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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
(NCHRP)

on Project 14-23

Handbook for Practical Bridge Preservation Actions and Investment Strategies

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by

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NOTE CONCERNING THE HANDBOOK SECTIONS

This document presents three formatted sections for the proposed Handbook. The developed sections, formatted in AASHTO style is provided as a separate file. An outline of the proposed additional section headings for a complete handbook is listed described in the Final Report for the project with annotations indicating planned contents.

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SECTION 1

INTRODUCTION

Many transportation departments have significant practical experience with bridge preservation and have developed conclusions regarding the effectiveness of bridge preservation actions based on those experiences. However, limited efforts have been made to identify, measure, evaluate, and document the short- and long-term performance of specific bridge preservation actions. Bridge preservation consists of actions to deter or correct deterioration of a bridge to extend its useful (service) life and does not entail structural or operational improvements beyond the originally designed strength or capacity of the bridge.

Often practitioners apply preservation strategies on the basis of judgment or common sense using available resources. However, it is difficult to translate these strategies into coherent and convincing arguments that will persuade legislatures and agency upper management to support and adequately fund aggressive and well planned programs of bridge preservation. These programs may be inadequately funded due to absence of a creditable, quantitative basis for measuring effectiveness.

1.1 Background, Objectives and Development Process

Based on the research under NCHRP Project 14-23 this Handbook was developed to assist state departments of transportation in making bridge preservation investment decisions for an individual bridge, for a category of bridges with similar characteristics, and at the network level. The content of the Handbook includes:

- Comparison of systems used to describe the major features of a bridge and guide the condition assessment of each (NBI, AASHTO CoRe, and AASHTO Bridge Element Inspection
- Definitions of terms related to preservation of bridge elements including element descriptions, typical defects occurring on each element, typical/feasible preservation actions and service conditions that impact the effectiveness of the preservation actions
- A catalog of bridge element preservation actions with
- Bridge elements organized by element and typical defects
- Feasible preservation actions for each type and level of severity/extent the of defect
- Estimated cost of the preservation actions, and
- Expected extension of element life under varying service conditions
- Metrics that can be used to analyze the effectiveness of bridge preservation actions considering when and which action to apply and the impacts of applying or delaying an action
- A method to prioritize bridge preservation actions according to the identified metrics – the method provides decision support for selecting among alternate preservation actions for elements, determining the impact on the element, determining costs, and compiling those actions for an individual bridge strategy
- A method to determine appropriate levels of funding to achieve bridge agency selected goals and performance measures at network-level bridge preservation – the method provides decision support for determining the appropriate level of funding over the planning horizon for a group of bridges and assessing the impact of the actions on the group of bridges.

- Software tools (based on Microsoft Excel) to apply the developed methods to assist in quantifying the benefits of selecting appropriate bridge preservation actions and investment strategies.

1.2 How to Use the Handbook

This Handbook has multiple uses. Chapter 2 provides detailed information on bridge elements, preservation actions that may be applied to elements and the service conditions that impact action effectiveness. Chapter 3 includes a catalog of preservation actions that can be applied to selected bridge elements as defined in the AASHTO Manual for Inspection of Bridge Elements, First Edition, 2013.

This section traces the evolution of systems for identifying and quantifying defects in bridges, first by major component and more recently by more specific elements. The element-level inspection system now provides standard descriptions of bridge elements as well as standard detailed language for defects that commonly occur on each element. This section also provides lists of general types of preservation actions and then provides action lists for each of the elements that are covered in the Handbook and the Catalog of Actions.

2.1 Bridge Condition Assessment

Periodic assessment of bridge conditions has been an important feature of bridge programs for inspection, maintenance, repair and eventual replacement of bridges for over four decades. In recent years there has been an increasing emphasis on preservation of bridges that are in good or fair condition rather than waiting until major repairs are necessary and assessment of the condition of a bridge is the first step in determining the best options for preservation of the various elements of the bridge. The first systematic approach to inspecting and categorizing the condition the bridge was established under the National Bridge Inspection Standards (NBIS). The current national standard in the United States is based on the NBI coding guide published by FHWA. During the safety inspections required under the NBIS, inspectors provide a general condition rating of the four major components of the bridge:

- Deck – Item 58,
- Superstructure – Item 59,
- Substructure – Item 60 and,
- Culvert – Item 62

These general condition ratings are qualitative in nature and provide an overall assessment of the entire deck, superstructure, and substructure of the bridge or an assessment of the condition of the culvert if the structure being inspected is a bridge length culvert. These four components share the same assessment descriptions and thus these descriptions are necessarily general.

The scale for evaluation of each component consists of numeric ratings from 0 through 9 where 0 is for a bridge that is in a failed condition, out of service and beyond corrective action and a rating of 9 indicates a new bridge. A condition of 3 or under is usually an unacceptable condition that requires immediate action. Other condition ratings that denote lesser damage include:

NBI Rating	Description of the Defect*
7	Good Condition - some minor problems.
6	Satisfactory Condition - structural elements show some minor deterioration.
5	Fair Condition - all primary structural elements are sound but may have minor section loss, cracking, spalling or scour.
4	Poor Condition - advanced section loss, deterioration, spalling or scour.

* *Excerpt from FHWA's Recording and Coding Guide for Structure Inventory and Appraisal of the Nation's Bridges, Report No. FHWA-PD-96-001*.

Ratings of 7, 6 and 5 generally indicate a condition where preservation actions may be feasible and cost-effective. The NBI ratings have been used successfully for many years to characterize the safety of the bridge and the general condition of the major components of the bridge. However, the qualitative nature of the rating scale, the use of very general descriptions for the defects and the fact that the ratings do not indicate the specific element of the component where the defect exists limits the use of these ratings as a basis for making decisions on effective preservation actions.

