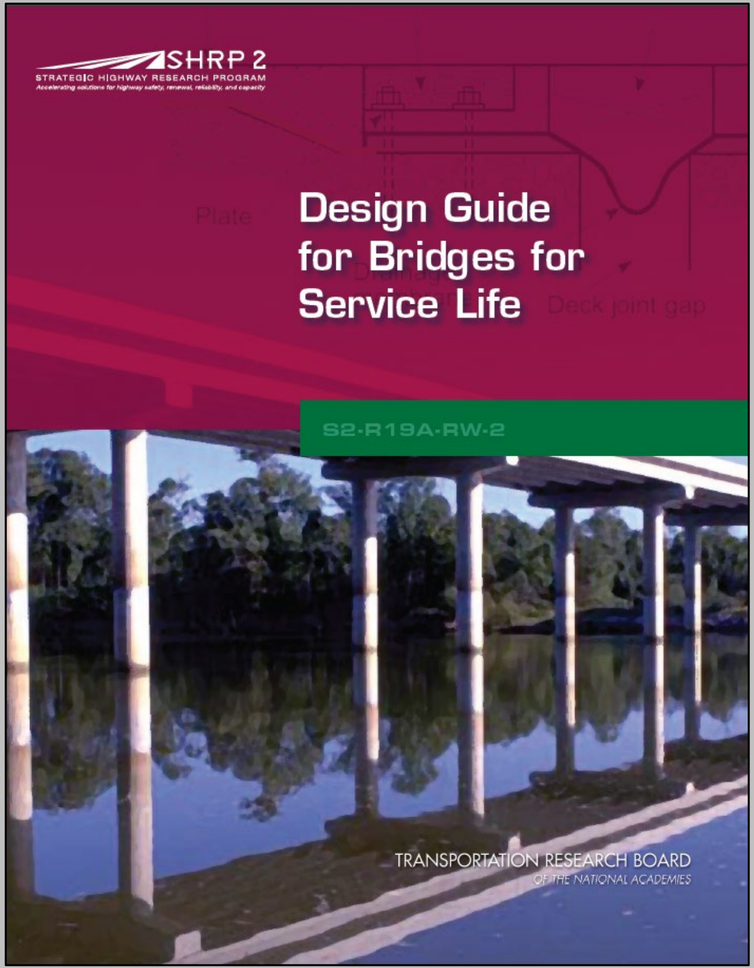

SHRP2
SOLUTIONS

Service Life Design for Bridges

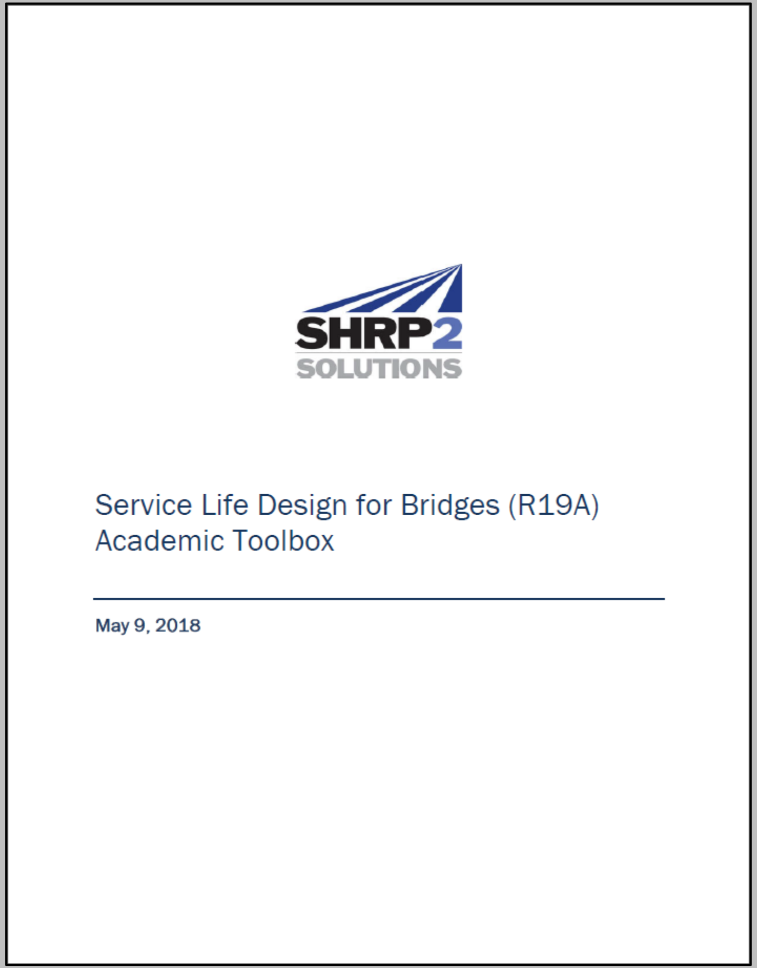
Summary Guide

April 29, 2019

SHRP2_Service Life Design for Bridges, Summary Guide (2019) (TRB)



SHRP2_Design Guide for Bridges for Service Life (TRB)

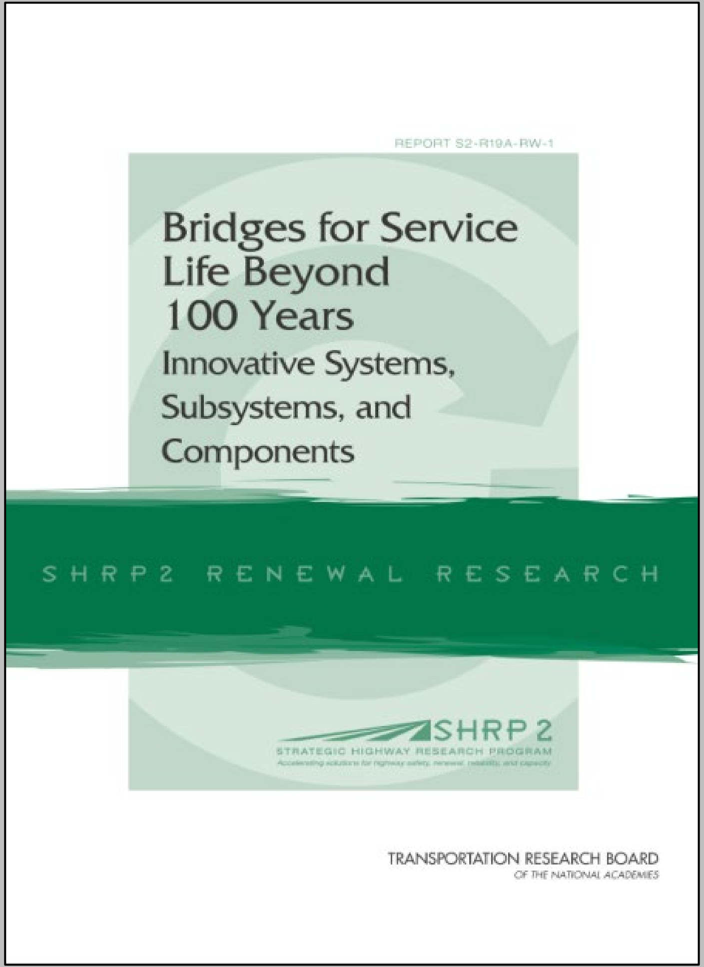

SHRP2
SOLUTIONS

Service Life Design for Bridges (R19A) Academic Toolbox

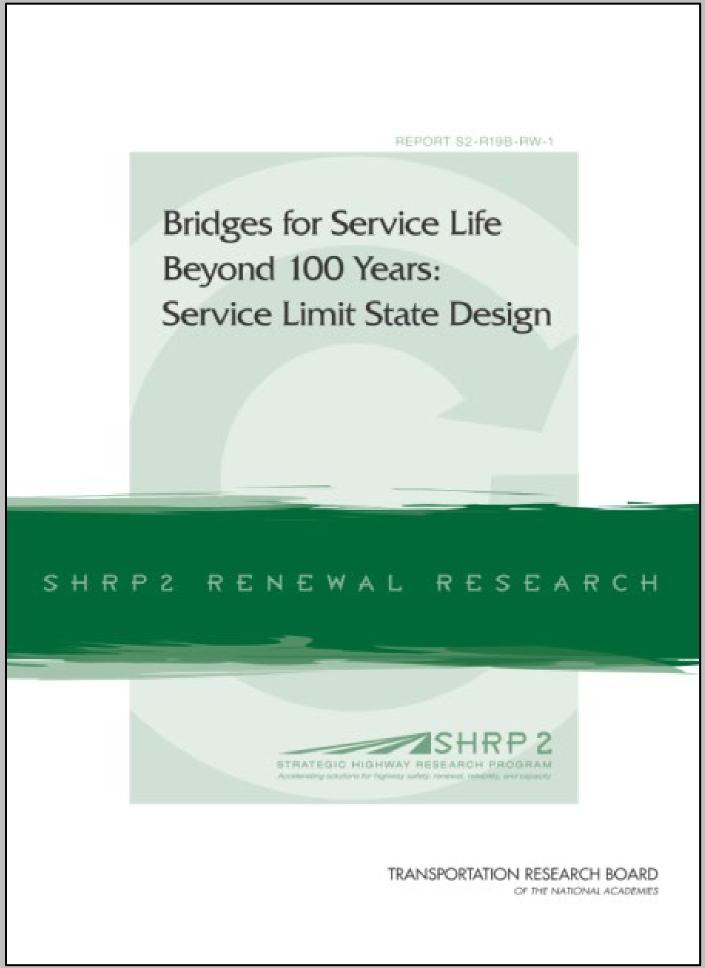
May 9, 2018

SHRP2 R19A Service Life Design for Bridges, Academic Toolbox (transportation.org)

