Bridge Management Systems Workshop

Participant Workbook

November 2020

U.S. Department of Transportation
Federal Highway Administration

Disclaimer

FHWA does not promote or endorse patented and proprietary products. Bridge management software is largely proprietary. Workshop content pertaining to proprietary software is included only to illustrate how bridge management system concepts and analyses are applied in practice. The included content shall not be construed as promotion or endorsement of specific software.

Table of Contents

Introduction

State Departments of Transportation (DOTs) are using bridge management system (BMS) software programs and analysis tools for different purposes. Many are just beginning to use BMS for analyzing investment strategies and recommending work actions and projects in accordance with an optimal investment strategy. Also, many are just beginning to use BMS to support decision making that considers long-term benefits of proposed work including life-cycle cost, condition, functional, and risk reduction-based benefits.

The Moving Ahead for Progress in the 21st Century legislation (MAP-21) as incorporated in 23 USC 119 requires that each State DOT develop an asset management plan for the National Highway System. Furthermore, MAP-21 legislation as incorporated in 23 USC 150 requires the use of BMS when developing and implementing asset management plans. These requirements are continued in Fixing America's Surface Transportation Act.

Given the state of current practice, some State DOTs require knowledge enhancement, implementation assistance, or opportunities to discuss questions and challenges associated with implementing and using their BMS. This workshop will serve as a resource to help address these needs. This will be a technical workshop and will not present or address Federal law or regulatory requirements.

Target Audience

The target audience for the BMS Workshop includes bridge management engineers, asset managers, bridge engineers, bridge managers, and data and systems support staff. It shall be assumed that participants have a basic to intermediary understanding of BMS, and the workshop content shall aim to raise participant understanding beyond basic to intermediate.

Agenda

The BMS Workshop is presented over the course of two days. The topics presented on Day 1 provide foundational information regarding BMS software operations. The Day 2 and Day 3 (referred to as Day 2/3 in the table below and in the presentations) topics expand on this information and provide insight into how BMS software programs can be used for project selection, optimization, and ultimately, a more efficient bridge program.

Day	Module	Title	Estimated Time (minutes)
1	1	Welcome and Workshop Introduction	20
1	2	Purpose and Value of Bridge Management Systems	30
1	3	Key Features and Workflow Steps of a BMS	20
1	4	Inventory and Condition Data; Agency Goals, Objectives and Performance Measures	90
1	5	Deterioration Models	40
1	6	Modeling Actions, Triggers, Costs and Effects	45
1	7	Life-Cycle Agency Costs and Life-Cycle Modeling	40
1	8	Life-Cycle User Costs and Functional Assessment and Improvement Models	15
1	9	Risk Assessment and Mitigation Models	20
1	10	Benefit-Cost Analysis	40
1	11	Optimization and Prioritization	45
1	12	Investment Strategy Simulation and Investigation	20
1	13	Program and Project Planning and Management	25
1	14	Communication and Reporting	15
2/3	1	BMS Software Implementation Steps	120
2/3	2	Deterioration Model Development, Use, and Maintenance	120
2/3	3	Life-Cycle Cost Analysis (LCCA) and Life-Cycle Modeling in a BMS	120
2/3	4	Benefit-Cost Analysis and Optimization	120
2/3	5	Using BMS for Performance Measure Validation and Selection, Investment Strategy Development, and Target Setting and Program Planning	120
2/3	6	Integrating BMS Processes and BMS Software	120
2/3	7	Host Agency BMS Software Program and Analysis Tools Review	240

The Participant Workbook is designed to be a useful tool in participating in this workshop.

- Slides – This course is supported by a PowerPoint presentation. Each slide in the presentation is displayed in the Participant Workbook.
- Key Message – The key message provides helpful guidance to make transitions between slides, activities, or lessons. It also serves as a summary of the information to be discussed for each slide.

Module Title: D1M1 - Welcome and Introduction

Module Time: 20 minutes

Module Summary

The objectives of the workshop will be presented, and the instructors introduced. The primary objective of the workshop is to advance the use of BMS software programs and analysis tools to support investment strategy analysis and selection, performance measurement and target setting, and project and program planning, with the goal of maximizing benefits and minimizing cost over the long-term. A BMS works best when it merges the institutional knowledge of an Agency’s bridge managers and practitioners with the data centric analytics of modern bridge management systems.

Expected Outcome(s)

Participants will gain an understanding of the day’s activities and objectives and the creation of interest and enthusiasm for the topics.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D1M1-Slide 1

Key Message

Welcome and Introduction to Bridge Management Systems Workshop.

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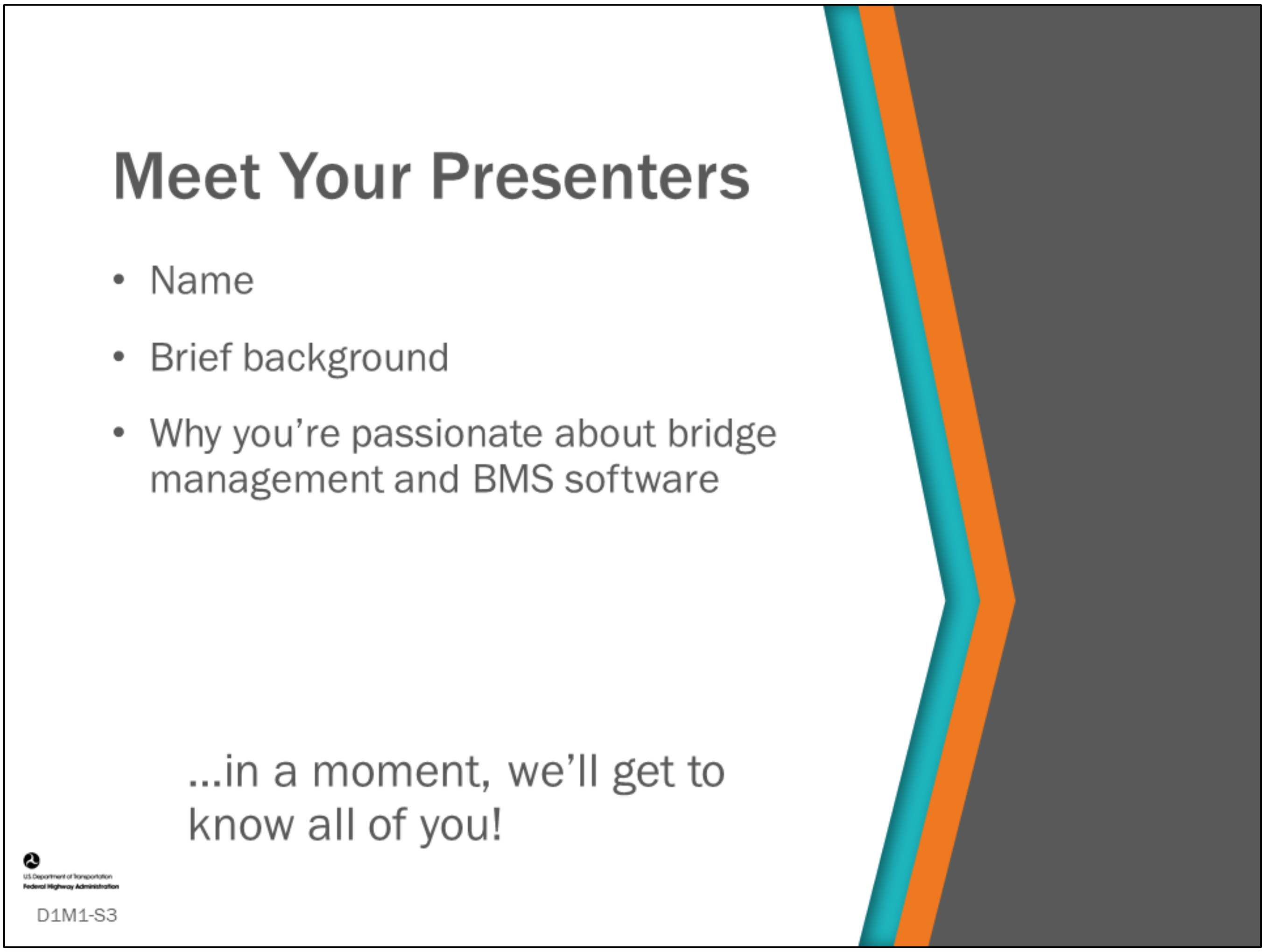
D1M1-Slide 2

Key Message

Review workshop outcomes.

D1M1-Slide 3



Key Message

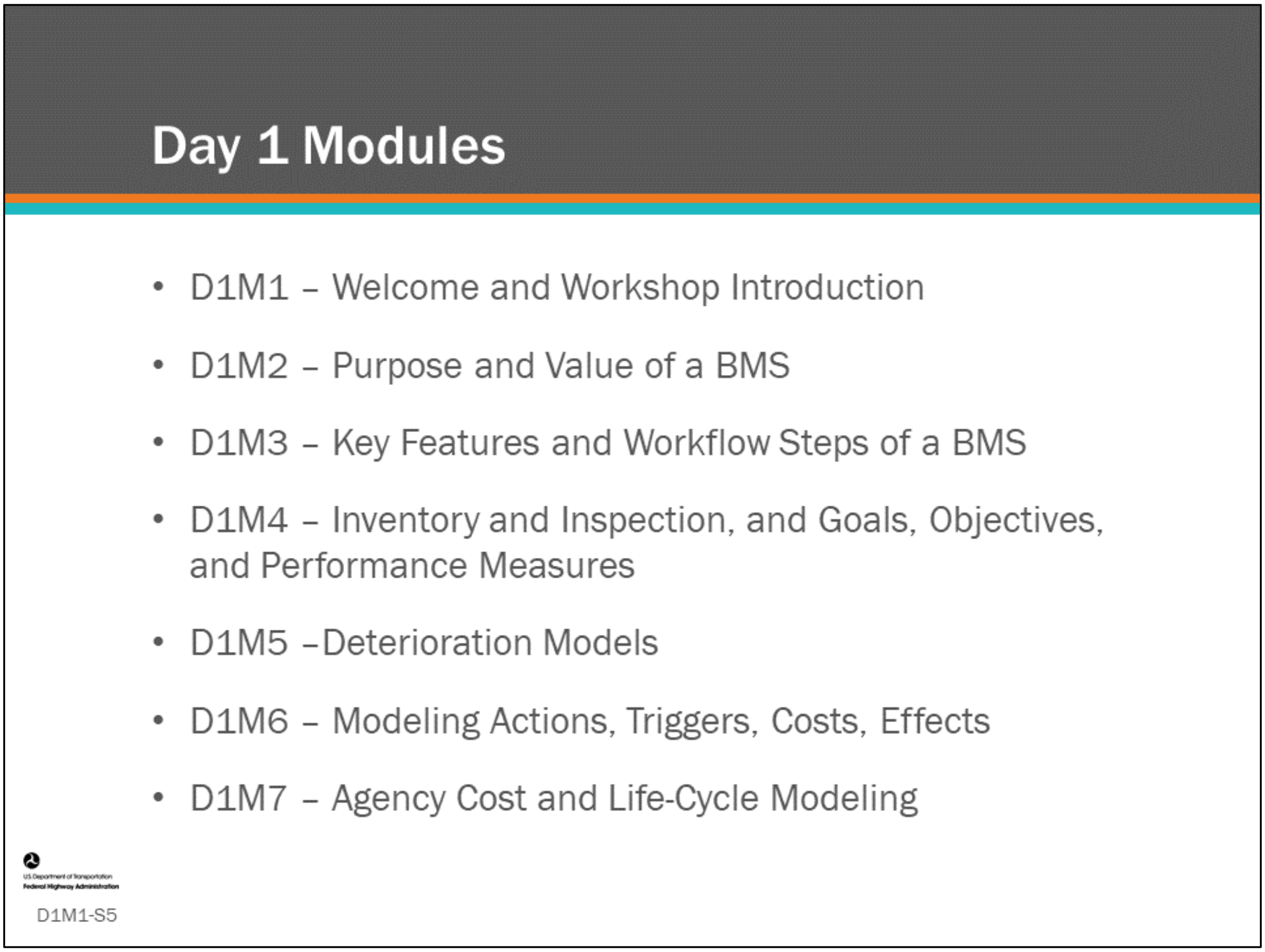
Get to know your presenters.

D1M1-Slide 4

Key Message

Review the training design. This workshop is designed so that the knowledge presented on Day 2/3 builds upon what is presented on Day 1.

D1M1-Slide 5



Key Message

Review modules being presented on Day 1.

D1M1-Slide 6

Day 1 Modules (con.)

- D1M8 – Functional Assessment, Life-Cycle User Cost, and Improvement Models
- D1M9 – Risk Assessment and Mitigation Models
- D1M10 – Benefit-Cost Analysis
- D1M11 – Optimization and Prioritization
- D1M12 – Investment Strategy Simulation and Investigation
- D1M13 – Project and Program Planning and Management
- D1M14 – Communication and Reporting

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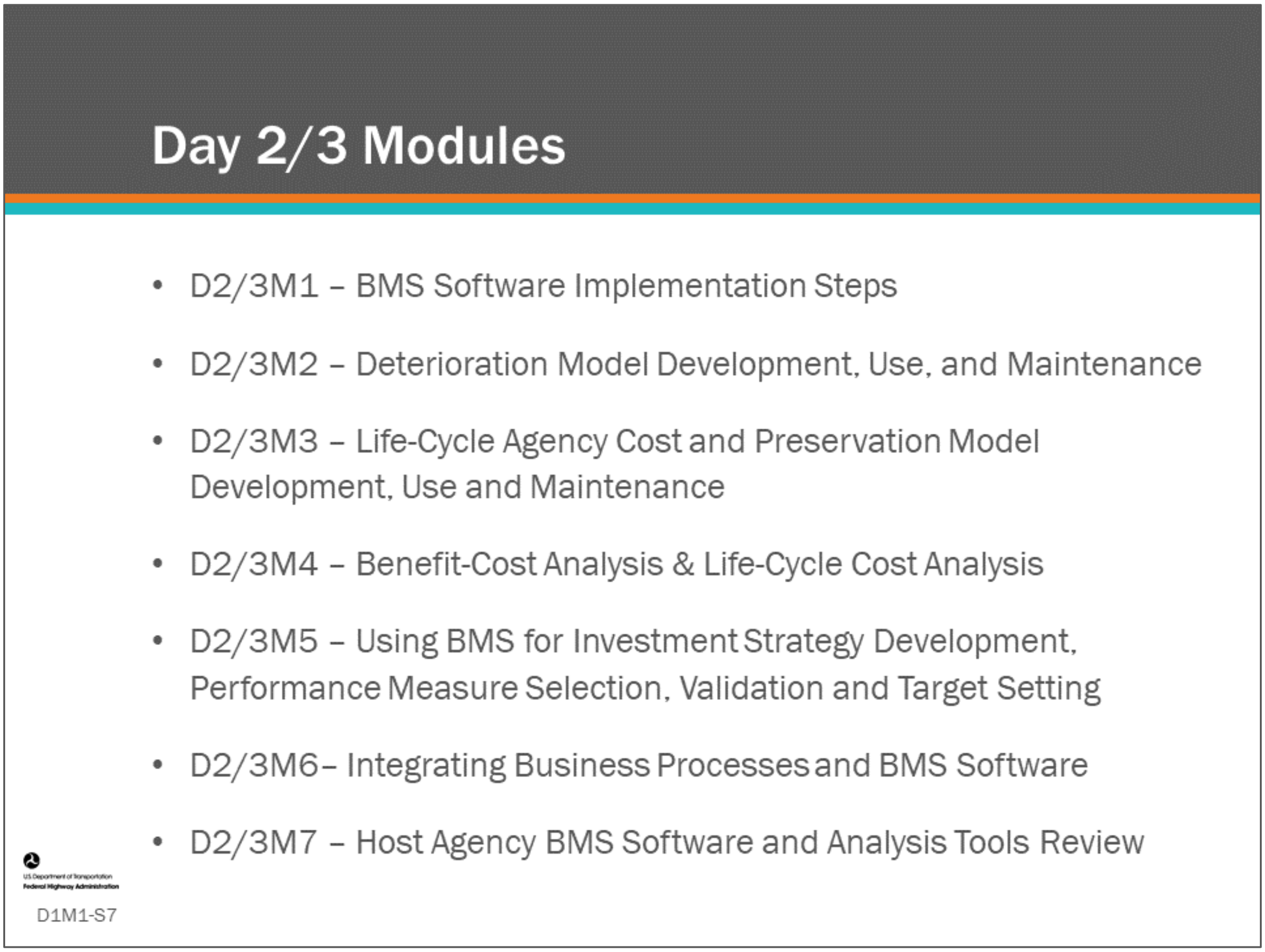
D1M1-S6

Key Message

Review more modules being presented on Day 1.

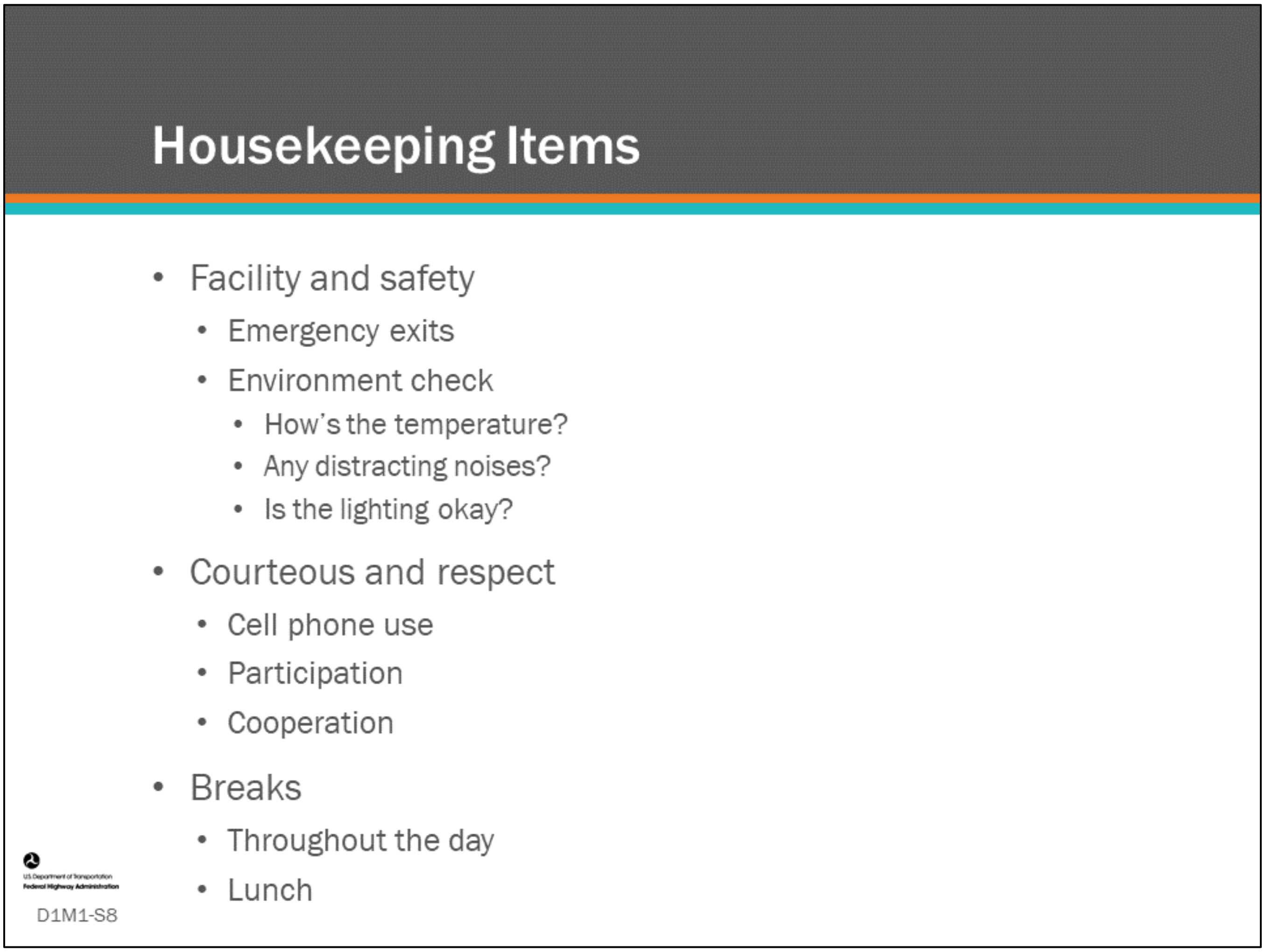
D1M1-Slide 7



Key Message

Review modules being presented on Day 2/3.

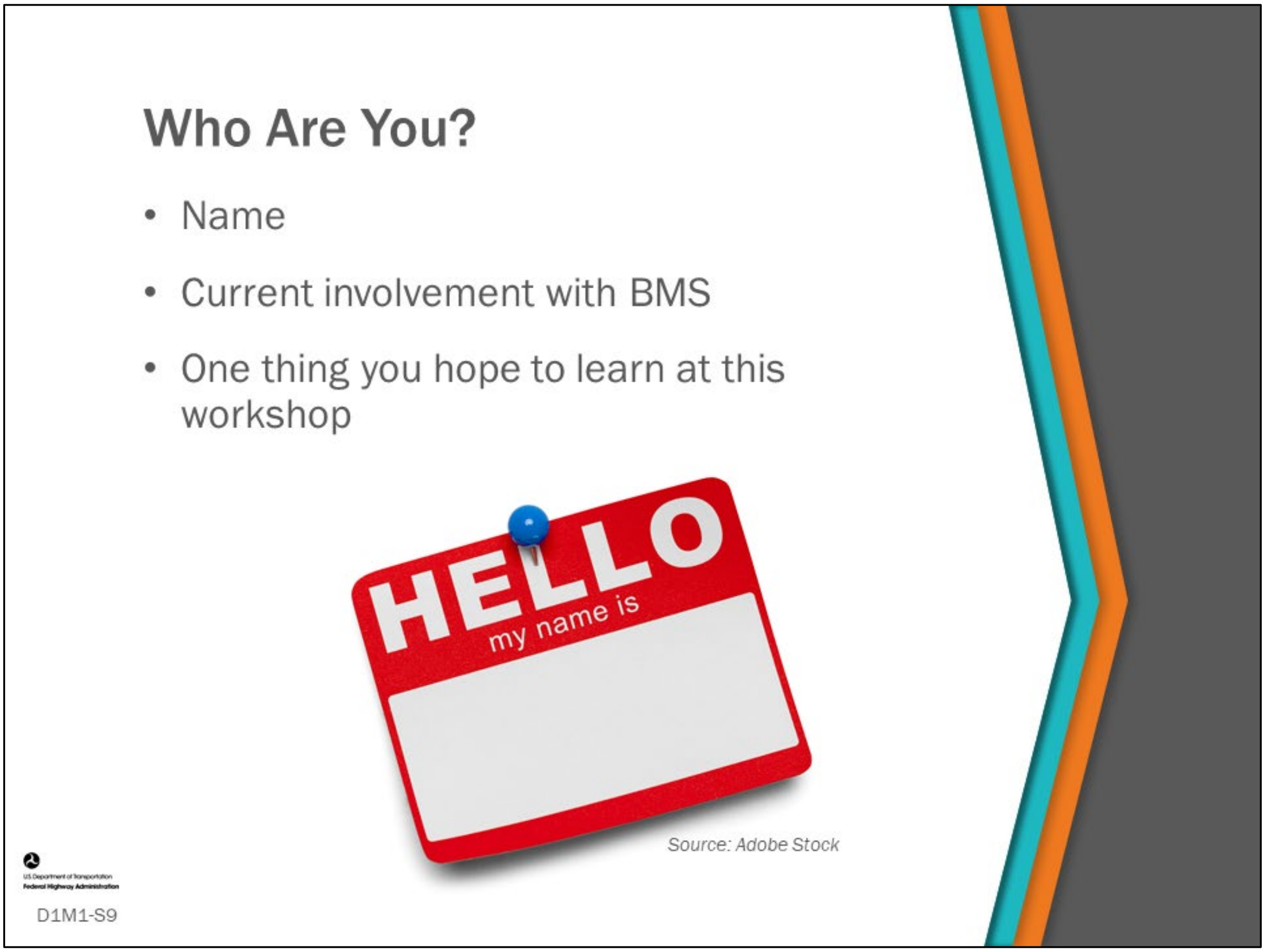
D1M1-Slide 8



Key Message

Review the facility and safety. Please be courteous and respectful of your presenters and peers. Silence cell phones, participate in discussions and activities and show cooperation when your presenters and peers are speaking, sharing, working.

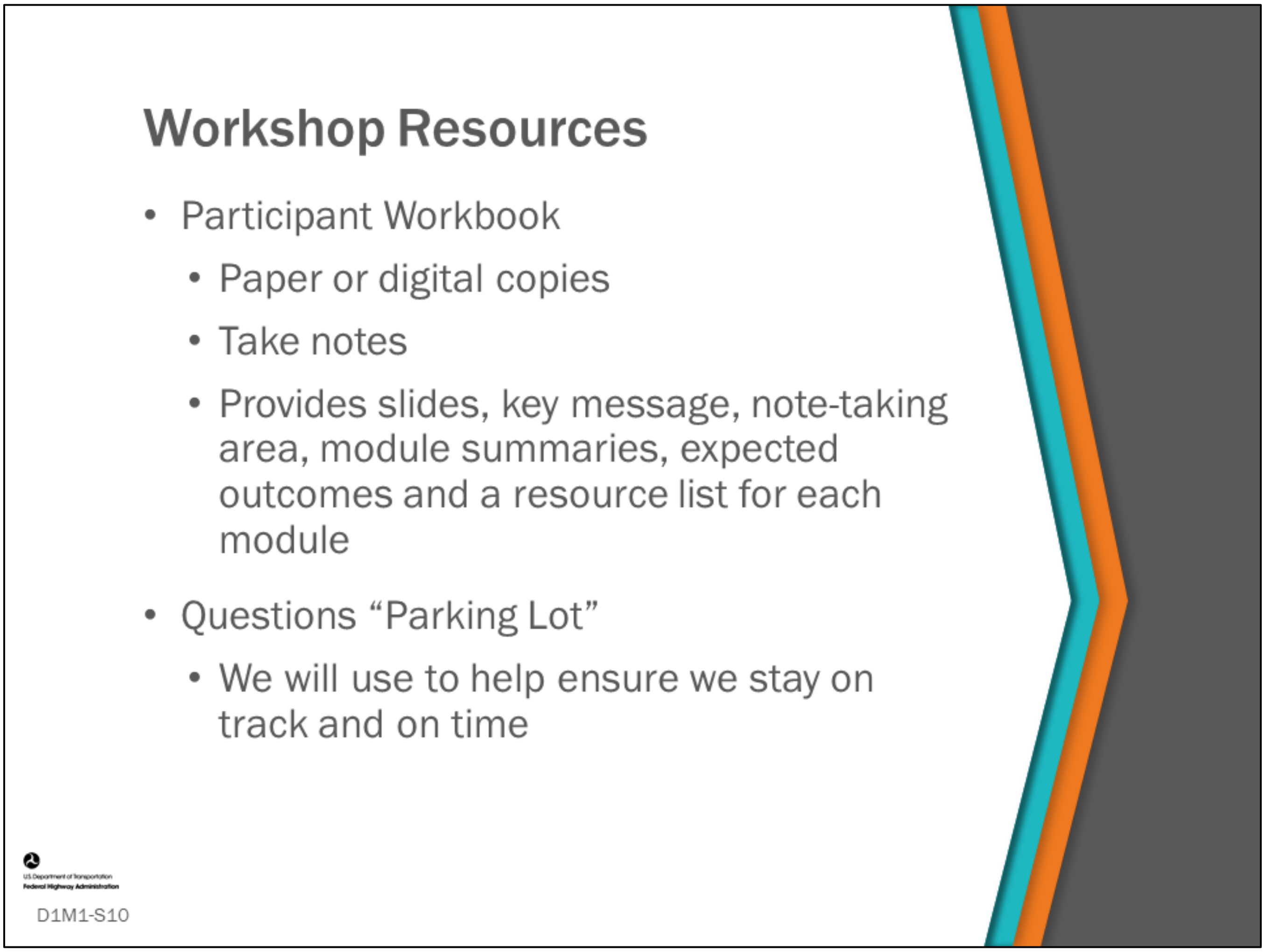
D1M1-Slide 9



Key Message

Please introduce yourself to your presenters and peers. Share your name, what your current involvement with BMS is, and one thing you hope to learn at this workshop.

D1M1-Slide 10

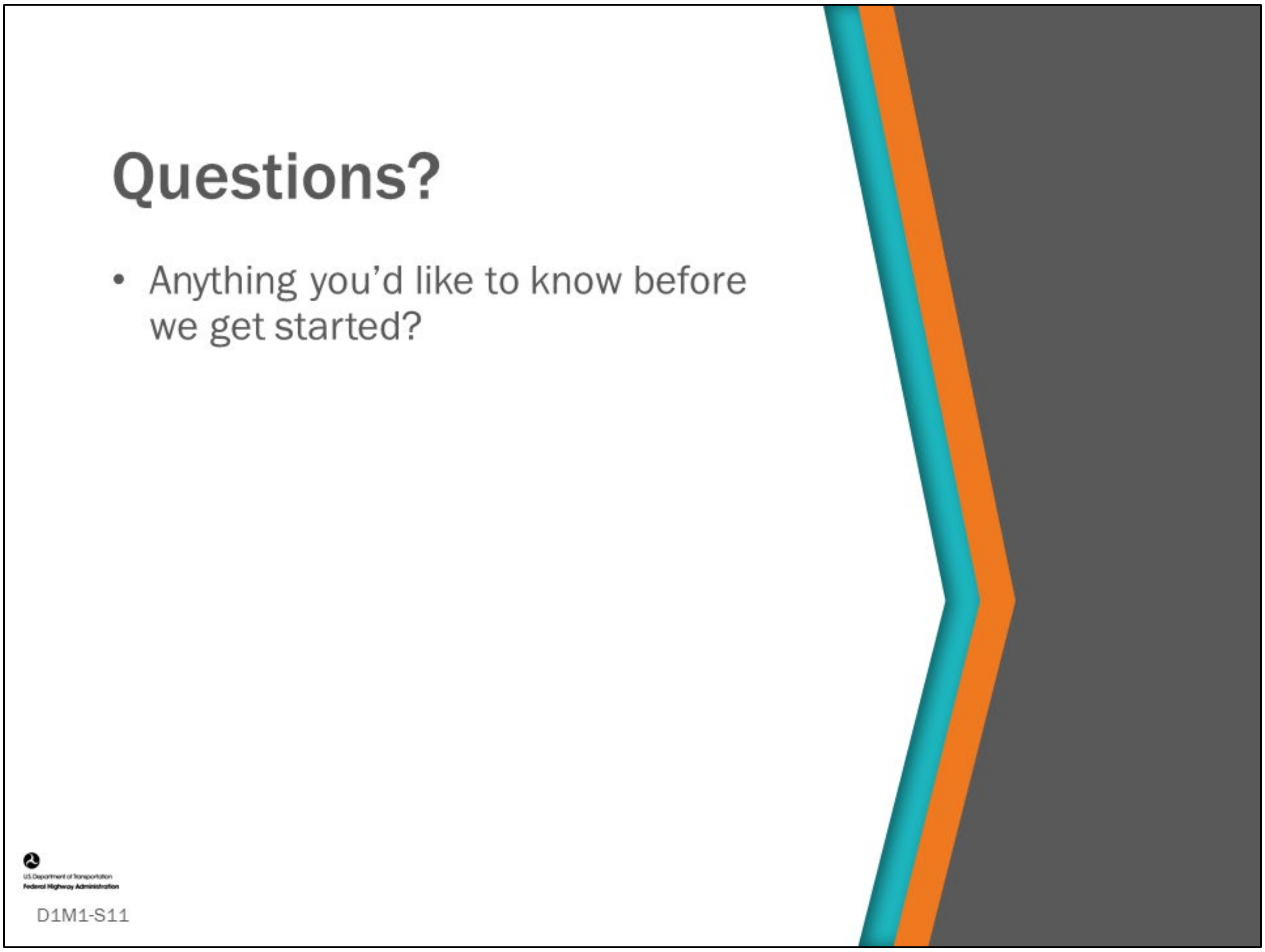


Key Message

The Participant Workbook (PW) for this workshop is yours to keep; feel free to take notes, draw, mark-up slides and fold-over pages as you wish. This is a handy resource for both during and after the workshop.

We will also use a "Parking Lot" to keep track of questions that may come up ahead of schedule, risk getting us off track or may be better addressed in Day 2/3, as the content is designed to build upon itself.

D1M1-Slide 11



Key Message

Is there anything you'd like to know before we get started?

D1M1-Slide 12

Slide #	Image Description	Source Information
1	A picture of a bridge along a body of water.	Adobe Stock.
1	A picture of a highway interchange.	Adobe Stock.
9	A "Hello, my name is" sticker held by a pin.	Adobe Stock.

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D1M1-S12

D1M1 Figure Source List

Module Title: D1M2 – Purpose and Value of Bridge Management Systems

Module Time: 20 minutes

Module Summary

A BMS helps Agencies manage their infrastructure efficiently, justify funding, provide credibility to the program, and meet state and Federal requirements. NCHRP *Report 866*, *Return on Investment in Transportation Asset Management Systems and Practices* provides a study on how Agencies have seen value (as Return on Investment (ROI) from analytical transportation asset management, including seeing the value of preservation, and identifying methods such as benefit-cost analysis that quantifies this value. Examples will be provided showing how a BMS has helped Agencies justify needed funds, allocate money to programs, forecast condition and performance to understand and plan for the future, do strategic analysis, select a program of projects that achieve the largest benefit over cost, and help Agencies make prioritized cost-effective decisions.

Expected Outcome(s)

The expected outcome of this module is to help participants understand the importance of a BMS and show how a BMS can be used to help an Agency manage, preserve and improve their bridges.

Resource List

Slide	Reference Information
4-7, 12,13	U.S. Code of Federal Regulations. *Title 23 Highways.* Volume 1. Chapter 1. Part 515-Asset Management Plans. Office of the Federal Registrar (OFR).
8,9	AASHTO. *Transportation Asset Management Guide: A Focus on Implementation*. Washington, DC, January 2013.
11	NCHRP. *Report 866 Return on Investment in Transportation Asset Management Systems and Practices*. Washington, DC, 2018.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D1M2-Slide 1

Key Message

This module will discuss the purpose and value of asset management and Bridge Management Systems.

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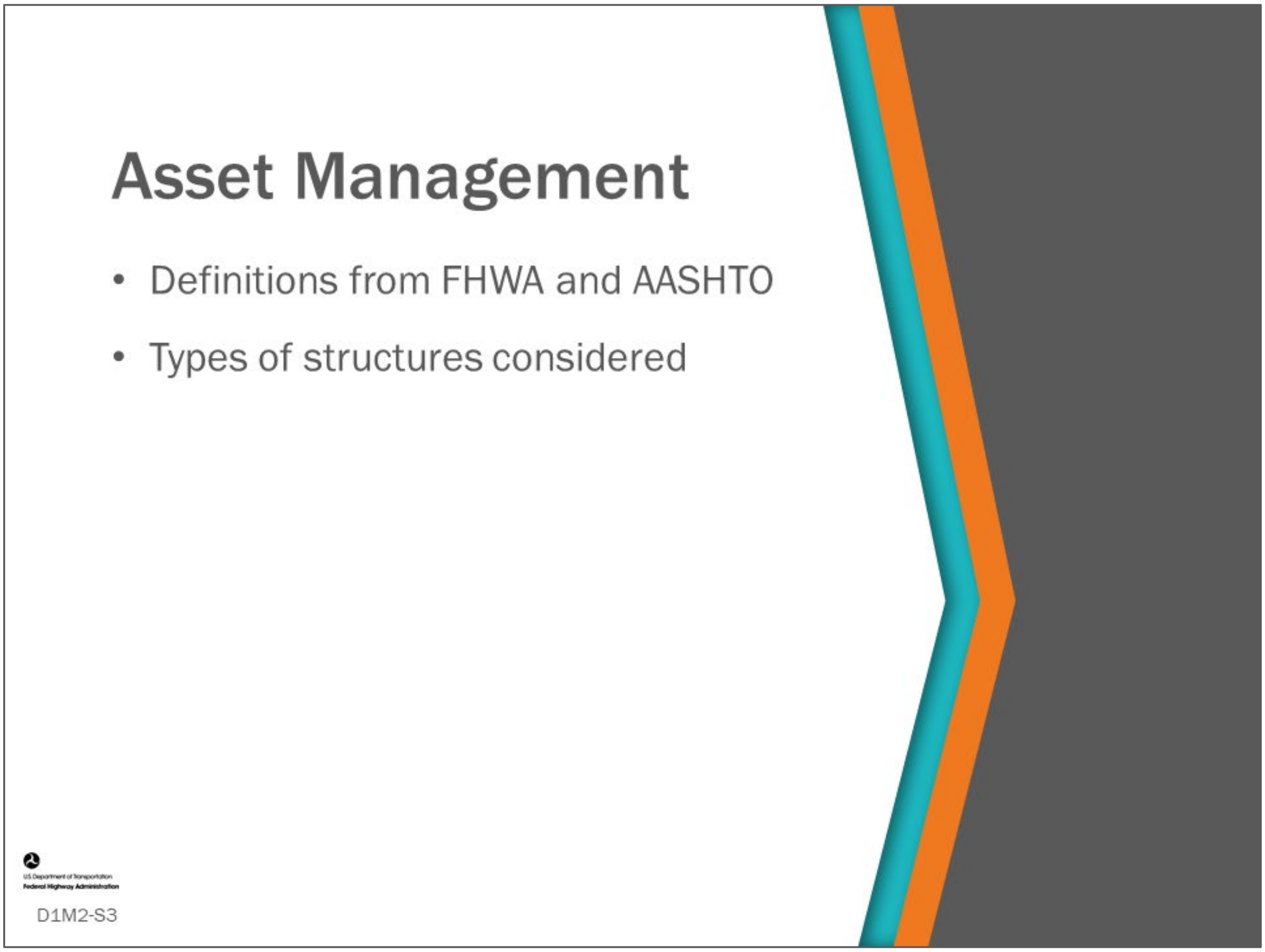
D1M2-Slide 2

Key Message

This module introduces asset management, bridge management and Bridge Management Systems (BMS). The participants will discuss their reasons for having a BMS and what its value is (or could be) to their Agency.