2.1.1 Condition State Systems

In order to support the functionality of modern bridge management systems a more detailed and granular approach to inspecting bridges and recording the condition the elements of the bridge was devised. This system was documented in the 2002 AASHTO Guide for Commonly Recognized (CoRe) Structural Elements. The original AASHTO CoRe element definitions had 3, 4 or 5 condition states. Each bridge was divided into several different elements and the quantity of each element was determined in appropriate units – length in feet, area in square feet, or a count of each. During the (usually) biennial bridge inspections, the quantity of each element in each of the applicable condition states is determined. The condition state definitions for the AASHTO CoRe elements were more specific and thus more helpful in determining the nature of the defect that needing repair or rehabilitation. For bridge management purposes, including developing preservation strategies, the CoRe element language was a useful development. Typical CoRe element condition states are shown in the table below.

Table 2.1 Typical CoRe Element Condition State Language

Element	**Reinforced Concrete Girder**
Condition State 1	Element shows little or no deterioration. There may be discoloration, efflorescence, and/or superficial cracking, but without effect on strength and/or serviceability.
Condition State 2	Minor cracks & spalls may be present, but there is no exposed reinforcing or surface evidence of rebar corrosion
Condition State 3	Some delaminations and/or spalls may be present, and some reinforcing may be exposed. Corrosion of rebar may be present, but loss of section is incidental and does not significantly affect the strength and/or the serviceability of either the element or the bridge.
Condition State 4	Deterioration is advanced. Corrosion of reinforcement and/or loss of section is sufficient to warrant analysis to ascertain the impact on the strength and/or serviceability of either the element or the bridge.

The evolution of bridge element descriptions condition state language continued with the adoption of the AASHTO Manual for Bridge Element Inspection (AASHTO, 2013) providing

revised set of element definitions and a consistent 1 to 4 scale for all element condition state data. The revised system includes a consistent set of National Bridge Elements, such as reinforced concrete deck, steel stringers and beams and concrete pier columns as well as a group of Bridge Management Elements (BME) including protective coating systems and deck wearing surface.

The tables below provide an illustration of the condition state definitions for typical defects that occur in reinforced concrete decks.

Table 2.2 Typical AASHTO Element Defect Condition State Language

Element	**Reinforced Concrete Deck Delamination/Spall/Patched Area**
Condition State 1	None.
Condition State 2	Delaminated. Spall 1 in. or less deep or 6 in. or less in diameter. Patched area that is sound.
Condition State 3	Spall greater than 1 in. deep or greater than 6 in. diameter. Patched area that is unsound or showing distress. Does not warrant structural review.
Condition State 4	Warrants structural review.
Element	**Reinforced Concrete Deck Cracking**
Condition State 1	Width less than 0.012 in. or spacing greater than 3.0 ft.
Condition State 2	Width 0.012–0.05 in. or spacing of 1.0–3.0 ft.
Condition State 3	Width greater than 0.05 in. or spacing of less than 1 ft.
Condition State 4	Warrants structural review.

Section 144 of the transportation legislation, Moving Ahead for Progress in the 21st Century (MAP 21), established the element language in the AASHTO Manual for Element Inspection as a new standard for reporting element condition data to FHWA. This approach to defining the condition of a bridge has several advantages when using condition data determine feasible actions and the best options for preservation of each individual element.

These advantages include:

- the element definitions include the material of which the element is made
- the descriptions of the defects for the damage to the element are more specific and represent common deficiencies that are found in the element's
- the quantity of each defect is also captured
- this type of data;
- is helpful in determining specific preservation actions that would be effective in preventing or slowing down the rate of deterioration of the element

- this type of data lends itself to deterioration modeling which can help determine the optimum timing for preservation actions

The nationwide application of the language in the AASHTO manual allows for the Handbook and the Catalog of Actions to be organized in a manner consistent with the manual.

2.1.2 Bridge Components & Elements

The system of inspection and condition rating required for the NBI rates only the major components of a bridge and uses general language to describe the condition of the component. This system does not provide adequate information upon which to base decisions on preservation actions. As noted above, the element descriptions and condition state language used in the AASHTO Manual for Bridge Element Inspection (AASHTO, 2013) can provide data that can be helpful in determining the type and timing of feasible preservation actions.

The catalog of preservation actions included in Chapter 3 of this Handbook is organized using the same element descriptions, units of measure and condition state language used in the AASHTO Manual. The example of an element definition and condition state language for defects for a reinforced concrete deck is provided in Table 2.4 for illustration.

Table 2.4 – AASHTO Element Definition and Defect Condition State Language

Element #: 12 — Reinforced Concrete Deck	
Description: This element defines all reinforced concrete bridge decks regardless of the wearing surface or protection systems used.	
Classification: NBE - National Bridge Element	**Units of Measurement:** SQ. FT.
Quantity Calculation: The quantity for this element includes the area of the deck from edge to edge including any median areas and accounting for any flares or ramps present.	

Condition State Definitions				
Defects	**1**	**2**	**3**	**4**
	GOOD	FAIR	POOR	SEVERE
Delamination/ Spall/ Patched Area (1080)	None	Delaminated. Spall 1 in. or less deep or 6 in. or less in diameter. Patched area that is sound.	Spalls greater than 1 in. deep or greater than 6 in. diameter. Patched area that is unsound or showing distress. Does not warrant structural review.	The condition warrants a structural review to determine the effect on strength or serviceability of the element or bridge; OR a structural review has been completed and the defects impact strength or serviceability of the element or bridge.
Exposed Rebar (1090)	None	Present without measurable section loss.	Present with measurable section loss, but does not warrant structural review.	
Efflorescence/ Rust Staining (1120)	None	Surface white without build-up or leaching without rust staining.	Heavy build-up with rust staining.	
Cracking (RC and Other) (1130)	Width less than 0.012 in. or spacing greater than 3.0 ft.	Width 0.012–0.05 in. or spacing of 1.0–3.0 ft.	Width greater than 0.05 in. or spacing of less than 1 ft.	
Load Capacity (5000)	No reduction	No reduction	No reduction	
Damage (7000)	Not applicable	The element has impact damage. The specific damage caused by the impact has been captured in condition state 2 under the appropriate	The element has impact damage. The specific damage caused by the impact has been captured in condition state 3 under the appropriate	The element has impact damage. The specific damage caused by the impact has been captured in condition state 4 under the appropriate

Condition State Definitions				
Defects	**1**	**2**	**3**	**4**
	GOOD	FAIR	POOR	SEVERE
		material defect entry.	material defect entry.	material defect entry.