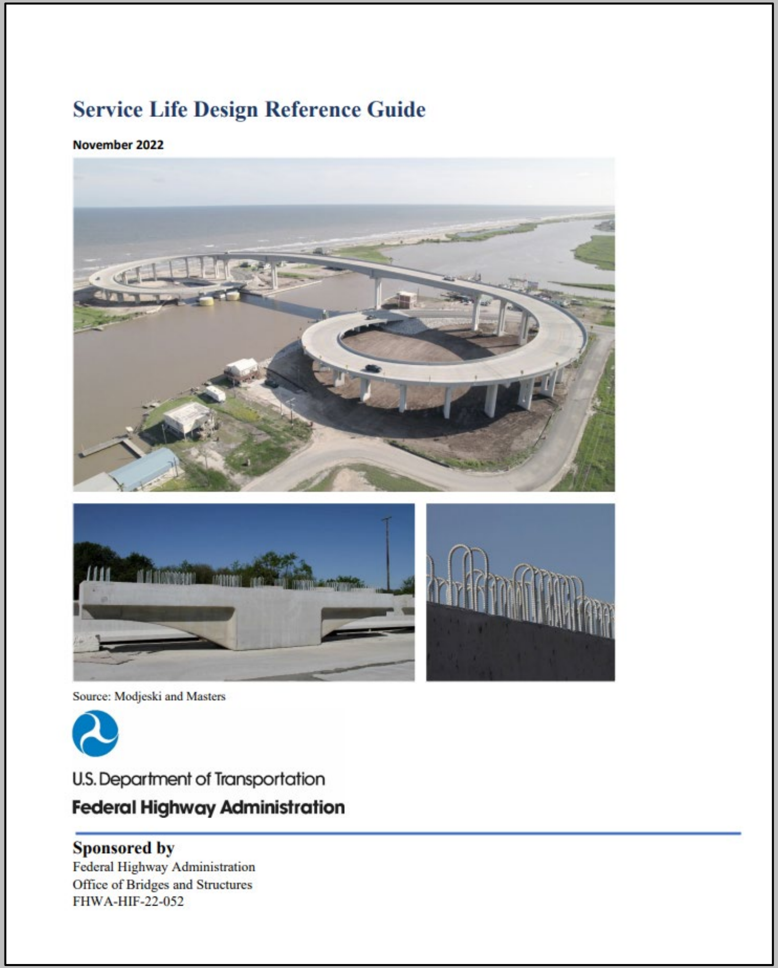
Resources



[SHRP2 S2-R19A-RW-1 -- Bridges for Service Life Beyond 100 Years - Innovative Systems, Subsystems, and Components | NAP]

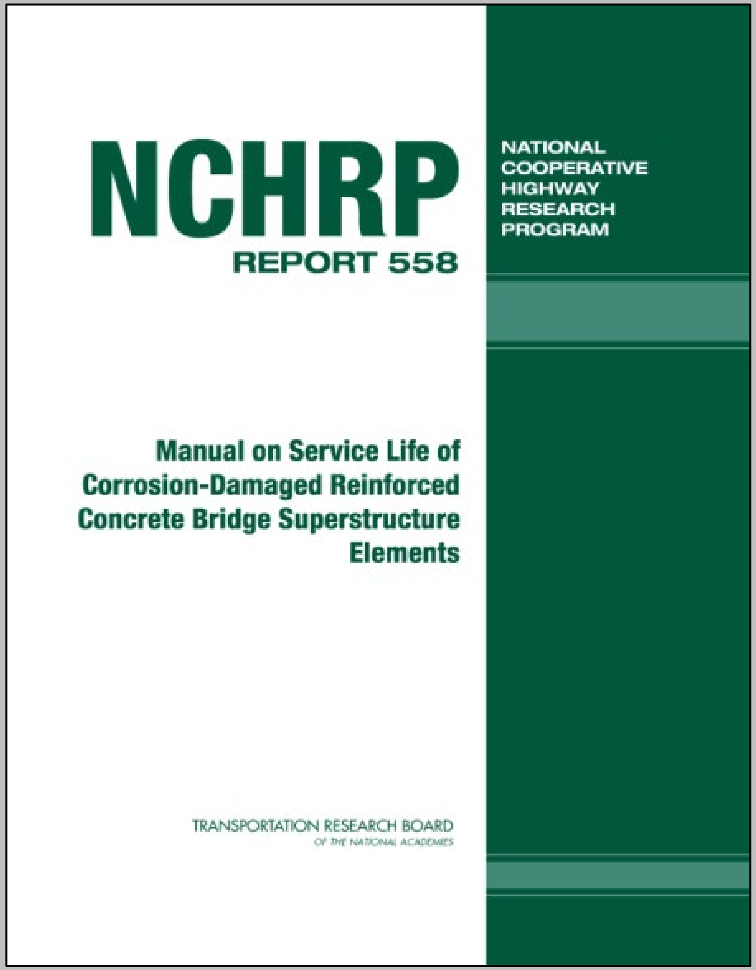


[SHRP2 S2-R19B-RW-1 Bridges for Service Life Beyond 100 Years: Service Limit State Design | NAP]

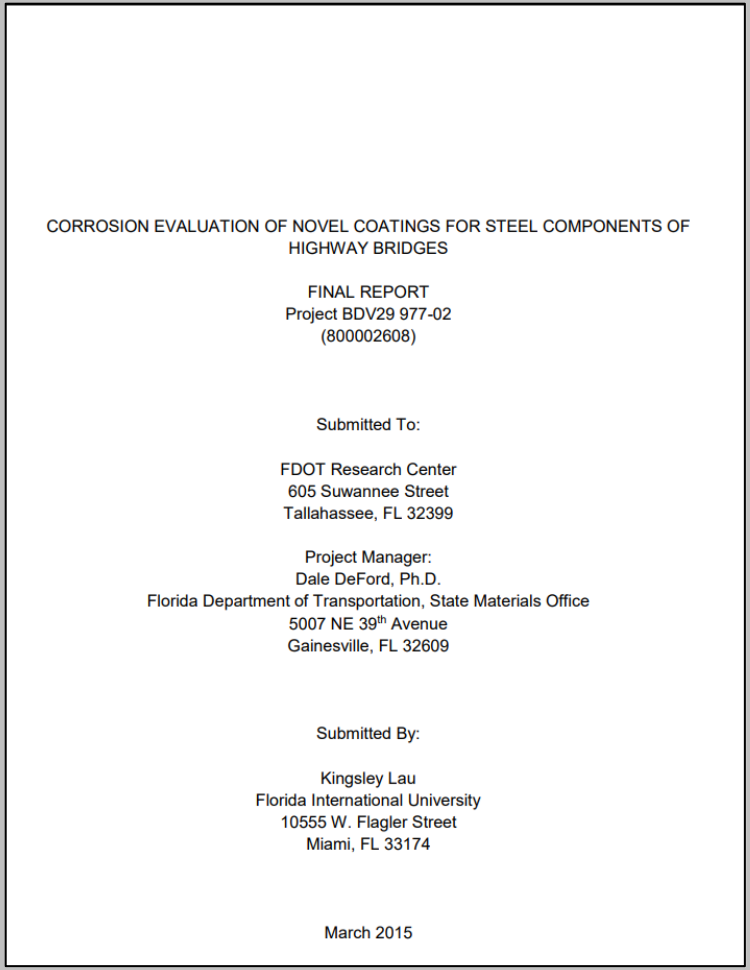


[Service Life Design Reference Guide (dot.gov)]

Resources



[Manual on Service Life of Corrosion-Damaged Reinforced Concrete Bridge Superstructure Elements (NAP)]



CORROSION EVALUATION OF NOVEL COATINGS FOR STEEL COMPONENTS OF HIGHWAY BRIDGES

FINAL REPORT
Project BDV29 977-02
(800002608)

Submitted To:

FDOT Research Center
605 Suwannee Street
Tallahassee, FL 32399

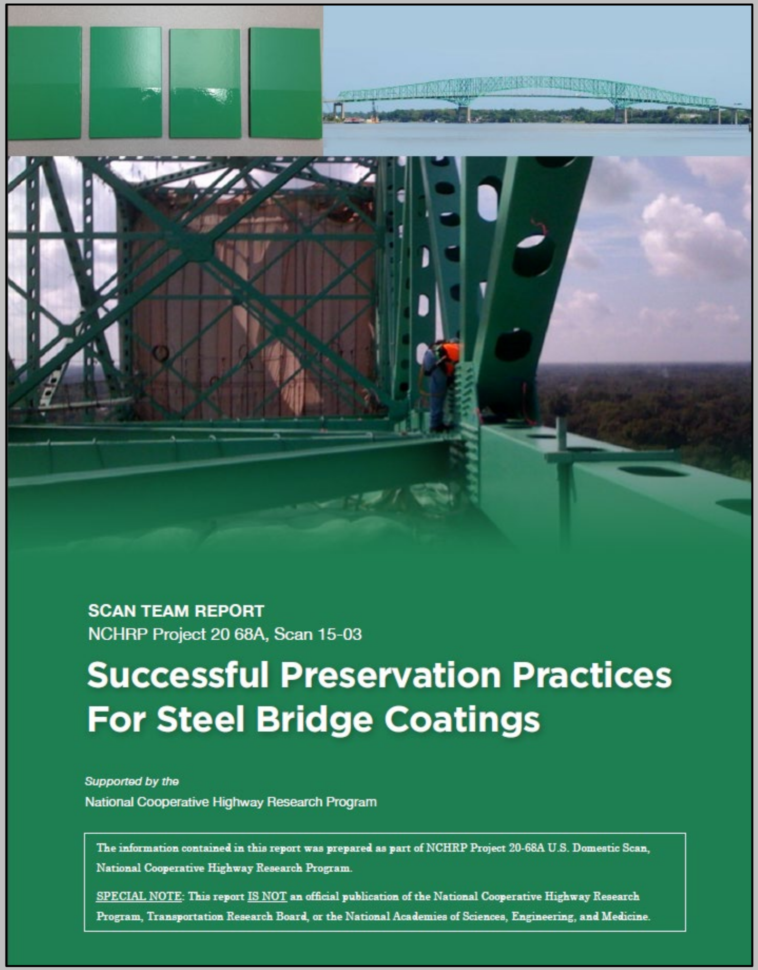
Project Manager:
Dale DeFord, Ph.D.
Florida Department of Transportation, State Materials Office
5007 NE 39th Avenue
Gainesville, FL 32609