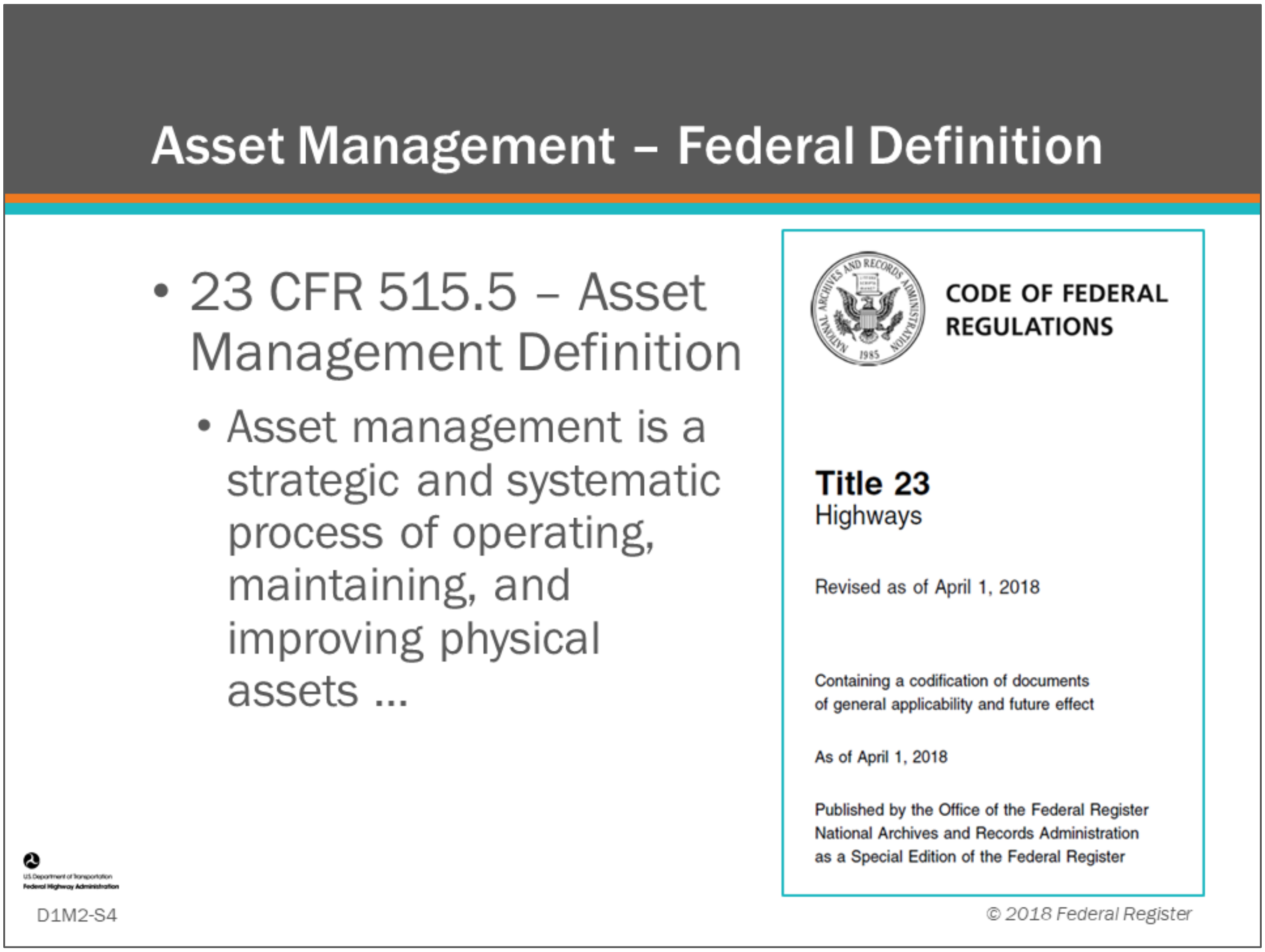
D1M2-Slide 3



Key Message

In this section, we will discuss asset management as defined by the FHWA and AASHTO and the types of structures considered.

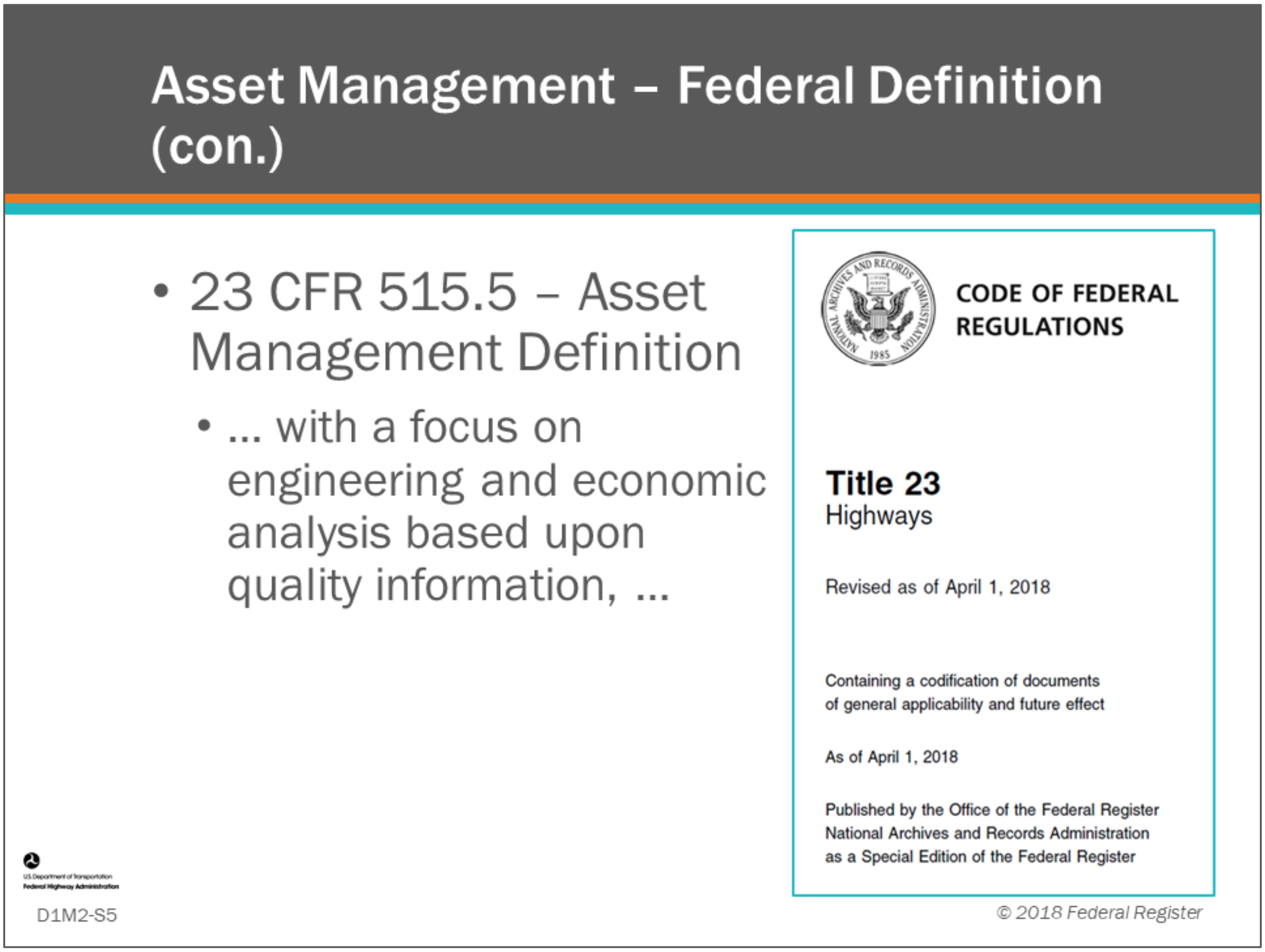
D1M2-Slide 4



Key Message

Title 23 Highways, of the U.S. Code of Federal Regulations, Part 515 – Asset Management Plans Section 515.5, *"*Definitions," defines asset management as a strategic and systematic process of operating, maintaining, and improving physical assets …

D1M2-Slide 5

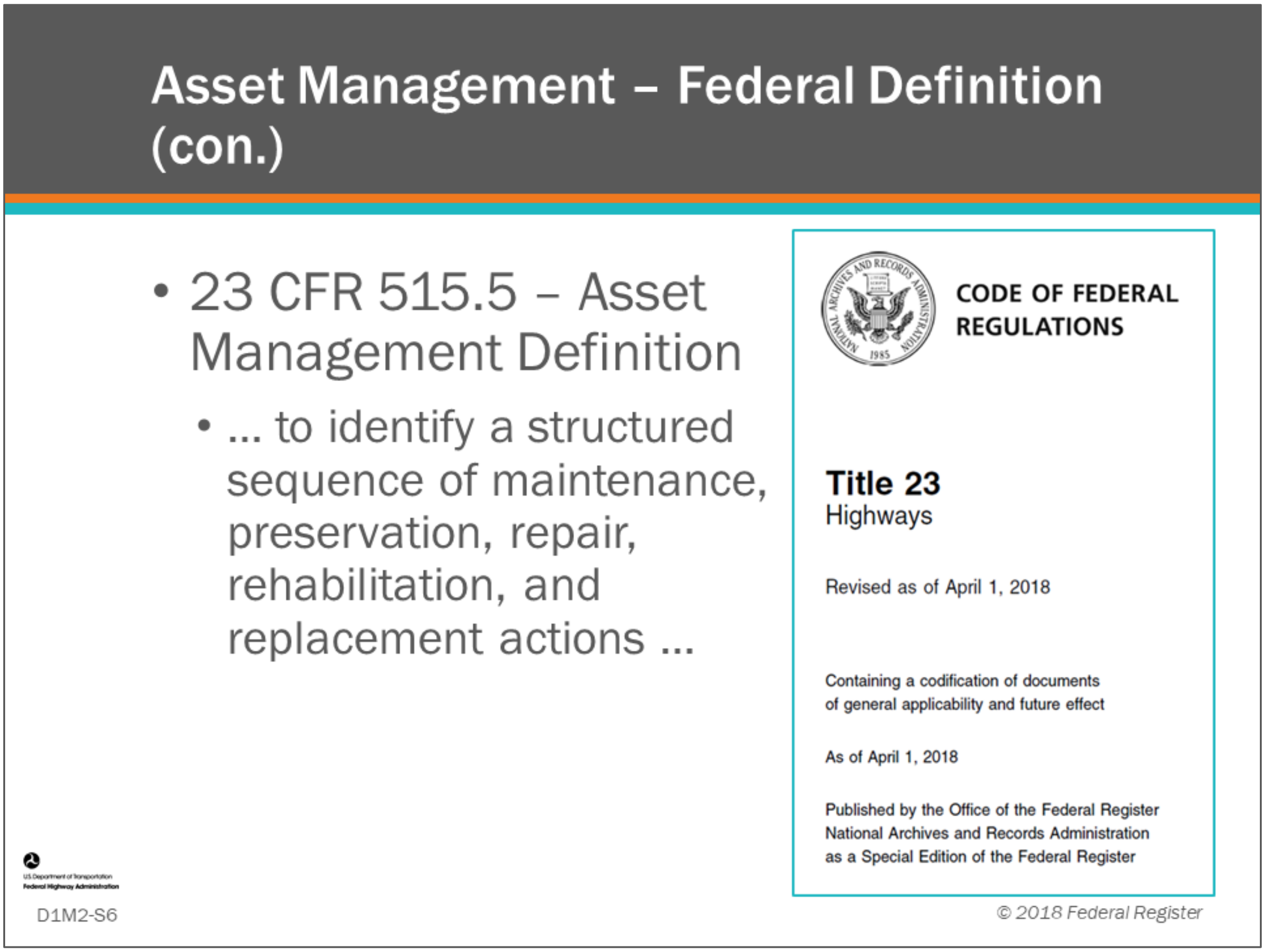


Key Message

Title 23 Highways, of the U.S. Code of Federal Regulations, Part 515.5, "Definitions" continues:

- ...with a focus on engineering and economic analysis based upon quality information, …

D1M2-Slide 6

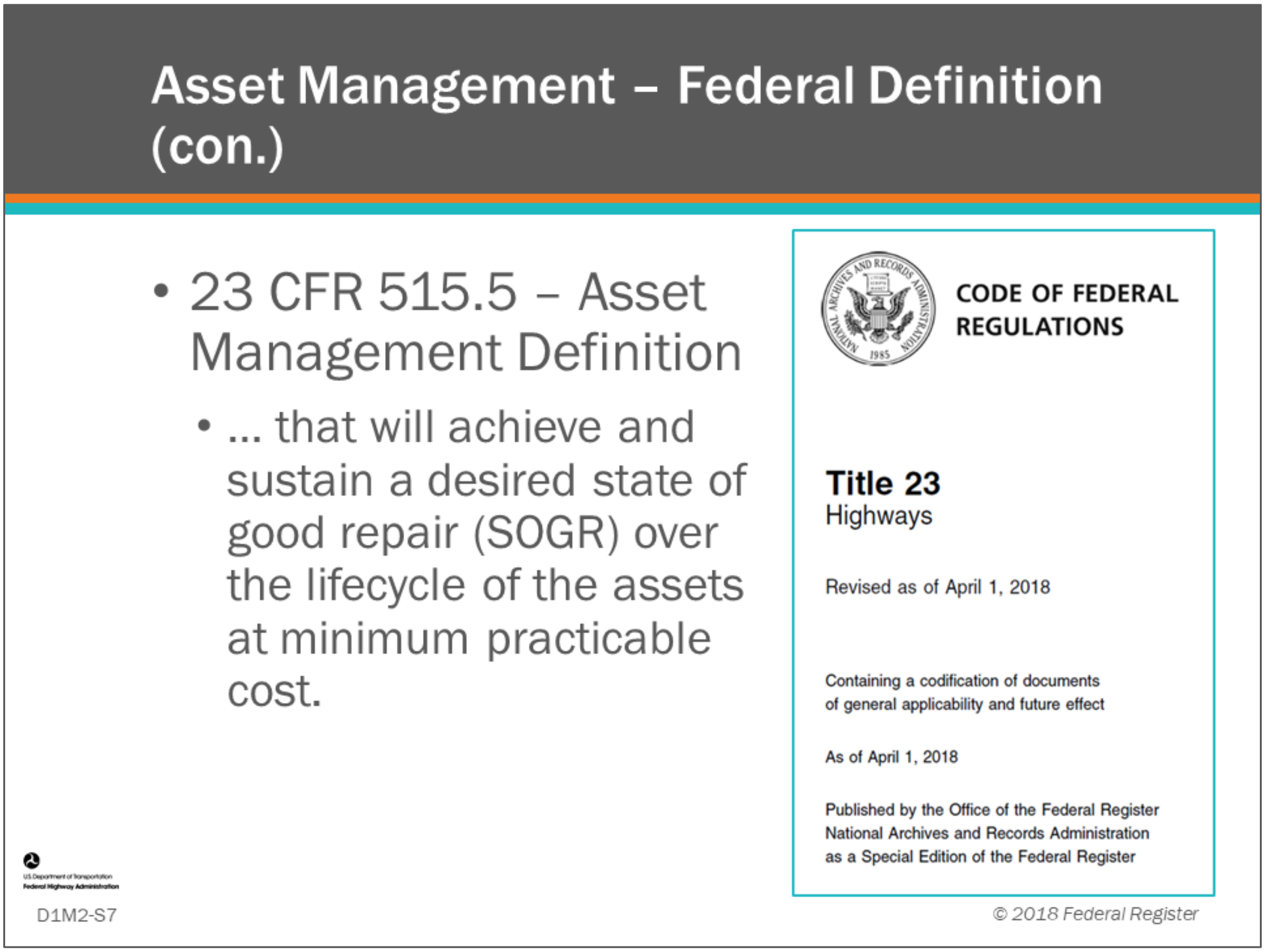


Key Message

Title 23 Highways, of the U.S. Code of Federal Regulations, Part 515.5, "Definition" continues:

- ...to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions …

D1M2-Slide 7

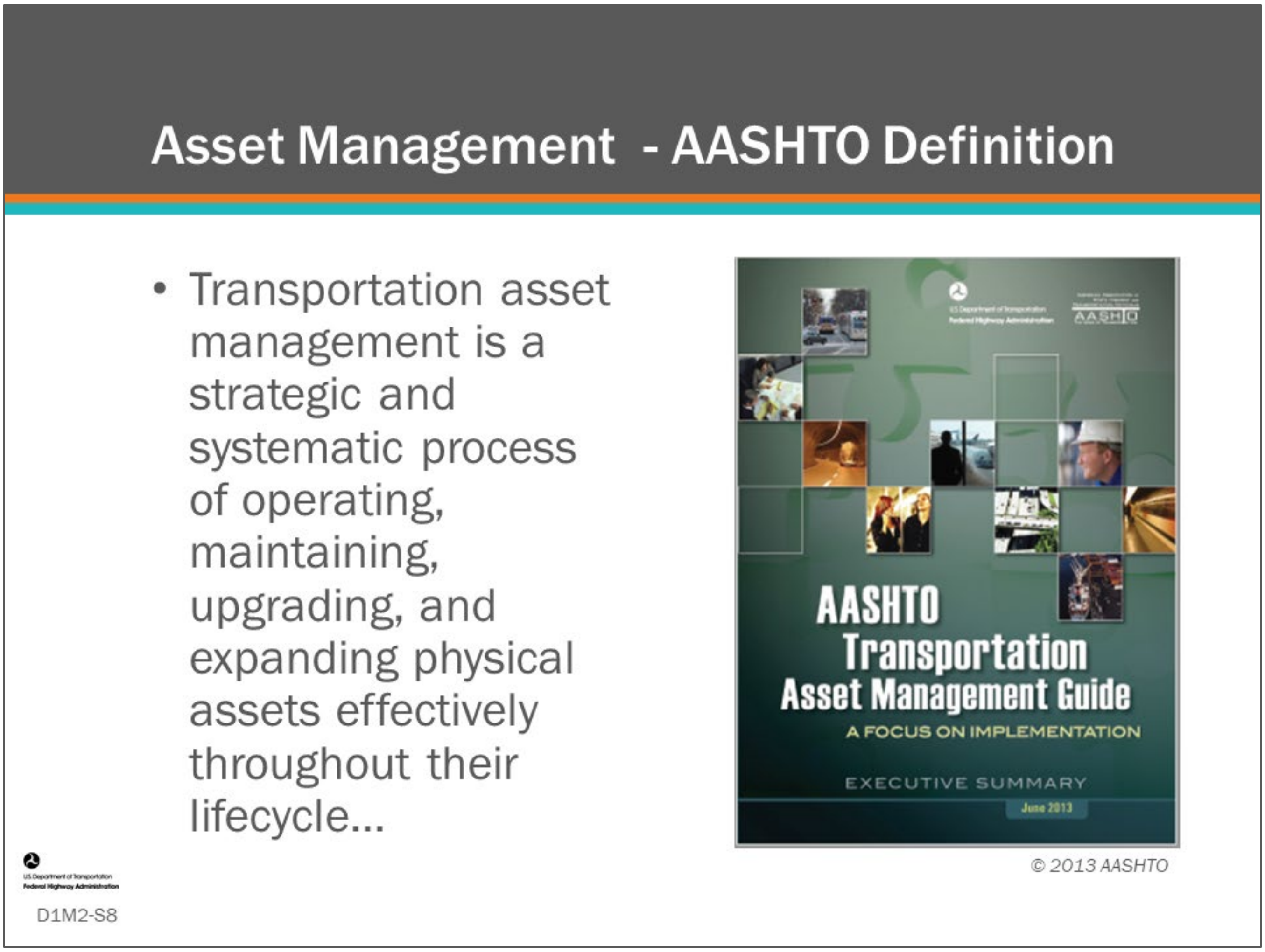


Key Message

Title 23 Code of Federal Regulations Part 515.5, “Definitions” continues:

- ... that will achieve and sustain a desired state of good repair (SOGR) over the lifecycle of the assets at minimum practicable cost.

D1M2-Slide 8



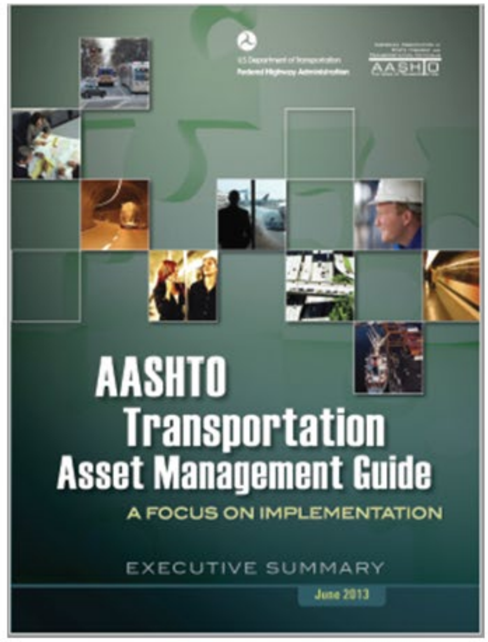
Key Message

The American Association of Highway Transportation Officials (AASHTO) and the FHWA collaborated to write the AASHTO *Transportation Asset Management Guide: A Focus on Implementation*. The AASHTO guide defines transportation asset management as "a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle…"

D1M2-Slide 9

Asset Management - AASHTO Definition (con.)

- … It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well defined objectives



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D1M2-S9

Key Message

The AASHTO guide continues... “It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well defined objectives. Bridge management is simply the management of the bridge portion of an agency’s assets.”

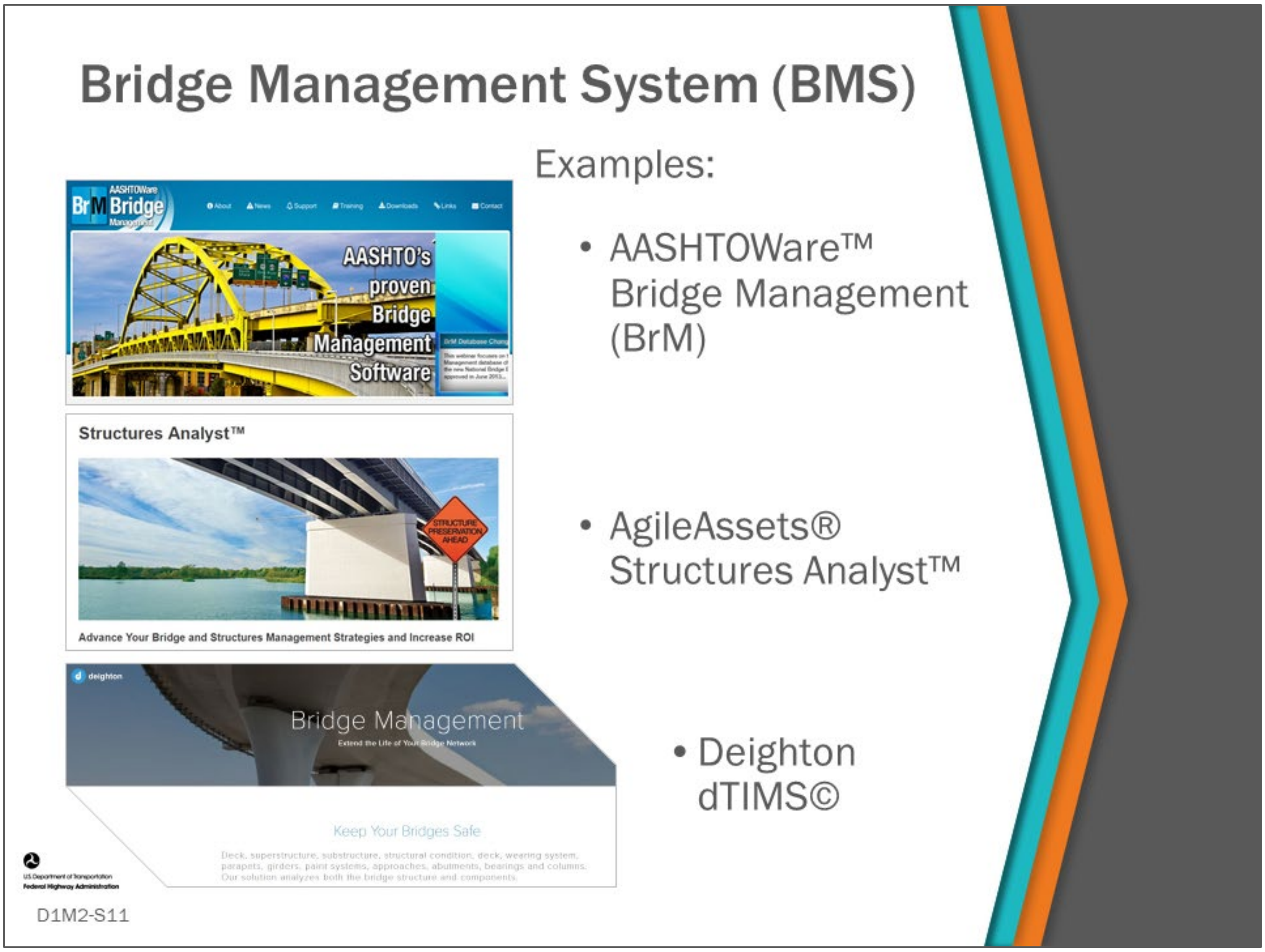
D1M2-Slide 10

Key Message

A key aspect of asset management is efficient resource allocation and planning.

- Bridges and structures are typically seen as part of the overall highway infrastructure system.
- Within the highway system resource allocation can be divided across networks such as the interstate system, other NHS, and other highway systems.
- Within each of these systems resources are divided among multiple assets including pavements, bridges, tunnels, lighting, sign and sign structures, retaining walls, drainage, traffic and safety features, sound walls, and pedestrian features.

D1M2-Slide 11

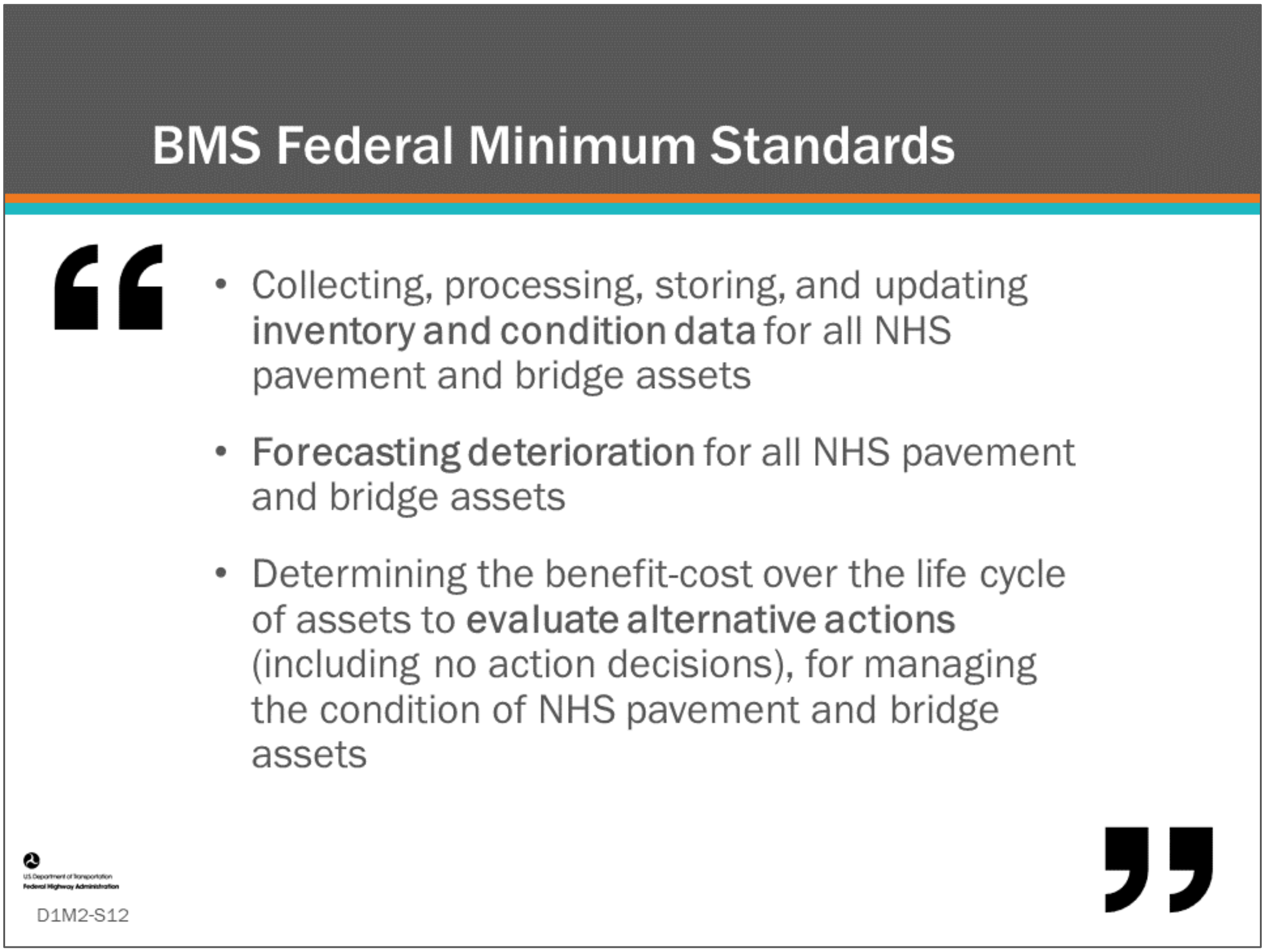


Key Message

This topic will discuss bridge management and introduce Bridge Management Systems (BMS).

Examples of the website home pages for several of the available BMS software are shown on this slide.

D1M2-Slide 12

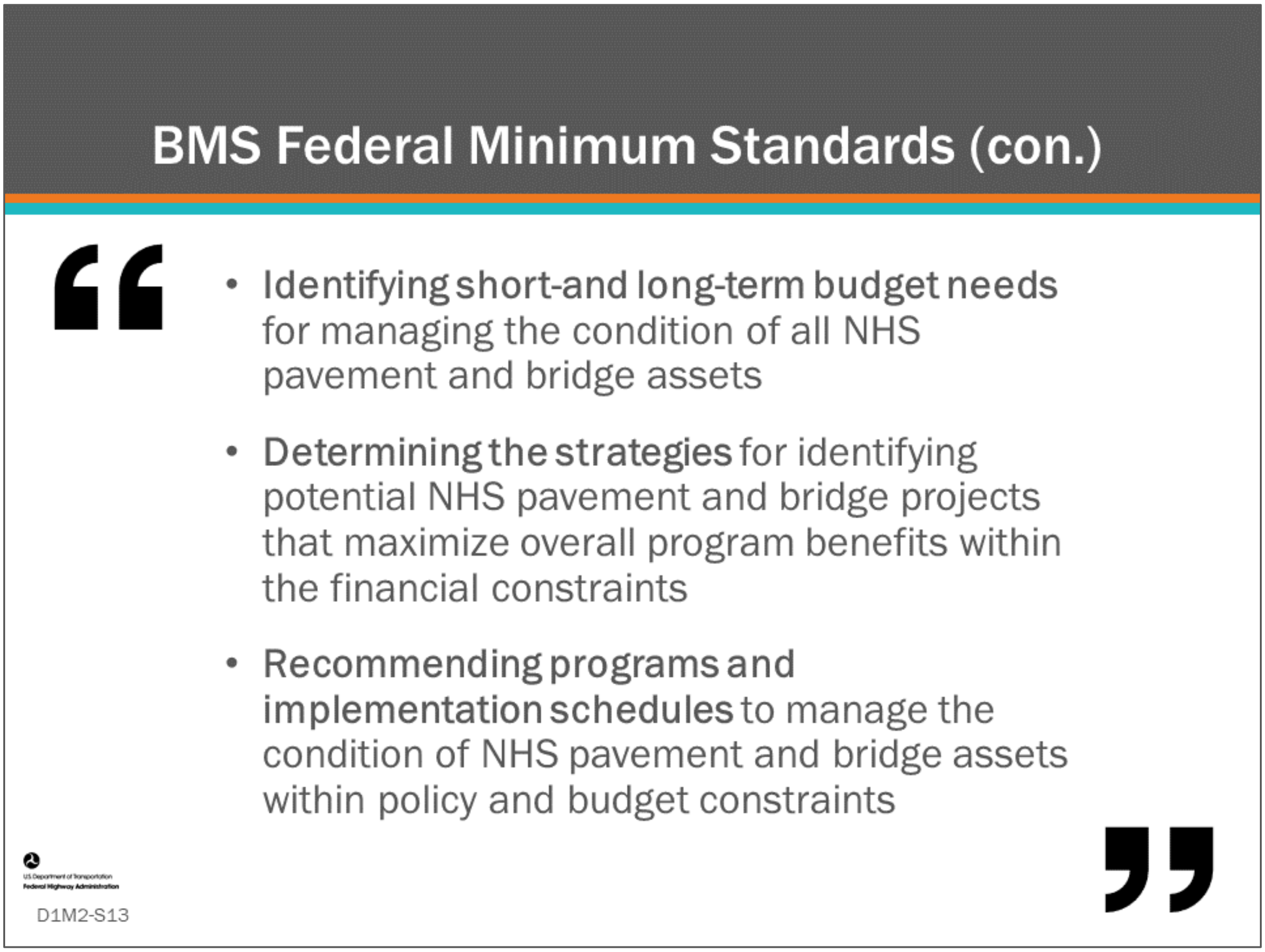


Key Message

A very relevant set of minimum requirements for a typical asset management system is contained in the code of federal regulations regarding the State's Transportation Asset Management Plans.

- The document section 23 CFR 515.17, "Minimum standards for developing and operating bridge and pavement management systems," describes BMS capabilities, as presented on the slide.

D1M2-Slide 13



Key Message

A very relevant set of minimum requirements for a typical asset management system is contained in the code of federal regulations regarding the State's Transportation Asset Management Plans.

- The document section 23 CFR 515.17, "Electronic Code of Federal Regulations, Minimum standards for developing and operating bridge and pavement management systems," describes BMS capabilities, as presented on this slide.

D1M2-Slide 14

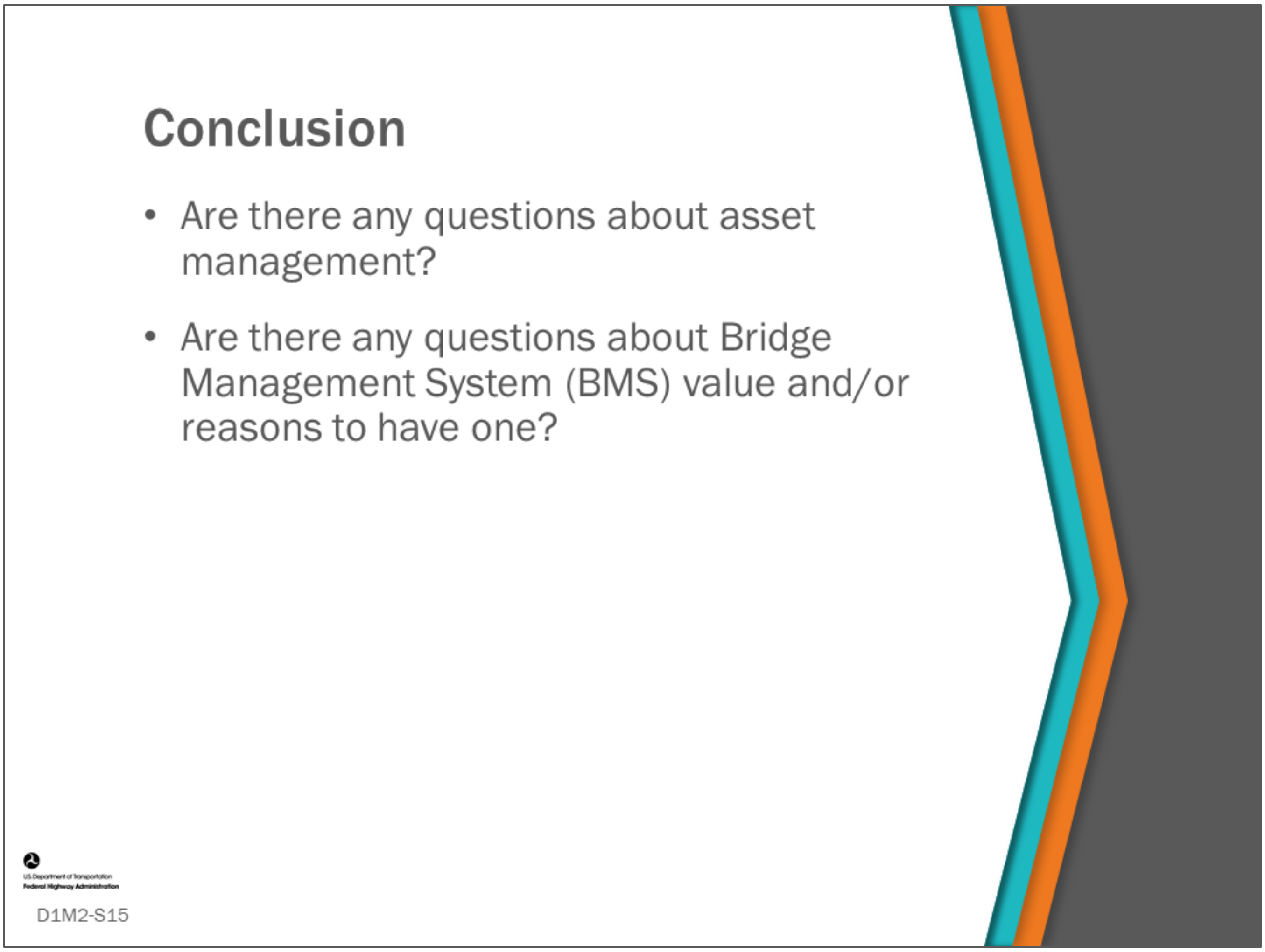
Key Message

There are many reasons beyond Federal laws and regulations why you should want to have a BMS. A few are listed here.

Achieving a "State of Good Repair" is an important one as it is listed in Federal legislation.

- Organizations and agencies have been working to define this.

D1M2-Slide 15



Key Message

This concludes D1M2: Purpose and Value of Bridge Management Systems.

D1M2-Slide 16

Slide #	Image Description	Source Information
4-7	Cover of the U.S. Code of Federal Regulations, *Title 23 Highways.*	U.S. Code of Federal Regulations. *Title 23 Highways.* Volume 1. Chapter 1. Part 515-Asset Management Plans. Office of the Federal Registrar (OFR).
8-9	Cover of AASHTO *Transportation Asset Management Guide: Focus on Implementation.*	AASHTO. *Transportation Asset Management Guide: A Focus on Implementation*. Washington, DC, January 2013.
10	Photo of highway sign structure.	Adobe Stock.
10	Photo of inside a highway tunnel.	Adobe Stock.
11	Screenshot of AASHTO(TM) BrM homepage.	AASHTOWare™ Bridge Management (BrM) homepage.
11	Screenshot of Structures Analyst™ homepage.	AgileAssets® Structures Analyst™ homepage.
11	Screenshot of dTIMS© homepage.	Deighton dTIMS© Infrastructure Asset Management Software homepage.

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D1M2-S16

D1M2 Figure Source List

Module Title: D1M3 – Workflow Steps and Key Features of Bridge Management Systems

Module Time: 20 minutes

Module Summary

BMS software have common features and workflow steps that need to be followed. This is a business process that is done on periodic basis (typically annually) within the agency. This module serves as a preview of the subsequent modules giving an overview of what will be covered in Day One of this workshop.

Expected Outcome(s)

The expected outcome of this module is to understand the key BMS features, the processes they perform and how they are interrelated.