Following the layout of the AASHTO Manual for Bridge Element Inspection (AASHTO, 2013), the matrix of elements are grouped into National Bridge Elements (NBEs) in Table 2.5 and Bridge Management Elements (BMEs) in Table 2.6, then by general element type, material, and in accordance to their physical location on the bridge to facilitate ease of use by planners and bridge inspectors in the field.

This section is designed to give Handbook users a quick reference guide to the elements included in the bridge preservation Handbook. Elements that are shown with a check mark (e.g.12 ☑) are included in the Handbook. Elements in italic (e.g. *28)* are not included in this Handbook.

Table 2.5 - National Bridge Elements

Decks and Slabs

Element	**Units**	**Decks**	**Slab**	**Other**
Reinforced Concrete Deck/Slab	AREA	12 ☑	38 ☑	
Prestressed Concrete Deck	AREA	13 ☑		
Prestressed Concrete Top Flange	AREA	15 ☑		
Reinforced Concrete Top Flange	AREA	16 ☑		
Steel Deck—Open Grid	AREA	*28*		
Steel Deck—Concrete Filled Grid	AREA	*29*		
Steel Deck—Corrugated/Orthotropic/Etc.	AREA	*30*		
Timber Deck/Slab	AREA	31☑	54☑	
Other Material Deck/Slab	AREA	*60*	*65*	
AREA = sq. ft.				

Railings

Element	Units	Steel	Prestressed Concrete	Reinforced Concrete	Timber	Masonry	Other
Metal Bridge Railing	LENGTH	330 ☑					
Reinforced Concrete Bridge Railing	LENGTH			331 ☑			
Timber Bridge Railing	LENGTH				332 ☑		
Other Bridge Railing	LENGTH						*333*
Masonry Bridge Railing	LENGTH					*334*	

LENGTH= ft.

Superstructure

Element	Units	Steel	Prestressed Concrete	Reinforced Concrete	Timber	Masonry	Other
Girder/Beam	LENGTH	107 ☑	109 ☑	110 ☑	111 ☑		*112*
Closed Web/Box Girder	LENGTH	*102*	*104*	*105*			*106*
Stringer	LENGTH	113 ☑	115 ☑	116 ☑	117 ☑		*118*
Truss	LENGTH	*120*			*135*		*136*
Arch	LENGTH	*141*	*143*	*144*	*146*	*145*	*142*
Floor Beam	LENGTH	152 ☑	154 ☑	155 ☑	156 ☑		*157*
Cable - Primary	LENGTH	*147*					
Cable – Secondary	EA	*148*					*149*
Gusset Plate	EA	*162*					
Pin, Pin and Hanger Assembly, or both	EA	*161*					

LENGTH= ft.
EA = each (counted)

Bearings

Element	Units	Steel	Prestressed Concrete	Reinforced Concrete	Timber	Masonry	Other
Elastomeric	EA						310 ☑
Moveable (roller, sliding, etc.)	EA						311 ☑
Enclosed/Concealed	EA						*312*
Fixed	EA						313 ☑
Pot	EA						*314*
Disk	EA						*315*
Other	EA						*316*

EA = each (counted)

Substructure

Element	Units	Steel	Prestressed Concrete	Reinforced Concrete	Timber	Masonry	Other
Columns	EA	*202*	204 ☑	205 ☑	206 ☑		*203*
Column Tower (Trestle)	LENGTH	*207*			*208*		
Pier Wall	LENGTH			*210*	*212*	*213*	*211*
Abutment	LENGTH	*219*		215 ☑	216 ☑	217 ☑	*218*
Pile	EA	*225*	*226*	*227*	*228*		*229*
Pier Cap	LENGTH	*231*	233 ☑	234 ☑	235 ☑		*236*
Pile Cap/Footing	LENGTH			*220*			

Element	Units	Steel	Prestressed Concrete	Reinforced Concrete	Timber	Masonry	Other
LENGTH= ft. EA = each (counted)							

Culverts

Element	Units	Steel	Prestressed Concrete	Reinforced Concrete	Timber	Masonry	Other
Culvert	LENGTH	*240*	*245*	*241*	*242*	*244*	*243*
LENGTH= ft.							

Table 2.6 - Bridge Management Elements

Joints

Element	Units	Element Number
Strip Seal Expansion Joint	LENGTH	300 ☑
Pourable Joint Seal	LENGTH	301 ☑
Compression Joint Seal	LENGTH	302 ☑
Assembly Joint/Seal (Modular)	LENGTH	303 ☑
Open Expansion Joint	LENGTH	304 ☑
Assembly Joint without Seal	LENGTH	305 ☑
Other Joint	LENGTH	*306*
LENGTH= ft.		

Approach Slabs

Element	Units	Element Number
Prestressed Concrete Approach Slab	AREA	*320*
Reinforced Concrete Approach Slab	AREA	*321*
AREA = sq. ft.		

Wearing Surfaces, Protective Coatings and Concrete Reinforcing Steel Protective Systems

Element	Units	Element Number
Wearing Surfaces	AREA	510 ☑
Steel Protective Coating	AREA	515 ☑
Concrete Reinforcing Steel Protective System	AREA	*520*
Concrete Protective Coating	AREA	*521*
AREA = sq. ft.		

2.1.3 Service Environment Definitions

The environment of a bridge element affects the rate of deterioration of the element and the rate of deterioration of any protective system for the element. Operational factors such as volume and weights of live loads from truck traffic also affect the rates of deterioration of some elements and some protective systems such as deck wearing courses. Service factors influencing deterioration include:

- Freeze-thaw cycles
- De-icing chemical exposure
- Wet-dry cycles
- Marine exposure
- Truck traffic loads and volume

All bridges owned by an agency are usually not in the same environment. Furthermore, all elements of a bridge are not subjected to the same environment. For example, decks are more affected by truck traffic than are superstructures and substructures. The degree to which superstructure and substructure are impacted by de-icing chemical spray from vehicles may

depend on whether there is a roadway under the bridge. The service environments used are the same as those defined by the AASHTO Manual of Bridge Element Inspection. Although agencies may be initially coding the entire bridge in a single service environment, there are advantages to coding the deck, superstructure, and substructure environments independently. Descriptions are provided in Table 2.7.