Submitted By:

Kingsley Lau
Florida International University
10555 W. Flagler Street
Miami, FL 33174

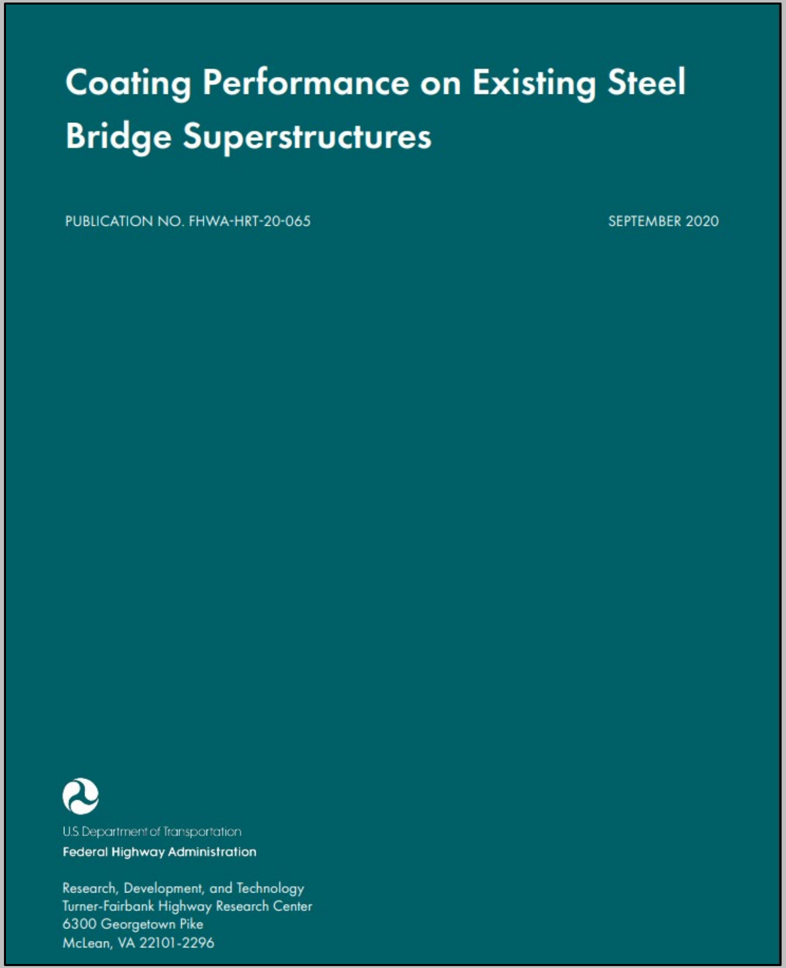
March 2015

[Corrosion evaluation of novel coatings for steel components of highway bridges. (bts.gov)]

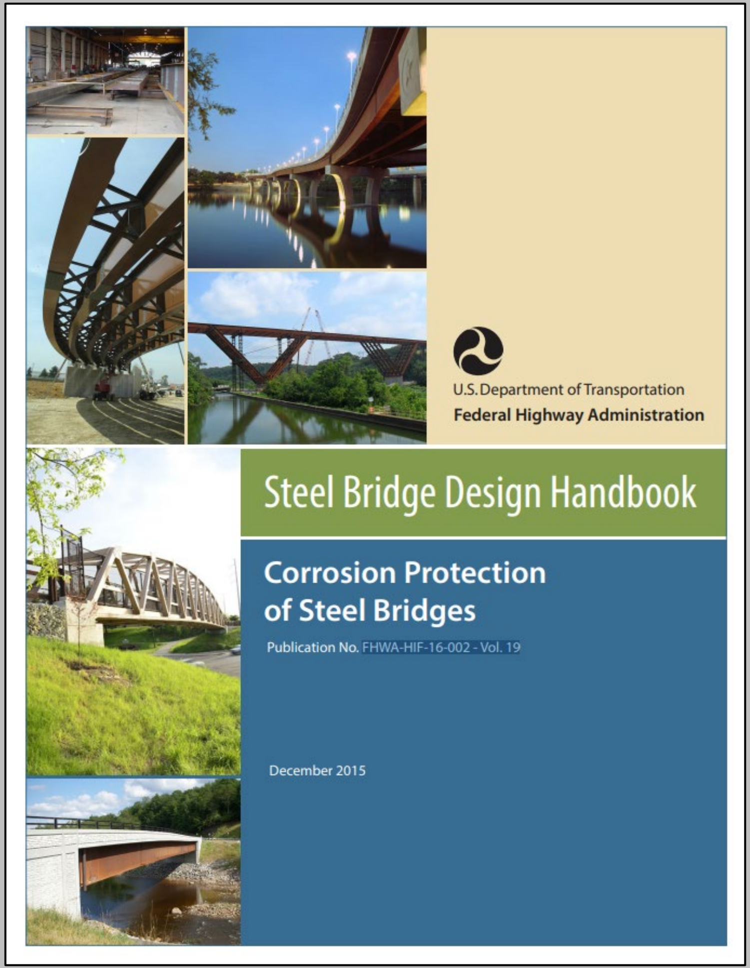


[NCHRP20-68A_15-03_Successful Preservation Practices for Steel Bridge Coatings (trb.org)]

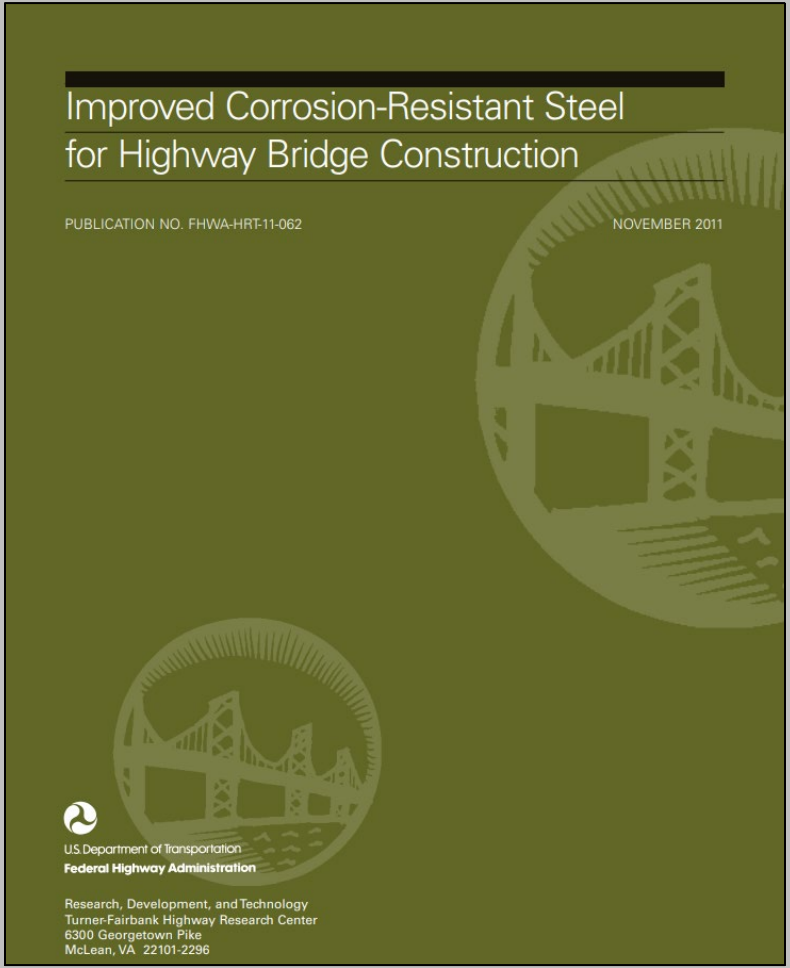
Resources



Coating Performance on Existing Steel Bridge Superstructures (bts.gov)



Steel Bridge Design Handbook: Corrosion Protection of Steel Bridges (bts.gov)



Improved Corrosion-Resistant Steel for Highway Bridges Construction (bts.gov)

Resources


Good Painting Practice
SSPC Painting Manual
Volume 1
Fifth Edition
SSPC
The Society For Protective Coatings


Systems and Specifications
SSPC Painting Manual
Volume 2
SSPC
The Society For Protective Coatings