Resource List

Slide	Reference Information
5	FHWA. *Bridge Preservation Guide: Maintaining a Resilient Infrastructure to Preserve Mobility.* Publication No. FHWA-HIF-18-022. Washington, DC, 2018.
12	AASHTO. *AASHTOWare™ Bridge Management (BrM) User's Manual*, version 5.2.3, Washington, DC, 2016.
14	MDOT. *The Use of Element Level Data & Bridge Management Software in the Network Analysis of Big Bridges*. Research Project No. 0R14-022. Transportation Pooled Fund Study No. TPF-5(308). 2017.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D1M3-Slide 1

Key Message

The previous module covered the purpose and value of BMS. We will now look at workflow steps and key features of a bridge management system. This module also serves as a preview of the following modules for this workshop.

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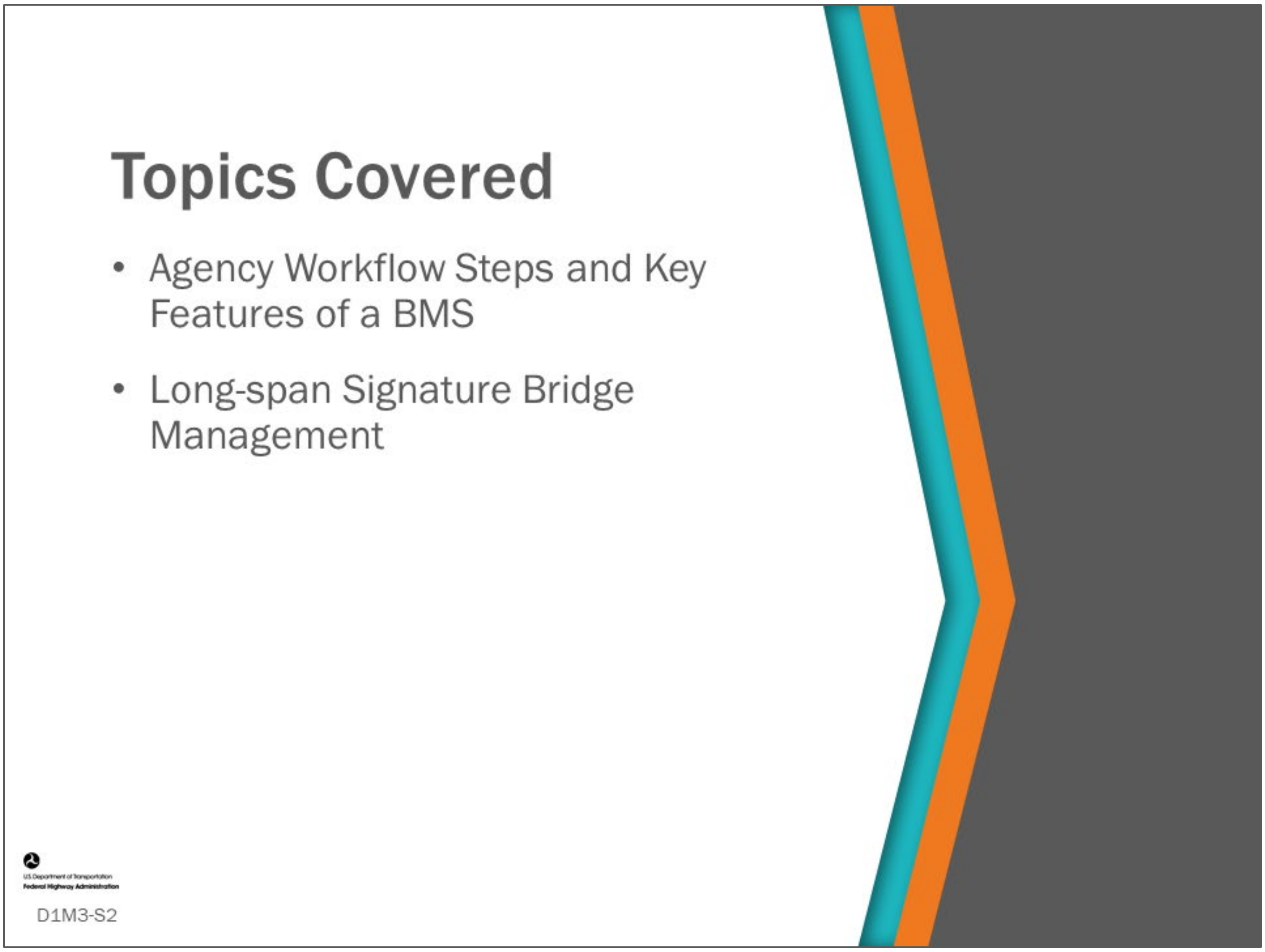
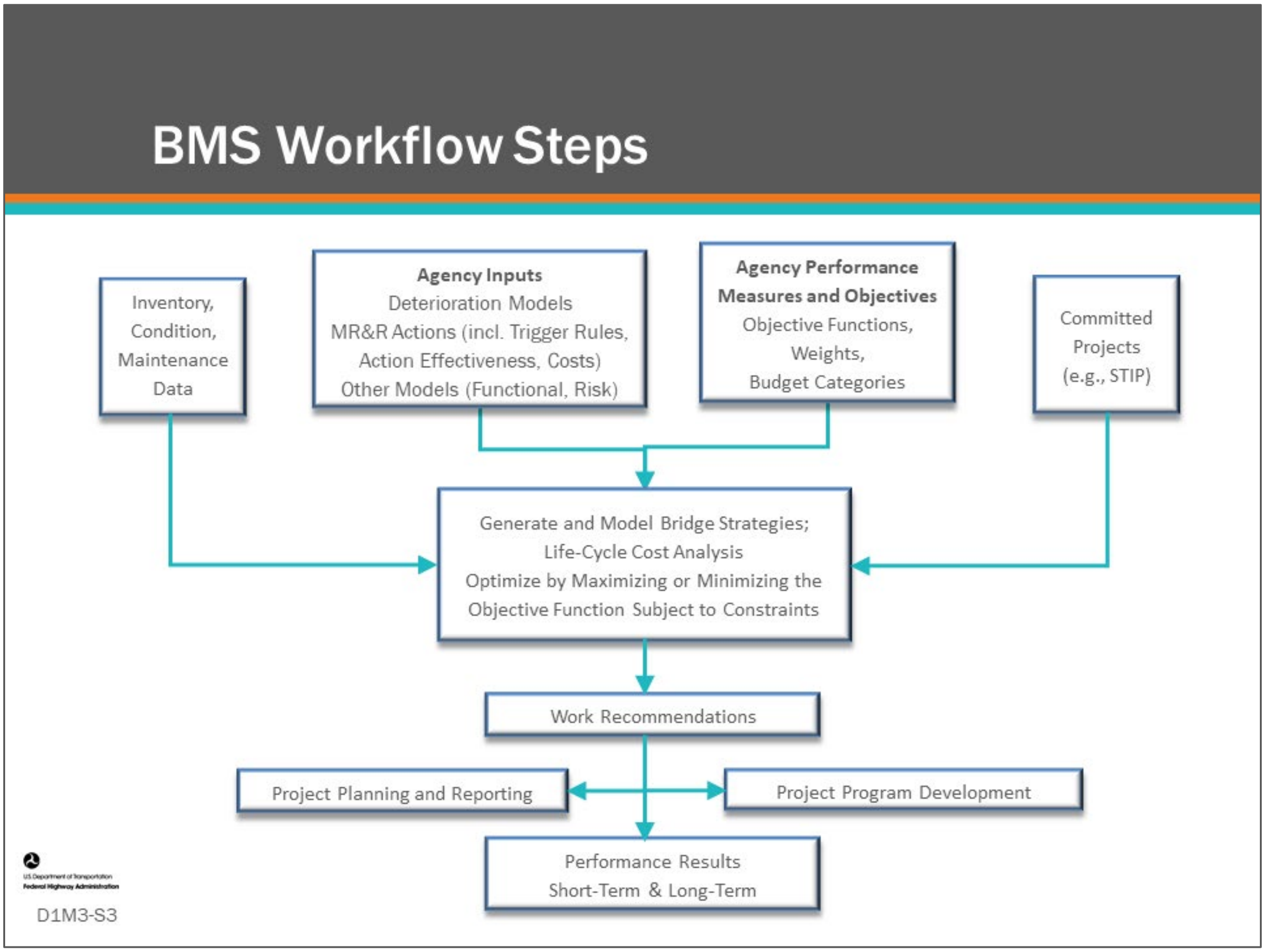
D1M3-Slide 2



Key Message

Topics covered during this module include Agency workflow steps and key features of a BMS. The module also takes a brief look at managing long-span signature bridges and how that can differ from managing a network of more conventional highway bridges.

D1M3-Slide 3



Key Message

The workflow steps of a BMS can be shown as a workflow diagram. This slide shows one example. Your workflow steps may be a little different depending upon your organizational structure and your call for projects process. The important thing to note is that a BMS helps you create a systematic process to manage your bridges in accordance to your agency's goals and objectives.

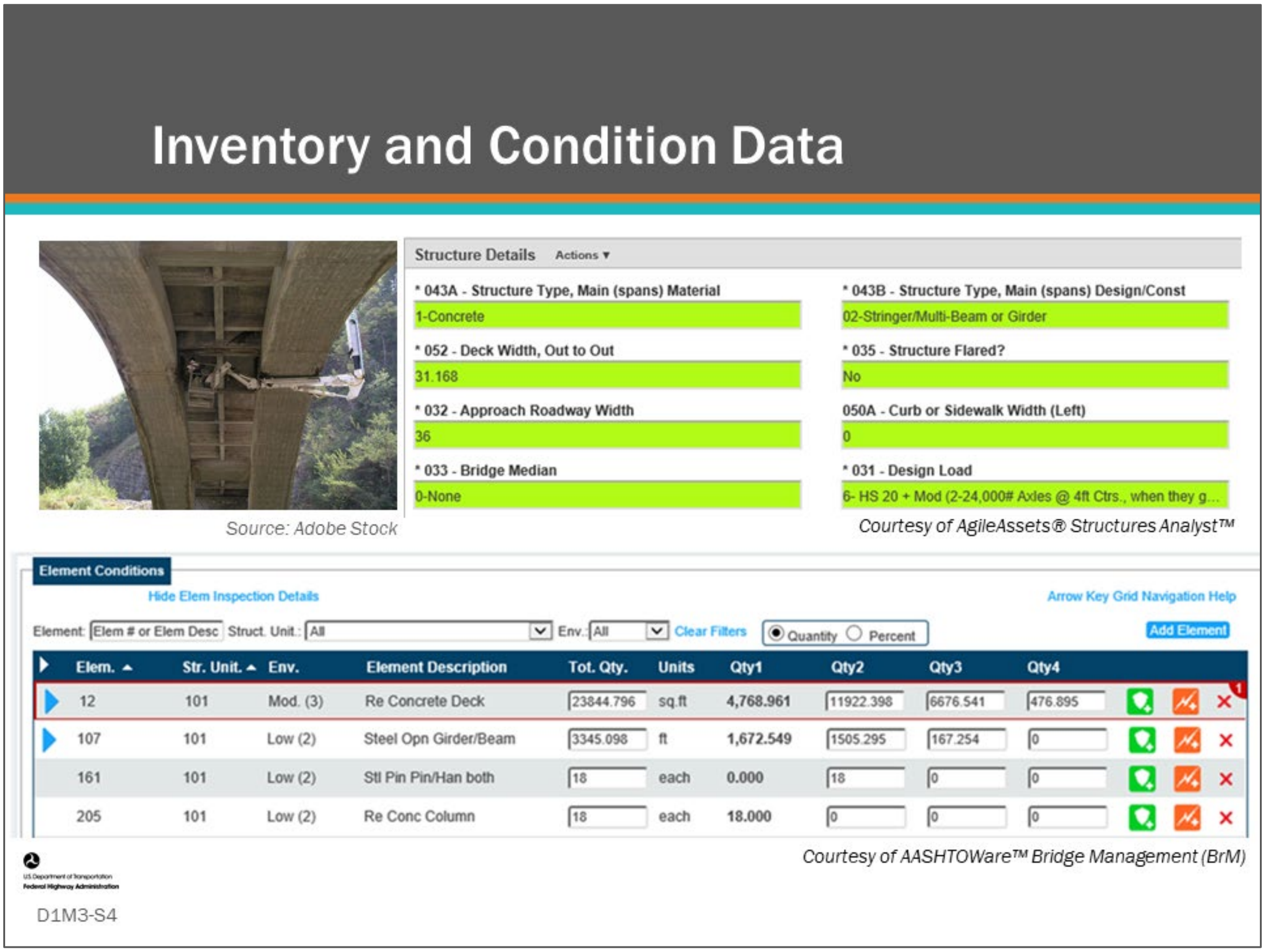
BMS software have common features and workflow steps that need to be followed. This is a cyclical business process that is done on periodic basis (typically annually) within the agency. Common workflow steps and features are shown on the slide, and include:

- Inventory and Condition Data
- Goals, Objectives and Performance Measures
- Deterioration Modeling
- Actions, Triggers and Benefit/Effects of Actions
- Life-Cycle Modeling and Risk Assessment
- Benefit/Cost Analysis
- Strategy Generation and Scenario Modeling
- Program and Project Planning
- Communication and Reporting

Each of these topics will be introduced in the following slides.

In the following modules, the interrelationship of these steps and progression from one step to another will be shown.

D1M3-Slide 4



Key Message

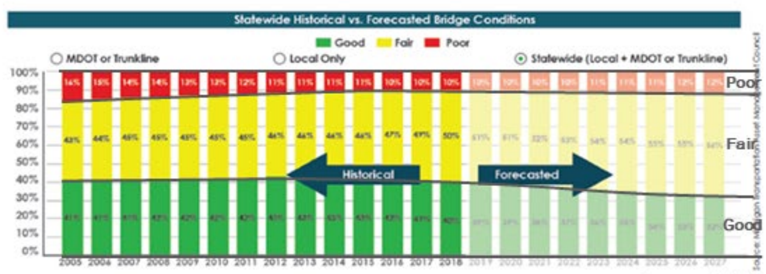
The foundation of any BMS is collecting, storing, and managing bridge inventory and condition assessment data including bridge inspection and load rating information. We will discuss how inventory data, including National Bridge Inventory (NBI) and agency defined inventory items are used in a BMS, and we will also show how General Condition Ratings (GCR) and element condition ratings are used in a BMS.

D1M3-Slide 5

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

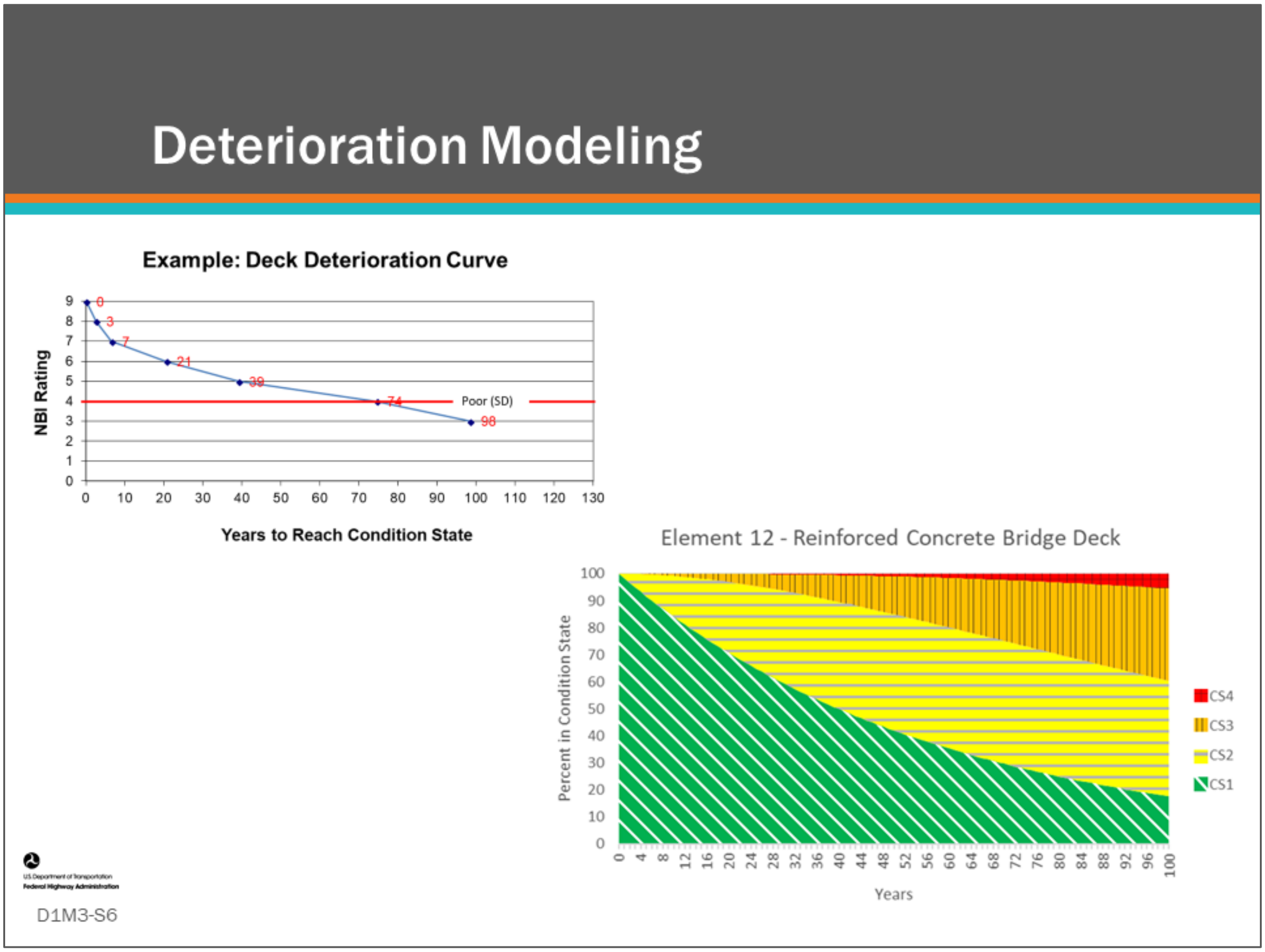
D1M3-S5

Key Message

The first step an agency should take when developing a bridge strategic plan and bridge management system is to develop goals, objectives, and performance measures. Module 4 defines what goals, objectives, and performance measures are and shows the important role they play in bridge management. Examples of agency performance measures will be shown as illustrated in the good, fair, and poor column charts shown on this slide.

The participants will also learn how to calculate a bridge health index which BMS software often uses as a performance measure.

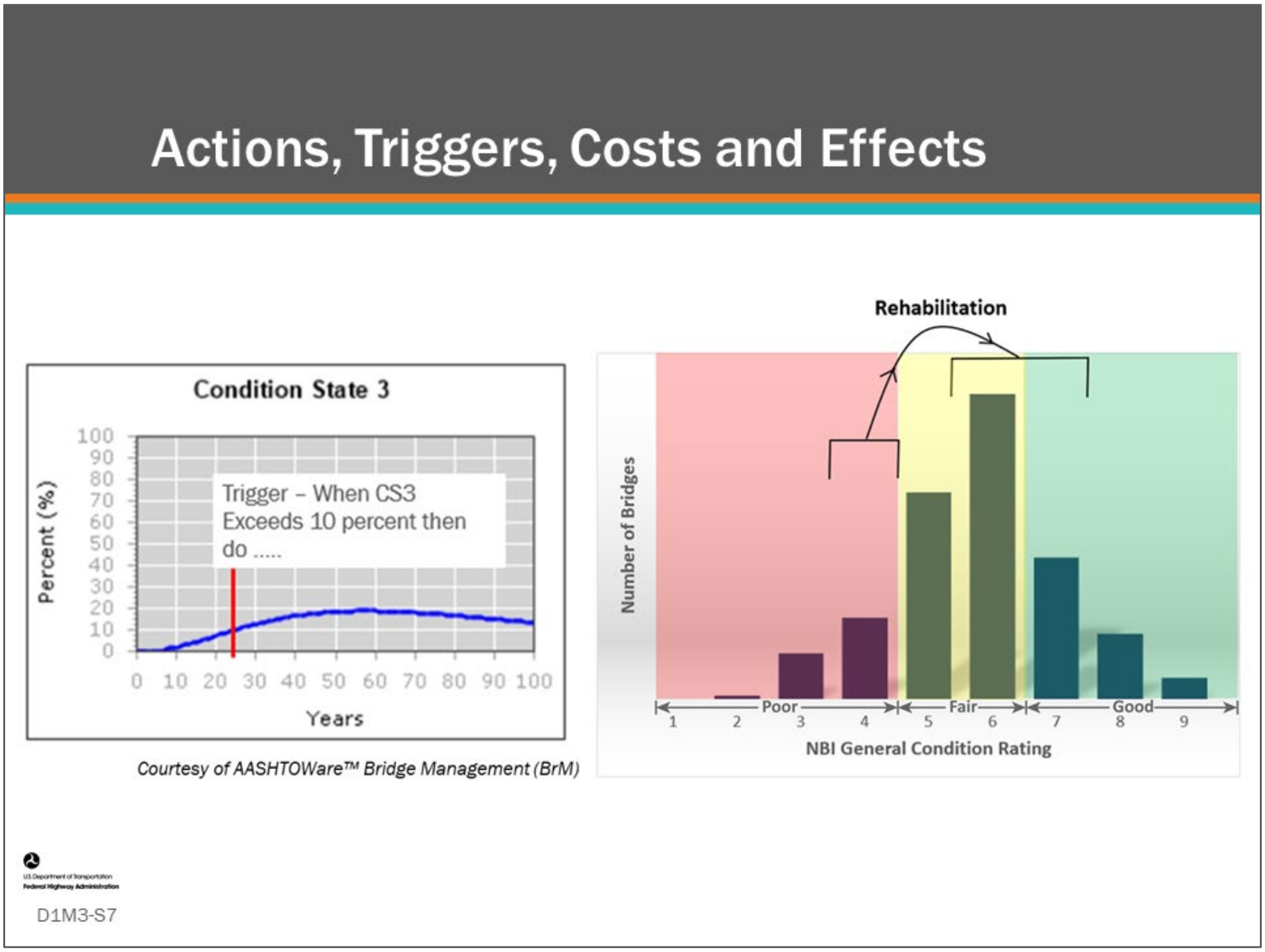
D1M3-Slide 6



Key Message

Deterioration models are very important to a BMS, as they allow us to predict the future condition of the bridge components and/or elements. Module 5 - Deterioration Models will explore how these models are created and input into a BMS.

D1M3-Slide 7

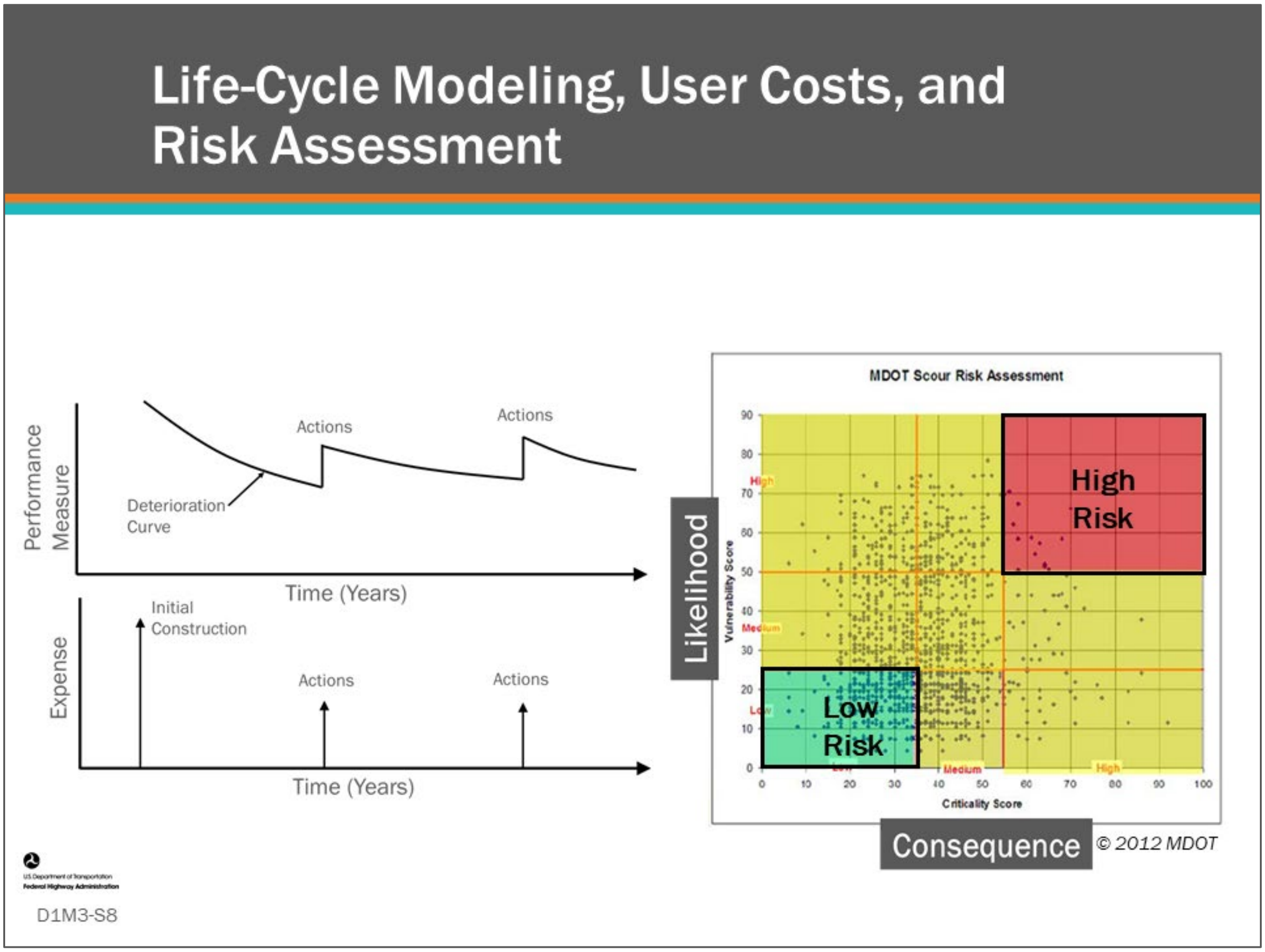


Key Message

Key inputs into a BMS are actions (also called treatments or projects), “triggers” that identify actions that are feasible to take, costs for these actions, and benefit of these actions. In BMS workflow, feasible actions are later analyzed to determine the optimal actions to perform. Module 6 will show how these are used in a BMS.

Actions are triggered by either agency rules or engineering-economic analysis. Agency rules are network level and project level. Network level agency rules can include determination of when a bridge becomes eligible for work in categories such as preservation, rehabilitation, and replacement projects. Project level agency rules can include a decision tree for selecting work actions dependent upon material type and condition.

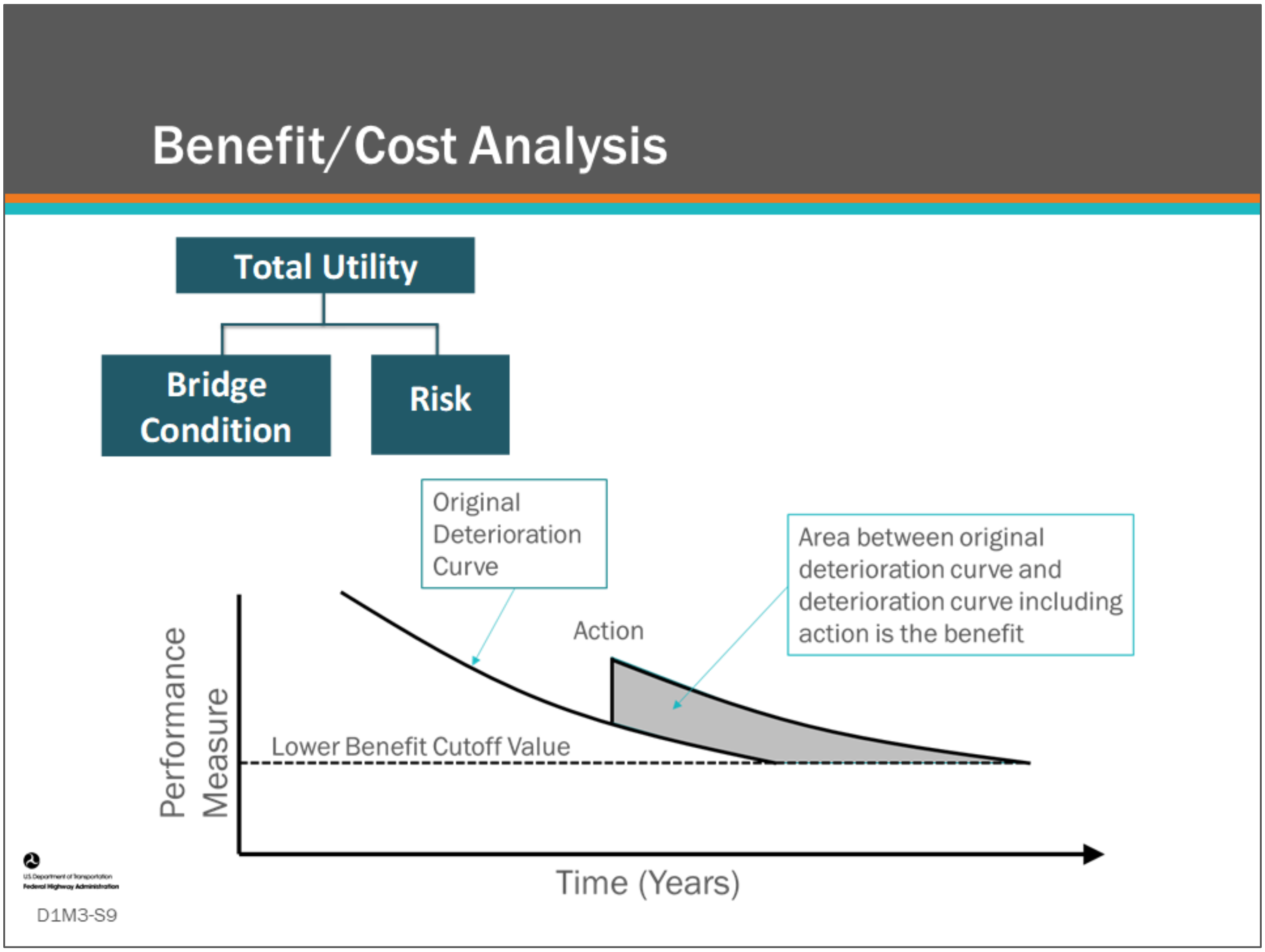
D1M3-Slide 8



Key Message

Life-cycle modeling and risk assessment are key components of a BMS. In Module 7, we will learn about agency costs and life-cycle modeling including life-cycle cost analysis. In Module 8 we will learn about user costs and how these can be incorporated into LCCA. In Module 9 we will learn how to do a risk assessment and see how it can be included in a BMS.

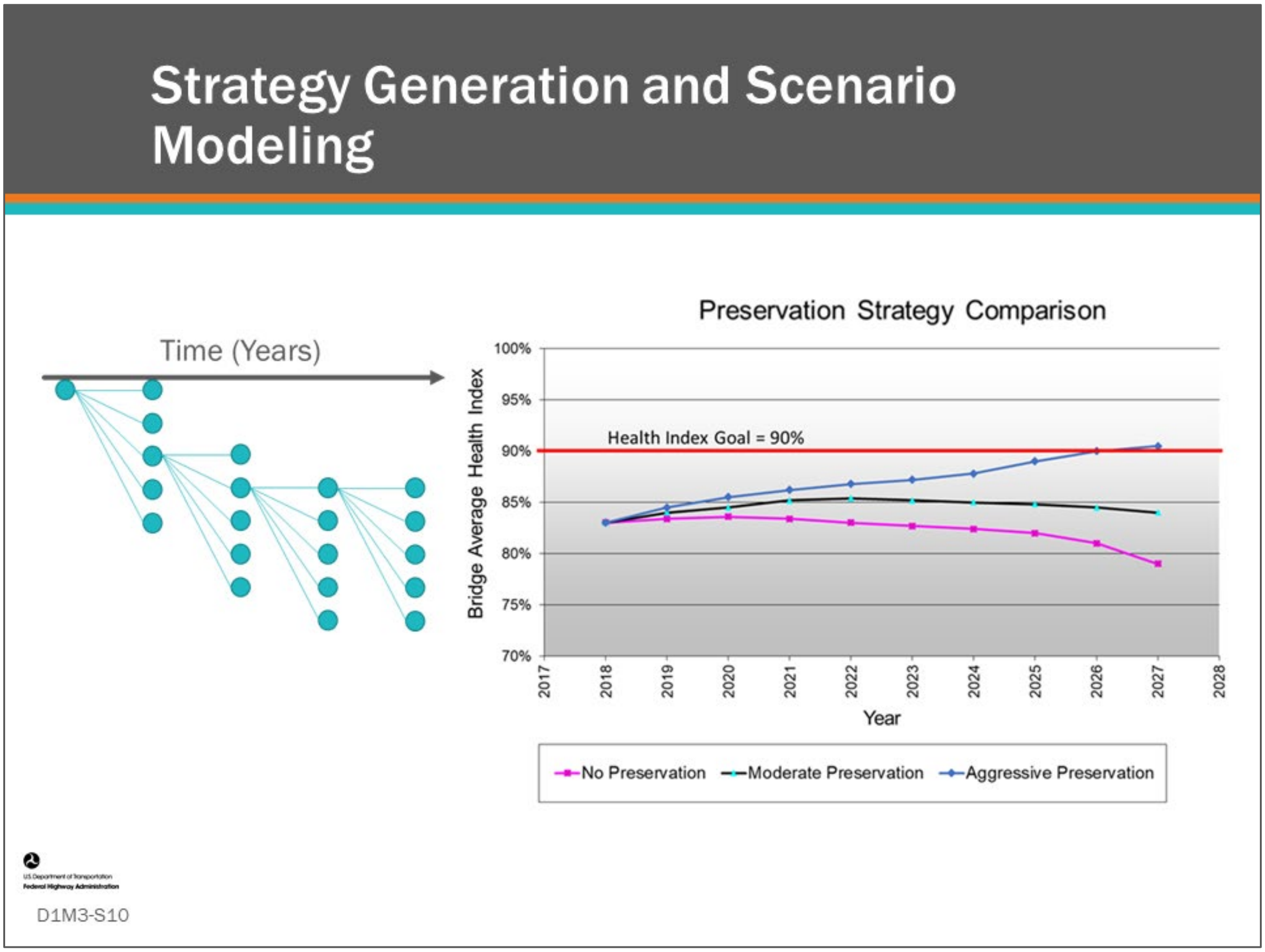
D1M3-Slide 9



Key Message

Benefit/Cost analysis is used in a BMS to compare the value of different actions (treatments) to a bridge or a network of bridges. It can compare different objectives on a common scale. In Module 10, we will learn how different BMS go about doing this, including utility theory, and showing benefit as area under the performance versus time curve.

D1M3-Slide 10



Key Message

Modules 11 and 12 will explore prioritization and optimization and will show how scenario models are used to develop optimum strategic investment plans. This is the primary function that advanced BMS software do.

D1M3-Slide 11

Program and Project Planning

Bridge Subprogram - By Work Category	
Maintenance	$5 Million
Preservation	$30 Million
Rehabilitation	$50 Million
Initial Construction / Reconstruction / Replacement	$80 Million

Bridge Subprogram - By District	
District 1	$40 Million
District 2	$50 Million
District 3	$20 Million

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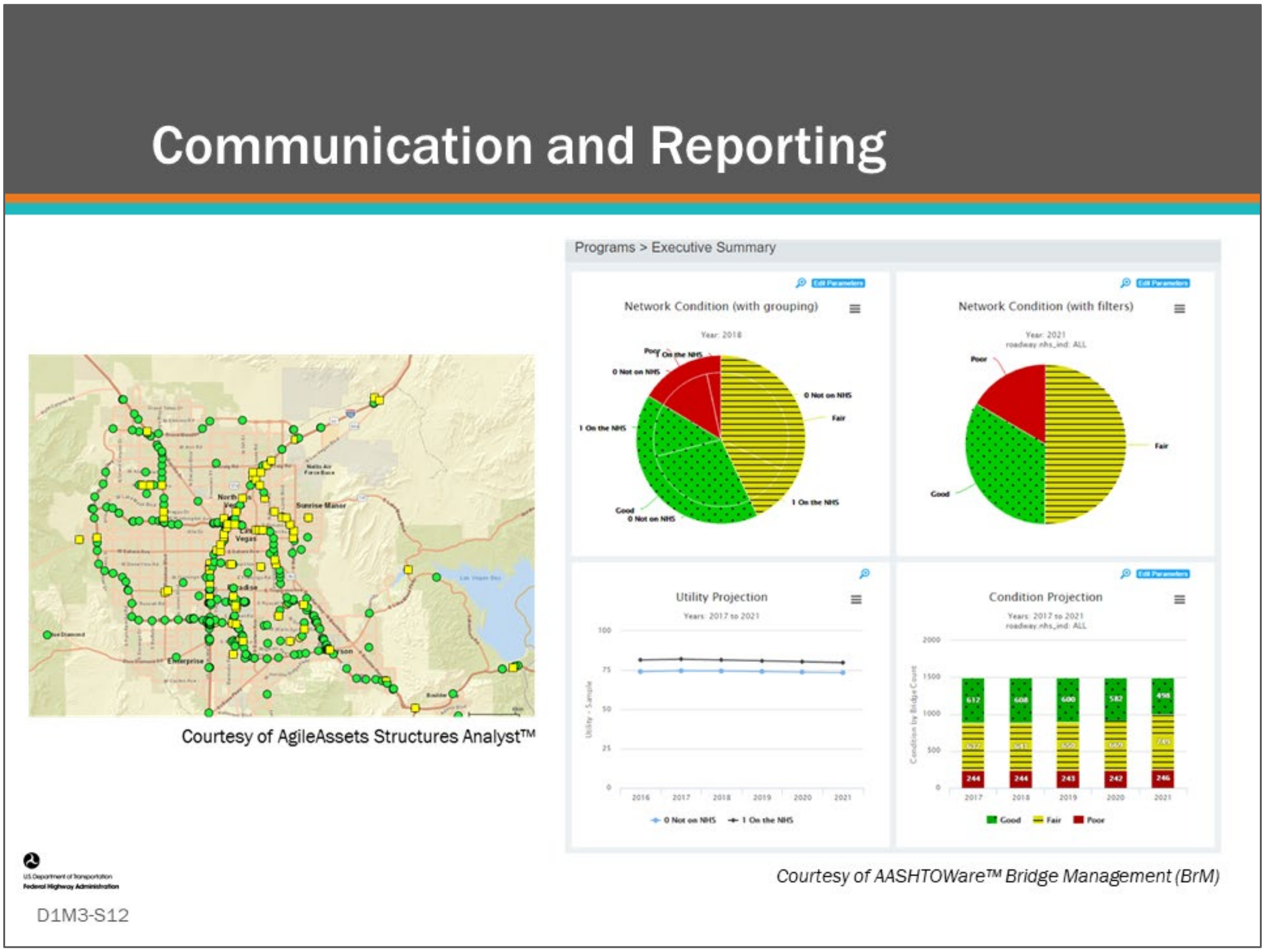
D1M3-S11

Key Message

Once you have the ability to model scenarios and develop a strategic investment plan, Module 13 will show how agencies develop programs and projects. We will see how BMS software allows input of work candidates and how it helps agencies organize and manage bridge projects.