Table 2.7 Service Environment Characteristics

Environment	Description
1—Benign	Neither environmental factors nor operating practices are likely to significantly change the condition of the element over time, or their effects have been mitigated by the presence of highly effective protective systems.
2—Low	Environmental factors, operating practices, or both either do not adversely influence the condition of the element, or their effects are substantially lessened by the application of effective protective systems.
3—Moderate	Any change in the condition of the element is likely to be quite normal as measured against the environmental factors, operating practices, or both that are considered typical by the agency.
4—Severe	Environmental factors, operating practices, or both, contribute to the rapid decline in the condition of the element. Protective systems are not in place or are ineffective.

The use of Service Environments in this fashion for enhancing the preservation process implies that agencies would, when using the analysis tool, classify the elements accordingly and gradually build this inventory information as an adjunct for the system. The customization of the Service Environments also applies in the Catalog of Actions where the projection of extension of life of each element is provided for each of four Service Environments for each element, element defect and feasible action.

2.2 Preservation Action Descriptions

Previous descriptions of feasible action types for each of the CoRe elements were general in nature. For example, the descriptions of types of actions included in the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements – December 1997, were:

- **Do Nothing** – Let the element deteriorate to a point where the action was most effective
- **Preemptive actions** – The element is treated prior to the start of any deterioration processes to prevent or forestall the initiation of deterioration.
- **Clean and Restore** – Process to remove the deterioration of the protective system and replace the removed material. This process is primarily for paint systems.
- **Repair** – In discrete sections of the element, fix the issue that is causing the condition to be less than Condition State 1.

- **Rehabilitate** – Work that is done to restore the structural integrity of the element. The rehabilitation process restores the element to near new. Some of the issues still remain such as age and material limitations.
- **Replace** – Removal and replacement in-kind of the element is completed. The element is restored to new.

2.2.1 General Categories of Feasible Actions

The descriptions of these actions were general and the cost for taking the action on a specific element could not be determined for the action. Feasible actions are now commonly described as being cyclical preservation actions, condition based preservation actions, repairs or rehabilitation. Replacement of individual parts of an element, such as replacing a portion of a timber deck, are also classified as rehabilitation. Replacement of the entire element is the final choice when the element condition is beyond cost-effective repair or rehabilitation. General types of feasible actions for cyclical activities, preservation activities & repair and rehabilitation activities are provided in the Tables 2.8 through 2.10.

Table 2.8 Cyclical Activities

Activity	Description
Wash	Washing of selected portions of components, usually those portions exposed to salt, salt spray, or standing water. These can include parapets facing traffic, gutters in decks, and areas below open joints. Any selective washing of portions of structures.
Sweep	Dry removal of sand, grit, or other minor detritus on bridge components.
Flush	The use of water at higher flow rate and/or pressure to clear more substantial size or amounts of detritus on bridge components.
Cleanouts	Maintenance of scuppers, troughs, pipes, and other drainage elements. Methods entail opening grates and cleanouts, removal of waste material, flushing as needed and reassembly of parts.
Vegetation	Trimming and/or removal of brush, trees, etc., on slopes, approach embankments, channel banks and within channels.
Tighten	Checking and tightening of bolts, anchors, rods and other threaded parts. *Tighten* also includes replacement of missing fasteners in otherwise complete connections.
Caulk	Removal and replacement of caulk in railings, fixed joints and construction joints.
Lubricate	Inspection and lubrication of bearings, expansion joints, railing joints and other moving or sliding parts.
Reposition	Inspection and re-centering or re-alignment of bearings, joints, and other parts needing periodic adjustment.

Table 2.9 Preservation Activities

Activity	Description

Activity	Description
Paint	Application of paint on bridge components, usually to an entire component.
Spot Paint, Zone Painting	Application of paint on selected areas of components that may include: areas of deteriorated paint, areas of special exposure (splash zones), damaged areas (as by collision), ends of beams, etc.
Seal Surface	Application of water-repelling or other surface treatments, usually to concrete or asphalt surfaces.
Seal	Use of epoxy, high-weight methyl-methacrylate or other pourable materials to fill existing cracks. Usually applied to concrete surfaces, but can be crack sealing in surfaces and crack sealing in timber elements.
Asphaltic Overlay	Waterproof membranes with asphaltic overlay on new or existing bridges usually provides an expendable wearing surface to extend the life of the concrete deck
Chemical Treatments	Surface application of preservatives for timber components. Surface application of herbicides or pesticides on slopes as part of bridge maintenance.
Surface Preparation	Preparation of surfaces for coating or painting if separate tracking of preparation cost is desired. Otherwise, surface preparation is part of a coating or painting action.

Table 2.10 Repair and Rehabilitation Activities

Activity	Description
Patch	Repairs to concrete components, concrete surfaces, or asphalt surfaces by filling with cementitious or bituminous material
Re-attach / Re-anchor	Work to restore lost or weakened anchors for railings, joints, bearings, or other components.
Straighten	For metal components, the use of bending or heat to restore proper shape.
Jack/Align	For pavements or substructures, the use of jacking and filling to mitigate tilting or settlement.
Reinforce /Strengthen	Application of welds, scab plates, concrete jackets, cables, post-tensioning, etc., to restore strength to weakened structural components.
Overlay	For bridge decks/slabs, removal of layer (shallow or deep) of deteriorated concrete and replace with thin overlay.

2.2.2 Element-Specific Action Lists

More specific lists of feasible actions, linked to each element covered in the Handbook are shown in Tables 2.11 through 2.31.