STANDARDS
SSPC-PA 1, Shop, Field, and Maintenance Painting of Steel

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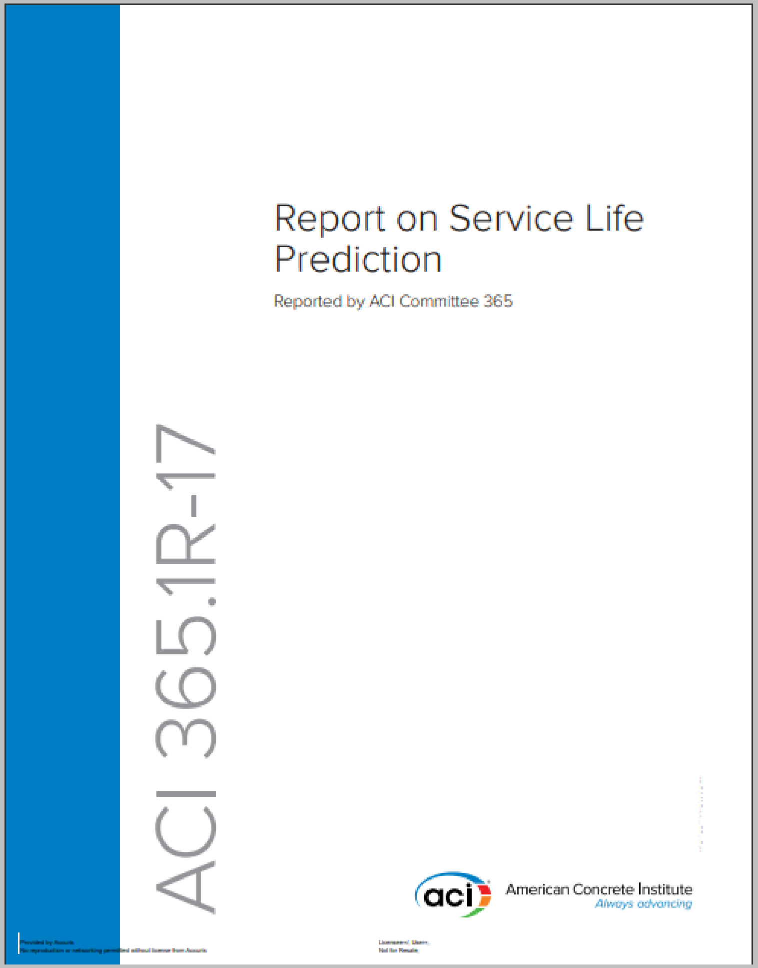
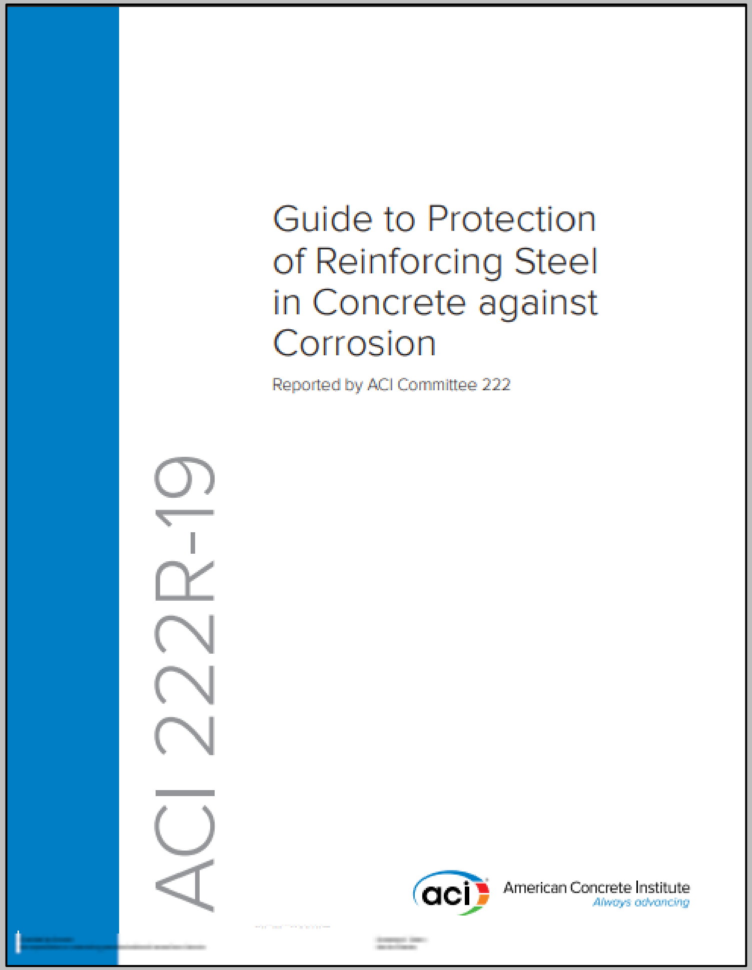
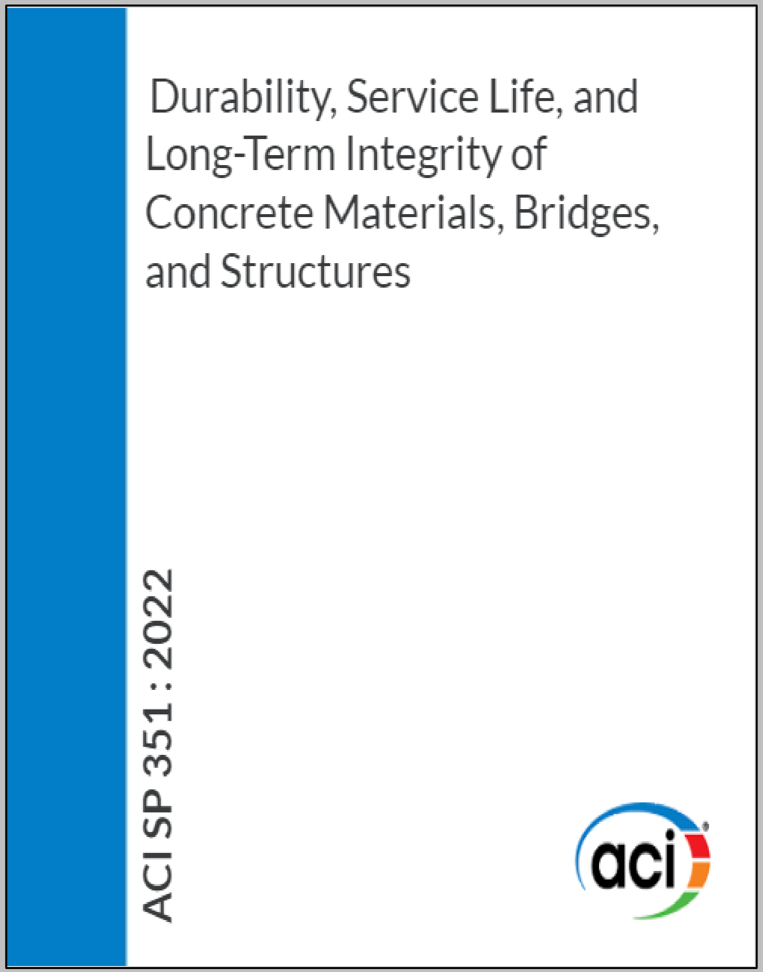
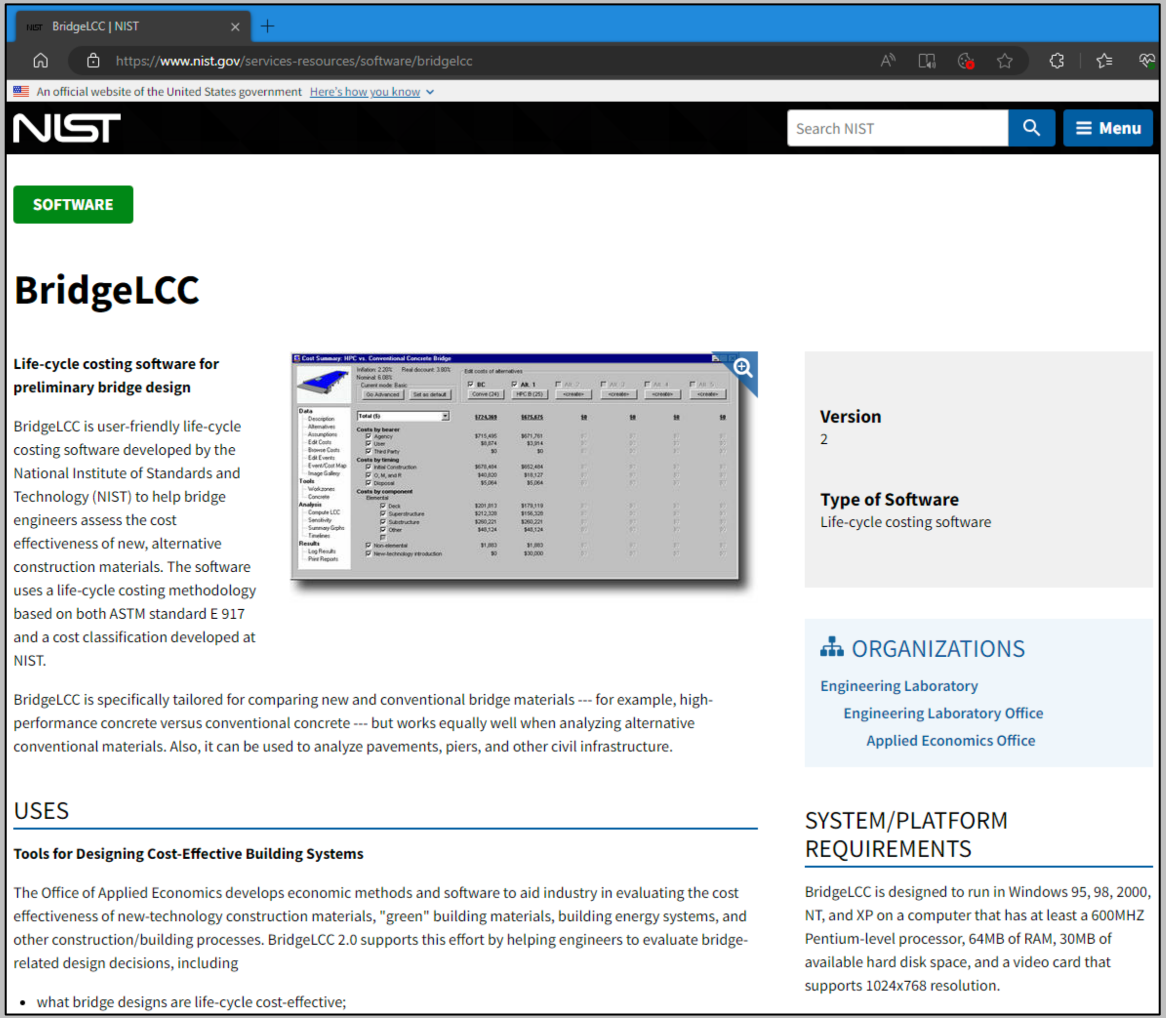