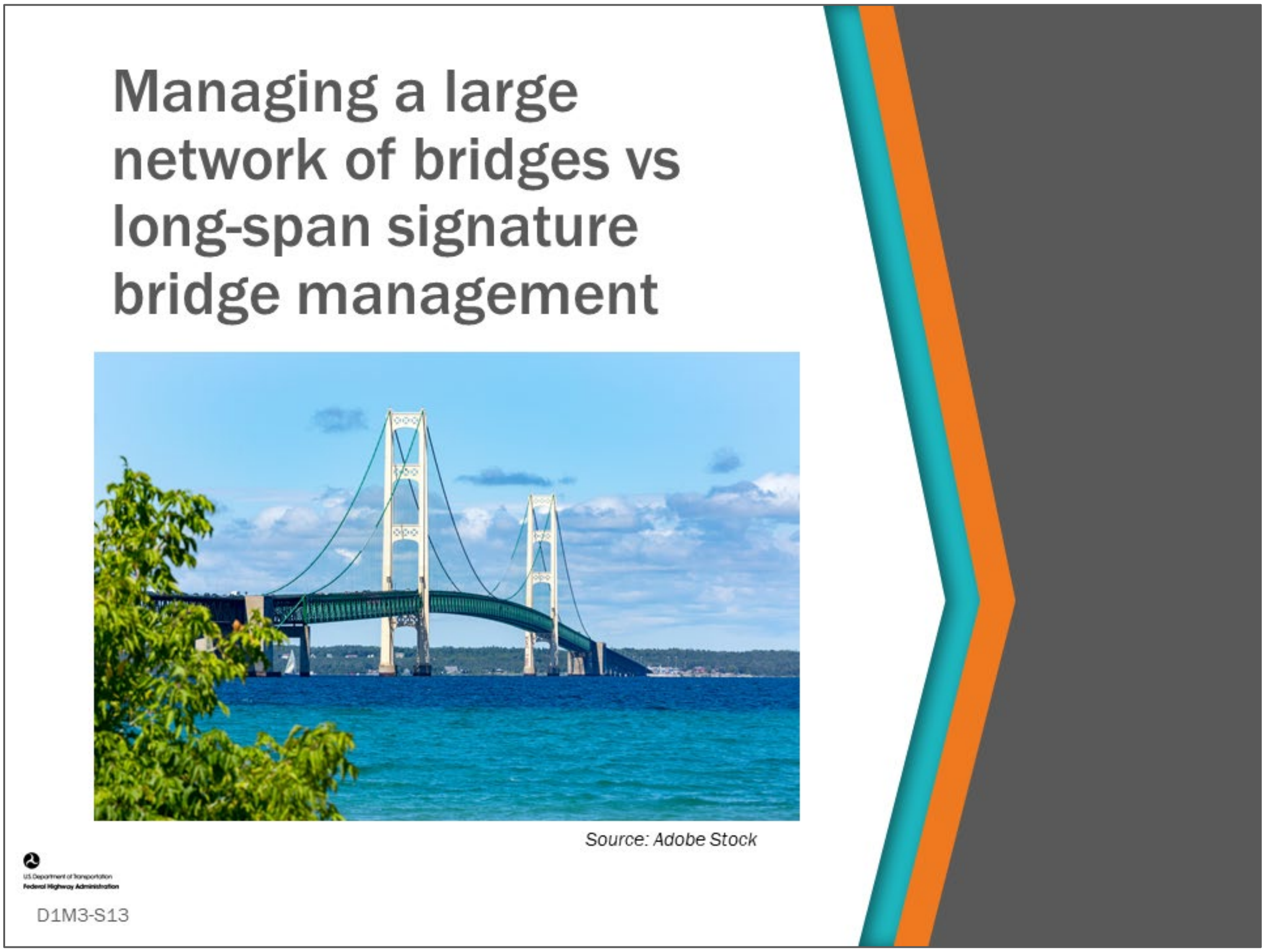
D1M3-Slide 12



Key Message

Finally, we will see how agencies communicate and report on their program to practitioners, executive leadership, and the public.

D1M3-Slide 13



Key Message

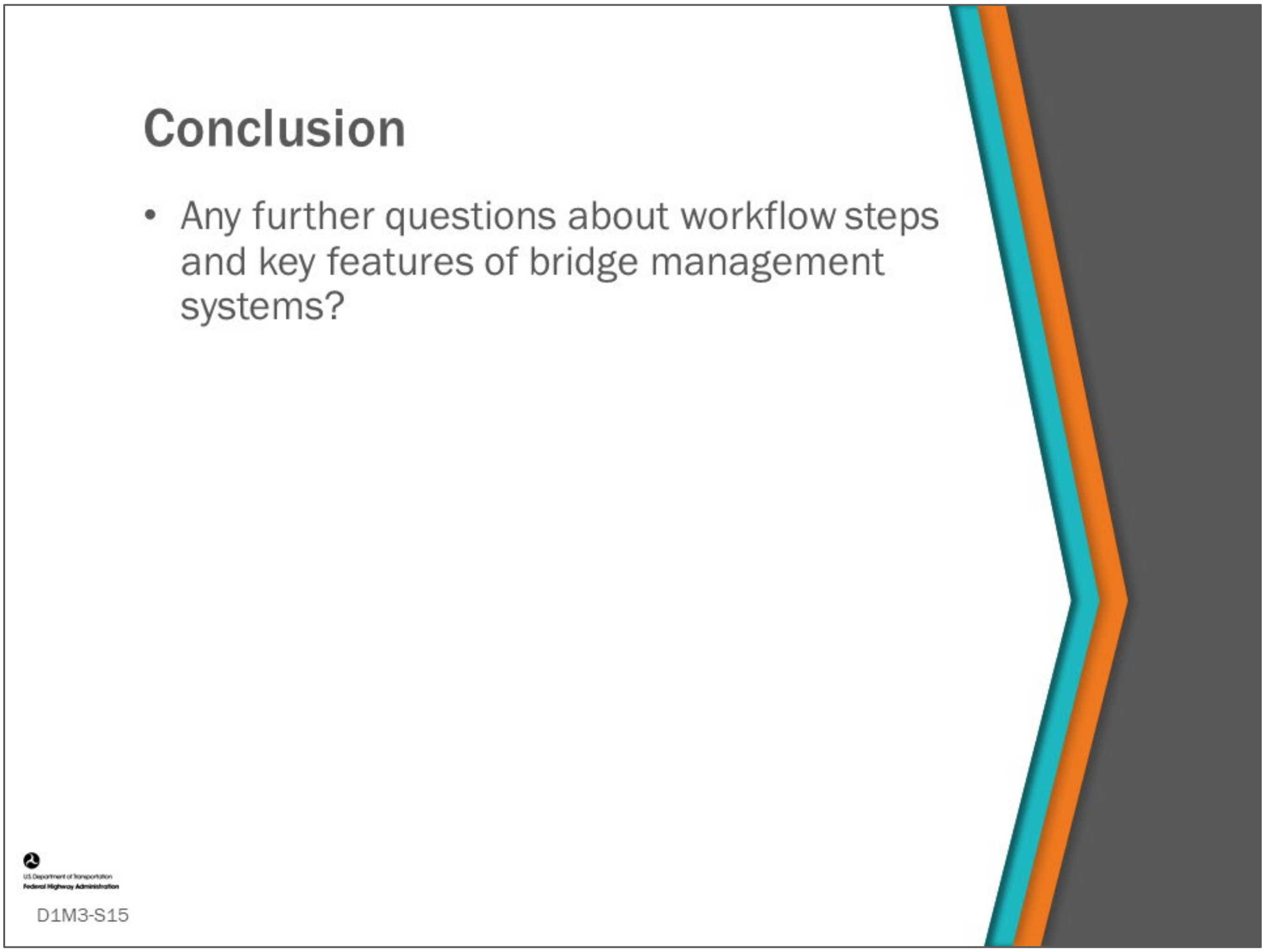
Before we get started with the workshop, we want to briefly mention management of long-span signature bridges. Preservation of these bridges is critically important, and they can and should be part of a BMS, but management of these bridges may require special management over and above what is typically done with current BMS software.

D1M3-Slide 14

Key Message

Whereas a BMS is built to manage a network of many bridges and structures (which is the focus of this workshop), there is also management of long-span signature bridges. These bridges have extensive value, both monetary and importance to society, and thus often have their own inspection practices, management strategies, and analysis systems. They often are composed of element types, costs, actions, and performance criteria and behavior that differ substantially from conventional bridges and are difficult to model and analyze using standard BMS inputs and models. Although this workshop does not have time to delve into this subject, the following research is recommended reading: *The Use of Element Level Data & Bridge Management Software in the Network Analysis of Big Bridges.*

D1M3-Slide 15



Key Message

This concludes D1M3: Workflow Steps and Key Features of Bridge Management Systems.

D1M3-Slide 16

Slide #	Image Description	Source Information
4	Picture of snooper truck crew inspecting bottom side of concrete arch bridge.	Adobe Stock.
4	Screenshot showing of AgileAssets Structures Analyst™ Asset Inventory, Bridge, Inventory screen.	AgileAssets® Structures Analyst™ software.
4	Screenshot showing AASHTOWare™ Bridge Management (BrM) bridge element quantity and condition rating screen.	AASHTOWare™ Bridge Management (BrM) software.
5	A screenshot of a spreadsheet shows element numbers, element names, total quantity, units, CS1, CS2, CS3, CS4, relative unit weight, the numerator of the equation for bridge health index, and the denominator for bridge health index.	This Workshop.
5	A column chart shows percentage on the y-axis and year on the x-axis.	FHWA. *Bridge Preservation Guide: Maintaining a Resilient Infrastructure to Preserve Mobility*. Publication No. FHWA-HIF-18-022. Washington D.C., 2018.
6	A chart for an example deck deterioration curve showing NBI rating on the y axis (0 - 9) and Years To Reach Condition State on the x axis (0 - 130).	This Workshop.
6	A chart titled, "Element 12 - Reinforced Concrete Bridge Deck"	This Workshop.

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D1M3-S16

D1M3 Figure Source List

D1M3-Slide 17

Slide #	Image Description	Source Information
7	Screenshot from AASHTOWare™ Bridge Management (BrM) software of CS3 deterioration curve.	AASHTOWare™ Bridge Management (BrM) software.
7	Screenshot of column chart with Number of Bridges on the y-axis and NBI General Condition Rating on the x-axis.	This Workshop.
8	Two charts are shown. The top chart is a line chart having Performance Measure on the y-axis and time in years on the x-axis. The bottom chart shows a life-cycle activity profile which is a horizontal line representing time with vertical arrows representing expenditures.	This Workshop.
8	A chart showing vulnerability score (likelihood) on the y-axis (0- 90)and criticality (consequence) on the x-axis (0 - 100). the chart is color coded for low, medium, and high risk on both axis. the area low vulnerability and low criticality is green, medium vulnerability and medium criticality is yellow, and high vulnerability and high criticality is red.	© 2012 MDOT.
9	A family tree chart shows Total Utility on the top row. It shows Bridge Condition and Risk on the second row.	This Workshop.
9	A line chart with Performance Measure on the y-axis and Time in Years on the x-axis.	This Workshop.
10	A graphic shows a series of markers in relation to a horizontal time scale.	This Workshop.
10	A line chart titled "Preservation Strategy Comparison."	This Workshop.
11	Table with title "Bridge Subprogram - By Work Category."	This Workshop.

D1M3-S17

D1M3 Figure Source List

D1M3-Slide 18

Slide #	Image Description	Source Information
11	Table titled, "Bridge Subprogram - By District."	This Workshop.
12	A Screenshot of AgileAssets Structures Analyst™ software showing a map of the greater Las Vegas area with markers showing good (green), fair (yellow), and poor (red) bridges.	AgileAssets® Structures Analyst™ software.
12	Screenshot of the AASHTOWare™ Bridge Management (BrM) software Executive Summary screen showing four charts, two pie charts showing good (green), fair (yellow), and poor (red), one with groupings, the other with filters, a utility projection line chart, and a condition projection column chart.	AASHTOWare™ Bridge Management (BrM) software.
13	Picture of the Mackinac Bridge.	Adobe Stock.
14	Screenshot of the cover for the research project, "The Use of Element Level Data & Bridge Management Software in the Network Analysis of Big Bridges."	MDOT. *The Use of Element Level Data & Bridge Management Software in the Network Analysis of Big Bridges*. Research Project No. 0R14-022. Transportation Pooled Fund Study No. TPF-5(308). 2017.

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D1M3-S18

D1M3 Figure Source List

Module Title: D1M4 – Inventory and Condition Data; Agency Goals, Objectives and Performance Measures

Module Time: 40 minutes

Module Summary

The foundation of any BMS is the inventory and condition data. This module reviews the types of inventory and condition used in BMS including national defined data as well as agency defined data. Agencies need to make many decisions when building a BMS including setting strategic goals, objectives, and performance measures. Bridge owners distinctively know the needs of their bridges, but they may not use performance measures to connect asset management decisions to strategic goals, and they may not have a good handle on future needs. Several examples of performance measures will be discussed including Good, Fair, and Poor bridges as well as an element-based health index. As BMS software systems advance, agencies can also consider life-cycle cost utility as a performance measure.

Expected Outcome(s)

Participants will gain a high-level understanding of the agency inventory and condition data available for input into the BMS and how agency goals, objectives, and performance measures are used in bridge management.

Resource List

Slide	Reference Information
5,8	FHWA. *Recording and Coding Guide For The Structure Inventory and Appraisal of the Nations Bridges*. Publication No. FHWA-PD-96-001. Washington, DC, 1995.
6	NYSDOT. *Bridge Inventory Manual*. July 2006.
10	FHWA. *Hydraulic Engineering Circular No. 18. Evaluating Scour at Bridges.* Publication No. FHWA-HIF-12-003. Fifth Edition, Washington, DC, 2012.
16	AASHTO. *Manual for Bridge Element Inspection*. Washington, DC, 2013.
17,18	MDOT. *Bridge Element Inspection Manual*. 2015.
19,20	NJDOT. *Bridge Element Inspection Manual*, rev. January 2015.
29	Ghanbari, M. *Business Goals vs. Objectives vs. Strategies vs. Tactics*, 2014.
29	FHWA. *Asset Management and Management of Highway Performance Peer Exchange*. Publication No. FHWA-HIF-10-006. Washington, DC, 2009.
29,30	NCHRP. *Report 632 An Asset-Management Framework for the Interstate Highway System*. Washington, DC, 2009.
31	Fitzgerald, A., et al. *2018 Purdue Road School Introduction to INDOT Bridge Asset Management Procedures*. 2018.
32	FHWA. Chart, Presentation, *National Performance Management Measures: Bridge Condition to Assess the National Highway Performance Program*. FHWA Office of Bridges & Structures. Washington, DC, 2017.
33	FHWA. *Bridge Preservation Guide: Maintaining a Resilient Infrastructure to Preserve Mobility*. Publication No. FHWA-HIF-18-022. Washington, DC, 2018.
34	Shepard, R. and M. Johnson. *Evaluating Bridge Health, California's Diagnostic Tool.* TR News No. 215. Transportation Research Board and National Research Council. Washington, DC, 2001.
35	Johnson, J. *AASHTOWare BrM 5.2.3. Deterioration and Life-Cycle Cost Analysis*. International Bridge Management Conference. April 2017.
37	FHWA. *Using a Life Cycle Planning Process to Support Asset Management.* Washington, DC, 2017.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D1M4-Slide 1

Key Message
Covered in this module are inventory data, condition data, and Agency bridge goals, objectives and performance measures.

Disclaimer
FHWA does not promote or endorse patented and proprietary products. Bridge management software is largely proprietary. Workshop content pertaining to proprietary software is included only to illustrate how bridge management system concepts and analyses are applied in practice. The included content shall not be construed as promotion or endorsement of specific software.

D1M4-Slide 2

Key Message

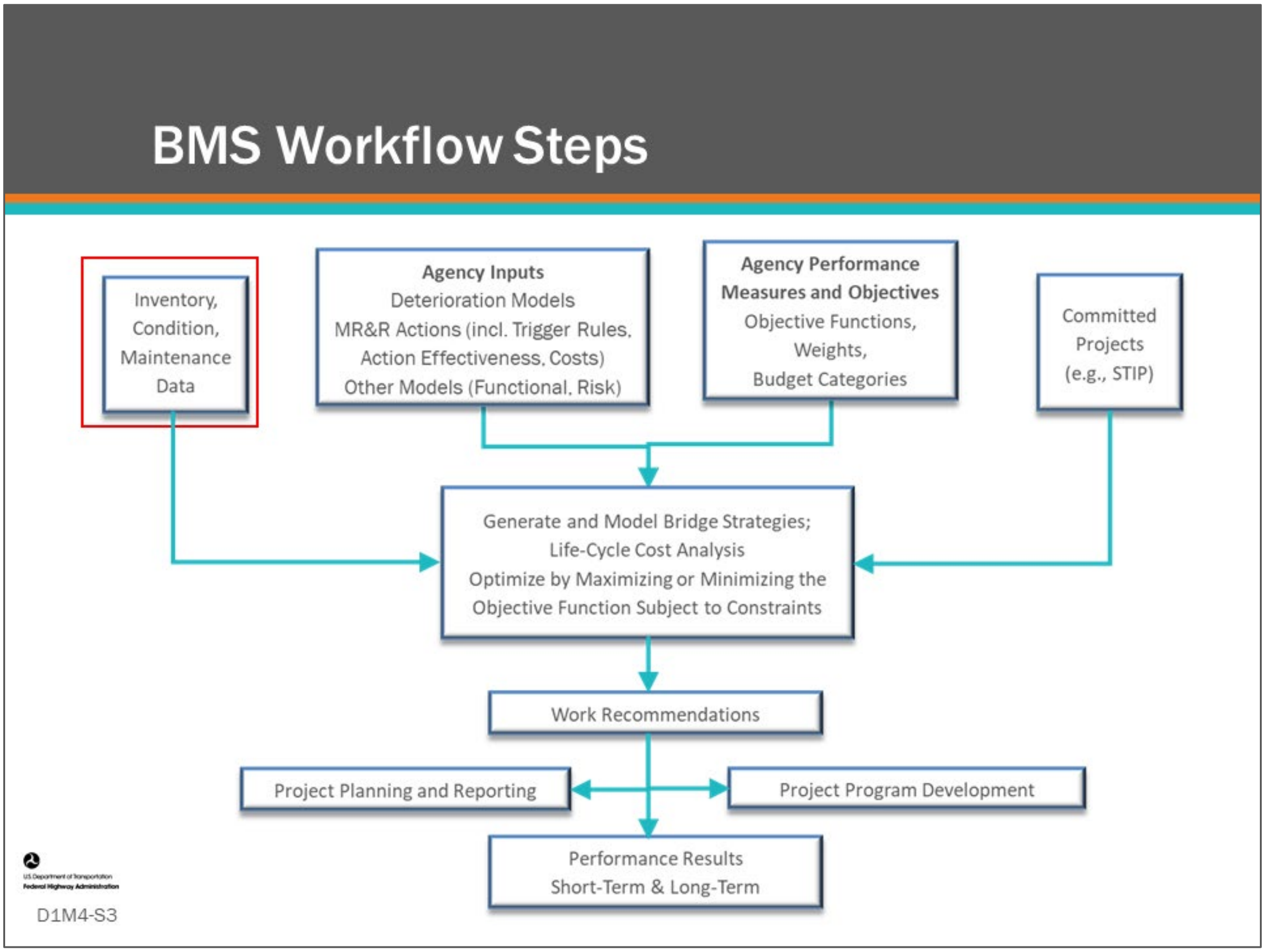
The last module showed workflow steps and key features of Bridge Management Systems (BMS).

This module reviews:

- Inventory and condition data
- Goals
- Objectives
- Performance measures

It shows what data is collected and how it used in a BMS, including data input into several BMS software, in order to help bridge managers to set goals, objectives and performance measures for Agency bridges.

D1M4-Slide 3



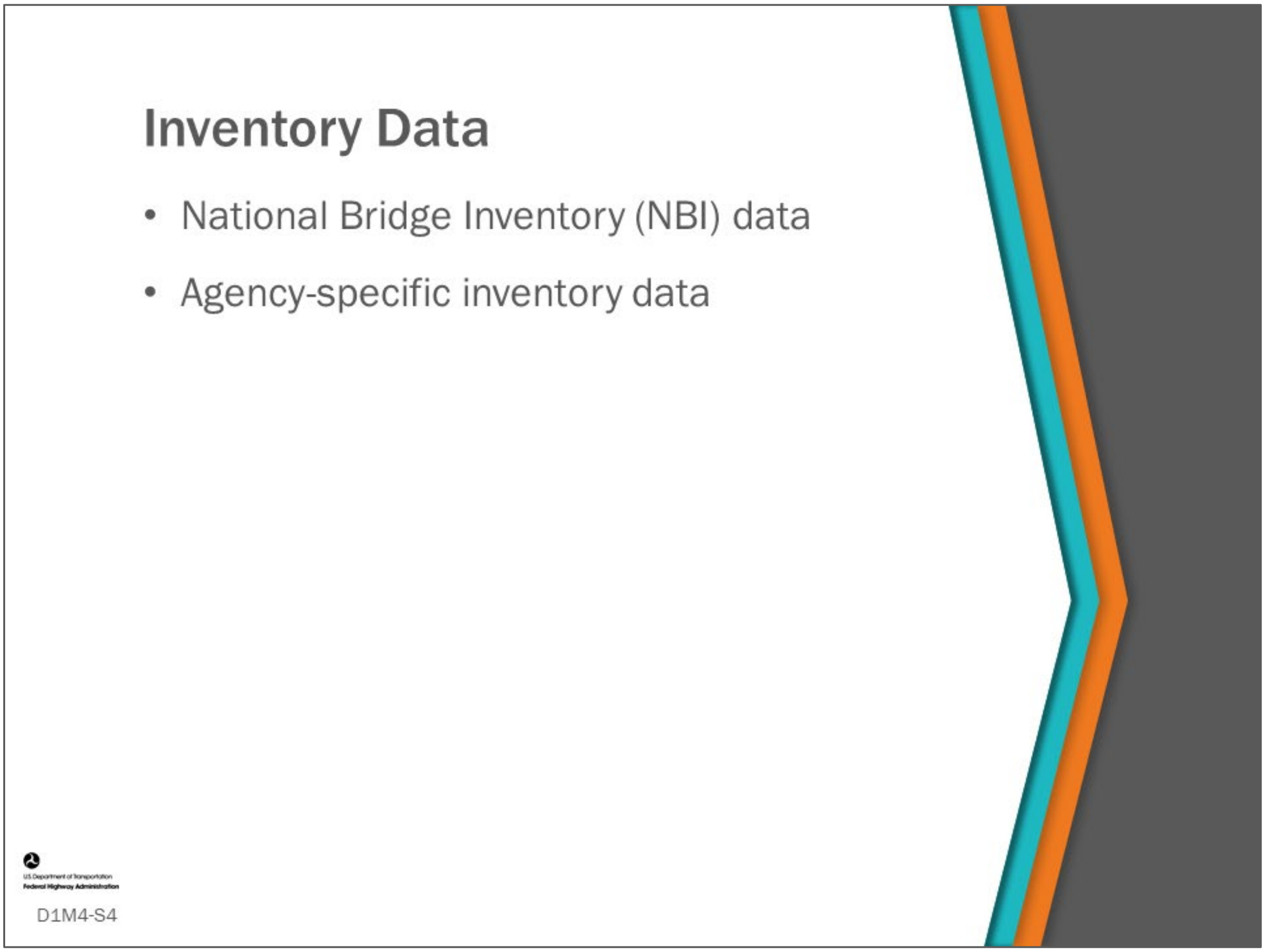
Key Message

Common workflow steps and features are shown on the slide. In this first section of this module, we will review Inventory and Condition Data.

Each of these topics will be introduced in the following slides.

In the following modules, the interrelationship of these steps and progression from one step to another will be shown.

D1M4-Slide 4

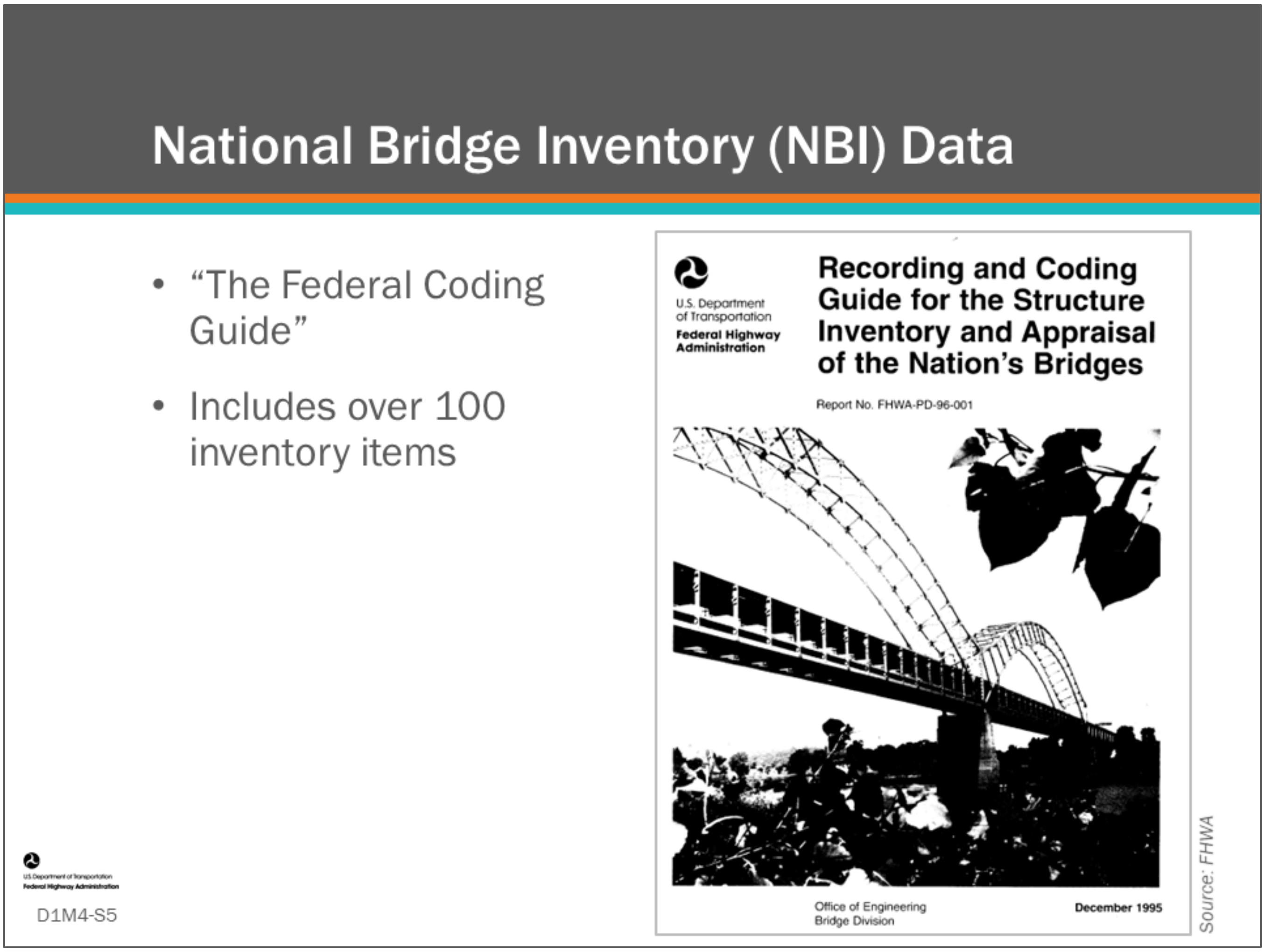


Key Message
The foundation of any BMS is the inventory data.

This topic will go over:

- National Bridge Inventory (NBI) and Agency-specific inventory data used in a BMS
- How inventory data is input, stored, and managed in a BMS

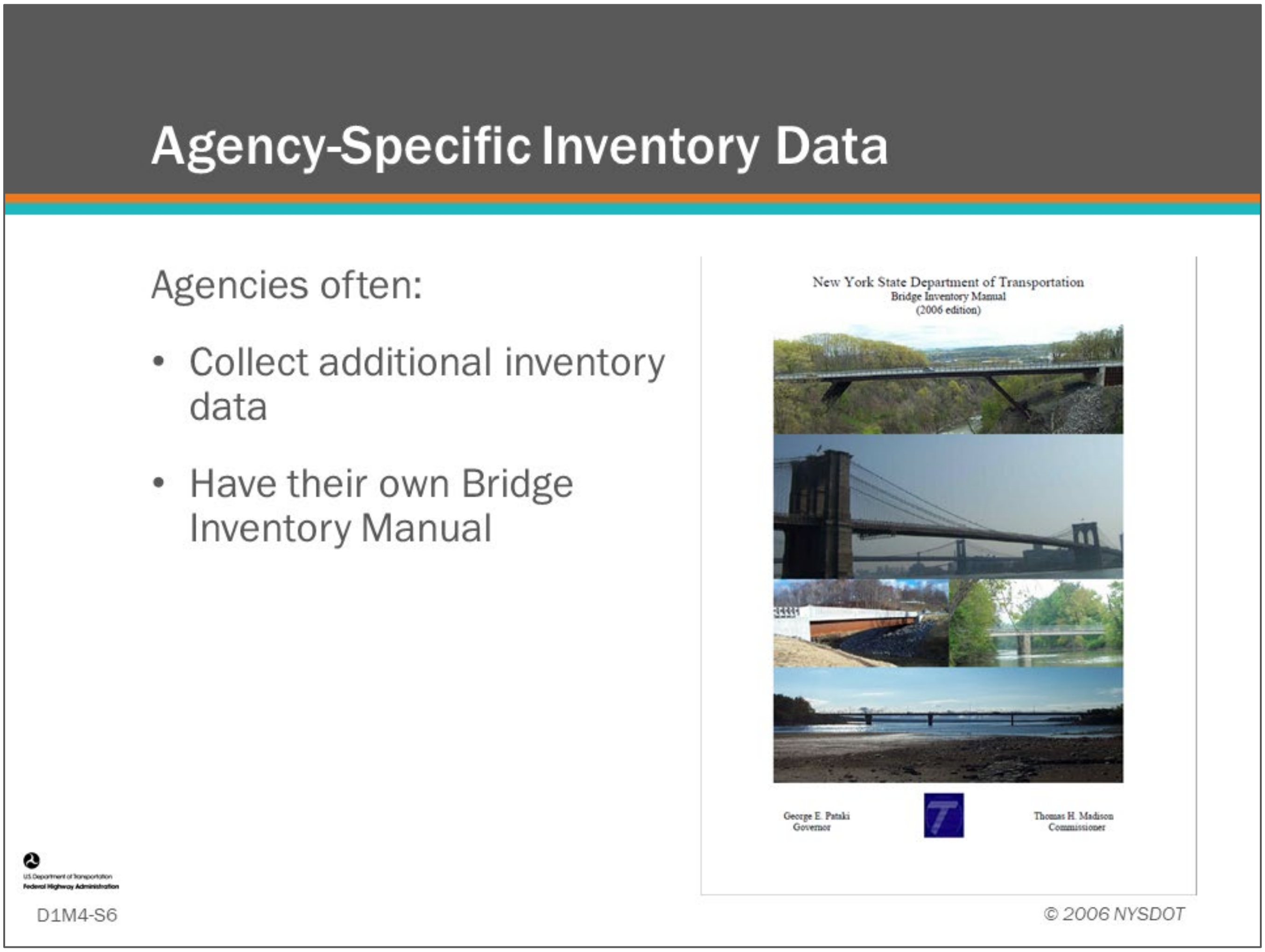
D1M4-Slide 5



Key Message

Bridge inventory data for bridges starts with the Federal Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges. This is often referred to as "The Federal Coding Guide". This guide includes over 100 inventory items.

D1M4-Slide 6

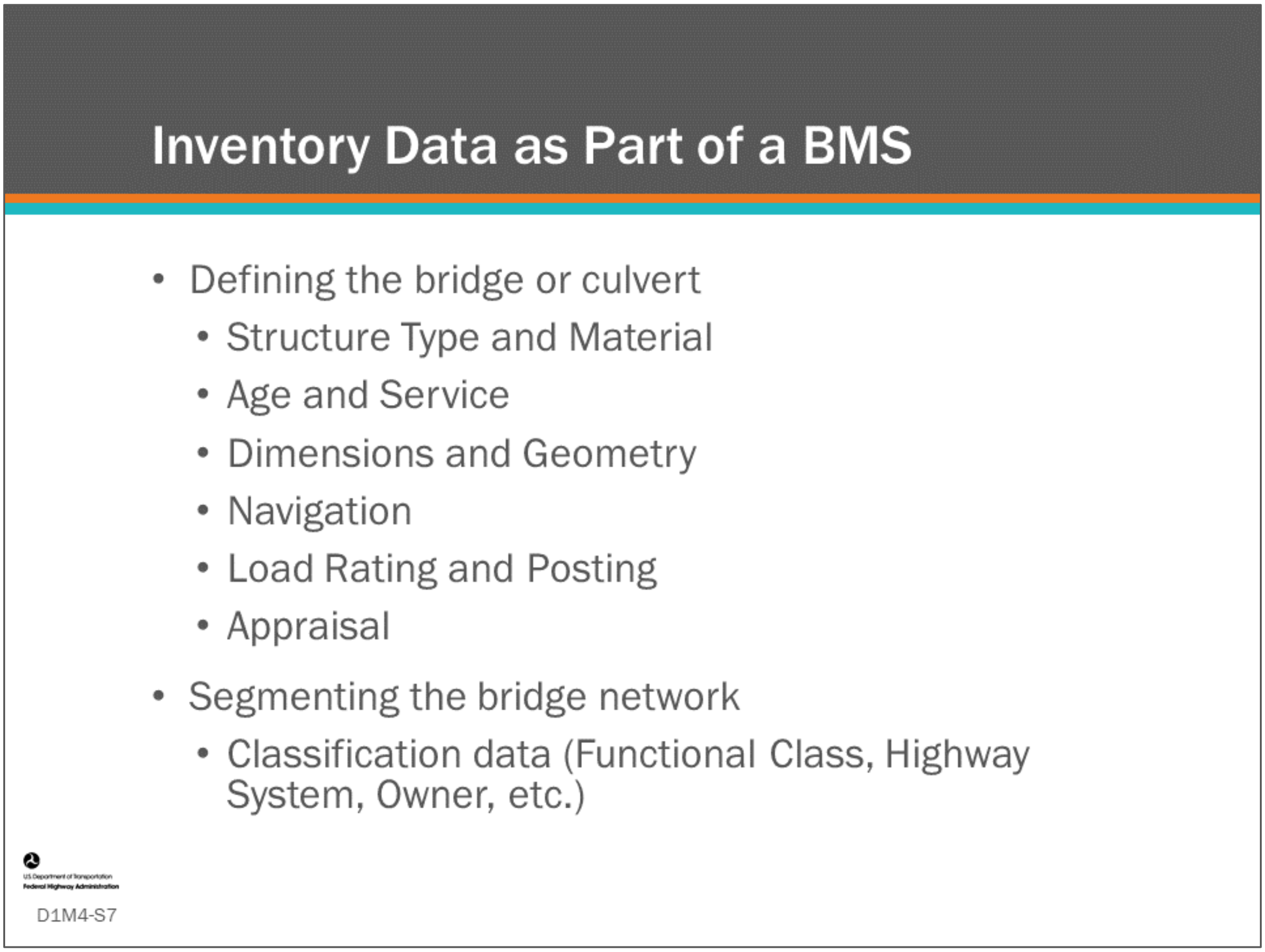


Key Message

Agencies sometimes collect additional inventory data to help manage their bridges. These additional inventory items are most often added to the Agency's BMS.

Shown on the slide is New York DOT's Bridge Inventory Manual.

D1M4-Slide 7



Key Message

Inventory data (NBI and Agency-specific) are an important part of a BMS.