Table 2.11 Preservation Actions for: Reinforced Concrete Decks (12), Slabs (38) & Top Flanges (16); Prestressed Concrete Decks (13) & Top Flanges (15)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Dry Sweep and/or Wash Deck, Parapets, etc.	SQFT	Water
PRESERVE	Seal Deck/Slab Cracks (Pourable Sealant)	SQFT	Crack Sealant
PRESERVE	Seal Deck/Slab Cracks (Pressure Inject Epoxy)	LINFT	Epoxy
PRESERVE	Seal Deck/Slab	SQFT	Sealer
PRESERVE	Asphaltic Overlay Wearing Surface	SQFT	Plantmix Bituminous Surface
REPAIR	Seal **Crack** in Asphalt Wearing Surface	LINFT	Patching

Table 2.11 Preservation Actions for: Reinforced Concrete Decks (12), Slabs (38) & Top Flanges (16); Prestressed Concrete Decks (13) & Top Flanges (15) (continued)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
REPAIR	Remove and Replace Asphalt Wearing	SQYD	Removal Of Bituminous Surface
			Plantmix Surfacing
			Plantmix Surfacing
REPAIR	Repair Deck/Slab Spalling/Delamination (Partial Depth)	SQFT	Removal Of Portion Of Deck
			Polymer Concrete Aggregate
			Polymer Concrete Resin
			Reinforcing Steel (Epoxy)
REPAIR	Repair Deck/Slab Spalling/Delamination (Full Depth) – RC Deck/Slab Only	SQFT	Removal Of Concrete Slab
			Fast-Setting Concrete
			Reinforcing Steel (Epoxy)
REPAIR	Repair Deck/Slab Soffit Spalling/Delamination	SQFT	Fast-Setting Concrete
REPAIR	Place Polymer Concrete Overlay	SQFT	Prep & Concrete Placement
			Polymer Concrete Aggregate
			Polymer Concrete Resin
			Polymer Concrete Overlay
REPAIR	Remove Deck Seal Concrete and Place Polymer Concrete Overlay	SQFT	Removal Of Portion Of Deck
			Prep & Concrete Placement
			Polymer Concrete Aggregate
			Polymer Concrete Resin
REPAIR	Remove and Replace Polymer Concrete Overlay	SQFT	Removal Of Portion Of Deck
			Prep & Concrete Placement
			Polymer Concrete Aggregate
			Polymer Concrete Resin
REHAB	Replace Portion of Concrete Deck	SQFT	Removal Of Concrete Slab
			Concrete
			Reinforcing Steel (Epoxy)

Table 2.12 Preservation Actions for Timber Decks (31) & Slabs (34)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Dry Sweep and/or Wash Deck/Slab, Parapets, etc.	SQFT	Water
CYCLICAL	Tighten Bolts or Replace Nails/Connectors	EA	Hardware/Connectors
PRESERVE	Seal Timber Deck/Slab	SQFT	Sealant
PRESERVE	Treat for Insects	SQFT	Insecticide
REPAIR	Repair Timber Deck/Slab Planking / Replace Only Deteriorated Portions	LBF	Timber Planks
REHAB	Replace All Timber Deck/Slab Planks	LBF	Removal Of Timber Planks
			Timber Planks

Table 2.13 Preservation Actions for: Steel Girder/Beams (107), Stringer (113) & Floor Beams (152)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Wash/Flush Superstructure Members	LFT	Water
PRESERVE	Clean & Spot Paint	SQFT	Hand & Power Cleaning Tools
			Paint; applicators
PRESERVE	Clean & Zone Painting	SQFT	Hand & Power Cleaning Tools
			Paint; applicators
PRESERVE	Overcoat Superstructure	SQFT	Hand Cleaning Tools
			Paint; applicators
REPAIR	Remove & Replace Coating System	SQFT	Hand & Power Cleaning Tools
			Paint; applicators
REPAIR	Repair Areas of Section Loss	SQFT	Repair Materials
REHAB	Fatigue Crack Mitigation	SQFT	

Table 2.14 Preservation Actions for Reinforced Concrete Girder/Beams (110), Stringer (116) & Floor Beams (155); Prestressed Concrete Girder/Beams (109), Stringer (115) & Floor Beams (154)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Wash/Flush Superstructure Members	LFT	Water
PRESERVE	Coat Concrete Members	LFT	Concrete Coating
REPAIR	Seal Cracks	LFT	Sealant
REPAIR	Clean & Patch Spalls	SQFT	Chipping Tools
			Concrete Patch Material
REPAIR	Repair Girder/Beam Ends	SQFT	Chipping Tools
			Concrete Patch Material

Table 2.15 Preservation Actions for Timber Girder/Beams (110), Stringer (116) & Floor Beams (155)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Wash/Flush Superstructure Members.	LFT	Water
CYCLICAL	Tighten Bolts or Replace Nails/Connectors	EA	Hardware/Connectors
PRESERVE	Seal Timber Superstructure Members	LFT	Sealant
PRESERVE	Treat for Insects	LFT	Insecticide
REPAIR	Repair Timber Superstructure Members / Replace Only Deteriorated Portions	LBF	Timber Members
REHAB	Replace Timber Superstructure Members	LBF	Removal Of Timber Members
			Timber Members

Table 2.16 Preservation Actions for Reinforced Concrete Columns (205), Abutments (215) &Pier Caps (234); Prestressed Concrete Columns (204), & Pier Caps (233)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Wash/Flush Substructure Members.	LFT	Water
PRESERVE	Coat Concrete Substructure Members	LFT	Concrete Coating
REPAIR	Seal Cracks	LFT	Sealant
REPAIR	Clean & Patch Spalls	SQFT	Chipping Tools
			Concrete Patch Material
REHAB	Replace Deteriorated Columns & Caps	EA	Removal of Deteriorated Member
			Concrete, rebars

Table 2.17 Preservation Actions for Timber Columns (206), Abutments (216) & Pier Caps (235)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Wash/Flush Substructure Members	LFT	Water
CYCLICAL	Tighten Bolts or Replace Nails/Connectors	EA	Hardware/Connectors
PRESERVE	Seal Timber Substructure Members	SQFT	Sealant

Table 2.17 Preservation Actions for Timber Columns (206), Abutments (216) & Pier Caps (235)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
REPAIR	Repair Timber Substructure Members / Replace Only Deteriorated Portions	LBF	Timber Planks
REHAB	Replace Timber Substructure Members	LBF	Removal Of Timber Planks
			Timber Planks