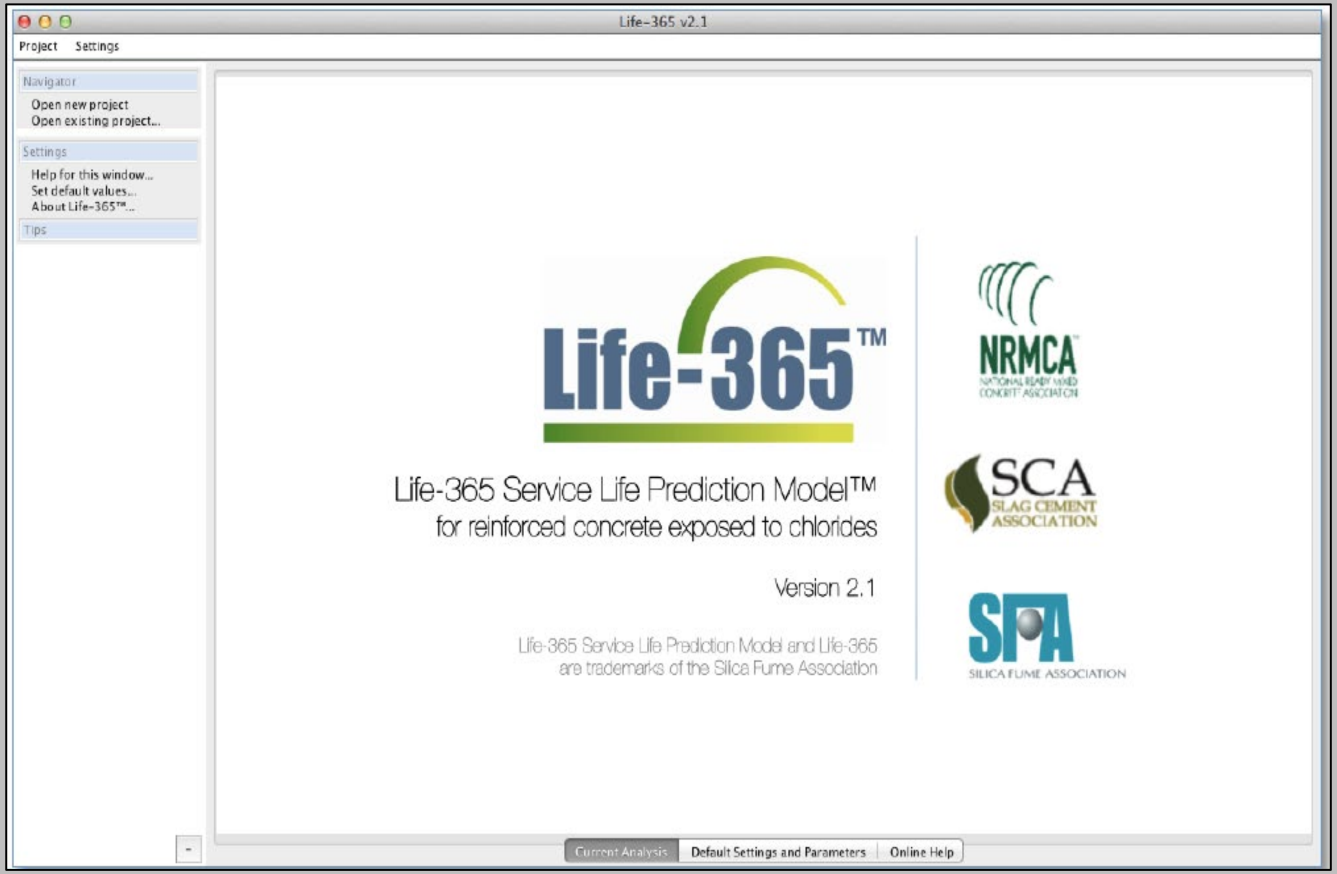


ACI Store

Free Bridge LCCA Tools



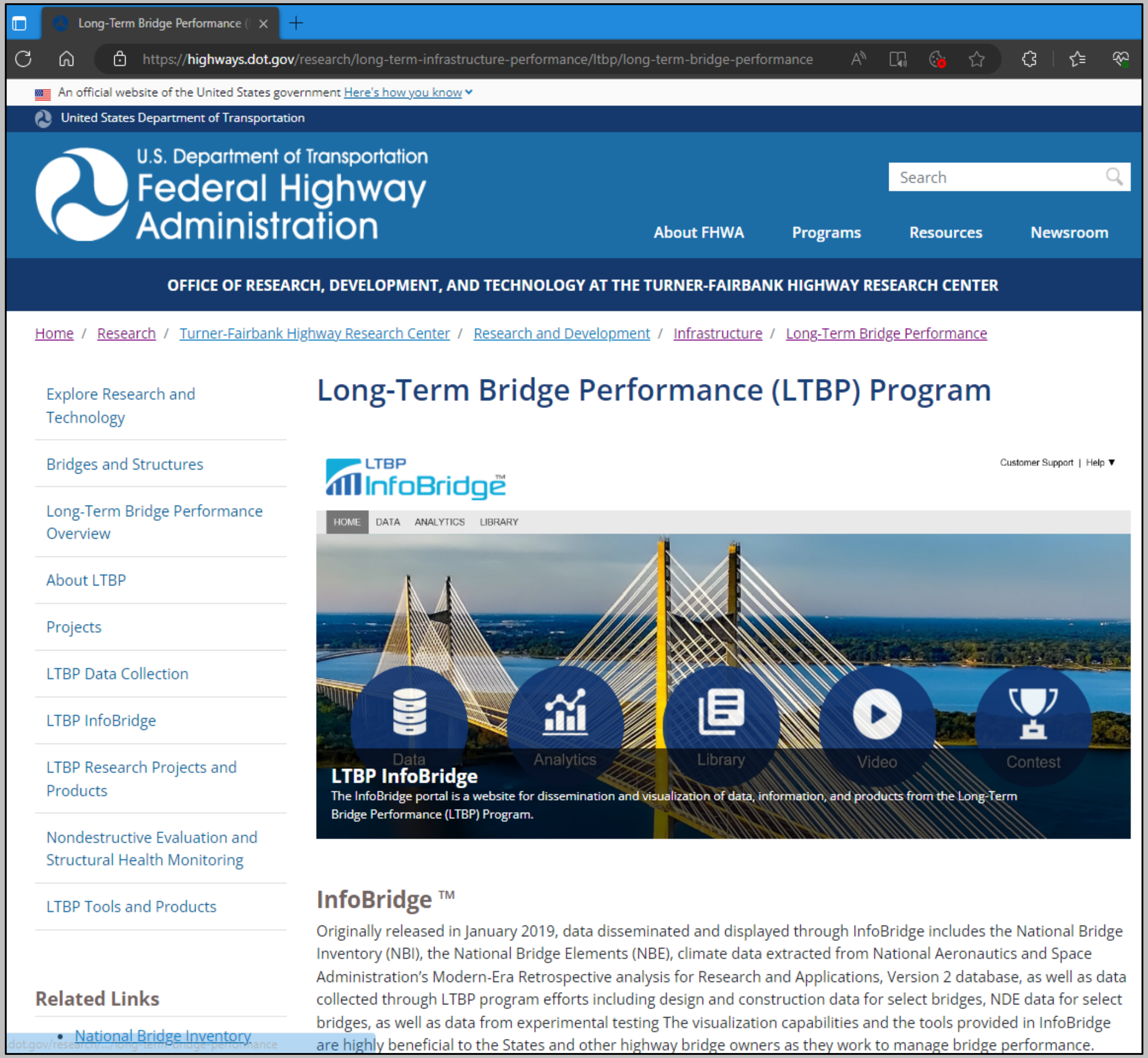
BridgeLCC | NIST



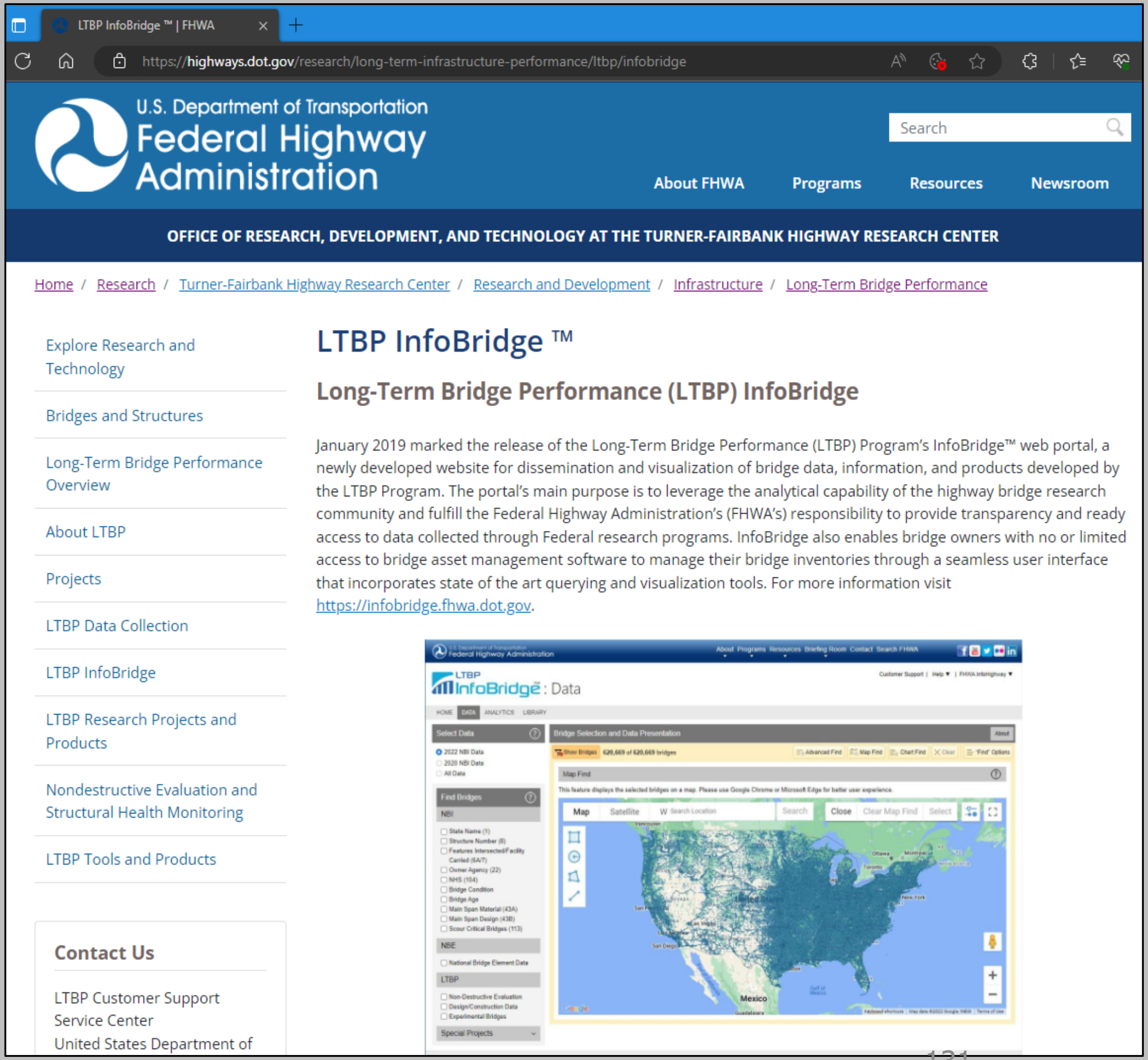
Life-365 Software Overview

Life-365 Software Download

Resources

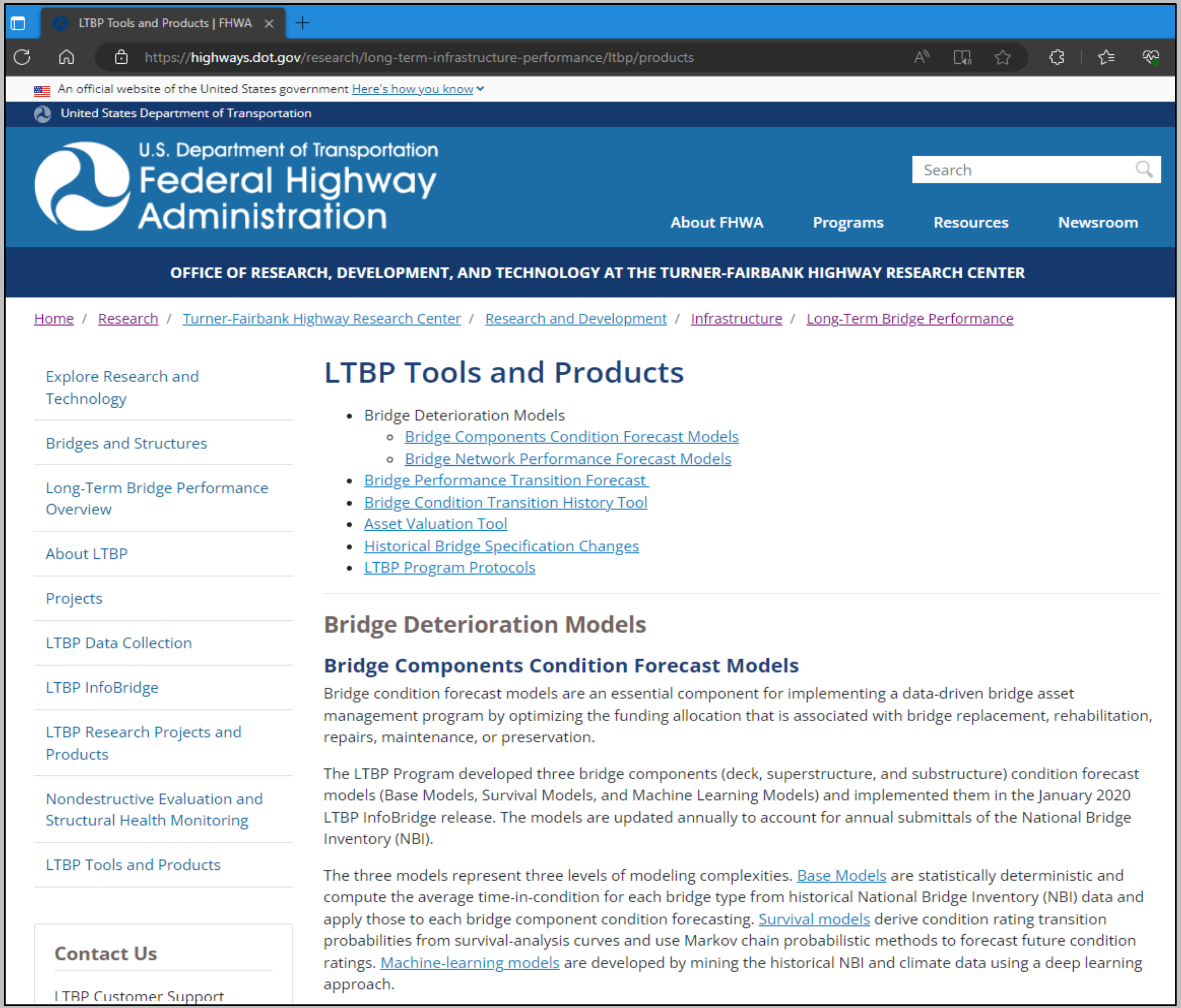


[Long-Term Bridge Performance (LTBP) Program | FHWA (dot.gov)]



[LTBP InfoBridge ™ | FHWA (dot.gov)]

Resources


LTBP Tools and Products | FHWA

https://highways.dot.gov/research/long-term-infrastructure-performance/ltbp/products

An official website of the United States government Here's how you know

United States Department of Transportation

U.S. Department of Transportation Federal Highway Administration

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  - Bridge Components Condition Forecast Models
  - Bridge Network Performance Forecast Models
- Bridge Performance Transition Forecast