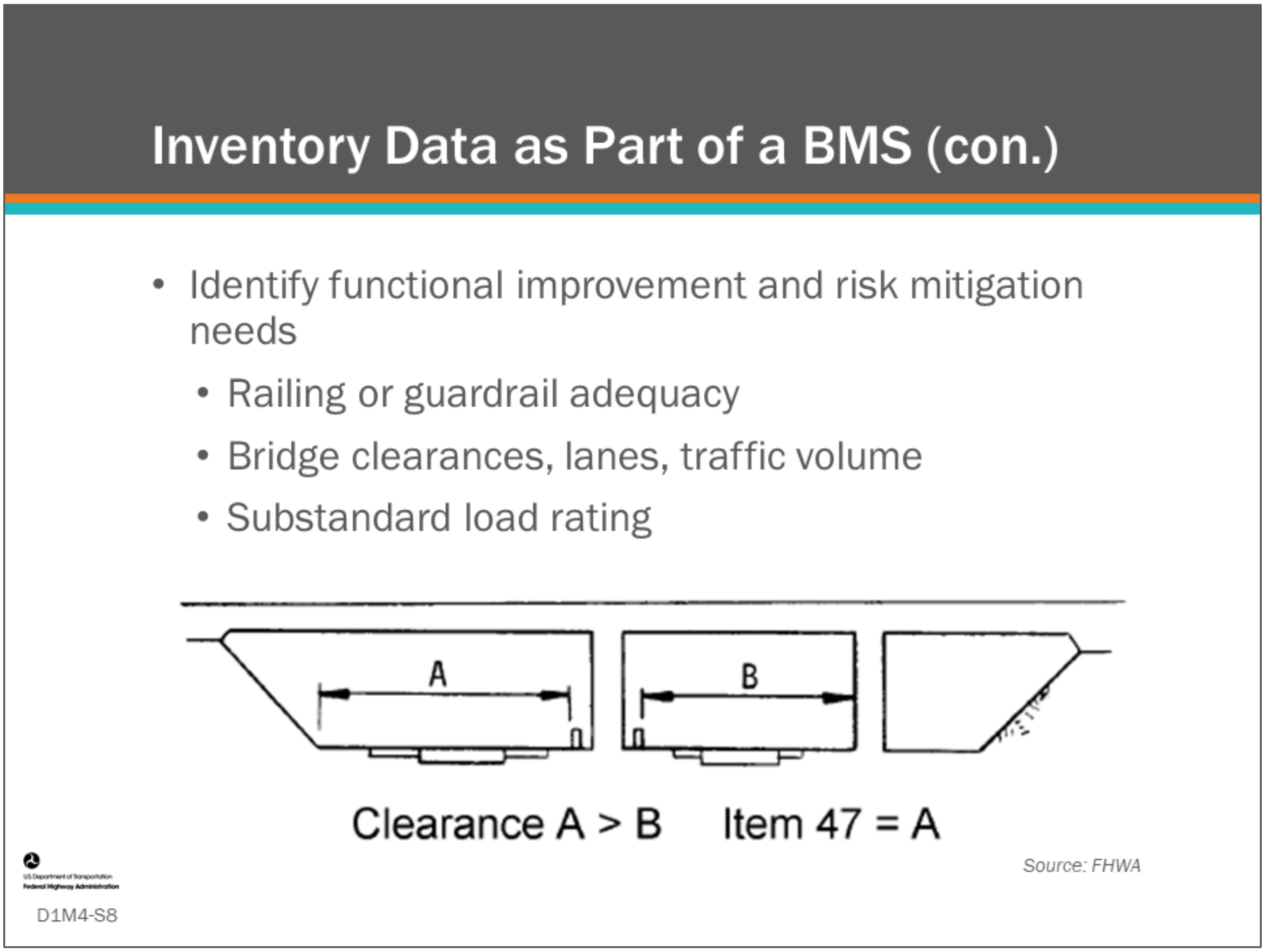
Common features of inventory data include:

- The inventory data is quasi-static where most data only changes because of construction or reconstruction activity (since load rating and appraisal items can change with condition, ADT, etc.)
- The inventory data is stored at the bridge level (one record per bridge) as opposed to condition data which is stored for each inspection

Inventory data items are used by BMS in many of their functions. Some include:

- Defining the bridge or culvert
- Segmenting the bridge network

D1M4-Slide 8

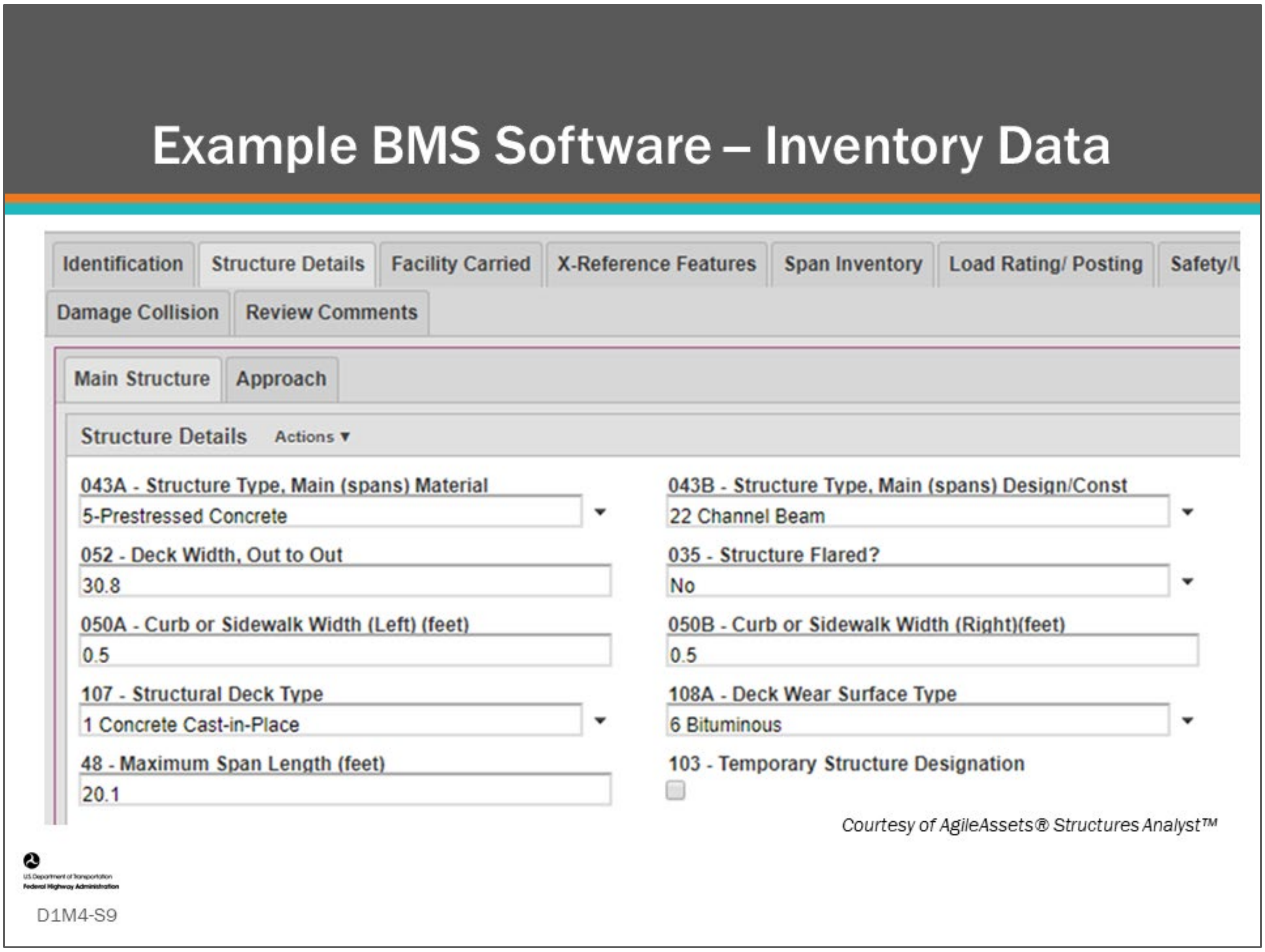


Key Message

Inventory data is used to identify and manage functional improvement and risk mitigation needs. The BMS may "flag" an inventory item that is not up to current standards; for example:

- A bridge barrier and approach guardrail that is not up to current standards;
- Inadequate horizontal and vertical clearances or the number of lanes on a bridge and roadway approach may be substandard for the traffic volume and be a potential cause of congestion, accidents, and/or truck detours;
- A bridge with substandard vertical or horizontal clearances under it may be hit by high loads; or,
- Load ratings that do not accommodate state legal loads can also drive needs for improvement.

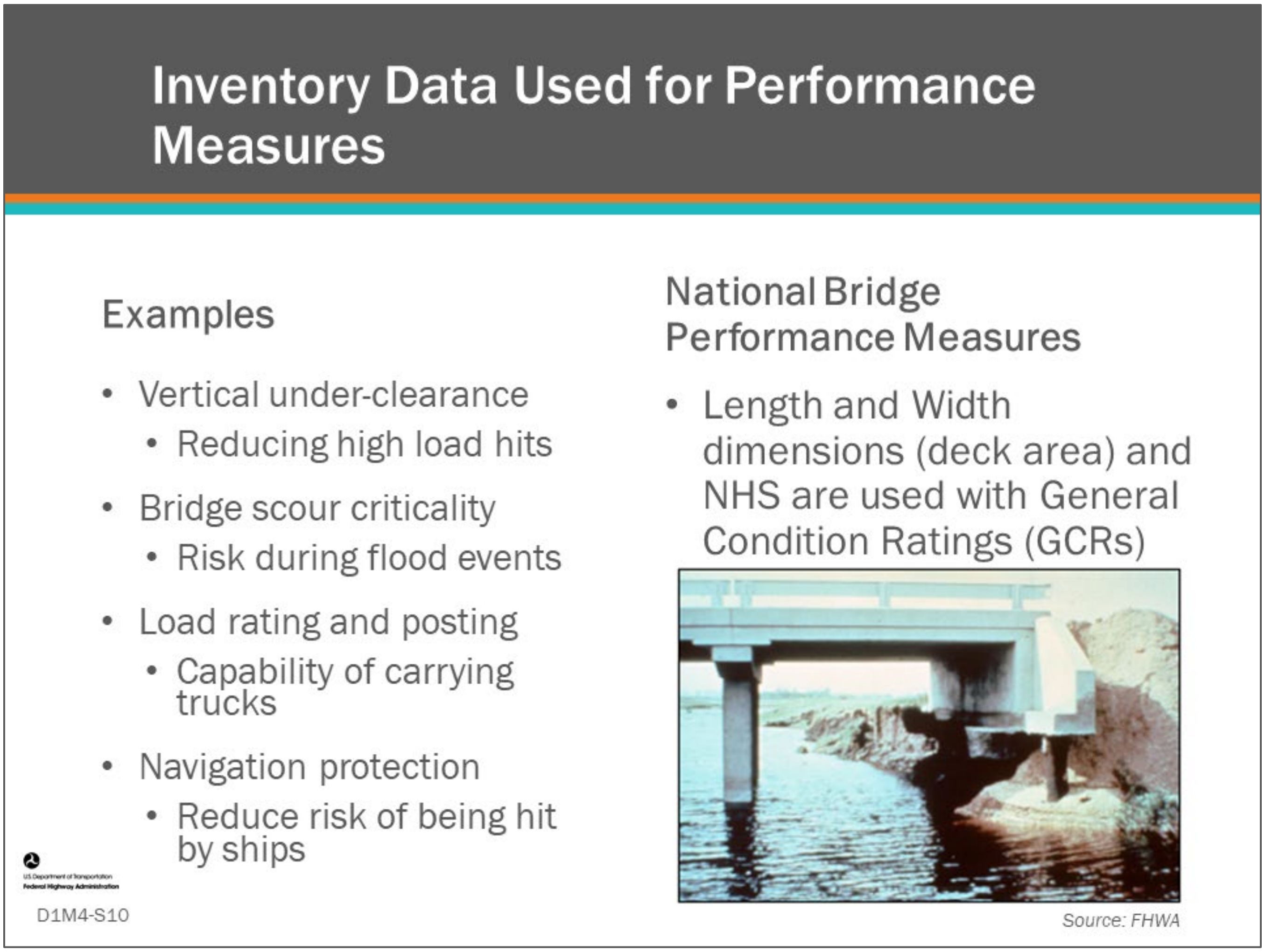
D1M4-Slide 9



Key Message

BMS software provide functionality to input, store, manage, view, and use agency bridge inventory data. Shown on slide is the AgileAssets® Structures Analyst™ inventory tabs for collection and management of an agency's bridge inventory data. Inventory data needs to be up-to-date and accurate in order for the BMS to provide useful results.

D1M4-Slide 10



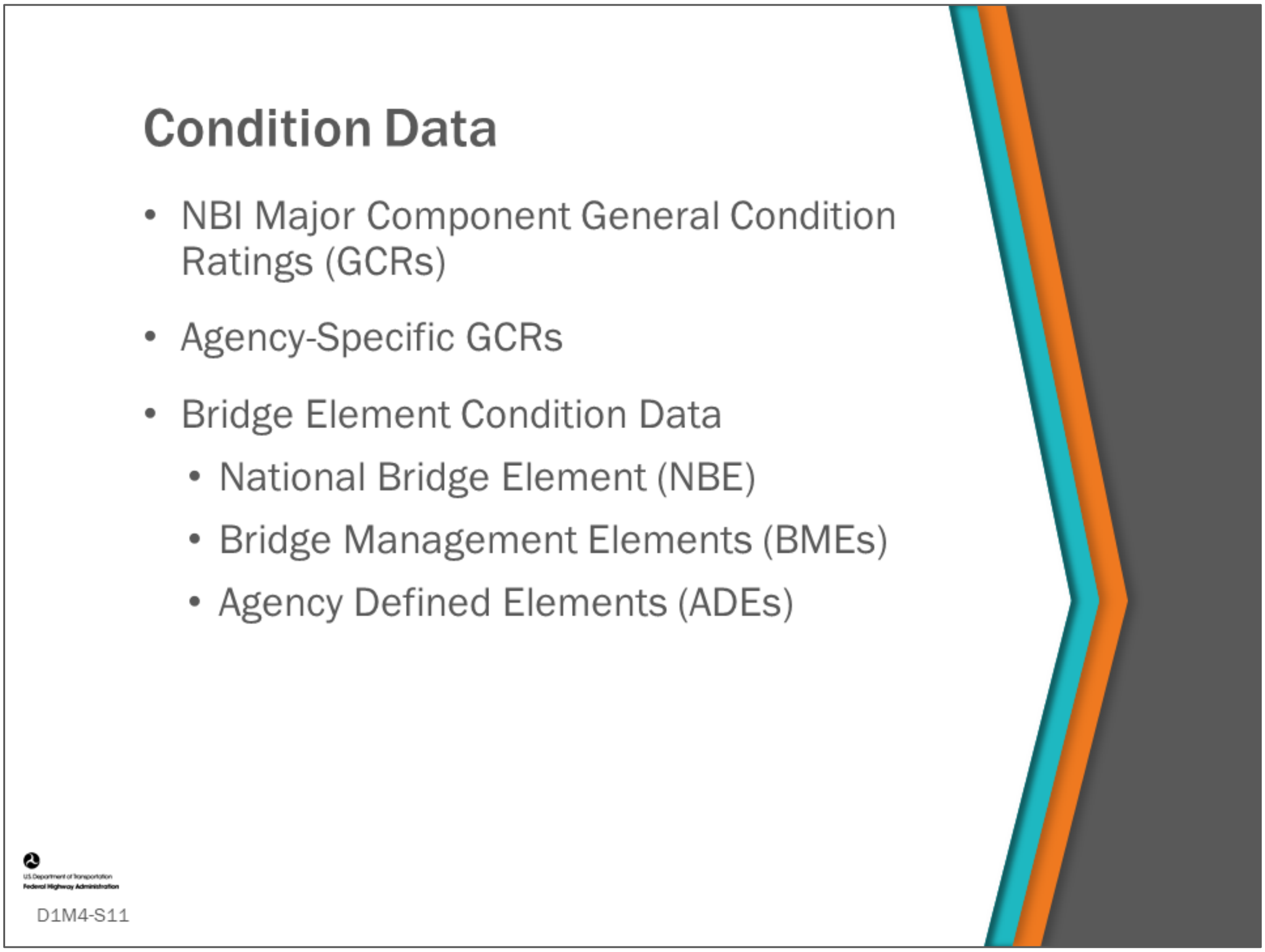
Key Message

Inventory data are an important component of any bridge performance measure.

Examples of how inventory data may be included in performance measures include:

- Vertical under-clearance used as a measure to reduce high load hits
- Bridge scour criticality (Item 113) used to measure an agency’s risk during flood events
- Load rating and posting used as a performance measure in carrying commercial truck traffic
- Deck area (for bridges, length multiplied by width; and for culverts, culvert length multiplied by approach roadway width) and National Highway System (NHS) used to determine national bridge condition performance measures

D1M4-Slide 11



Key Message

Condition data is information collected during bridge inspections that describe the condition of major components and elements.

Condition data:

- Can change with each bridge inspection
- Is considered dynamic
- Is stored in a “inspection” data table that new inspections can be added to
- Is modelled in the BMS (to be demonstrated in this workshop

D1M4-Slide 12

Key Message

The familiar NBI Major Component General Condition Ratings (GCRs) provide an overall characterization of the "general condition" of the entire component for:

- Deck
- Superstructure
- Substructure
- Culvert

D1M4-Slide 13

NBI Major Components – General Condition Ratings (GCRs)

Rating Number	NBI Descriptor	Performance Measure Classification (23 CFR 490)
9	EXCELLENT CONDITION	GOOD
8	VERY GOOD CONDITION	
7	GOOD CONDITION	
6	SATISFACTORY CONDITION	FAIR
5	FAIR CONDITION	
4	POOR CONDITION	POOR
3	SERIOUS CONDITION	
2	CRITICAL CONDITION	
1	"IMMINENT" FAILURE CONDITION	
0	FAILED CONDITION	

D1M4-S13

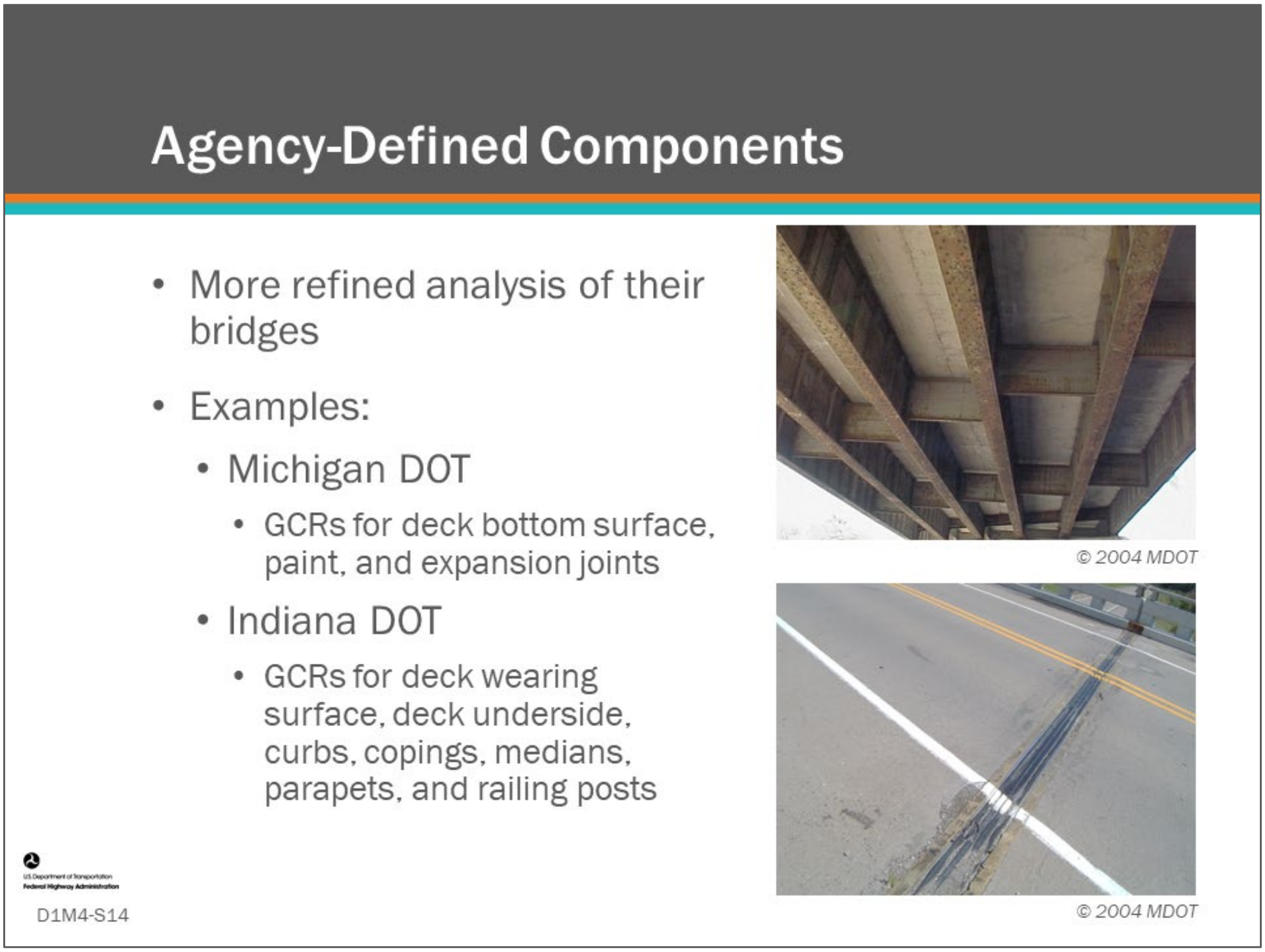
Key Message

GCRs for deck, superstructure, substructure, or culvert are rated on the “zero” to “nine” numerical rating scale, found in the Federal Coding Guide, along with descriptor for each rating, shown in the middle column of the table on this slide.

More recently, the FHWA created national performance measures for NHS bridges, assigning overall classifications to bridges as “good,” “fair,” or “poor,” as shown in the right column of the table on this slide.

- These measures may be extended to non-NHS or smaller bridges at the state’s discretion.
- GCRs can be used for network-level bridge management where bridges are put in broad categories of need such as maintenance, preservation, rehabilitation, or reconstruction (replacement).
- However, more specificity and quantification are needed for more detailed analysis.

D1M4-Slide 14



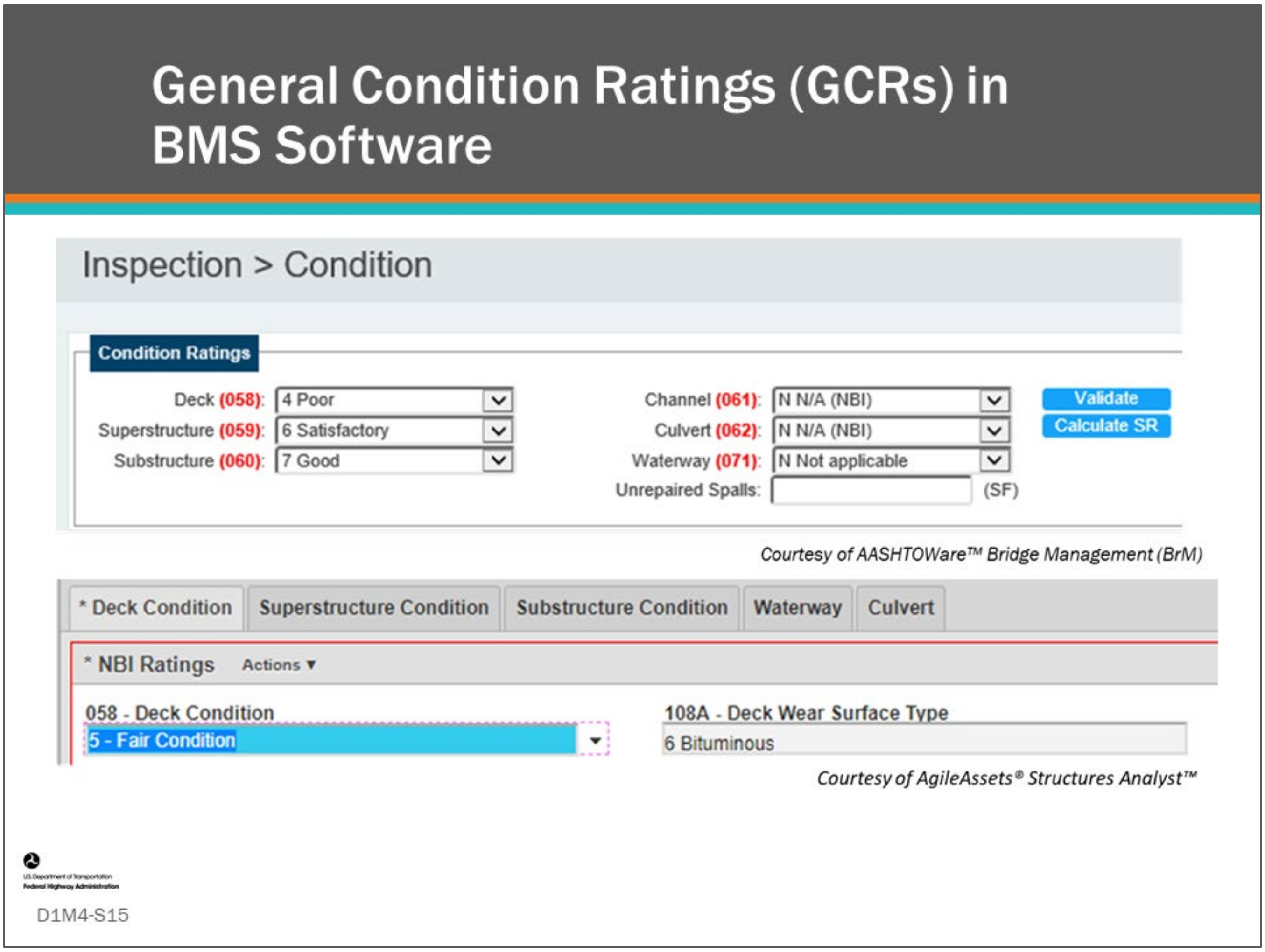
Key Message

Over the years, some Agencies have assigned GCRs to specific bridge components used by the Agency for bridge management and may include them as part of their BMS.

For example:

- Michigan DOT has found it helpful to have a bridge deck bottom surface rating to help indicate when a bridge deck replacement is needed, and they have a deck expansion joint GCR to indicate when these joints need repair or replacement.
- Indiana DOT has GCRs for deck wearing surface, deck underside, curbs, copings, medians, parapets, and railing posts.

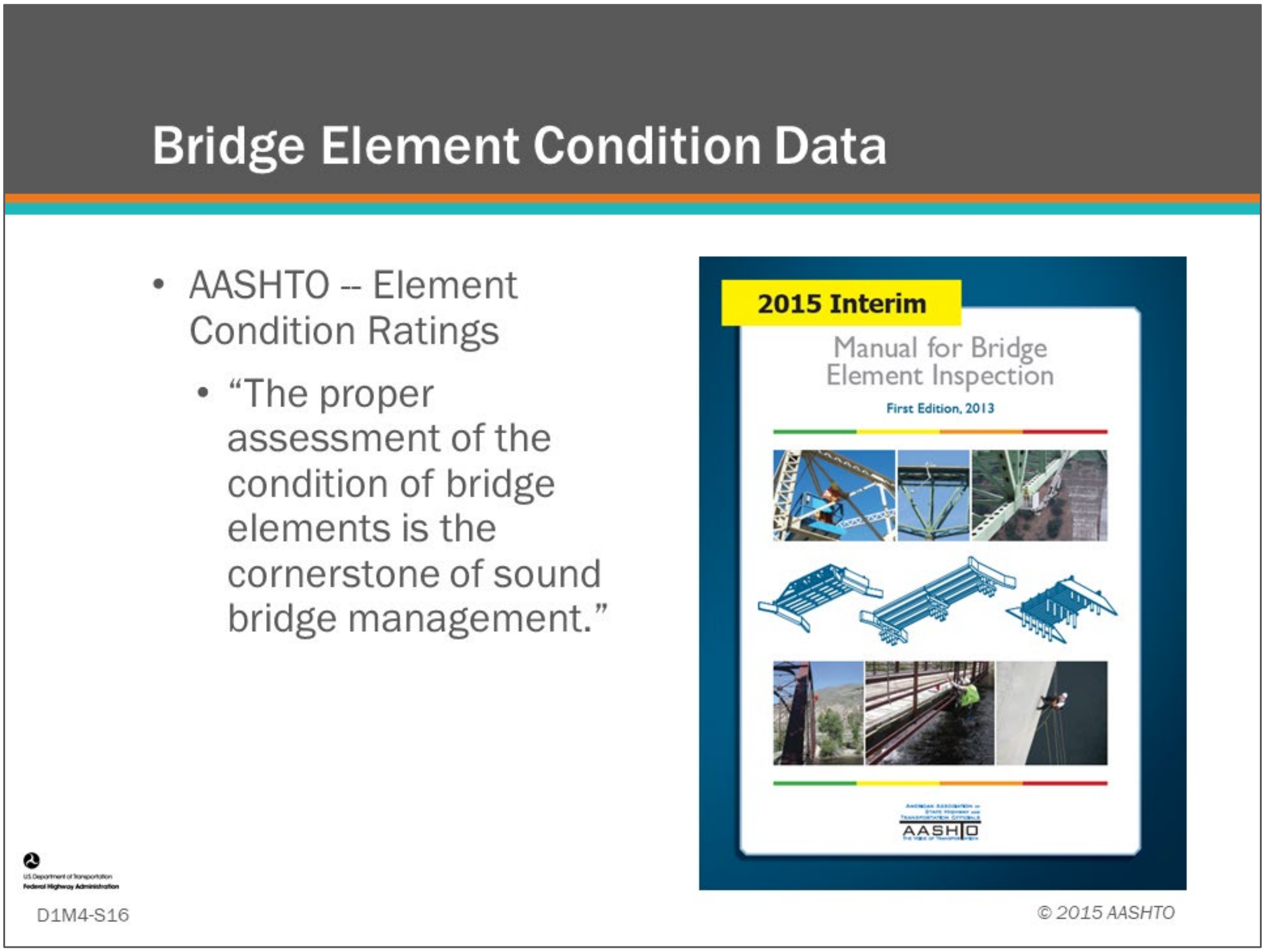
D1M4-Slide 15



Key Message

BMS software provide tools to record bridge major component inspections. Shown on this slide are screenshots of the input screens from AASHTOWare™ Bridge Management (BrM) software.

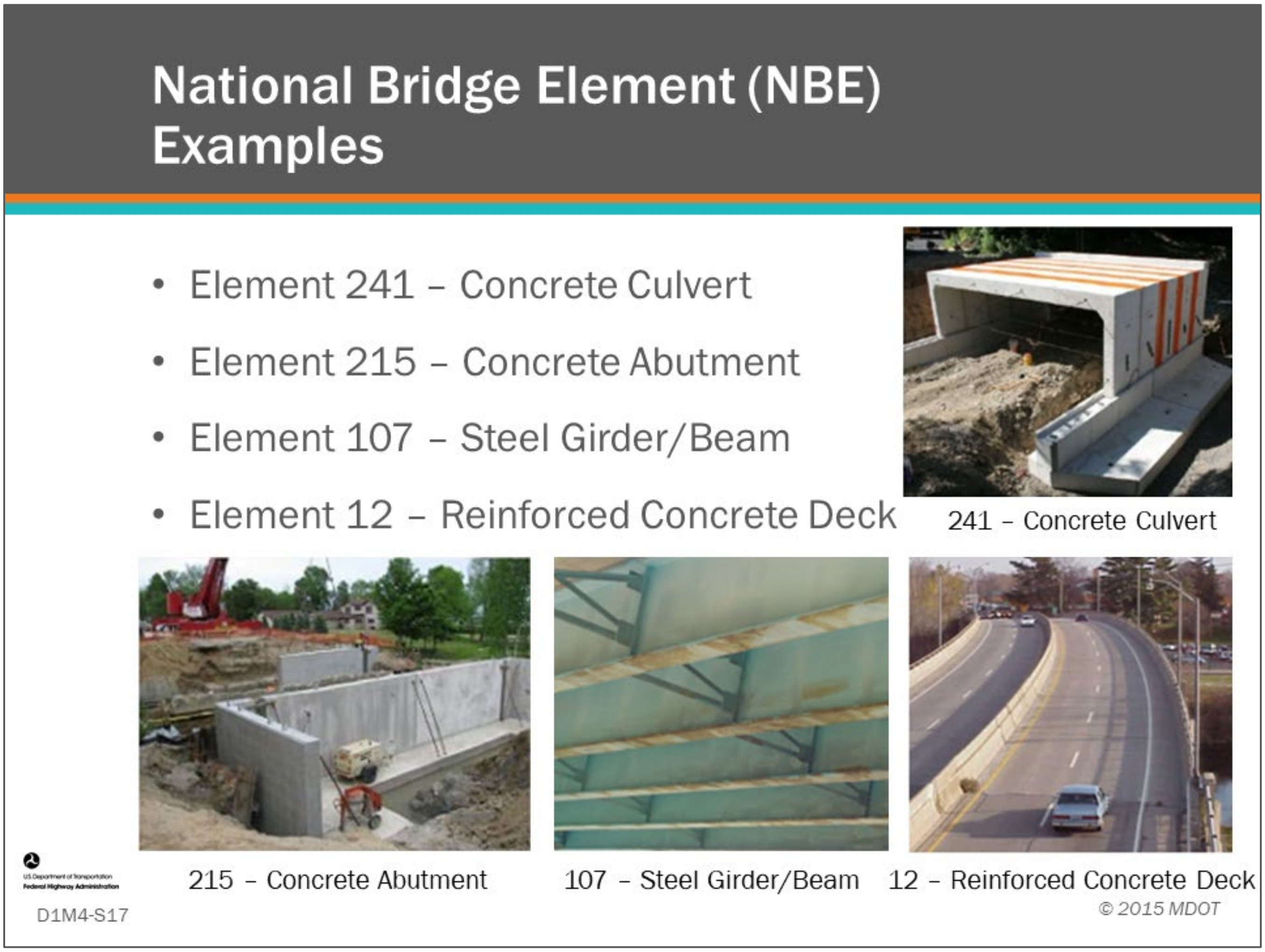
D1M4-Slide 16



Key Message

Bridge element inspection was first introduced in the 1990s. Today, we have AASHTO's *Manual for Bridge Element Inspection*, or MBEI. All BMS software include the ability to use element inspection data and either have, or are working to have, advanced bridge management analysis procedures using elements and defects.

D1M4-Slide 17



Key Message

National bridge elements are those elements that define the primary load carrying members of a bridge. They are also important because they:

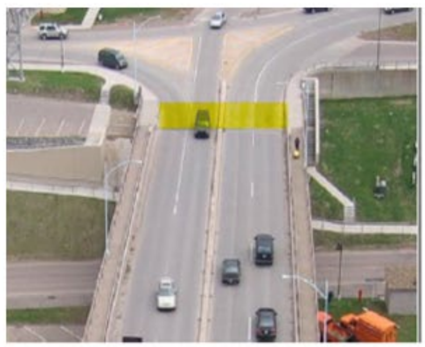
- Are collected and submitted to the FHWA; and,
- Better define the structural components of a bridge for more refined analysis in the BMS.

D1M4-Slide 18

Bridge Management Elements (BMEs)

- Bridge Management Elements (BME)
  - Element 300 – Strip Seal Expansion Joints
  - Element 321 – Reinforced Concrete Approach Slabs
  - Element 515 – Steel Protective Coating

300 – Strip Seal Expansion Joints



321 – Reinforced Concrete Approach Slabs

515 – Steel Protective Coating

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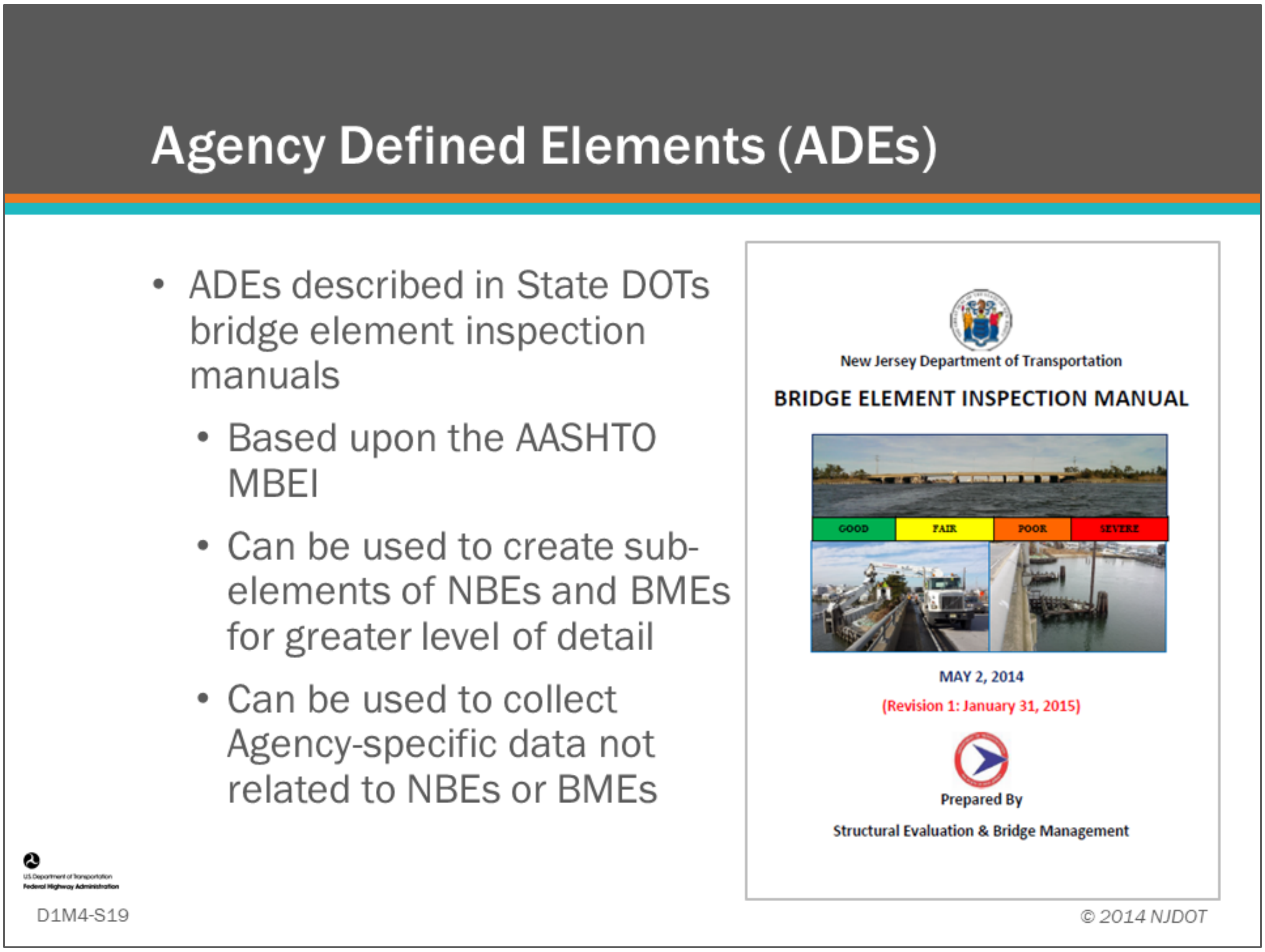
D1M4-S18

Key Message

- BMEs include members of bridges such as joints, wearing surfaces, protective coating systems, concrete reinforcing steel protection systems and approach slabs that are typically managed by agencies utilizing a BMS.
- BMEs are important data to include in an agency's BMS if they want to make more detailed management decisions, especially as it relates to bridge preservation activities.

D1M4-Slide 19



Key Message

Most Agencies have Agency-defined Elements (ADEs) which are described in their bridge element manual.

- As per the AASHTO *MBEI*, ADEs provide the "flexibility for an Agency to define custom elements in accordance with the defined element framework that may be sub-elements of NBEs or BMEs or may be Agency-defined elements without ties to the elements defined in this manual."
- With NBEs, BMEs, and ADEs, Agencies have great flexibility to create elements that will meet the needs of any BMS.

D1M4-Slide 20

Example ADEs

2.3 Agency Defined Elements (800+)

2.3.1 Decks and Slabs

Element	Units	Steel	Prestressed Concrete	Reinforced Concrete	Timber	Masonry	Other Material
Curbs/Sidewalks	ft.	801		802	803		804
Sound barrier wall on/attached to Structure	ft.						805

2.3.2 Superstructure

Element	Units	Element Number
Seismic Retrofit Components	each	811
Bridge Mounted Sign Structures	each	812

2.3.3 Bearings

Element	Units	Element Number
Isolation Bearing	each	831
Sliding Plate Bearing - Expansion/Moveable	each	832
Rocker Bearing - Expansion/Moveable	each	833
Spherical Bearing	each	834
Bond Breaker Bearing - Expansion/Moveable	each	835

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D1M4-S20

Key Message

State DOT bridge element manuals will often contain a list of ADEs they feel they need for bridge asset management. Shown here is a partial list of New Jersey DOT's ADEs.