Table 2.18 Preservation Actions for Steel Bridge Railings (330)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Wash Steel Bridge Railings	LFT	Water
CYCLICAL	Tighten Bolts or Replace Connections	EA	Hardware/Connectors
PRESERVE	Clean & Paint	LFT	Hand & Power Cleaning Tools
			Paint; applicators
REPAIR	Repair Damaged Rail Sections	LFT	Railing Sections
REHAB	Remove & Replace Damaged Rail Sections	LFT	Railing Sections

Table 2.19 Preservation Actions for Reinforced Concrete Bridge Railings (331)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Wash Reinforced Concrete Bridge Railings	LFT	Water
CYCLICAL	Tighten Bolts or Replace Nails/Connectors	EA	Hardware/Connectors
PRESERVE	Seal/Coat Reinforced Concrete Bridge Railings	LFT	Sealant
REPAIR	Repair Reinforced Concrete Bridge Railings	LFT	Railing Sections
REHAB	Remove & Replace Damaged Rail Sections	LFT	Removal of Deteriorated Member
			Concrete, rebars

Table 2.20 Preservation Actions for Timber Bridge Railings (332)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Wash Timber Bridge Railings	LFT	Water
CYCLICAL	Tighten Bolts or Replace Nails/Connectors	EA	Hardware/Connectors
PRESERVE	Seal Timber Railings	LFT	Sealant
PRESERVE	Treat for Insects	LFT	Insecticide
REPAIR	Repair Timber Railings	LBF	Timber Planks
REHAB	Replace Timber Railings	LBF	Removal Of Timber Railings
			NewTimber Railings

Table 2.21 Preservation Actions for Elastomeric Bearings (310)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Wash Bearing Area, Remove Debris	EA	Water
REPAIR	Replace Anchors	EA	
REPAIR	Reset Bearings	EA	
REHAB	Replace Bearings	EA	Jack Superstructure
			New Bearings

Table 2.22 Preservation Actions for Actions for Moveable Bearings (311)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Wash Bearing Area, Remove Debris	EA	Water
REPAIR	Replace Anchors	EA	
REPAIR	Reset Bearings	EA	
PRESERVE	Clean & Coat Bearings	EA	Cleaning Tools; Coating
REHAB	Replace Bearings	EA	Jack Superstructure
			New Bearings

Table 2.23 Preservation Actions for Actions for Fixed Bearings (313)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Wash Bearing Area, Remove Debris	EA	Water
REPAIR	Replace Anchors	EA	
REPAIR	Reset Bearings	EA	
PRESERVE	Clean & Coat Bearings	EA	Cleaning Tools; Coating
REHAB	Replace Bearings	EA	Jack Superstructure
			New Bearings

Table 2.24 Preservation Actions for Strip Seal Expansion Joint (301)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Clean & Reseal Joints.	LFT	Water; Joint Sealer
REPAIR	Remove, Replace Deteriorated Joint Sections	LFT	Joint Material
REHAB	Remove, Replace Entire Joint	LFT	Joint Material

Table 2.25 Preservation Actions for Pourable Joint Seal Joints (302)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Clean & Reseal Joints.	LFT	Water; Joint Sealer
REPAIR	Remove, Replace Deteriorated Joint Sections	LFT	Joint Material
REHAB	Remove, Replace Entire Joint	LFT	Joint Material

Table 2.26 Preservation Actions for Compression Joint Seal Joints (303)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Clean & Reseal Joints.	LFT	Water; Joint Sealer
REPAIR	Remove, Replace Deteriorated Joint Sections	LFT	Joint Material
REHAB	Remove, Replace Entire Joint	LFT	Joint Material

Table 2.27 Preservation Actions for Assembly Joint with Seal (304)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Clean & Reseal Joints.	LFT	Water; Joint Sealer
REPAIR	Remove, Replace Deteriorated Joint Sections	LFT	Joint Material
REPAIR	Repair Joint Header	LFT	Concrete
REHAB	Remove, Replace Entire Joint	LFT	Joint Material

Table 2.28 Preservation Actions for Open Expansion Joint (305)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
REPAIR	Remove, Replace Deteriorated Joint Sections	LFT	Joint Material
REPAIR	Repair Joint Header	LFT	Concrete
REHAB	Remove, Replace Entire Joint	LFT	Joint Material

Table 2.29 Preservation Actions for Assembly Joint without Seal (306)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
REPAIR	Remove, Replace Deteriorated Joint Sections	LFT	Joint Material
REPAIR	Repair Joint Header	LFT	Concrete
REHAB	Remove, Replace Entire Joint	LFT	Joint Material

Table 2.30 Preservation Actions for Wearing Surfaces (510)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Dry Sweep and/or Wash Deck	SQFT	Water
PRESERVE	Seal Wearing Surface Cracks	EA	Sealant
PRESERVE	Seal Wearing Surface	SQFT	Sealant
REHAB	Remove & Replace Wearing Surface	LBF	Removal Of Wearing Surface
			New Wearing Surface

Table 2.31 Actions for Steel Protective Coatings (515)

CATEGORY	ACTION	UNIT	ACTION COMPONENTS
CYCLICAL	Wash/Flush Superstructure & Substructure Members	SQFT	Water
PRESERVE	Apply Protective Coating	SQFT	Apply Coating System
REPAIR	Clean Deteriorated Coatings; Recoat	SQFT	Remove Existing Coating
			Apply Coating System
REPAIR	Remove & Replace Protective Coating	SQFT	Remove Existing Coating
			Apply Coating System

2.3 Preservation Decision Metrics

In order to support decision-making about feasible preservation actions, ways to measure of the impact and the effectiveness of the action are necessary. Preservation actions result in two possible types of impact: in some cases, the preservation action does not improve the condition state of the element but serves to increase the time that the element remains in its current state; in other cases, the preservation action “resets” the condition state of the element to a higher level. In both cases, the action is intended to extend the service life of the element. In the former case, the measure of the impact and effectiveness of the preservation action is not immediately apparent and the proof of performance of the action will be only revealed years later. In the latter case, proof the impact comes immediately in the improvement in condition state; however proof of the overall effectiveness of the action in extending the service life of the element must wait for years to pass.