- Bridge Condition Transition History Tool
- Asset Valuation Tool
- Historical Bridge Specification Changes
- LTBP Program Protocols

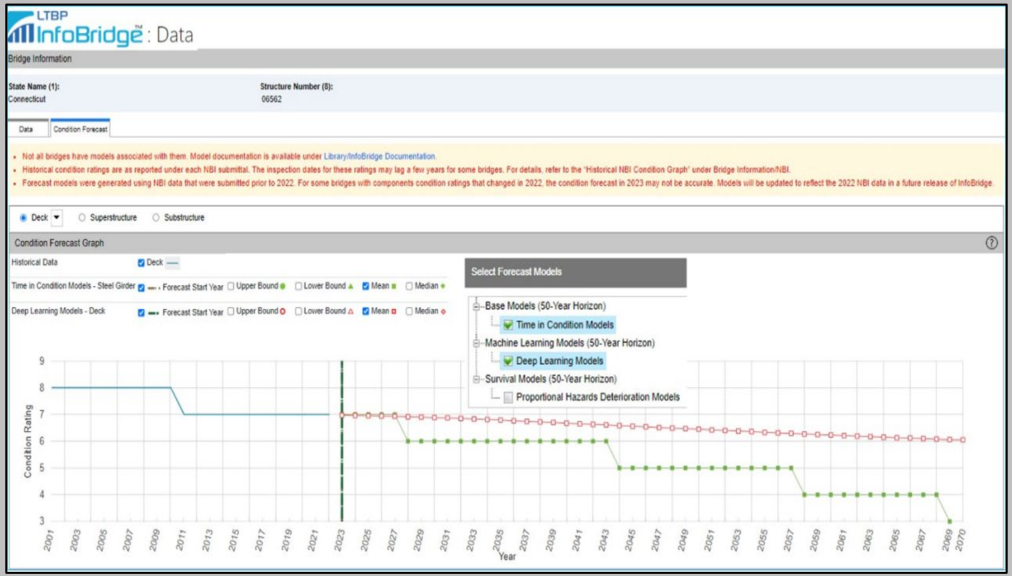
Bridge Deterioration Models

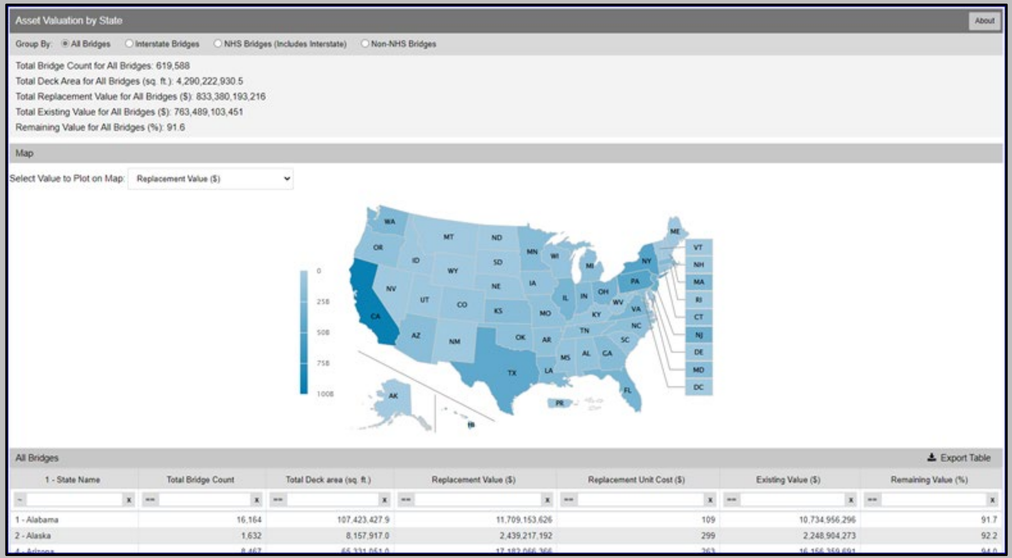
Bridge Components Condition Forecast Models

Bridge condition forecast models are an essential component for implementing a data-driven bridge asset management program by optimizing the funding allocation that is associated with bridge replacement, rehabilitation, repairs, maintenance, or preservation.

The LTBP Program developed three bridge components (deck, superstructure, and substructure) condition forecast models (Base Models, Survival Models, and Machine Learning Models) and implemented them in the January 2020 LTBP InfoBridge release. The models are updated annually to account for annual submittals of the National Bridge Inventory (NBI).