D1M4-Slide 21

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)

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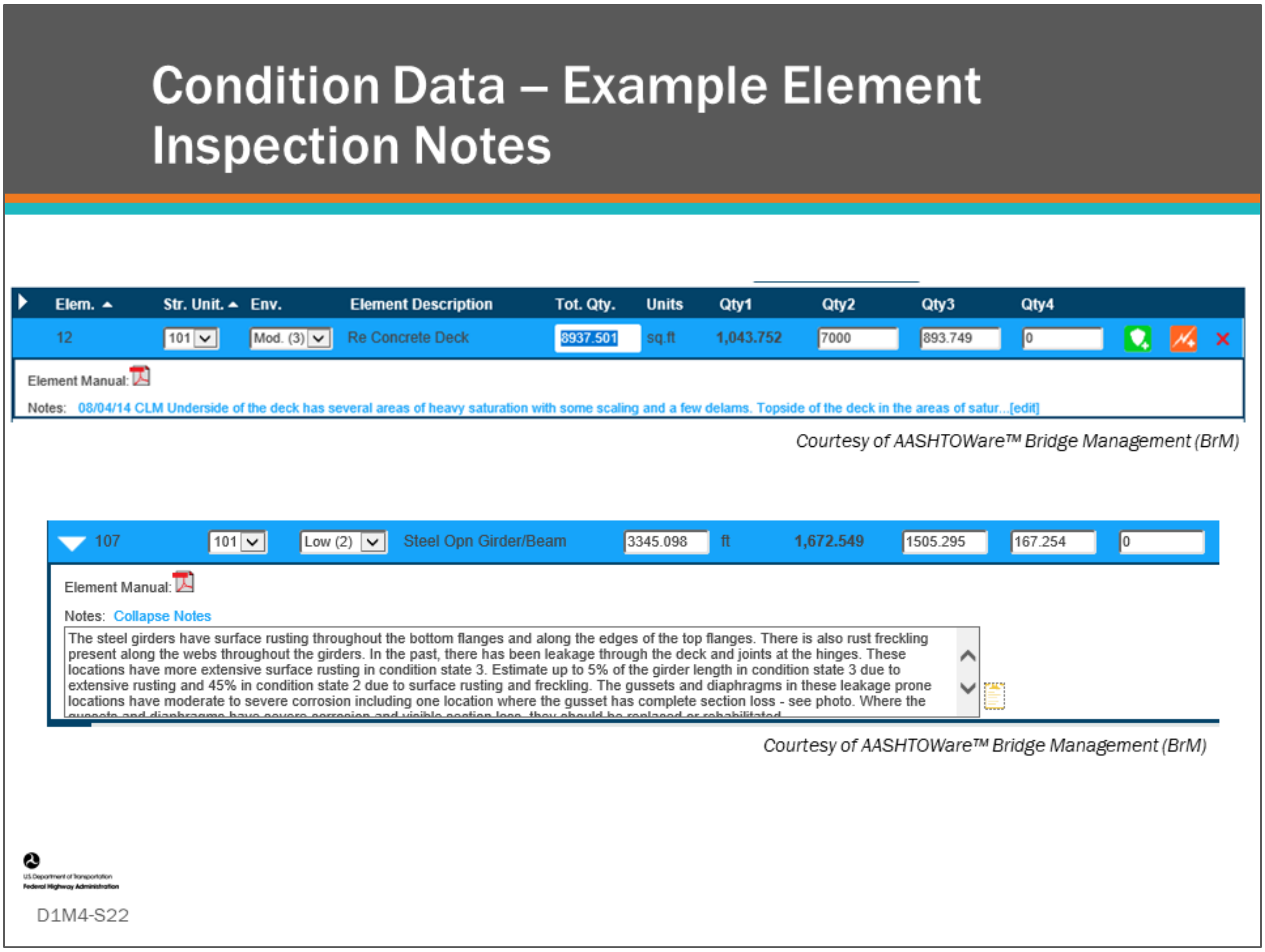
D1M4-S21

Key Message

Bridge element inspections are entered into the BMS showing in detail the element types, quantities and breakdown of condition quantities as shown on this slide.

D1M4-Slide 22

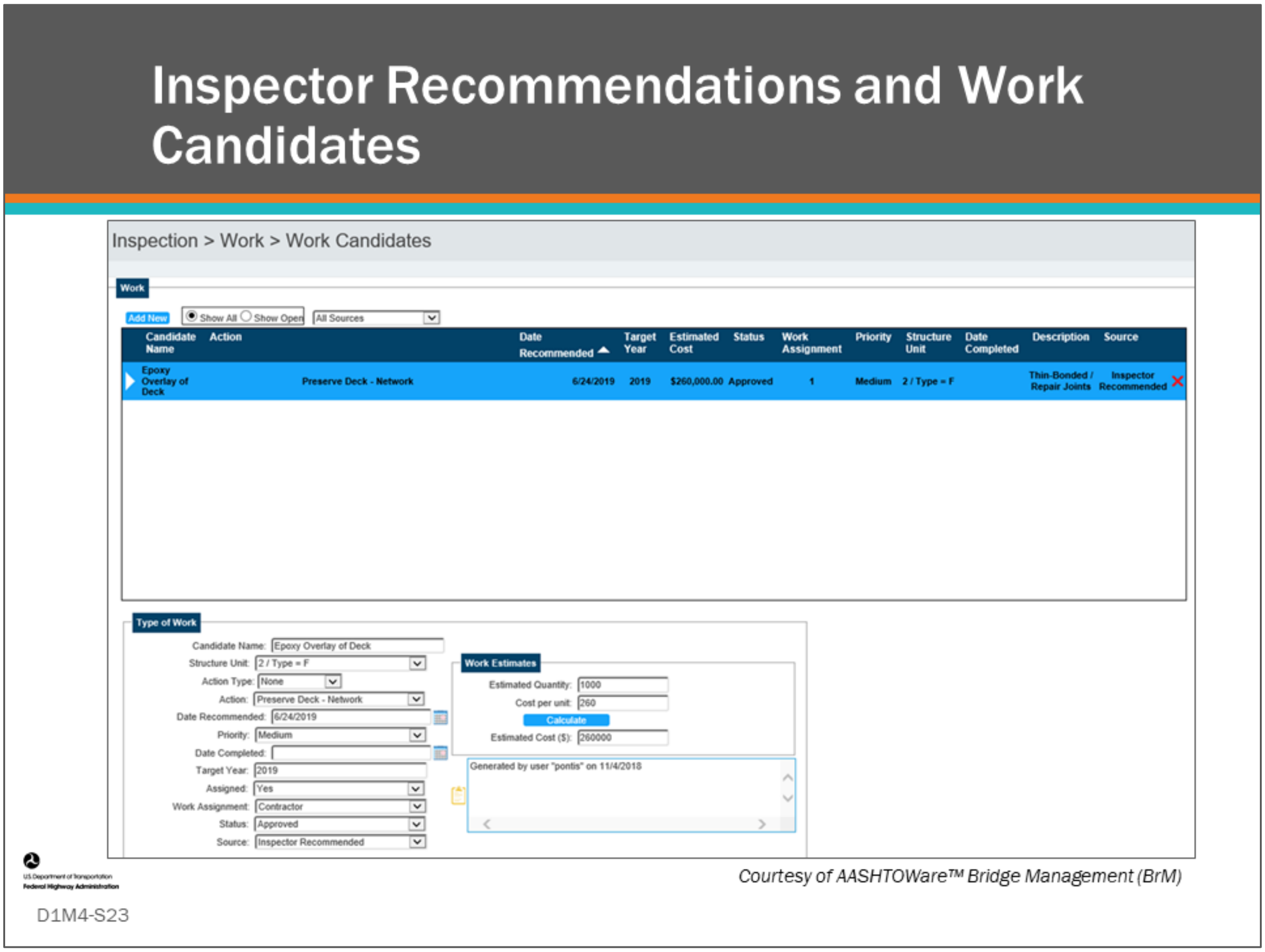


Key Message

Although inspector notes cannot be used for modeling and analysis in a BMS, they are important to the bridge manager because they:

- Describe the distress to the element in greater detail.
    - For example, when element defect data is not recorded, inspection notes can be referenced to identify the type of distress.
- Can be used to assist in manual refinement or automated project-level recommendations.

D1M4-Slide 23

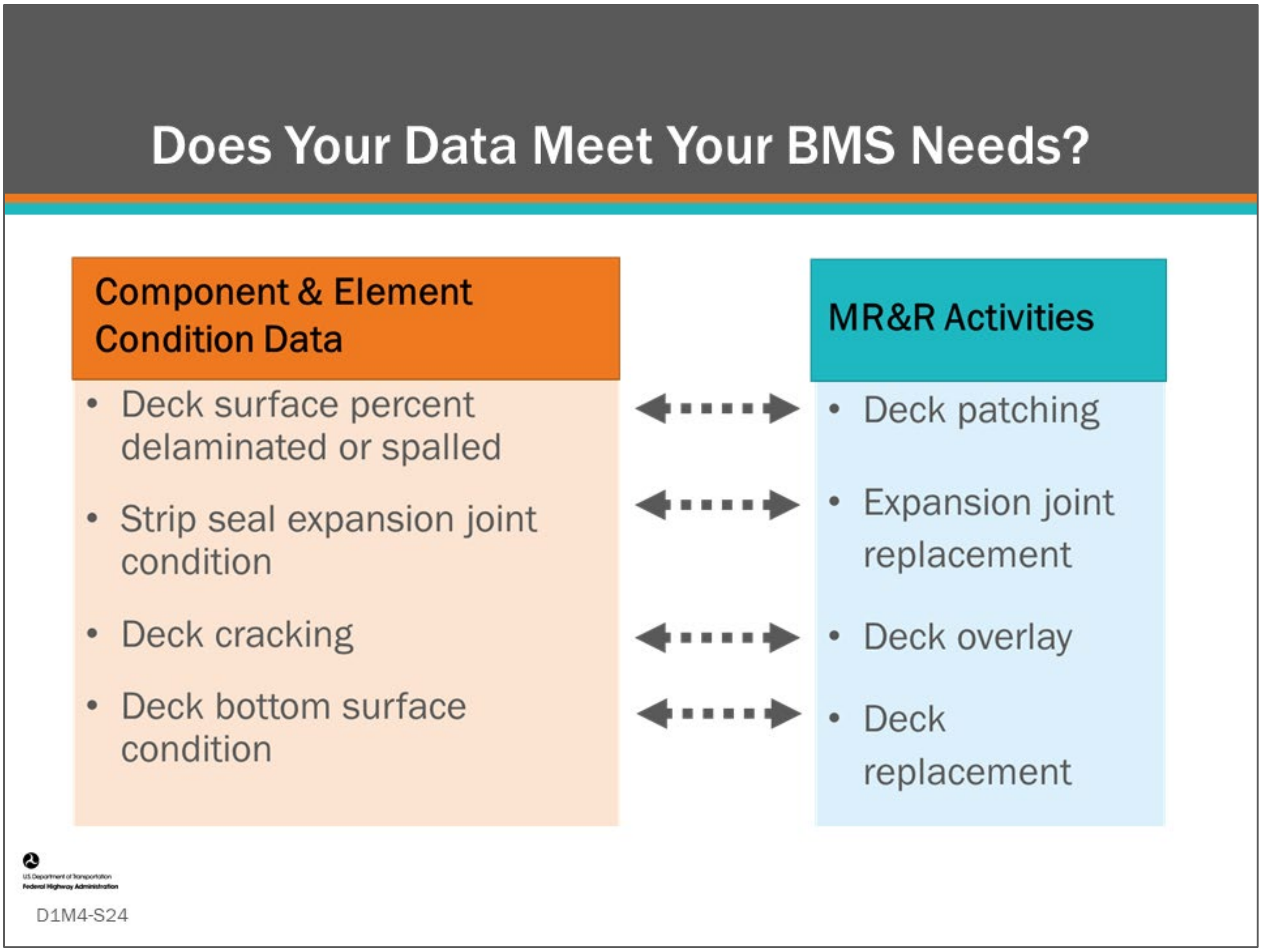


Key Message

Your Agency may use inspector recommendations for preservation, repair, rehabilitation, or even bridge replacement activities.

- BMS software often offers functionality for inspector or maintenance staff to enter recommendations for projects or preservation activities
- Bridge managers can prioritize these activities and assign responsibility for the work
- Inspection recommendations can be used by a bridge manager to:
    - Compare to analysis results (discussed in later workshop modules)
    - Add to the Agency's Maintenance Management System (MMS)
    - Set "committed projects" to be part of the analysis (to account for work that is already planned).
        - Example: Utah DOT uses the AASHTOWare™ Bridge Management (BrM) software to allow bridge inspectors to identify work candidates. These are later prioritized and assigned responsibility.

D1M4-Slide 24



Key Message

A BMS needs to match condition data with maintenance, repair, rehabilitation (MR&R) and reconstruction actions (projects). A good exercise for an agency to complete is:

- Review what condition data they collect with the MR&R and reconstruction actions they perform
- Identify any cross-reference between the two for matches

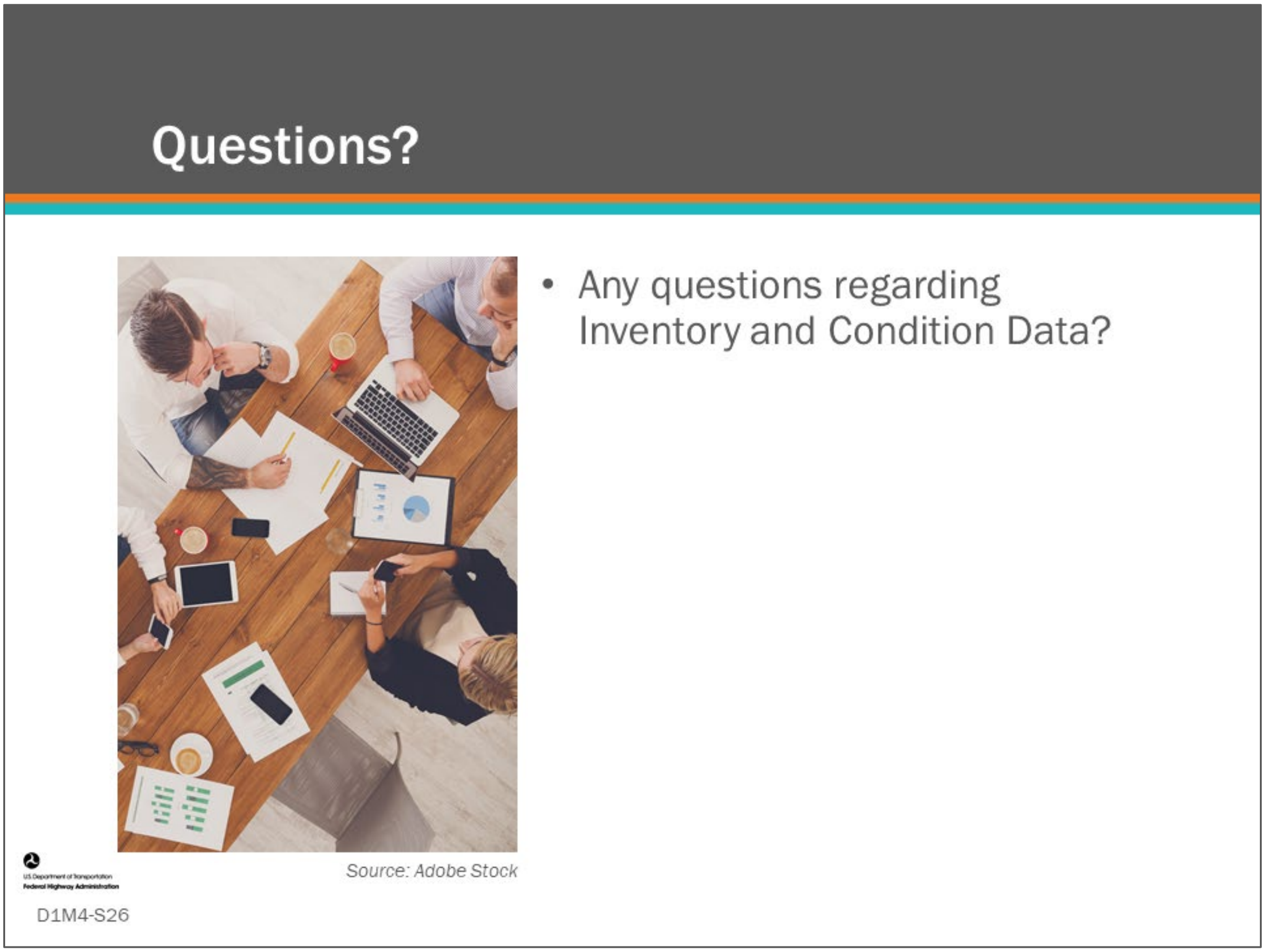
D1M4-Slide 25

Key Message

A BMS relies upon quality, up-to-date data; this includes condition data as well as inventory data.

- If the bridge inspection doesn't represent the actual condition of the bridge, the BMS results will not be accurate.
- The National Bridge Inspection Standards definitions of Quality Control and Quality Assurance are provided on this slide.
- BMS software often have quality control procedures built into the software.

D1M4-Slide 26



Key Message

Before we continue with this module, are there any questions regarding Inventory and Condition Data?

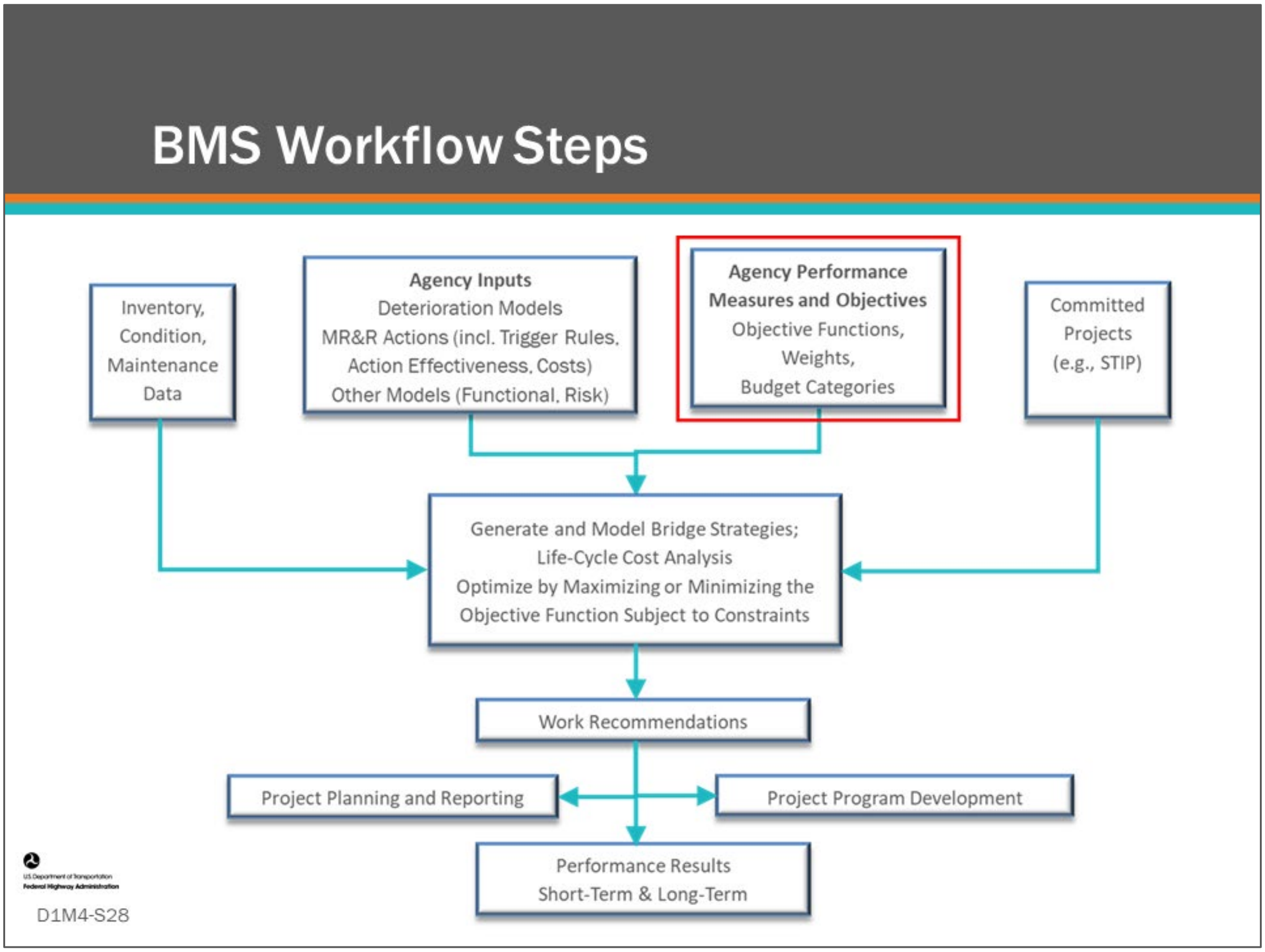
D1M4-Slide 27

Key Message

Agencies need to make many decisions when building a BMS including:

- Setting strategic goals objectives for good bridge management
- Creating performance measures required for BMS

D1M4-Slide 28



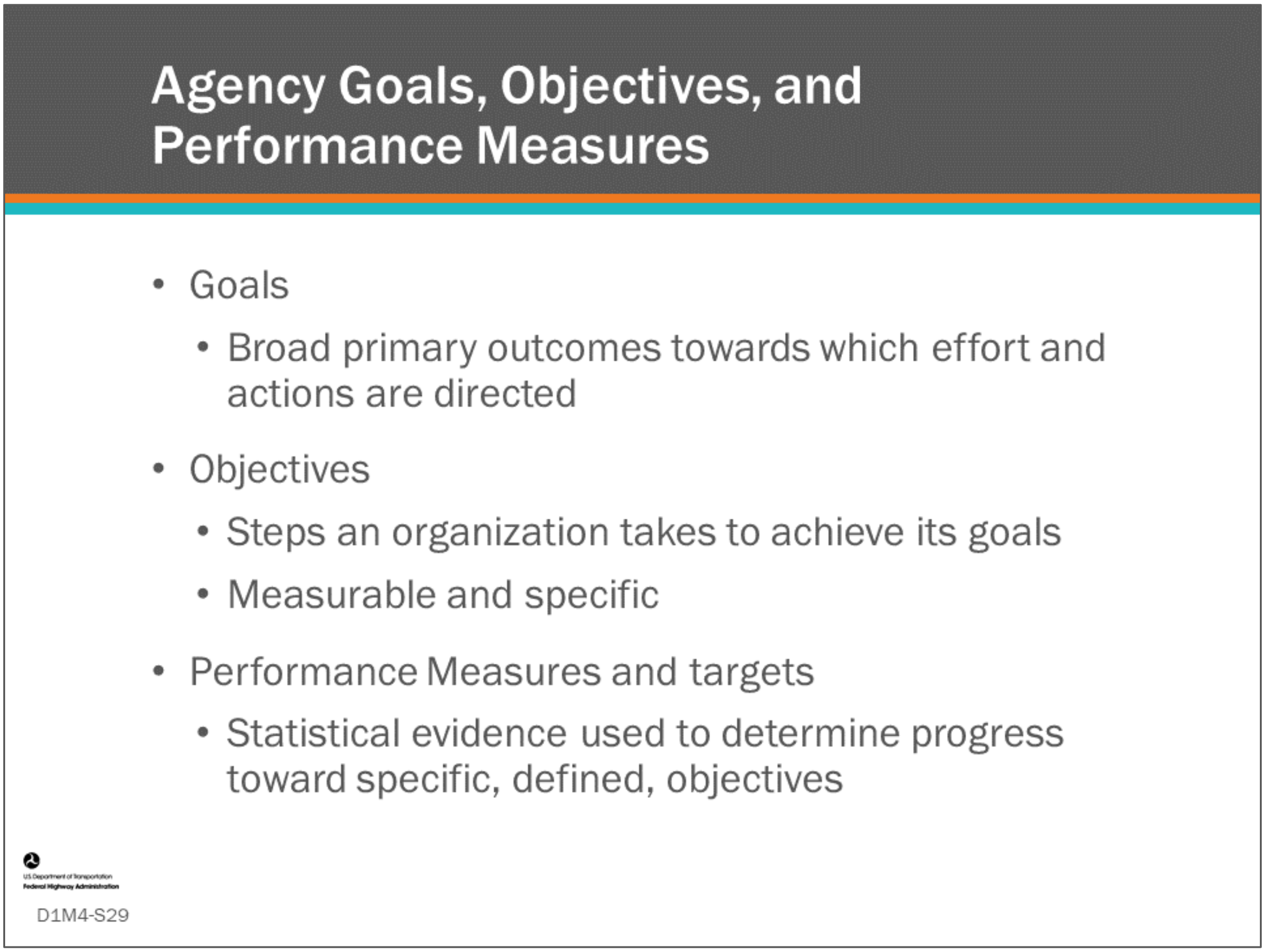
Key Message

Common workflow steps and features are shown on the slide. In the second section of this module, we will review Agency Performance Measures and Objectives.

Each of these topics will be introduced in the following slides.

In the following modules, the interrelationship of these steps and progression from one step to another will be shown.

D1M4-Slide 29



Key Message

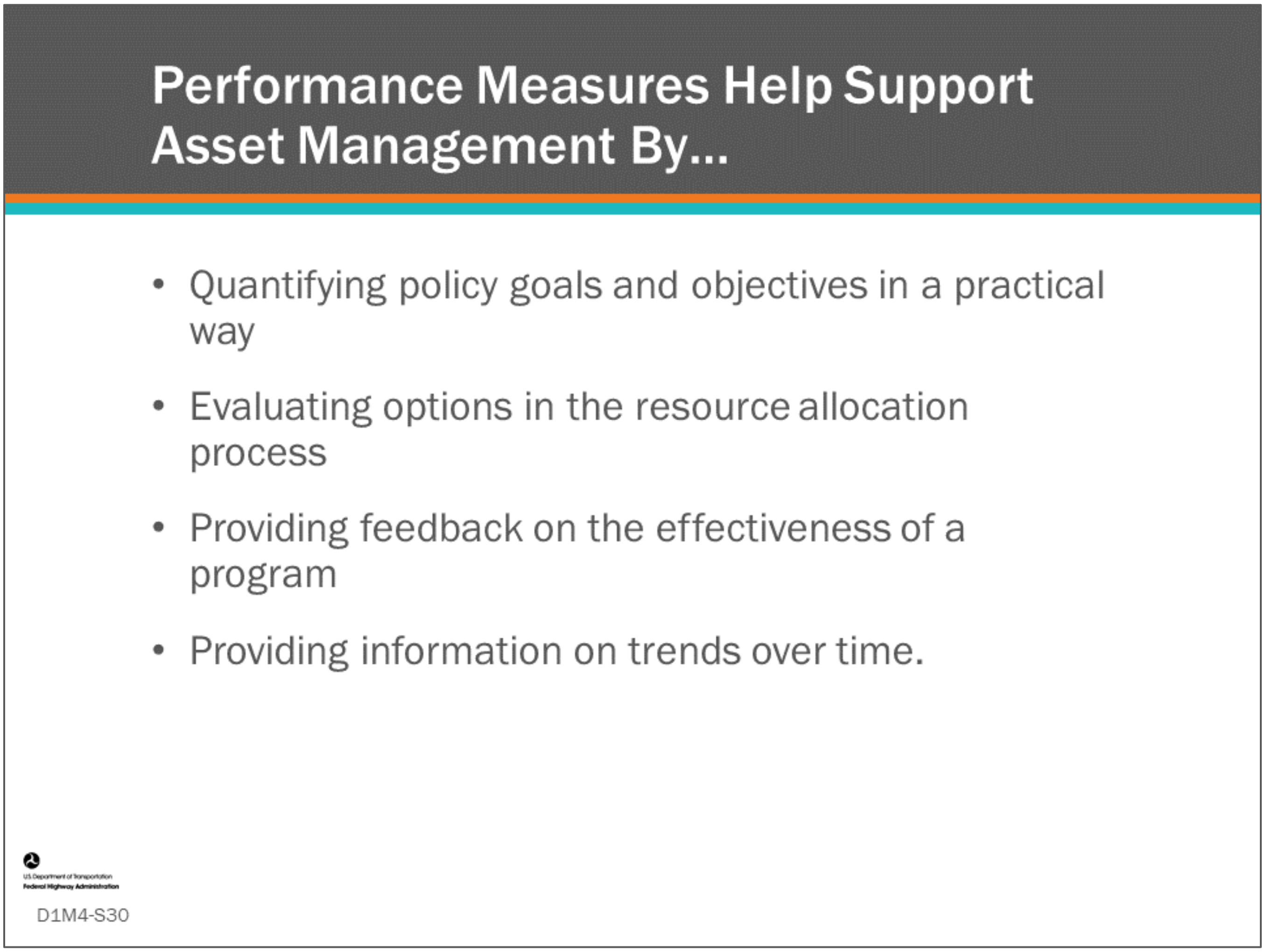
- Goals are the broad "What"– not the "How"
  - Example: Maintain a safe and functional bridge inventory at least cost.
- Objectives are the measurable and specific steps necessary to achieve a goal. Objectives quantify the needed efforts and actions and set a target in order to develop a strategy
  - Example: Reduce bridge deficiencies and substandard geometry.
- Performance measures and targets use data to help an agency track how close to or how far from achieving their objectives they are
  - Example: Network ≥ 85% Health Index (HI) and ≤10% Bridges by area with substandard geometry by 2030.

Measure means an expression based on a metric that is used to establish targets and to assess progress toward achieving the established targets.

Metric means a quantifiable indicator of performance or condition. Source 23 CFR 490 National Performance Measures.

Agencies should clearly define their goals and objectives before establishing performance measures and targets.

D1M4-Slide 30

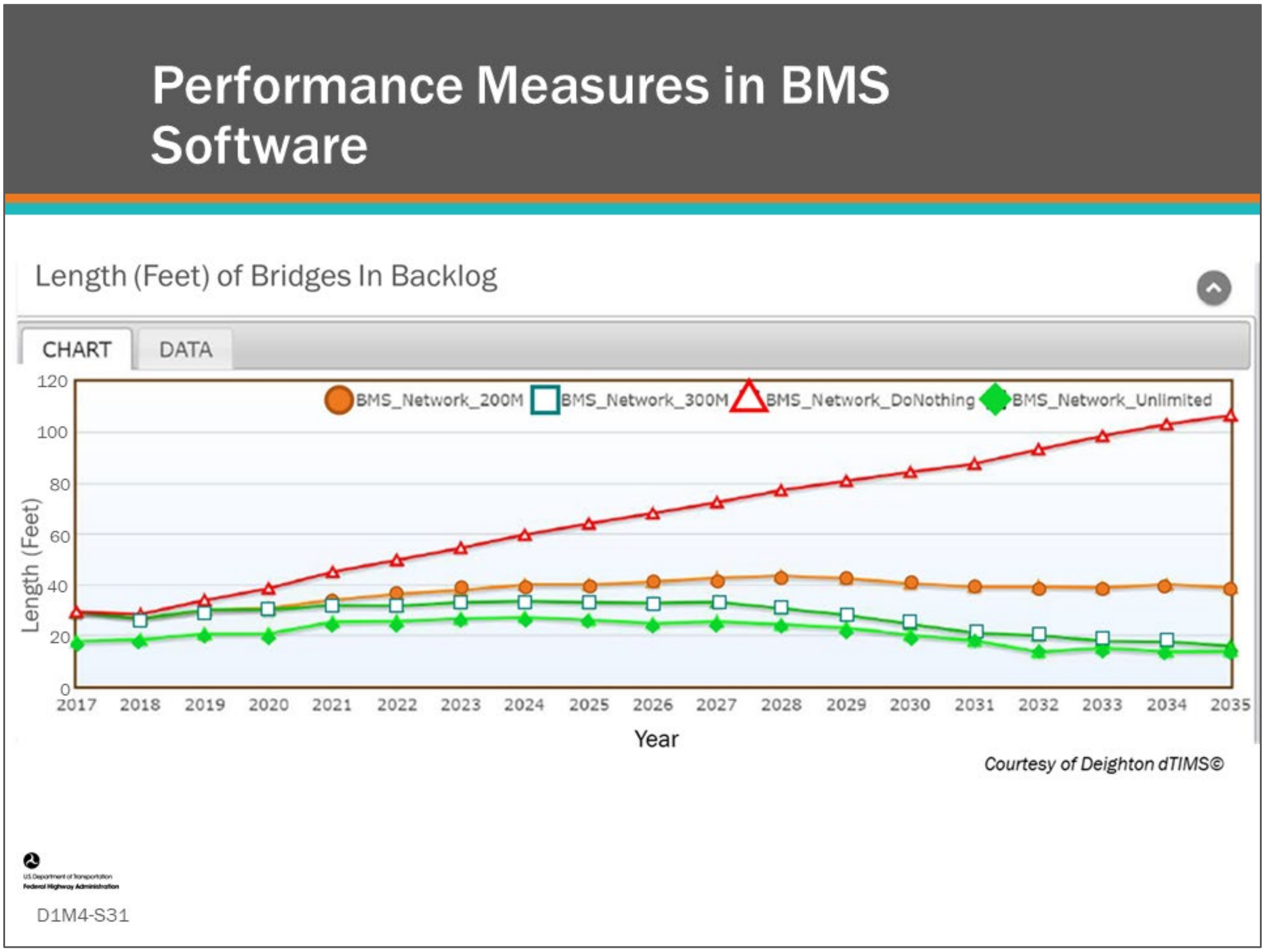


Key Message

Performance measures can be used for:

- Quantifying policy goals and objectives in a practical way
- Evaluating different options in the resource allocation process
- Providing feedback on the effectiveness of a program
- Providing information on trends over time

D1M4-Slide 31

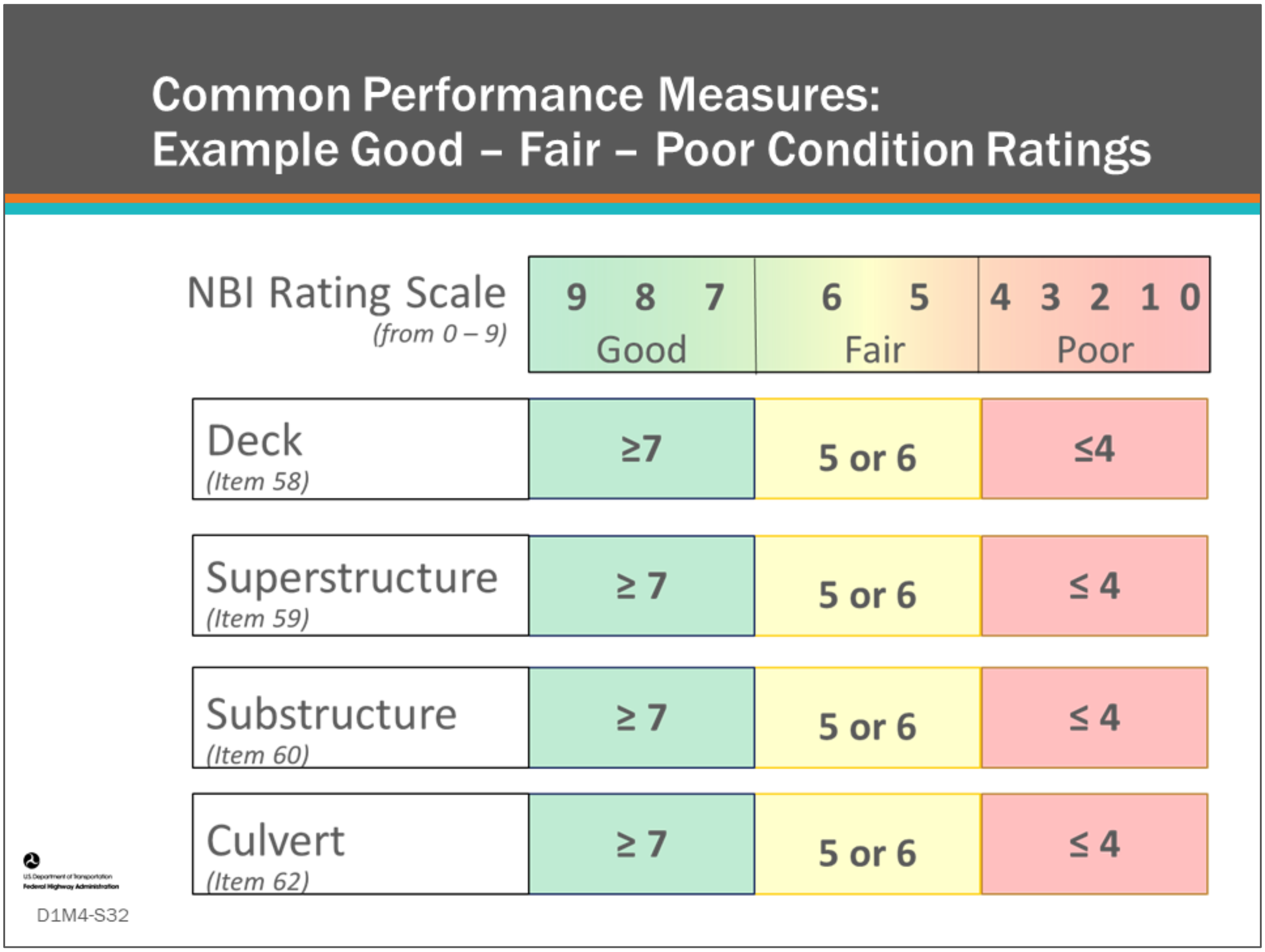


Key Message

One important feature of a BMS is that it can be used to predict your performance measures into the future. Shown on this slide is an example performance measure chart for "Length (Feet) of bridges in Backlog." Backlog is defined by the agency. More commonly, "deck area" of bridges is used over length.

- You can track current status and past trends without a BMS; however, a BMS enables you to predict what some measures will look like in the future under various scenarios.
  - For example, the BMS enables you to see how the measure will trend over time under a specific funding scenario.
- To be able to do this, your measure will need to depend on specific indices that are being modeled in your system.
  - For example, if you are modeling your component NBI ratings, then the Condition Index we just mentioned will be able to be predicted, because it depends on the component ratings.
- Similarly, for FHWA measures, the BMS is able to model the component NBI ratings in order to predict the total percent of good, fair and poor bridges forecasted in your network.