Three factors must be considered when evaluating the possible data and metrics needed. First, what is essential data for use in a practical analytical model? Second, what is reasonable to expect might be available as basic bridge data from the inspection process and what can be reasonably distilled by agencies (such as costs and impacts) from their records or from their subject matter experts? Finally, what are the metrics that indicate impacts of preservation actions on the bridge elements?

Any metric considered for use in measuring impact and effectiveness of preservation actions should undergo a thorough evaluation which addresses the following factors:

- What information is necessary to support calculation of the metric,
- How that information is or could be collected and the costs associated with collection,
- How that information is or could be stored and accessed for analysis,
- Availability of historical records of that information,
- The method of calculating the metric,
- Relative granularity of the data- for example the NBI condition rating of 6 for a superstructure as compared to the assessment of superstructure girders using element level condition data for several condition states, as compared to data collected from specific test procedures such half-cell potential readings
- Potential for direct or indirect correlation of the metric to bridge preservation actions
- The rate at which the data changes as a function of time and typical degradation processes that affect bridge components,
- Potential for use of the information as a trigger for optimum deployment timing of the preservation action,
- Potential for use of the information to predict/measure the life of preservation and maintenance action before return to original application state, and
- Potential for use of the information to predict/measure the life cycle cost effectiveness of preservation and maintenance action.

In prioritizing potential metrics, the highest priorities are given to metrics that are practical and effective, that would be simple to incorporate in the agency's bridge management programs.

Some features that weigh most heavily in the priorities are:

- The relative ease by which the metric can be implemented by agencies;
- The degree to which data (NBI ratings, element level condition state data, etc.) that is currently collected can be used to calculate the metric;
- Any additional costs of using the metric such as personnel, training, inspection technology, data collection costs and IT costs for data management; and,
- The clarity of the connection between the metric and an extension of service life.

The metrics that are considered most useful for measuring the effectiveness of preservation actions include:

- Impact of each preservation option:
  - Increase in element condition state
  - Prolonged time in element condition state
  - Service life estimate of preservation treatment
  - Extension of the service life of the element as a result of the action
- Impact of actions on bridge condition:
  - Increase in bridge average element condition state
  - Increase in bridge weighted average condition state
  - Increase in bridge health index
- Impact of actions on a selected network of bridges:
  - Increase in bridge network average condition states of elements
  - Increase in bridge network average element condition state
  - Increase in bridge network weighted average condition state
  - Increase in bridge network health index.

The Catalog of Preservation Actions is a reference tool intended to assist bridge preservation practitioners select a cost-effective approach to preservation of an element on a bridge or of the same element on a group of bridges that serve in a consistent Service Environment. The Catalog is organized in a manner that is consistent with the AASHTO Manual for Inspection of Bridge Elements. The element descriptions are the same as the AASHTO Manual and each element has four condition states with the same language as the Manual.

To use the Catalog, the user must select the element and provide two input parameters: the condition state of the element that the agency wishes to affect by application of a preservation treatment and the service environment in which the bridge element is situated. For each element and each condition state, the Catalog provides feasible actions for element preservation. The Do Nothing option is always included as are actions that represent cyclical preservation treatments, condition-based preservation actions as well as repair and rehabilitation actions. The preservation actions are classified in the manner used in Section 2.2.1, General Categories of Feasible Actions. For example, if a reinforced concrete element is in Condition State 2 in the presence of cracking, a feasible action may be sealing the cracks. The Catalog does not specify a type of sealer.

Once the element, the condition state, and the Service Environment are identified, the Catalog provides the estimated cost of the action on a per unit basis, the impact of the action on the condition state of the element, the expected time period before repetition of the treatment would be necessary and the expected extension of life of the element.

The impact of the preservation action on the condition state of the element falls into one of two categories: The action preserves the element without any change in the condition and element life is extended for a period of time; or, the action preserves the element and raises the condition of the element and element life is extended for a period of time.

The parameter values in the Catalog are based on generic scenarios, but the Catalog is not intended to be a “one size fits all” product. The values in the tables of the Catalog will vary significantly from state to state and also within a particular state. The Catalog is designed to allow for customization by the user. Features that can be customized include: the specific details of each type of preservation action. For example, the user may wish to specify a type of sealer material. Based on that decision, the user can, if desired adjust the other factors in the table for cost of the action, expected need for retreatment and expected extension of life for the element. If desired, the user may customize the Service Environment definitions, the action costs, the expected period before which retreatment would be necessary and the extension of life of the element. In doing so, the user can make allowances for preferred practices, regional cost variations, the difference between cost of treatments applied by state forces and contract bid costs as well as performance history for the treatment in different Service Environments.

Figure 3.1 on the following pages provide an example of the Catalog format for AASHTO deck element #12, reinforced concrete deck/slab, and the element defects being addressed by preservation actions are cracking and delaminations/spalls/patched areas, with values for cost, effect on element condition, expected life of the treatment and expected extension of life of the element as a result. The full catalog is presented in Appendix A.

Figure 3.1 – Example Catalog Pages
Element #: 12 — Reinforced Concrete Deck

Description: This element defines all reinforced concrete bridge decks regardless of the wearing surface or protection systems used.

Defect: Cracking

State	Condition Description	Activity Category	Action	Resulting Condition State		Cost of Action ($)	Units	Service Environment (SE)							
								SE1		SE2		SE3		SE4	
								Action Cycle (yrs)	Element Added Life (yrs)	Action Cycle (yrs)	Element Added Life (yrs)	Action Cycle (yrs)	Element Added Life (yrs)	Action Cycle (yrs)	Element Added Life (yrs)
1	Width less than 0.012 in. or spacing greater than 3.0 ft.	Do Nothing	--	1	None	0.00	SQ FT	50	0	42	0	35	0	25	0
		Cyclical	Clean and Wash	1	No change – sustains current conditions	0.50	SQ FT	50	0	5	0.5	2	0.5	1	0.5
		Preserve	Seal Cracks	1	No change – sustains current conditions	2.00	SQ FT	10	3.8	8	2.5	6	1.8	4	1
		Preserve	Thin Overlay	1	No change – sustains current conditions	10.00	SQ FT	25	20	20	15	15	10	12	5
2	Width 0.012–0.05 in. or spacing of 1.0–3.0 ft.	Do Nothing	--	2	None	0.00	SQ FT	50	0	42	0	35	0	25	0
		Cyclical	Wash	2	No change – sustains current conditions	0.50	SQ FT	50	0	5	0.5	2	0.5	1	0.5
		Preserve	Seal Cracks	2	No change – sustains current conditions	2.50	SQ FT	10	3.8	8	2.5	6	1.8	4	1
		Preserve	Thin Overlay	2	No change – sustains current conditions	15.00	SQ FT	25	20	20	15	15	10	12	5