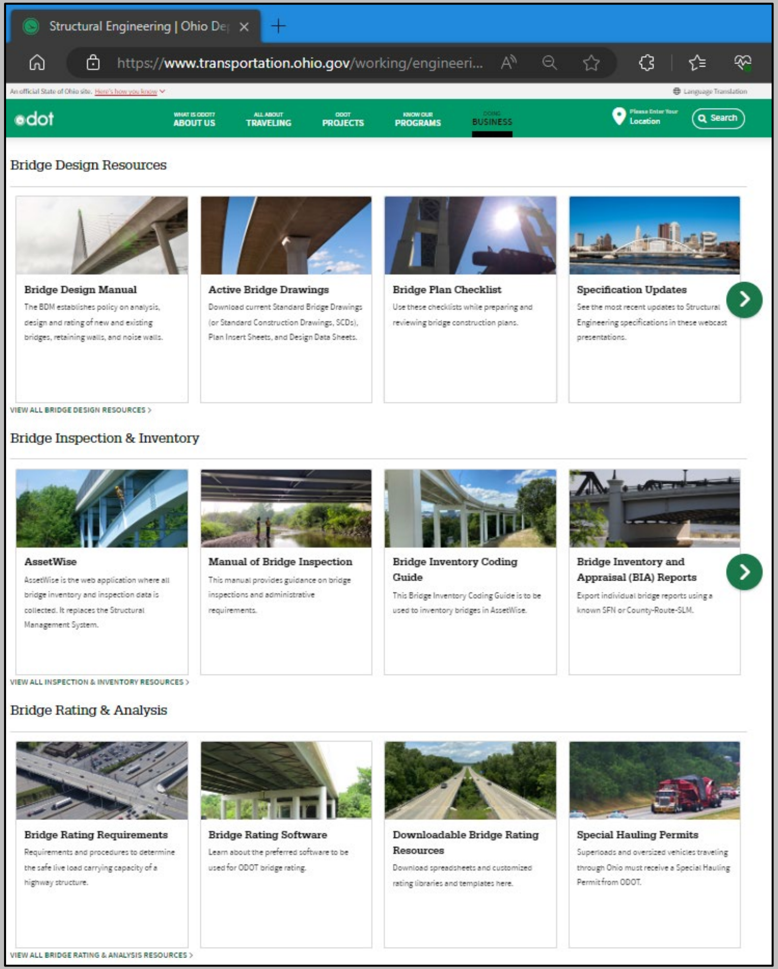
The three models represent three levels of modeling complexities. Base Models are statistically deterministic and compute the average time-in-condition for each bridge type from historical National Bridge Inventory (NBI) data and apply those to each bridge component condition forecasting. Survival models derive condition rating transition probabilities from survival-analysis curves and use Markov chain probabilistic methods to forecast future condition ratings. Machine-learning models are developed by mining the historical NBI and climate data using a deep learning approach.



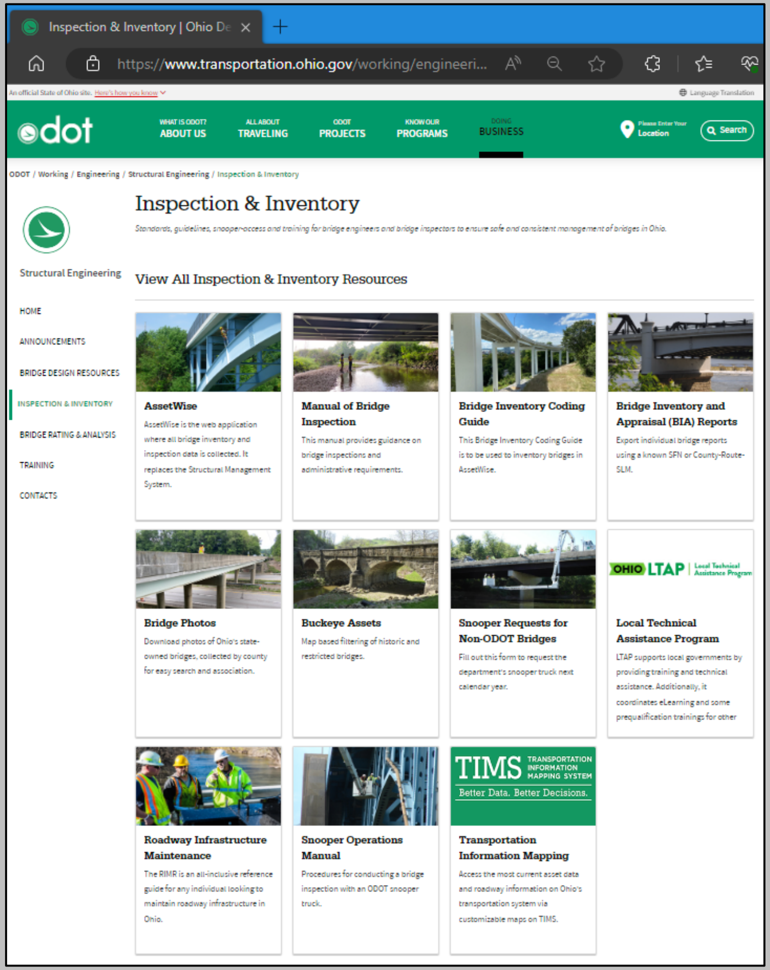


[LTBP Tools and Products | FHWA (dot.gov)]

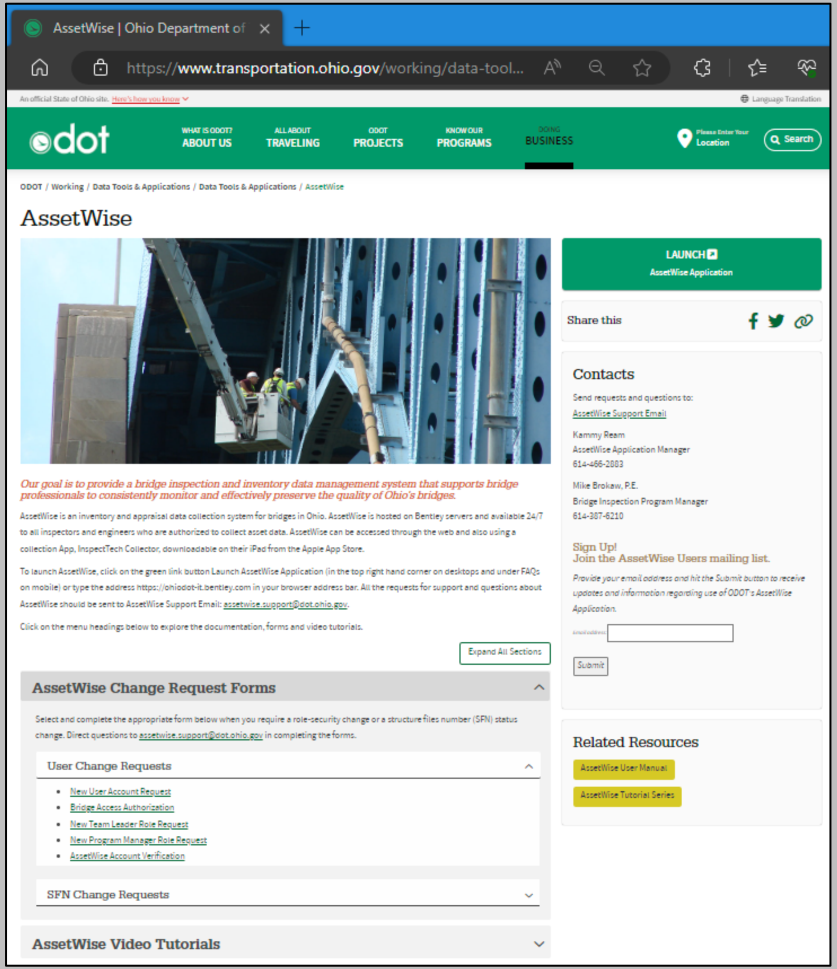
Resources



[Structural Engineering | ODOT (ohio.gov)]

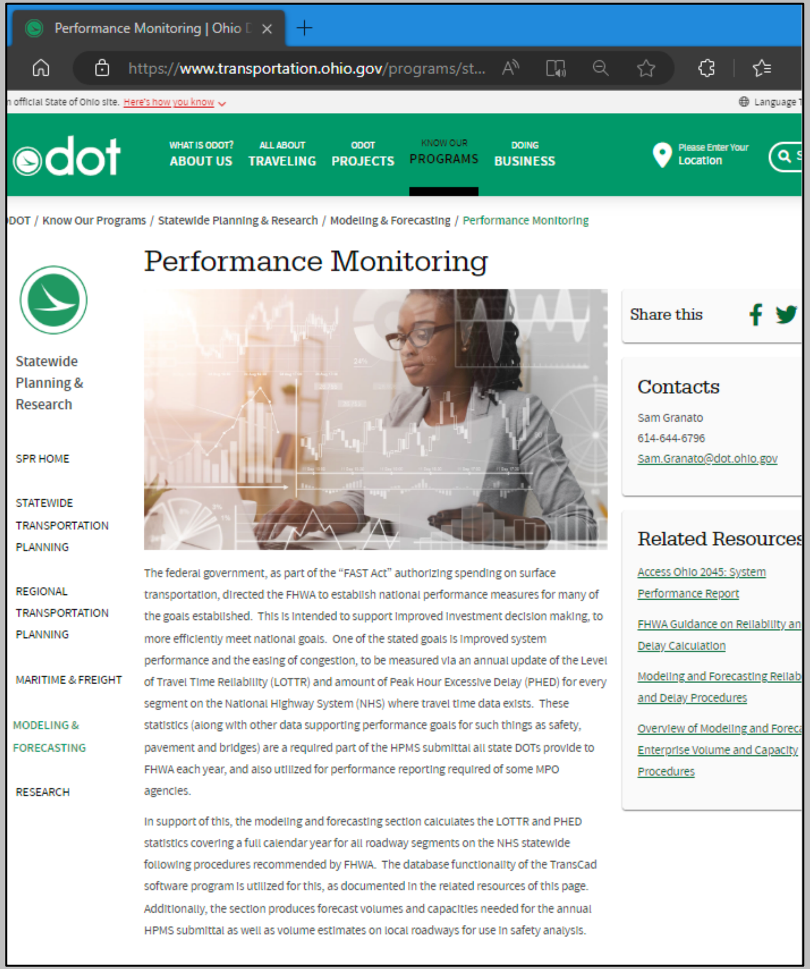


[Bridge Inspection & Inventory | ODOT (ohio.gov)]