D1M4-Slide 32



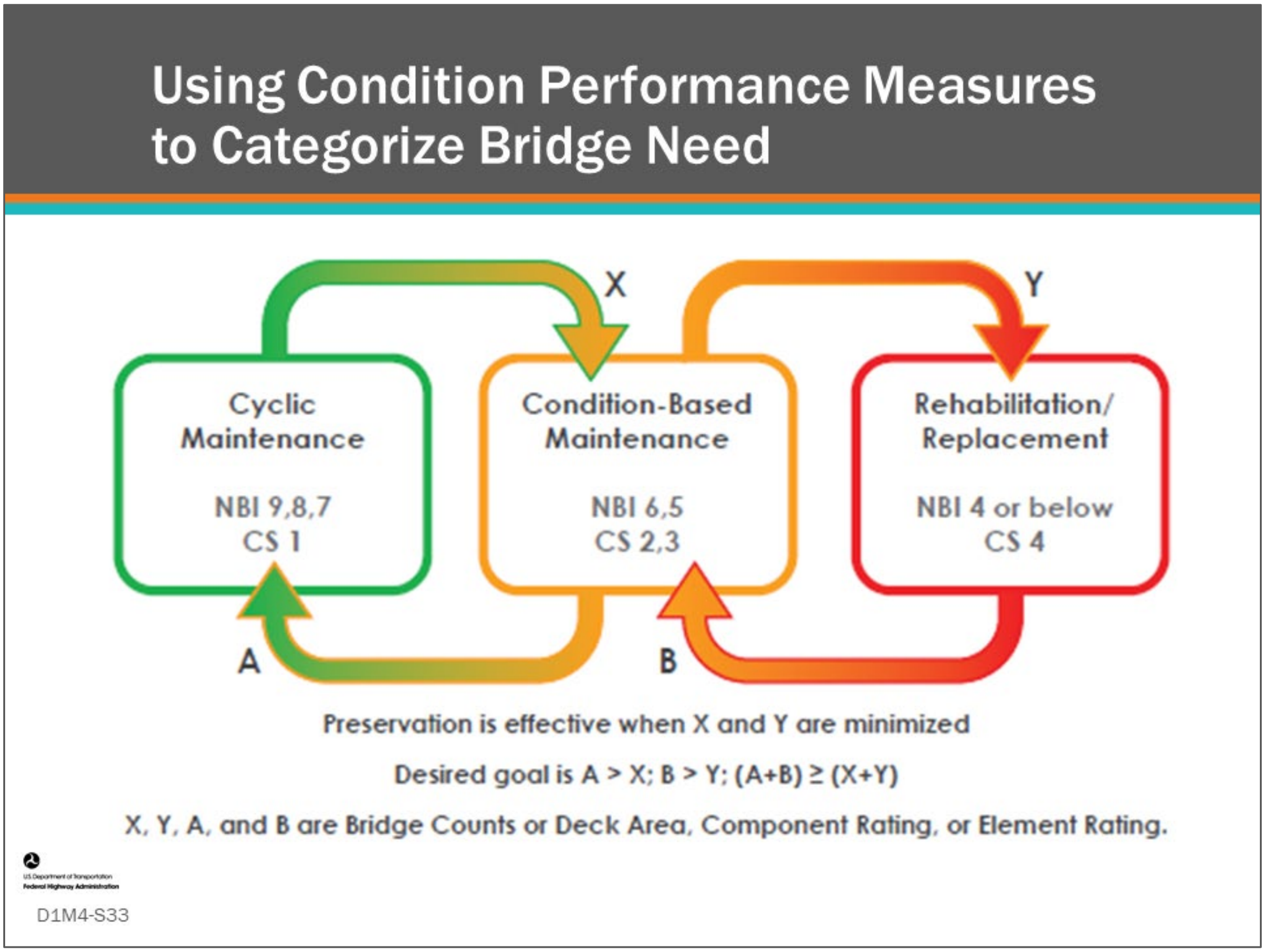
Key Message

Percent Good-Fair-Poor is a condition-based bridge performance measure defined in *23 CFR § 490.409 Measure Calculations*. This Federally-required performance measure, is an example based on the NBI GCRs, for the major components. These components are rated:

- Good when the GCR is 7 or above
- Fair when the GCR is rated 5 and 6
- Poor when the GCR is rated 4 or below

Finally, the lowest of these major component ratings is used to assign a “worst-condition component rating” to the entire bridge.

D1M4-Slide 33



Key Message

Good-Fair-Poor condition performance measures can be used to categorize bridge need, in a general way.

- Bridges in good condition typically only need cyclic maintenance activity
- Bridges in fair condition typically need condition-based maintenance
- Bridges in poor condition need rehabilitation or replacement

A BMS can annually track these categories of need and can show when bridges are transitioning from one need category to the next (arrows x and y).

D1M4-Slide 34

Common Performance Measures: California Health Index

Following are the formulas for the computation of the California Bridge Health Index:

$$HI = (\sum CEV / \sum TEV) \times 100$$

$$TEV = TEQ \times FC$$

$$CEV = \sum (QCS_i \times WF_i) \times FC$$

$$WF = [1 - (CS\# - 1)(1/\text{State Count} - 1)]$$

where

- HI = Health Index;
- CEV = current element value;
- TEV = total element value;
- TEQ = total element quantity;
- FC = failure cost of element;
- QCS = quantity in a condition state; and
- WF = weighting factor for the condition state.

				WF_{CS1}	WF_{CS2}	WF_{CS3}					
				1	0.75	0.5					
Element Number	Element Name	Total Quantity	Units	CS1	CS2	CS3	CS4	Unit Failure Cost	TEV	CEV	Element Health Index
12	Concrete Deck	300	SFT	0		300		$600.00	$180,000	$90,000	50.00%
107	Steel Girder/Beam	100	LFT	61	34	5		$3,500.00	$350,000	$311,500	89.00%
215	Concrete Abutment	24	LFT	24				$7,700.00	$184,800	$184,800	100.00%
300	Strip Seal Expansion Joint	24	LFT	0			24	$556.00	$13,344	$0	0.00%
205	Reinforced Concrete Columns	4	Each	4				$9,000.00	$36,000	$36,000	100.00%
								Total	$764,144	$622,300	

Bridge Health Index
81.4%

D1M4-S34

Key Message

Another common performance measure is the ratio-based health index. The health index, typically based on a 100-point scale with 100 being a bridge in excellent condition, can be calculated in several ways. We will look at two of them. First, shown on this slide is the California Health Index, which has been around for many years.

- A July-August 2001 TR News article describes the index as, "The premise of the Health Index (HI) is that each bridge element has an initial asset value when new. An element may deteriorate to a lower condition state, reducing its asset value. ...With maintenance or rehabilitation, the condition of the element is likely to improve and the corresponding asset value to increase. The Health Index for the bridge is the ratio of the current element value to the initial element value of all elements on the bridge."
- Health Index is often included in BMS software.

The Condition State coefficients (CS1, CS2, CS3) are chosen by the Agency. The values shown on this slide were taken form an article on the California Health Index. The default values in AASHTOWare™ Bridge Management (BrM) are:

- CS1 = 1
- CS2 = 0.66
- CS3 = 0.33

D1M4-Slide 35

Common Performance Measures: Software Example

$$HI = Bridge\ Health\ Index = \frac{\sum_e q_e \omega_e HI_e}{\sum_e q_e \omega_e},\ where$$

w_e = Relative Unit Weight

$$HI_e = Element's\ Health\ Index = cs_1 + \frac{3}{4} cs_2 + \frac{1}{2} cs_3$$

CS_e = Percent Element in Condition State

q_e = Element's Total Quantity

				WF_1	WF_2	WF_3					
				1	0.75	0.5					
Element Number	Element Name	Total Quantity	Units	CS1	CS2	CS3	CS4	ω_e	HI_e	$q_e\omega_e HI_e$	$q_e\omega_e$
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%

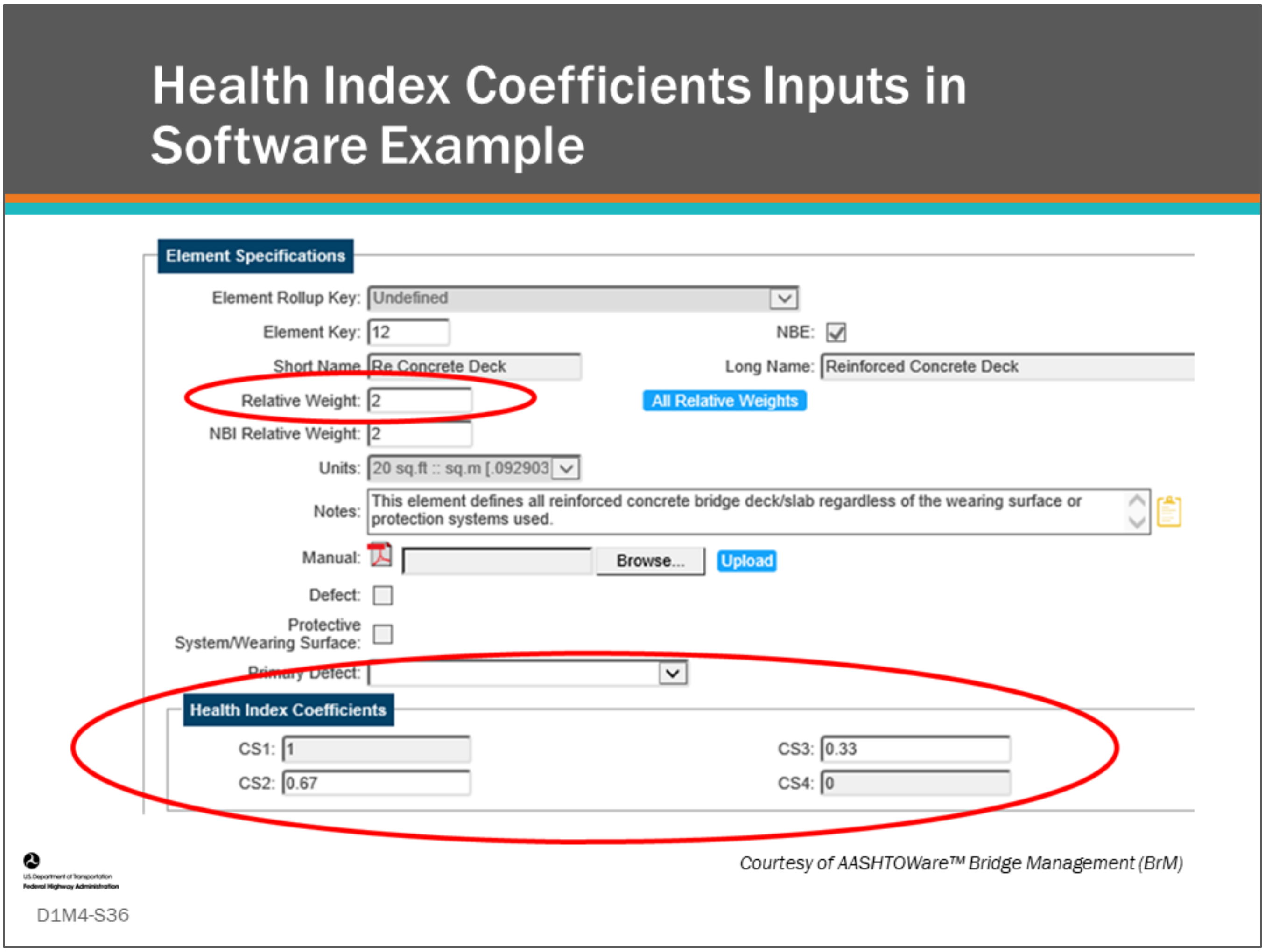
U.S. Department of Transportation
Federal Highway Administration

D1M4-S35

Key Message

The Health Index in AASHTOWare™ Bridge Management (BrM) software is similar to the California Health Index. The Unit Failure Cost (FC) of the California Health Index is replaced with a Relative Unit Weight of the element.

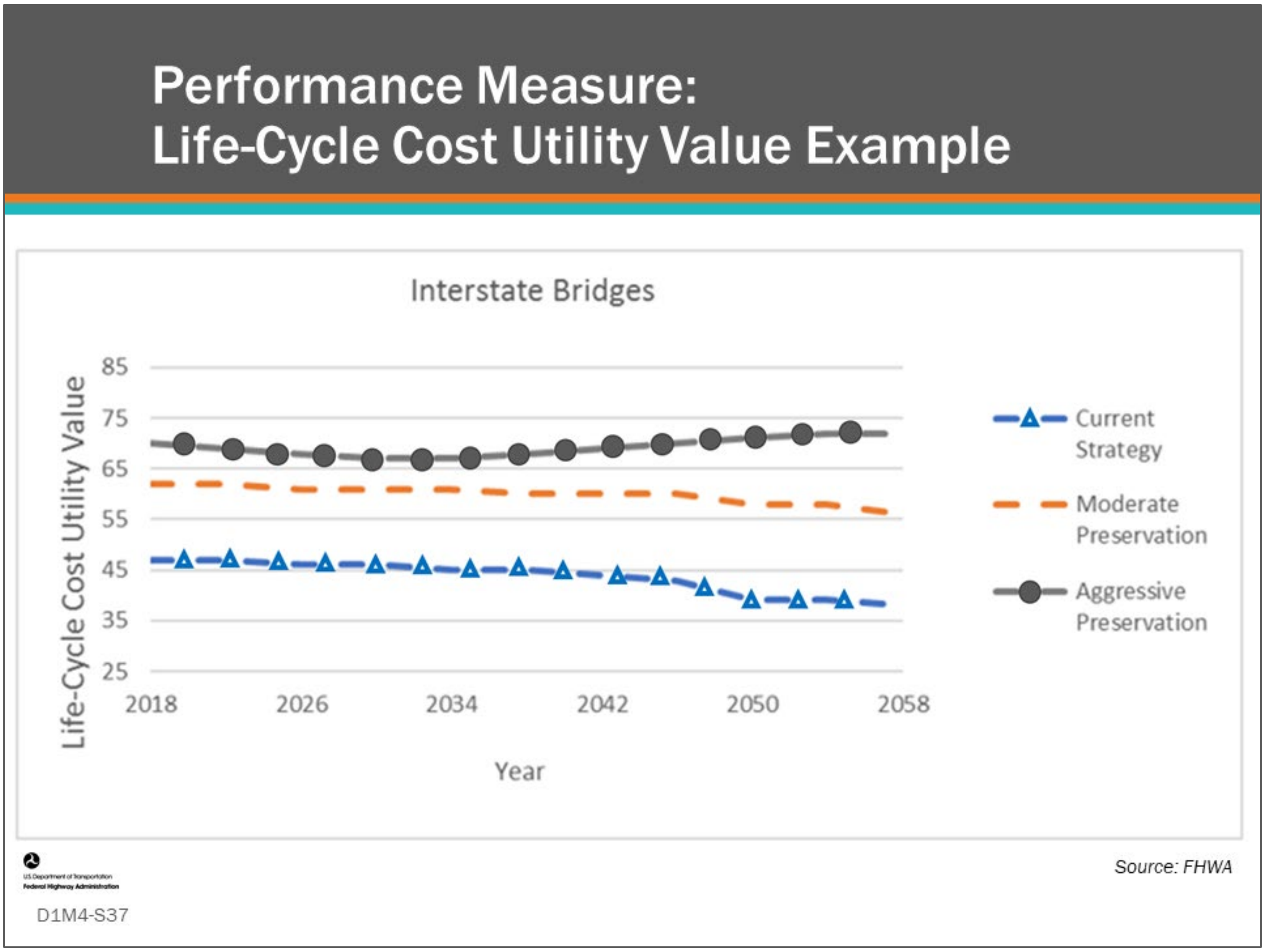
D1M4-Slide 36



Key Message

A screenshot of the AASHTOWare™ Bridge Management (BrM) software shows the relative weight and Health Index coefficients that are input for each element.

D1M4-Slide 37



Key Message

As agencies aim to maintain or improve future conditions and minimize life-cycle cost (LCC), performance measures representing LCC can be used to inform decision making. If the BMS can perform LCC computations, those costs can be used to evaluate alternative bridge-level work actions and network-level investment strategies. LCC is a valuable measure because condition measures alone are not indicative of the cost-efficiency of alternative work actions or investment strategies. Just like replacing a bridge before the end of its service life or deferring needed preventive maintenance on a good bridge increases LCC, indiscriminate condition goals for poor bridges and good bridges are not economically efficient. LCC is a measure that can be used to inform work actions and investment strategies, establish LCC goals and targets, or inform condition goals and targets.

D1M4-Slide 38

Key Message

This concludes D1M4: Inventory and Condition Data; Agency Goals, Objectives and Performance Measures.

D1M4-Slide 39

Slide #	Image Description	Source Information
5	Picture showing the cover page for the FHWA Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges.	FHWA. *Recording and Coding Guide For The Structure Inventory and Appraisal of the Nations Bridges*. Publication No. FHWA-PD-96-001. Washington, DC, 1995.
6	Picture showing the New York Department of Transportation Bridge Inventory Manual.	NYSDOT. *Bridge Inventory Manual*. July 2006.
8	Drawing showing bridge horizontal clearance measurements.	FHWA. *Recording and Coding Guide For The Structure Inventory and Appraisal of the Nations Bridges*. Publication No. FHWA-PD-96-001. Washington, DC, 1995.
9	Screenshot from AgileAssets® Structures Analyst™ of inventory data.	AgileAssets® Structures Analyst™.
10	Picture showing scoured bridge abutment.	FHWA. *Hydraulic Engineering Circular No. 18. Evaluating Scour at Bridges.* Publication No. FHWA-HIF-12-003. 5th Edition, Washington, DC, 2012.
12	Picture of steel beam superstructure.	MDOT.
12	Picture of snooper truck crew inspecting bottom side of concrete arch bridge.	Adobe Stock.
13	Table showing columns; Rating Number, NBI Description, and performance measure descriptor.	This Workshop.
14	Picture of a bridge deck bottom surface.	MDOT.
14	Picture of a bridge deck expansion joint.	MDOT.

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D1M4-S39

D1M4 Figure Source List

D1M4-Slide 40

Slide #	Image Description	Source Information
15	Screenshot shows AASHTOWare™ BrM General Condition Ratings Input screen.	AASHTOWare™ Bridge Management (BrM).
15	Screenshot shows AgileAssets General Condition Ratings Input screen.	AgileAssets® Structures Analyst™.
16	A picture showing the cover of the AASHTO Manual for Bridge Element Inspection, First Edition, 2013 with 2015 Interim	AASHTO. *Manual for Bridge Element Inspection*. Washington, DC, 2013.
17	Picture showing element 215 - Concrete Abutment.	MDOT. *Bridge Element Inspection Manual.* 2015.
17	Picture showing Element 107 - Steel Girder/Beam.	MDOT. *Bridge Element Inspection Manual.* 2015.
17	Picture showing Element 12 - Reinforced Concrete Deck.	MDOT. *Bridge Element Inspection Manual.* 2015.
17	Picture showing Element 241 - Concrete Culvert.	MDOT. *Bridge Element Inspection Manual.* 2015.
18	Picture showing Element 300 - Strip Seal Expansion Joint.	MDOT. *Bridge Element Inspection Manual.* 2015.
18	Picture showing element 321 - Reinforced Concrete Approach slab.	MDOT. *Bridge Element Inspection Manual.* 2015.

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D1M4-S40

D1M4 Figure Source List

D1M4-Slide 41

Slide #	Image Description	Source Information
18	Picture showing element 515 - Steel Protective Coating.	MDOT. *Bridge Element Inspection Manual.* 2015.
19	Picture showing the New Jersey Department of Transportation Bridge Element Inspection Manual.	NJDOT. *Bridge Element Inspection Manual*, rev. January 2015.
20	A partial page from the New Jersey Bridge Element Inspection Manual shows deck/slab, superstructure, and bearing Agency Defined Elements.	NJDOT. *Bridge Element Inspection Manual*, rev. January 2015.
21	Screenshot showing AASHTOWare™ bridge element quantity and condition rating screen.	AASHTOWare™ Bridge Management (BrM).
22	Screenshot for AASHTOWare™ BrM showing element inspection ratings and notes.	AASHTOWare™ Bridge Management (BrM).
22	Screenshot for AASHTOWare™ BrM showing example of element notes.	AASHTOWare™ Bridge Management (BrM).
23	Screenshot showing AASHTOWare™ BrM software work candidates screen.	AASHTOWare™ Bridge Management (BrM).
31	Screenshot showing Deighton dTIMS© performance measures screen.	Deighton dTIMS©.
32	A table with columns for NBI GCR ratings (9 to 0) also listing good, fair, and poor, and rows showing deck, superstructure, substructure, and culvert major components.	FHWA. *Chart, Presentation, National Performance Management Measures: Bridge Condition to Assess the National Highway Performance Program.* FHWA Office of Bridges & Structures. Washington, DC, 2017.

U.S. Department of Transportation Federal Highway Administration

D1M4-S41

D1M4 Figure Source List

D1M4-Slide 42

Slide #	Image Description	Source Information
33	Graphic showing three boxes; cyclic maintenance, condition-based maintenance, and rehabilitation/replacement. Arrows show progression form each box from left to right at the top and right to left at the bottom.	This Workshop.
34	List showing variables used to calculate health index.	Shepard, R. and M. Johnson. *California Bridge Health Index.* Transportation Research Board, No. 215. National Research Council. 2001.
34	Table showing Health Index calculations.	This Workshop.
35	Table showing Health Index calculations.	This Workshop.
36	A screenshot of a BMS element Specifications screen is shown. Relative Weight and Health Index Coefficients are circled in red to bring attention to these fields.	AASHTOWare™ Bridge Management (BrM).
37	A line chart, titled, "Interstate Bridges," with "Life-Cycle Cost Utility Value" on the y-axis with a scale ranging from 25 to 85, and years on the x-axis with a scale of 2108 to 2058. Three example strategies are shown; Current Strategy, Moderate Preservation, and Aggressive Preservation.	FHWA. *Using a Life Cycle Planning Process to Support Asset Management*. Washington, DC, 2017.

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D1M4-S42

D1M4 Figure Source List

Module Title: D1M5 – Deterioration Models

Module Time: 40 minutes

Module Summary

Deterioration models are an important component of a Bridge Management System (BMS). Representative deterioration models for the location and environment a bridge resides are needed to produce accurate forecasts of future bridge condition. These models are used for short, medium, and long-range planning, comparison of performance of structure types and materials, and identification when work actions should be done.

Expected Outcome

Participants will understand the reasons for modeling deterioration into the future, the different types of deterioration models (major component, element) and how they are input in common BMS Software.

Resource List

Slide	Reference Information
5	Utah DOT. 2015–2040 *Long-Range Transportation Plan Transportation in Utah's Rural Areas*.
6	Morcous, G. *Developing Deterioration Models for Nebraska Bridges*. Page 44. University of Nebraska-Lincoln.
7, 28	FHWA. *Bridge Preservation Guide*. Publication No. FHWA-HIF-18-022. Washington, DC, 2018.
8	Kelley, R. *A Process for Systematic Review of Bridge Deterioration Rates.* Page 6. Michigan Department of Transportation, March 2016.
10	FHWA. *Recording and Coding Guide For The Structure Inventory and Appraisal of the Nations Bridges*. FHWA-PD-96-001. Washington, DC, December 1995.
18	Nelson, et al. *Deterioration Rates of Minnesota Concrete Bridge Decks*. Page 24. Bloomington, MN, October 2014.
25	Springer, T. *Deterioration Modeling Bridge Management System Analysis 2017*. Bridge Management User Group Meeting, Virginia Department of Transportation. Washington, DC, September 2017.
26	AASHTO. *Manual for Bridge Element Inspection*. Washington, DC, 2013.

Module Workbook

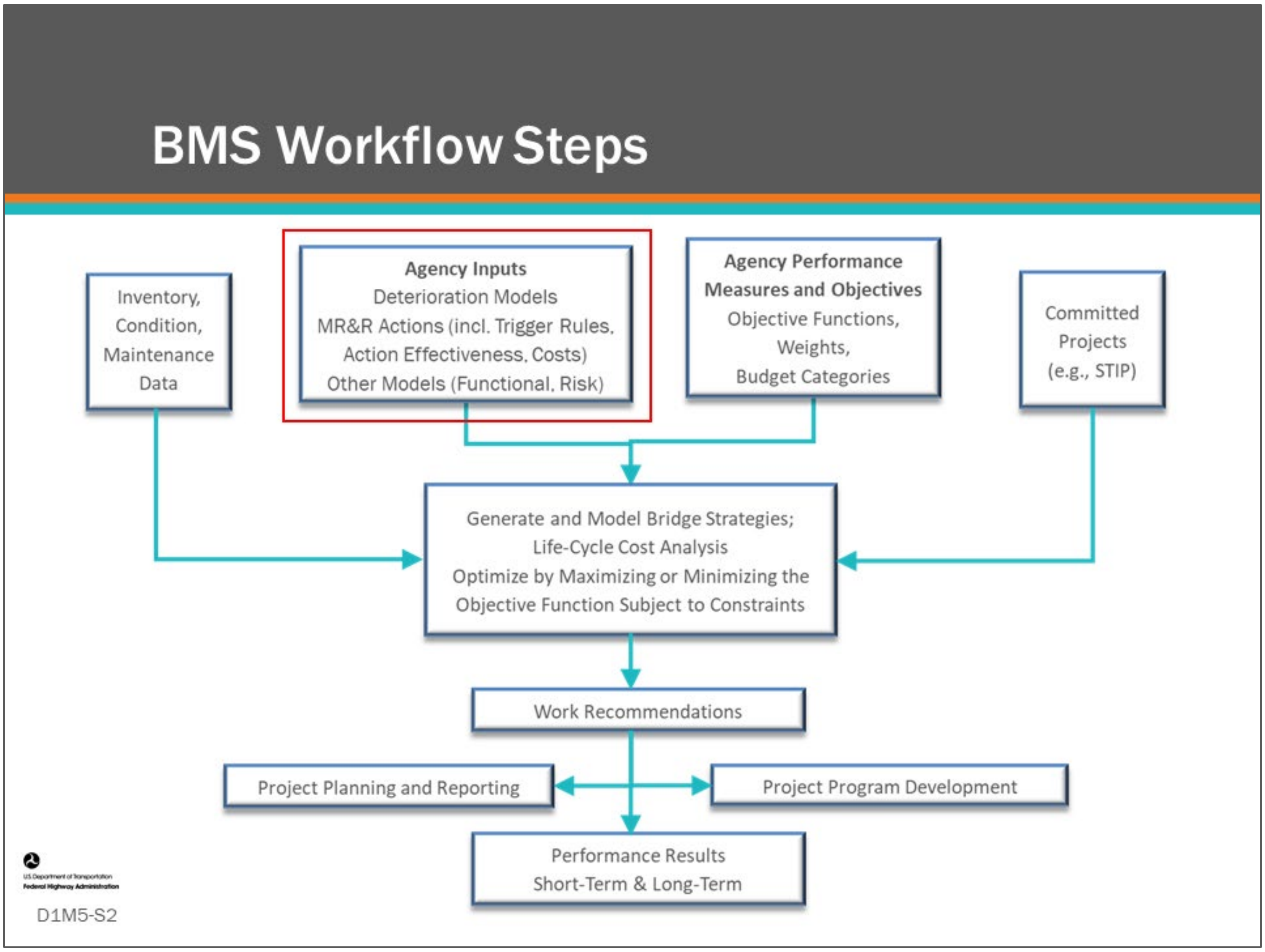
The following provides the key message and visual of each slide, along with space for you to take notes.

D1M5-Slide 1

Key Message
We will now discuss Deterioration Models and their role as input to BMS software.

Disclaimer
FHWA does not promote or endorse patented and proprietary products. Bridge management software is largely proprietary. Workshop content pertaining to proprietary software is included only to illustrate how bridge management system concepts and analyses are applied in practice. The included content shall not be construed as promotion or endorsement of specific software.

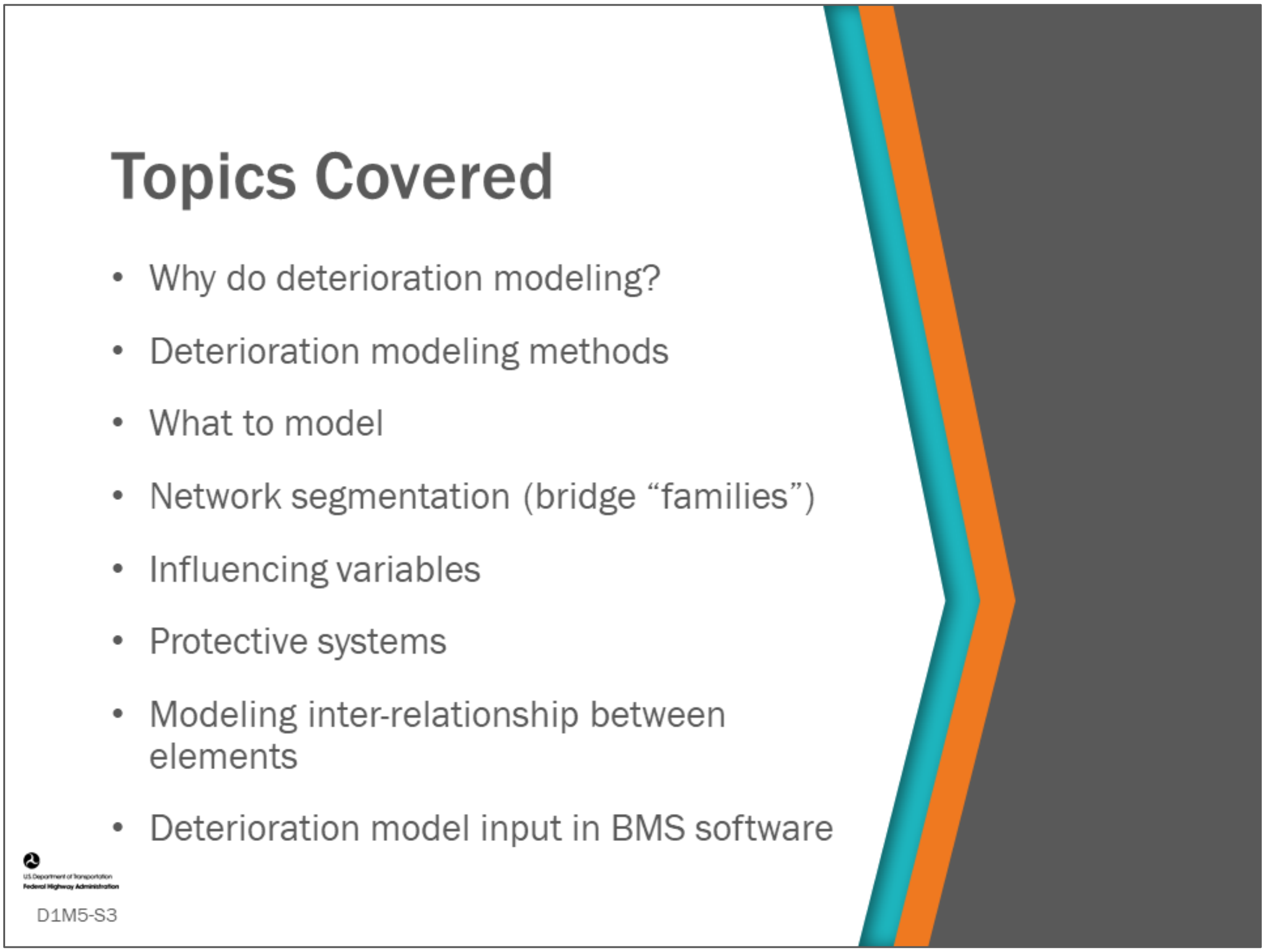
D1M5-Slide 2



Key Message

BMS workflow steps are shown on the slide. Agency inputs including deterioration models are highlighted by the red box.

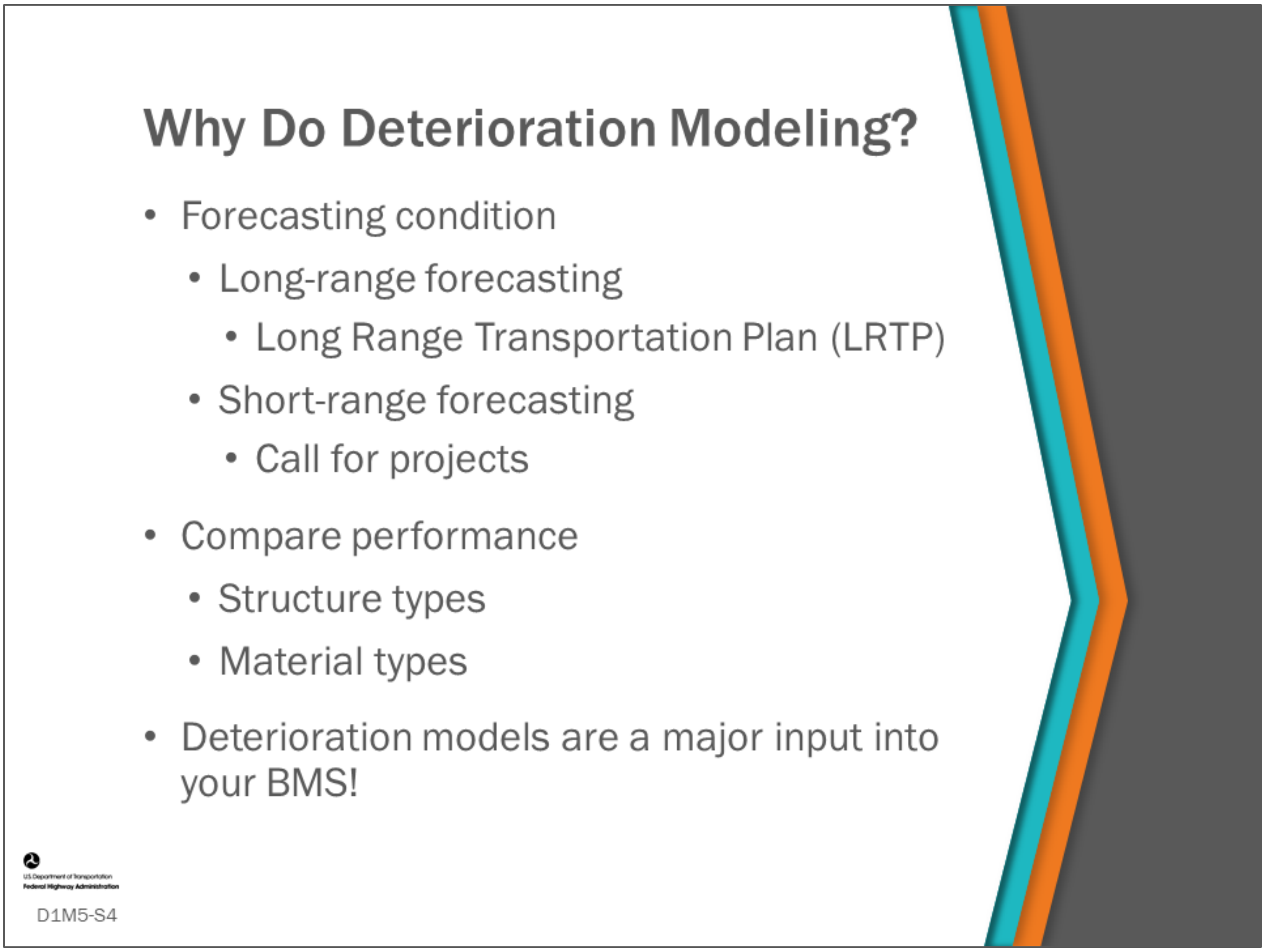
D1M5-Slide 3



Key Message

This module introduces deterioration modeling and shows how it is used in a bridge management system with agency examples. It presents network segmentation, or bridge families, and discusses variables that influence bridge deterioration. Finally, it shows how deterioration models are input into BMS software.

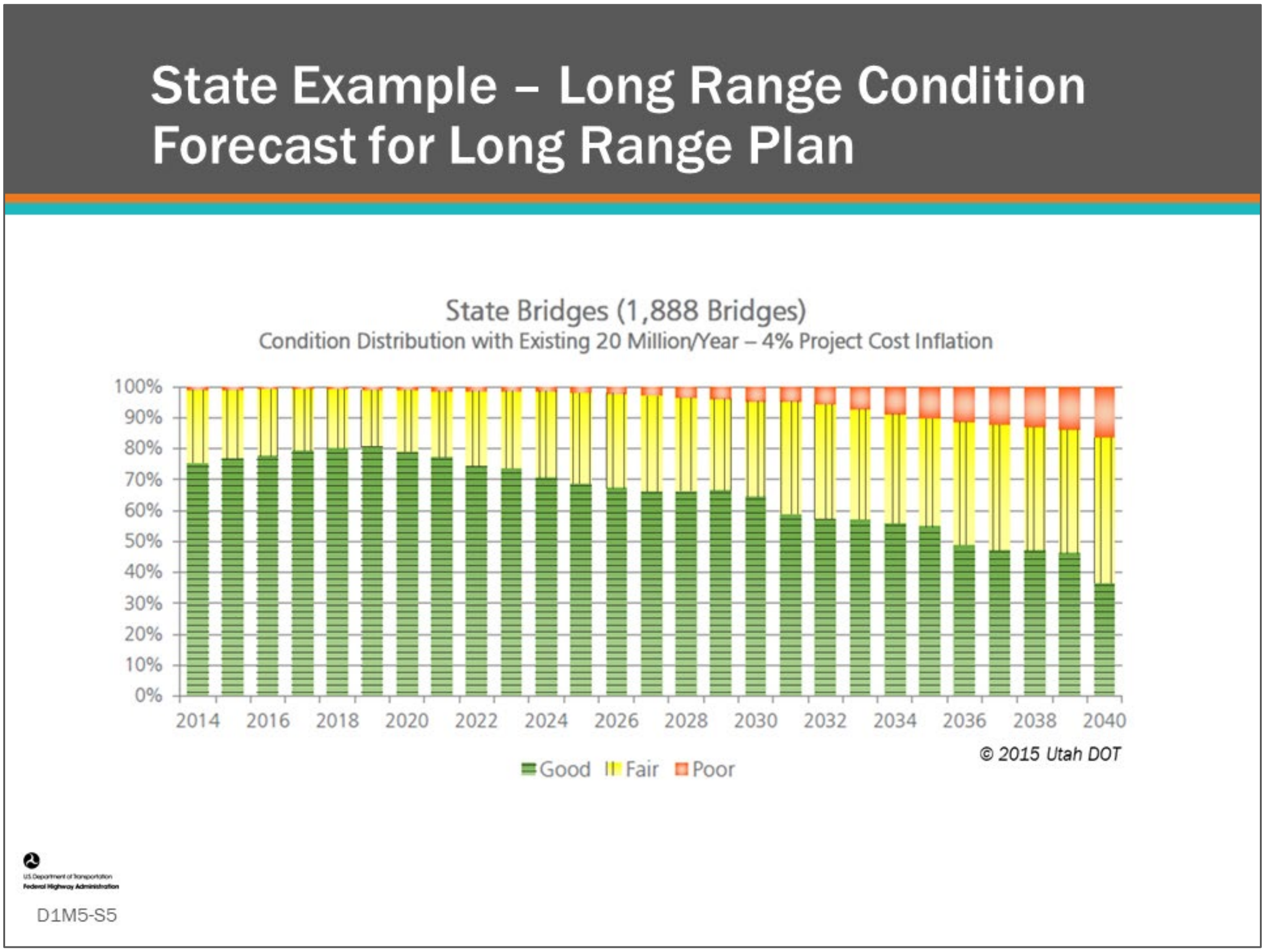
D1M5-Slide 4



Key Message

Why do deterioration modeling? This topic will show the importance of deterioration modeling by showing how it is used to do short and long-range forecasting, and comparing performance of structure types and materials, which are both an integral part of your BMS.