Figure 3.1 – Example Catalog Pages (continued)

Defect: Cracking (continued)

State	Condition Description	Activity Category	Action	Resulting Condition State		Cost of Action ($)	Units	Service Environment (SE)							
								SE1		SE2		SE3		SE4	
								Action Cycle (yrs)	Element Added Life (yrs)	Action Cycle (yrs)	Element Added Life (yrs)	Action Cycle (yrs)	Element Added Life (yrs)	Action Cycle (yrs)	Element Added Life (yrs)
3	Width greater than 0.05 in. or spacing of less than 1 ft	Do Nothing	--	3	No Change	0.00	SQ FT	50	0	42	0	35	0	25	0
		Preserve	Seal Cracks	3	sustains current conditions	3.00	SQ FT	10	3.8	8	2.5	6	1.8	4	1
		Rehab	Thin Overlay	2	Reset to Condition 2	20.00	SQ FT	25	-	21	-	18	-	15	-
4	Warrants structural review	Do Nothing	--	4	None	0.00	SQ FT	0	0	0	0	0	0	0	0
		Rehab	Thin Overlay	2	Reset to Condition 2	30.00	SQ FT	20	-	21	-	18	-	15	-
		Replace	Remove and Replace	1	Reset to Condition 1	60.00	SQ FT	50	-	42	-	35	-	25	-

Note: Estimated costs only include direct cost; indirect costs such maintenance of traffic, engineering and other miscellaneous are not included.

Figure 3.1 – Example Catalog Pages (continued)

Defect: Delamination/Spall/Patched Area

State	Condition Description	Activity Category	Action	Resulting Condition State		Cost of Action ($)	Units	Service Environment (SE)							
								SE1		SE2		SE3		SE4	
								Action Cycle (yrs)	Element Added Life (yrs)	Action Cycle (yrs)	Element Added Life (yrs)	Action Cycle (yrs)	Element Added Life (yrs)	Action Cycle (yrs)	Element Added Life (yrs)
1	None	Do Nothing	--	1	None	0.00	SQ FT	50	0	42	0	35	0	25	0
		Cyclical	Clean and Wash	1	No change – sustains current conditions	0.50	SQ FT	50	0	5	0.5	2	0.5	1	0.5
		Preserve	Seal Deck	1	No change – sustains current conditions	2.50	SQ FT	10	8	10	8	10	6	10	4
		Preserve	Thin Overlay	1	No change – sustains current conditions	10.00	SQ FT	25	20	20	15	15	10	10	5
2	Delaminated. Spall 1 in. or less deep or 6 in. or less in diameter. Patched area that is sound.	Do Nothing	--	2	None	0.00	SQ FT	50	0	42	0	35	0	25	0
		Cyclical	Clean & Wash	2	No change – sustains current conditions	0.50	SQ FT	50	0	5	0.5	2	0.5	1	0.5
		Preserve	Seal Deck	2	No change – sustains current conditions	2.50	SQ FT	10	8	10	5	8	4	8	3
		Repair	Clean and Patch	2	No change – sustains current conditions	30.00	SQ FT	10	7	8	6	6	3	4	2
		Preserve	Thin Overlay	2	No change – sustains current conditions	15.00	SQ FT	25	20	15	12	10	7	10	5

Figure 3.1 – Example Catalog Pages (continued)

Defect: Delamination/Spall/Patched Area (continued)

State	Condition Description	Activity Category	Action	Resulting Condition States		Cost of Action ($)	Units	Service Environment (SE)							
								SE1		SE2		SE3		SE4	
								Action Cycle (yrs)	Element Added Life (yrs)	Action Cycle (yrs)	Element Added Life (yrs)	Action Cycle (yrs)	Element Added Life (yrs)	Action Cycle (yrs)	Element Added Life (yrs)
3	Spall greater than 1 in. deep or greater than 6 in. diameter. Patched area that is unsound or showing distress. Does not warrant structural review.	Do Nothing	--	3	None	0.00	SQ FT	50	0	42	0	35	0	25	0
		Cyclical	Clean and Wash	3	No change – sustains current conditions	0.50	SQ FT	50	0	5	0.5	2	0.5	1	0.5
		Preserve	Seal Deck	3	No change – sustains current conditions	2.50	SQ FT	10	6	10	4	8	3	8	3
		Repair	Clean and Patch	2	Reset to Condition 2	30.00	SQ FT	10	7	8	6	6	3	4	2
		Preserve	Thin Overlay	2	Reset to Condition 2	20.00	SQ FT	25	20	15	12	10	7	10	5
		Rehab	Concrete Overlay	1	Reset to Condition 1	20.00	SQ FT	30	25	30	20	20	15	20	10
4	Warrants structural review	Do Nothing	--	4	None	0.00	SQ FT	50	0	42	0	35	0	25	0
		Repair	Clean and Patch	3	No change – sustains current conditions	30.00	SQ FT	10	-	8	-	6	-	4	-
		Rehab	Concrete Overlay	2	No change – sustains current conditions	20.00	SQ FT	30	15	30	15	20	10	20	5
		Replace	Remove and Replace	1	Reset to Condition 1	60.00	SQ FT	50	0	42	0	35	0	25	0

Note: Preliminary data for the various catalog tables has been compiled in an excel spreadsheet for populating the catalog tables electronically and for populating the database of the proposed decision support tool. The data should be adjusted by the user to reflect the costs, durations and impacts experienced by their agency. The Final Report Appendix E tables were generated from the data in the spreadsheet named: *NCHRP 14-23 Sample Action Impact Metric Summary Tables 2014-03-31*