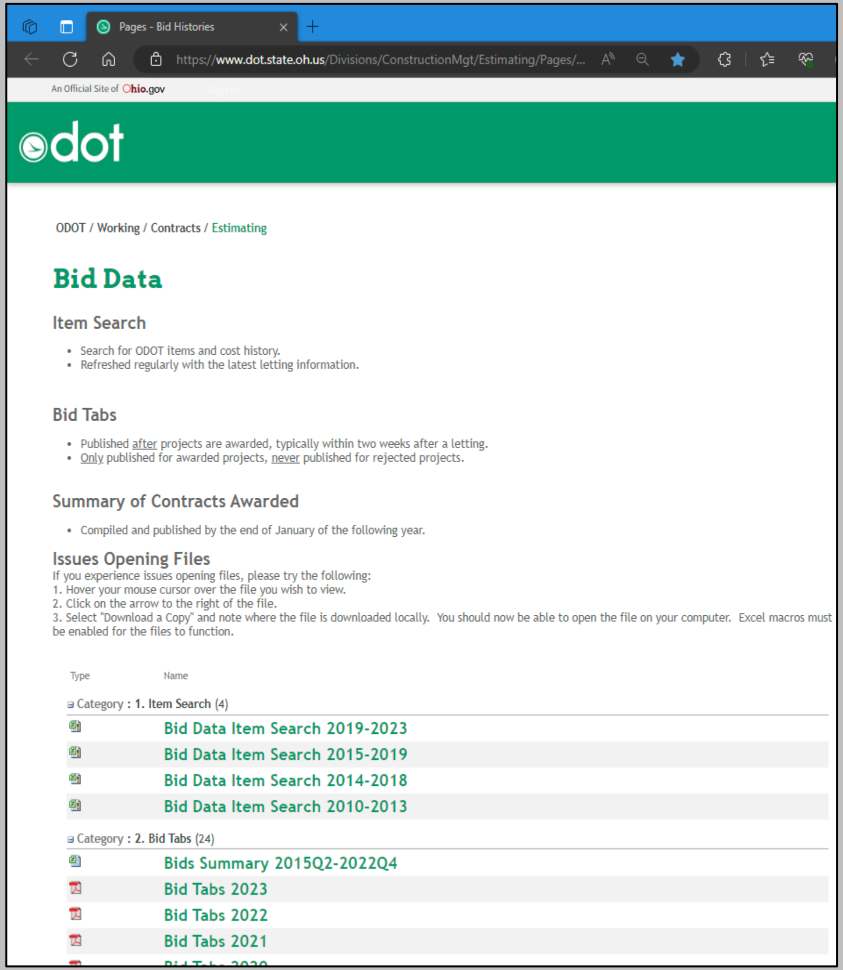


[AssetWise | ODOT (ohio.gov)]

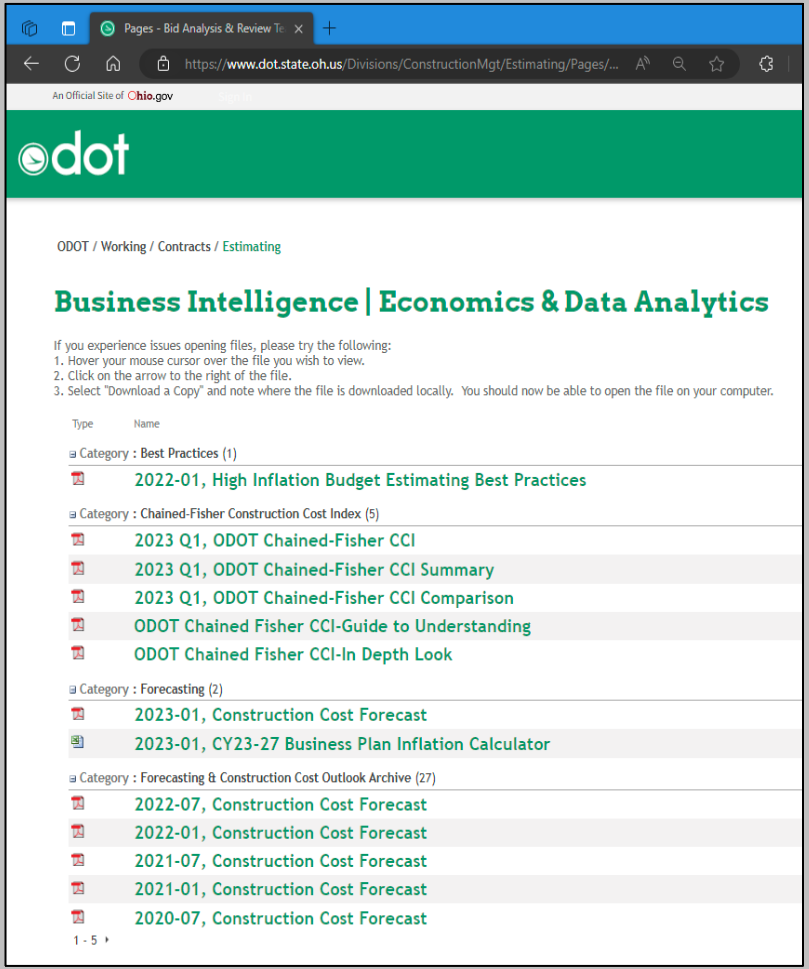
Resources



Performance Monitoring | ODOT (ohio.gov)



Bid Histories | ODOT (ohio.gov)



Bid Analysis & Review | ODOT (ohio.gov)

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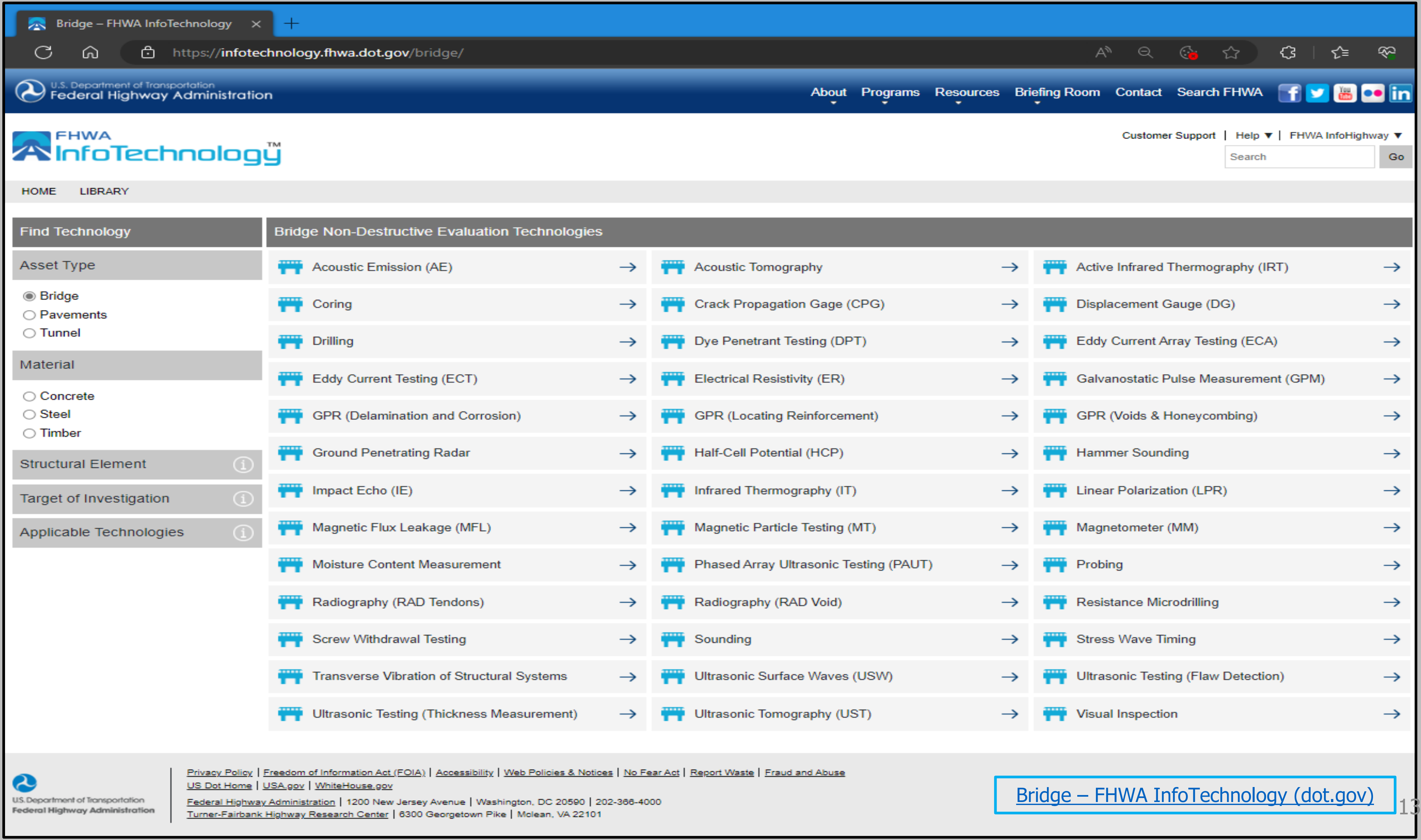

Bridge – FHWA InfoTechnology (dot.gov)

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robert.hinman@dot.gov
(614) 280-6837