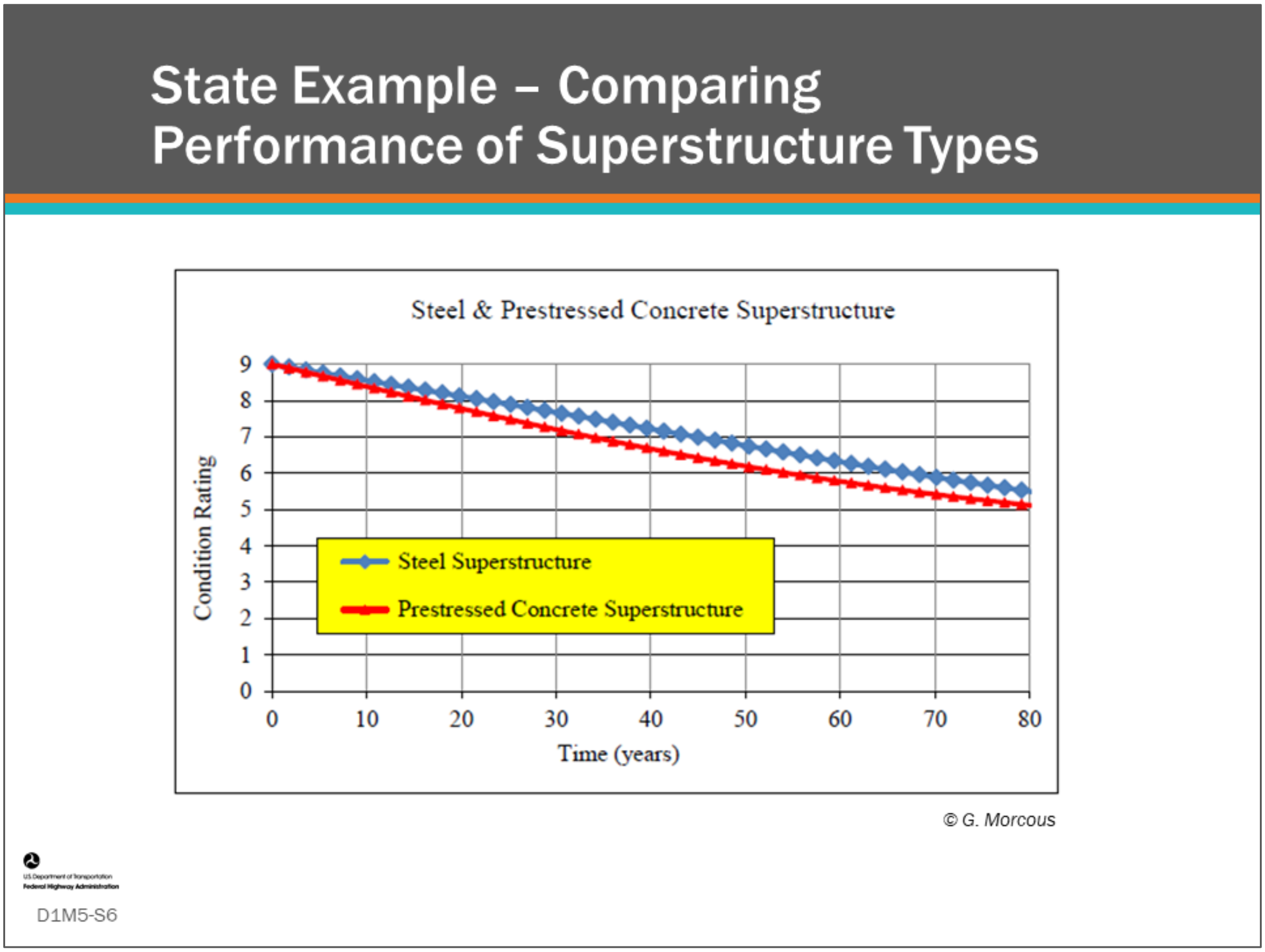
D1M5-Slide 5



Key Message

This slide shows an example of a Utah long range forecast showing percent of Utah bridges in good, fair, and poor condition through 2040. Long range bridge condition forecasts start with deterioration model, then estimates of programs of projects that improve bridges are added to create a forecast of future bridge condition. Both must be accurate for the forecast to be of value.

D1M5-Slide 6

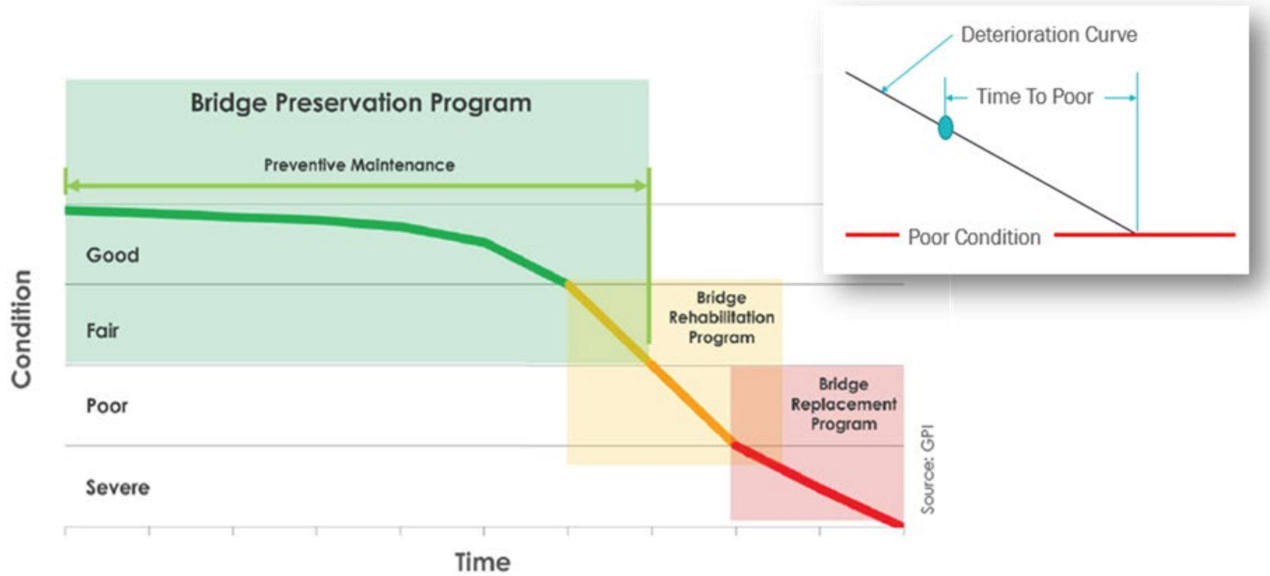


Key Message

Deterioration models are often used to compare the performance of materials and structure types. In this chart, researchers for the Nebraska DOT compare deterioration curves for steel and prestressed concrete superstructures.

D1M5-Slide 7

Deterioration Modeling and Project Selection



Bridge condition over time.

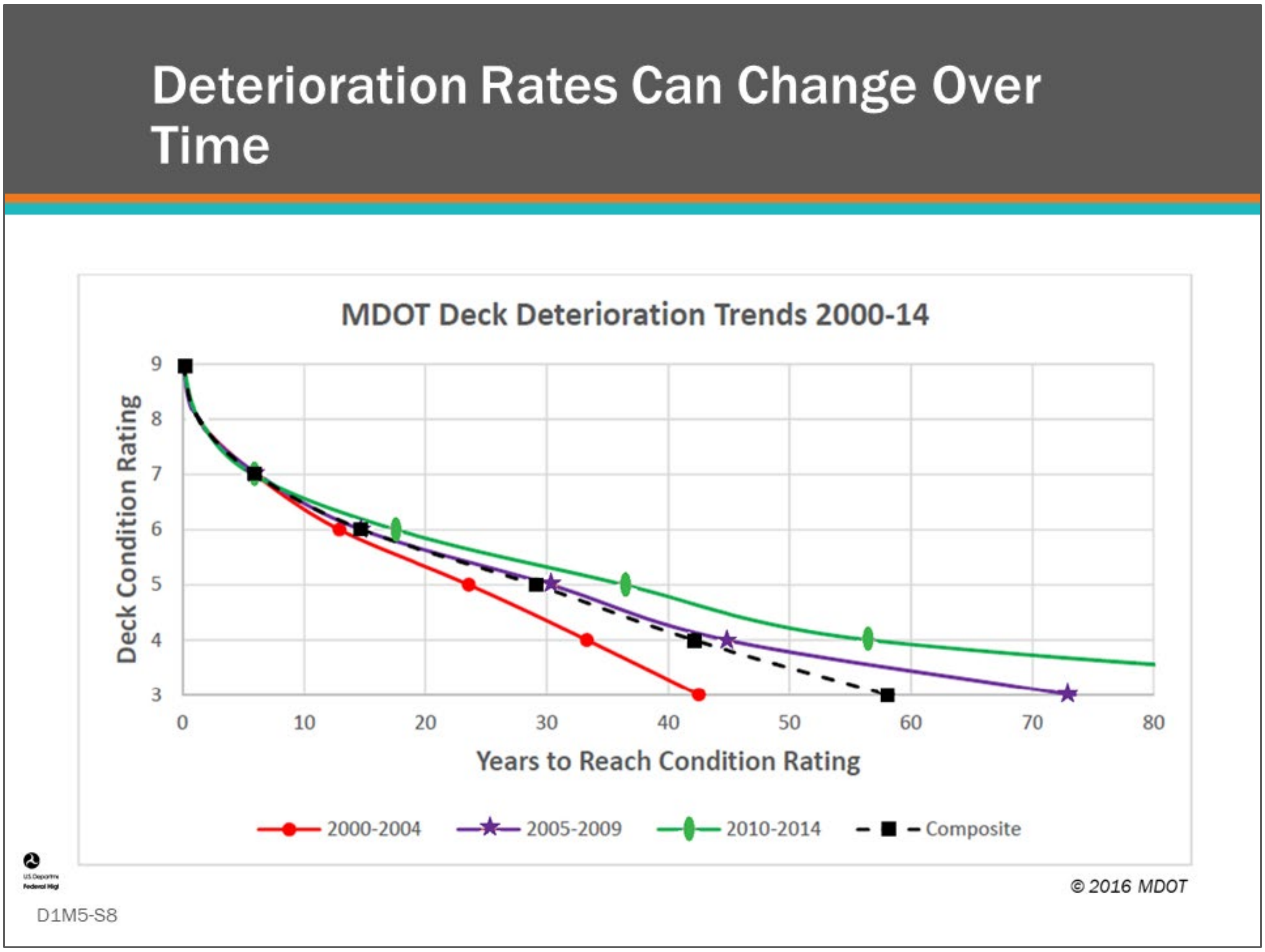
D1M5-S7

Key Message

As shown in this chart, taken from the FHWA Bridge Preservation Guide, bridge deterioration modeling is an important part of determining bridge programs and project selection. As bridges deteriorate, they enter different categories of work. Bridges in good to fair condition typically only need cyclic or preventive maintenance. Bridges in fair to poor condition need rehabilitation, and bridges in poor or worse condition often need partial or full replacement.

Note that bridges with multiple components in poor or worse condition often need replacement. For example, bridges with only deck in poor condition often only need decks replaced.

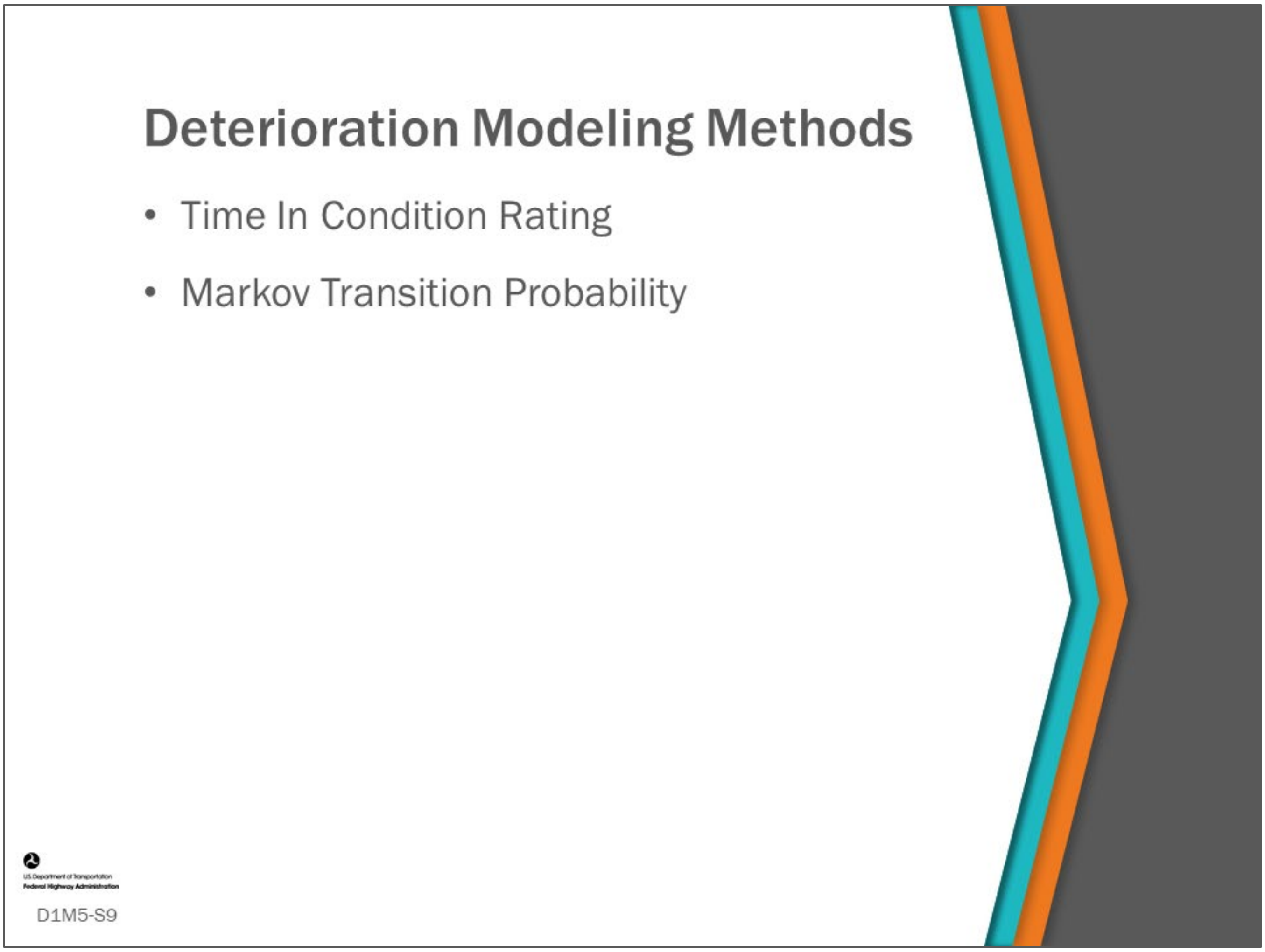
D1M5-Slide 8



Key Message

Deterioration curves will vary depending on the time window from which data is mined to develop the curves. Variances may occur from changing design, construction, maintenance, and preservation policies. Keep in mind that generally native deterioration curves without the effects of preservation actions are input in BMS. When using native curves, applying planned work actions have the effect of placing a component or element at a higher position on the curve, or in the case of applied protective systems, slows the rate of deterioration of the protected component or element.

D1M5-Slide 9



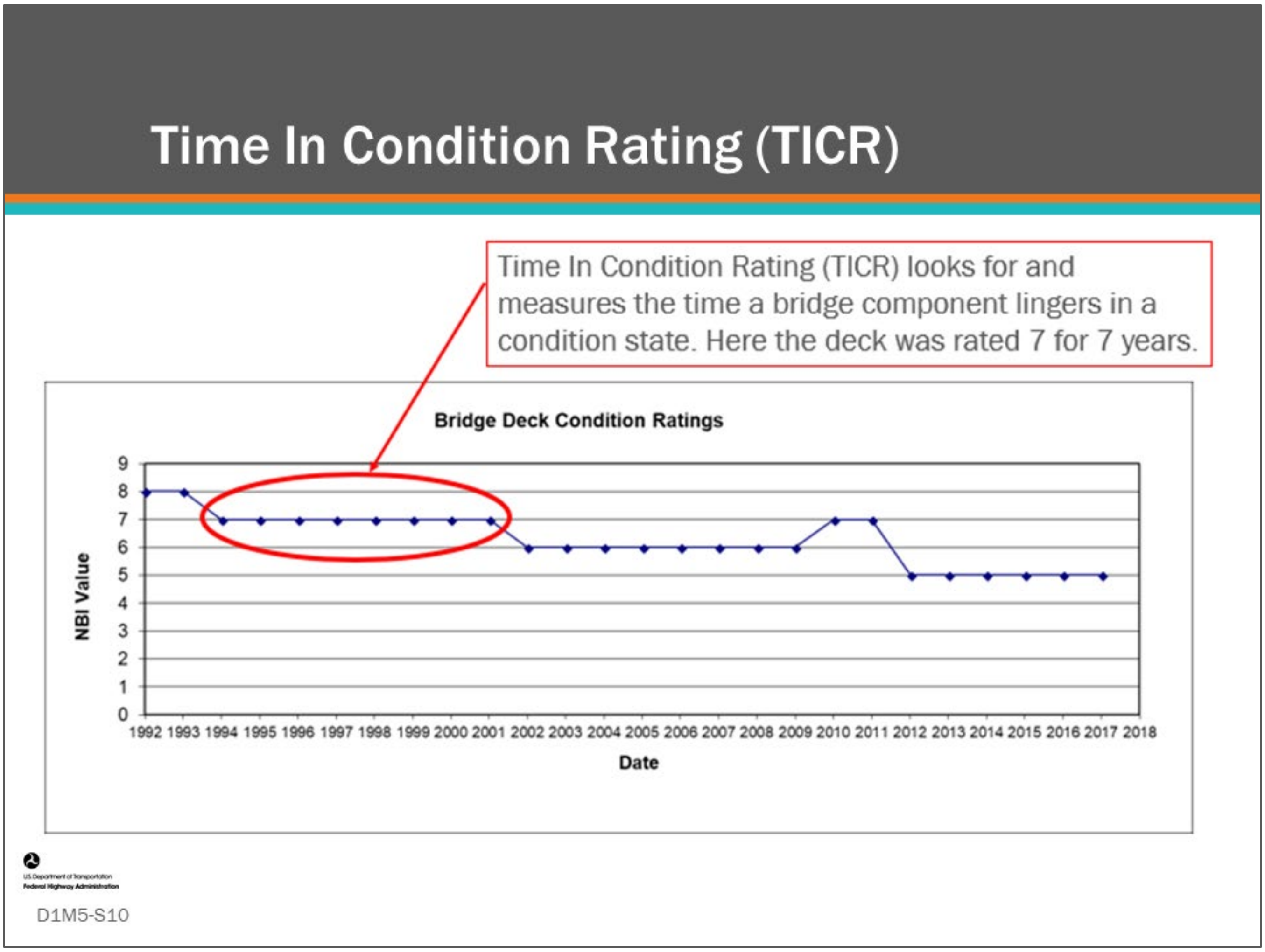
Key Message

Next we will provide a short preview of the Day 2/3 module on deterioration modeling methods. This preview is provided to give a general understanding of two deterioration modeling methods commonly used in BMS software.

These two methods include:

- Time In Condition Rating
- Markov Transition Probability

D1M5-Slide 10

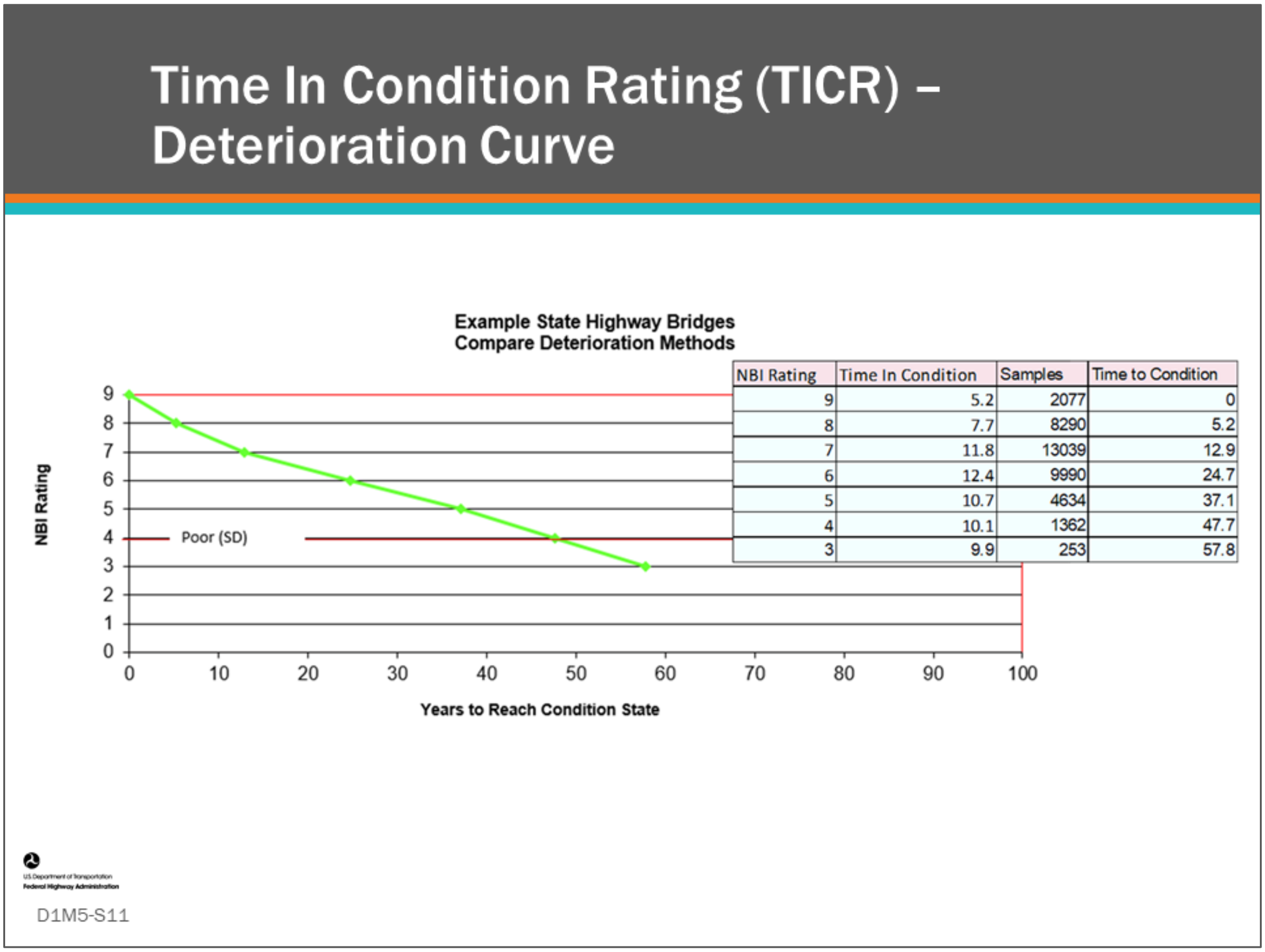


Key Message

Time In Condition Rating (TICR) is a method used for analyzing condition data to estimate deterioration rates. It measures the time a component lingers in a condition rating.

NBI General Condition Rating (GCR) bridge major component condition data is available going back to 1992. For any bridge, this data can be used to show the condition of that component in each year or at each inspection. This is shown for a bridge in the above chart which shows NBI GCR condition rating for the bridge deck on the y axis and year on the x axis. Once this is plotted for a bridge, the data can be reviewed to find occurrences where a condition rating was entered and then exited to a lower condition rating as shown in the chart.

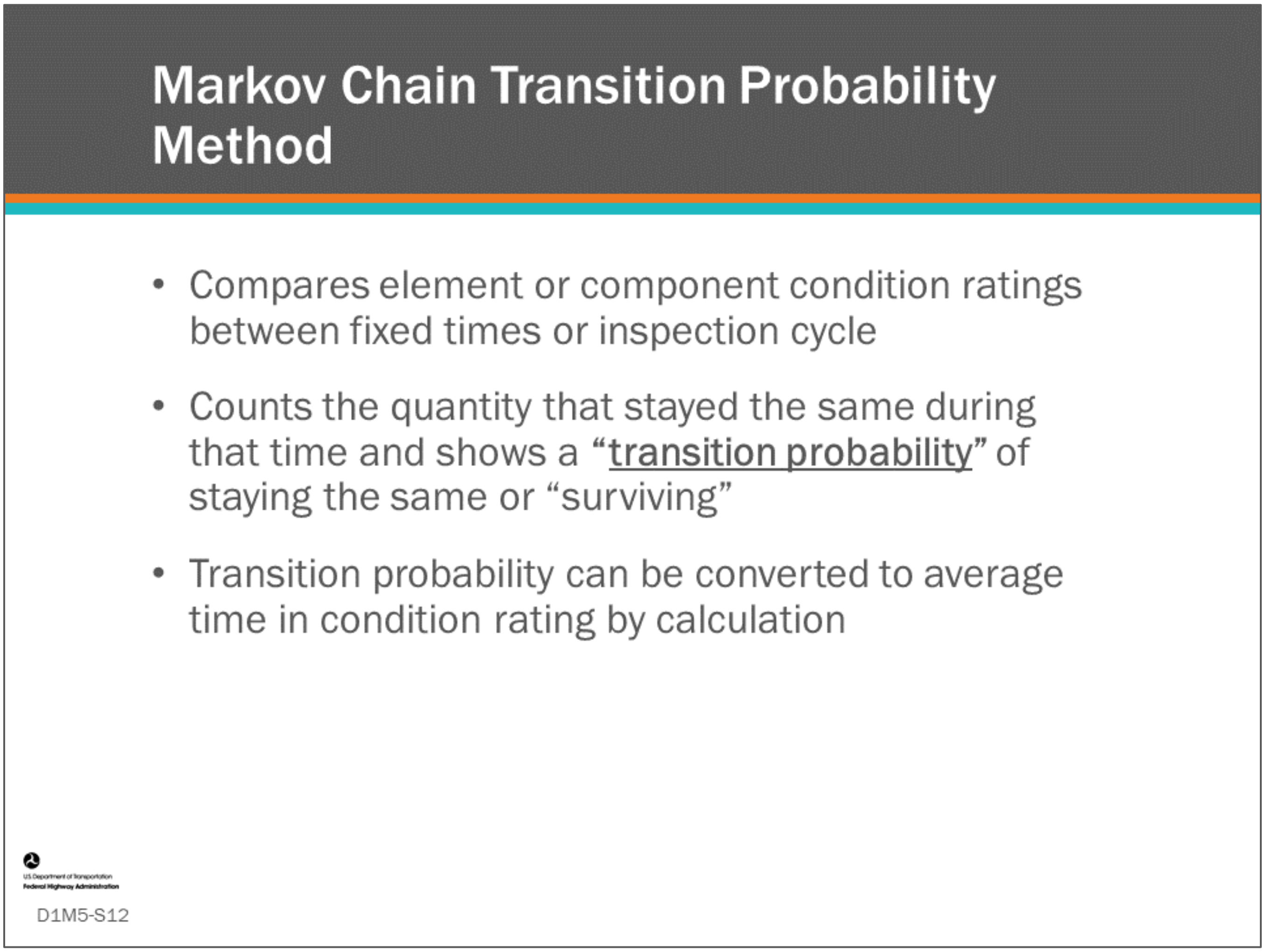
D1M5-Slide 11



Key Message

A deterioration curve was derived using the Time In Condition Rating (TICR) method. The table at the right side of the slide shows average time in condition rating, sample size, and the cumulative time to condition for the results of the analysis. The chart shows the resulting deterioration curve.

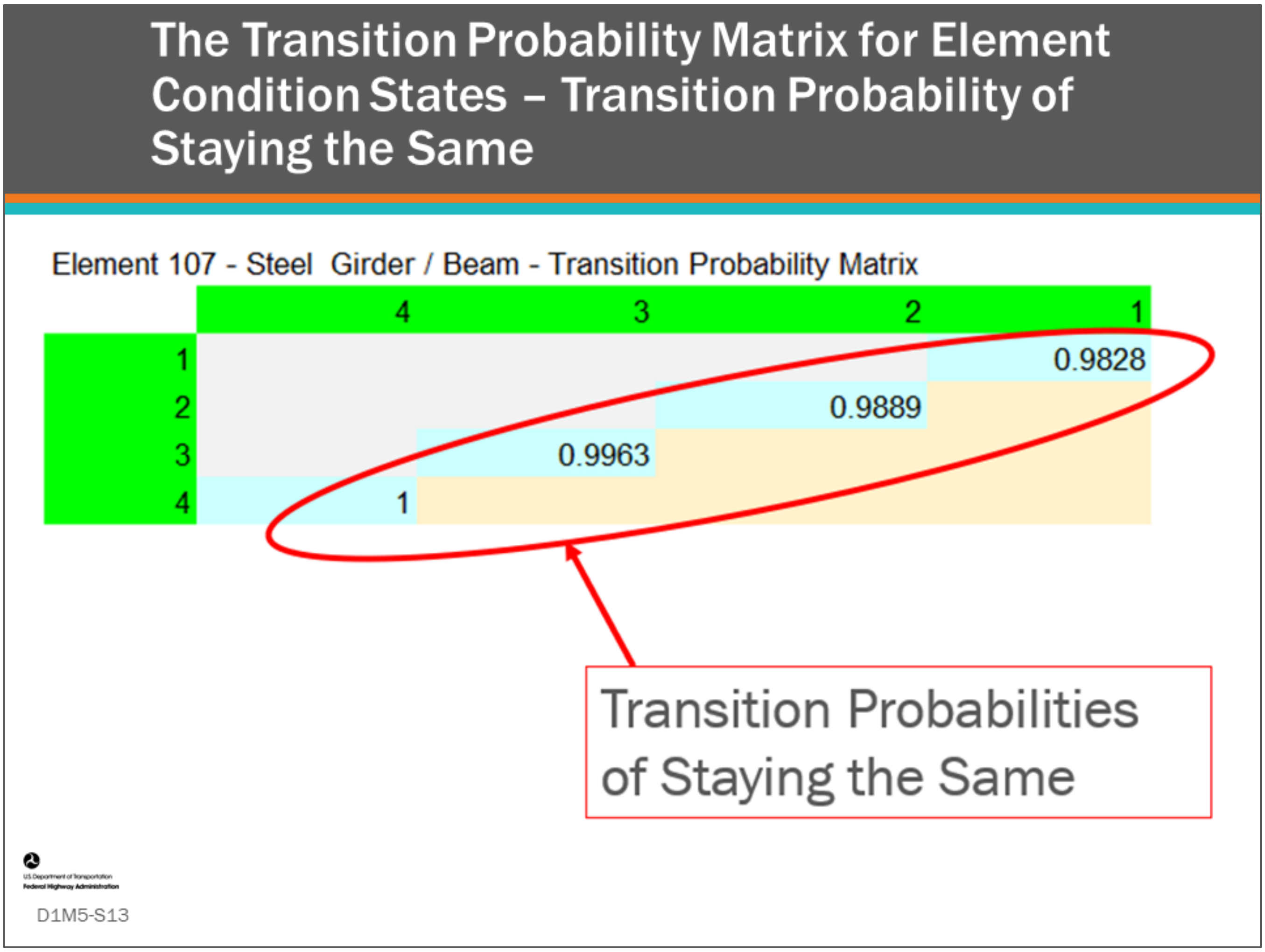
D1M5-Slide 12



Key Message

The Markov chain transition probability method estimates deterioration of components by counting how many condition ratings stayed the same during a fixed time frame (example - one year or yearly) or inspection cycle (such as every two years) and show that as a transition probability of staying the same or "surviving." Transition probabilities can be converted to average time in condition rating by calculation. These slides will demonstrate this method and will discuss the benefits and challenges this method has to offer.

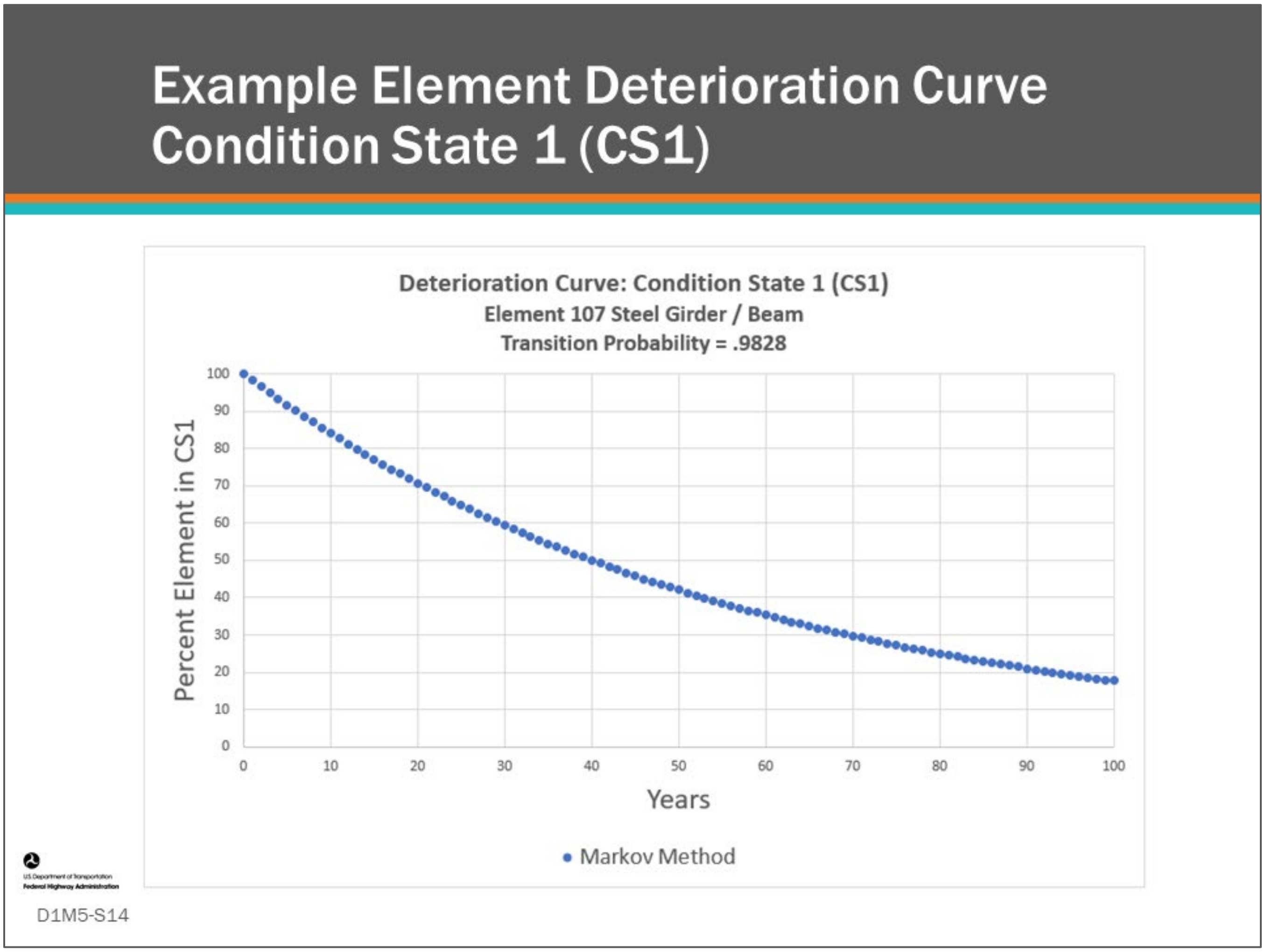
D1M5-Slide 13



Key Message

Shown here is a transition probability matrix for steel girder / beam. The values shown on the diagonal are the transition probability that the quantity of this element will not change from one year to the next. On the second day of this workshop, we will demonstrate how to calculate and use these matrixes.

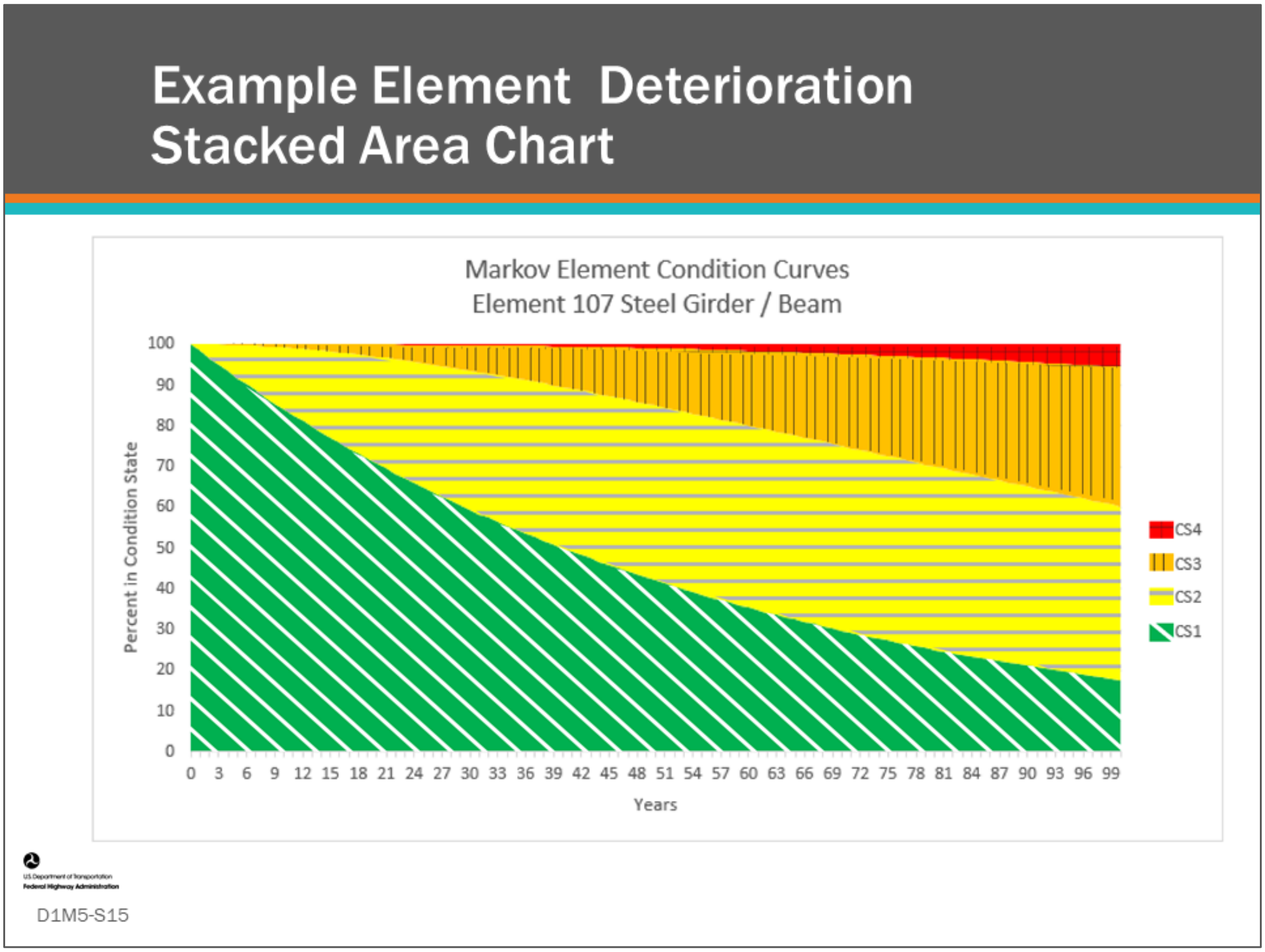
D1M5-Slide 14



Key Message

Using the Transition Probability (TP) from the previous slides (TP = .9828) a percent element in CS1 over time chart is shown. This shows how the percentage of CS1 reduces over time.

D1M5-Slide 15



Key Message

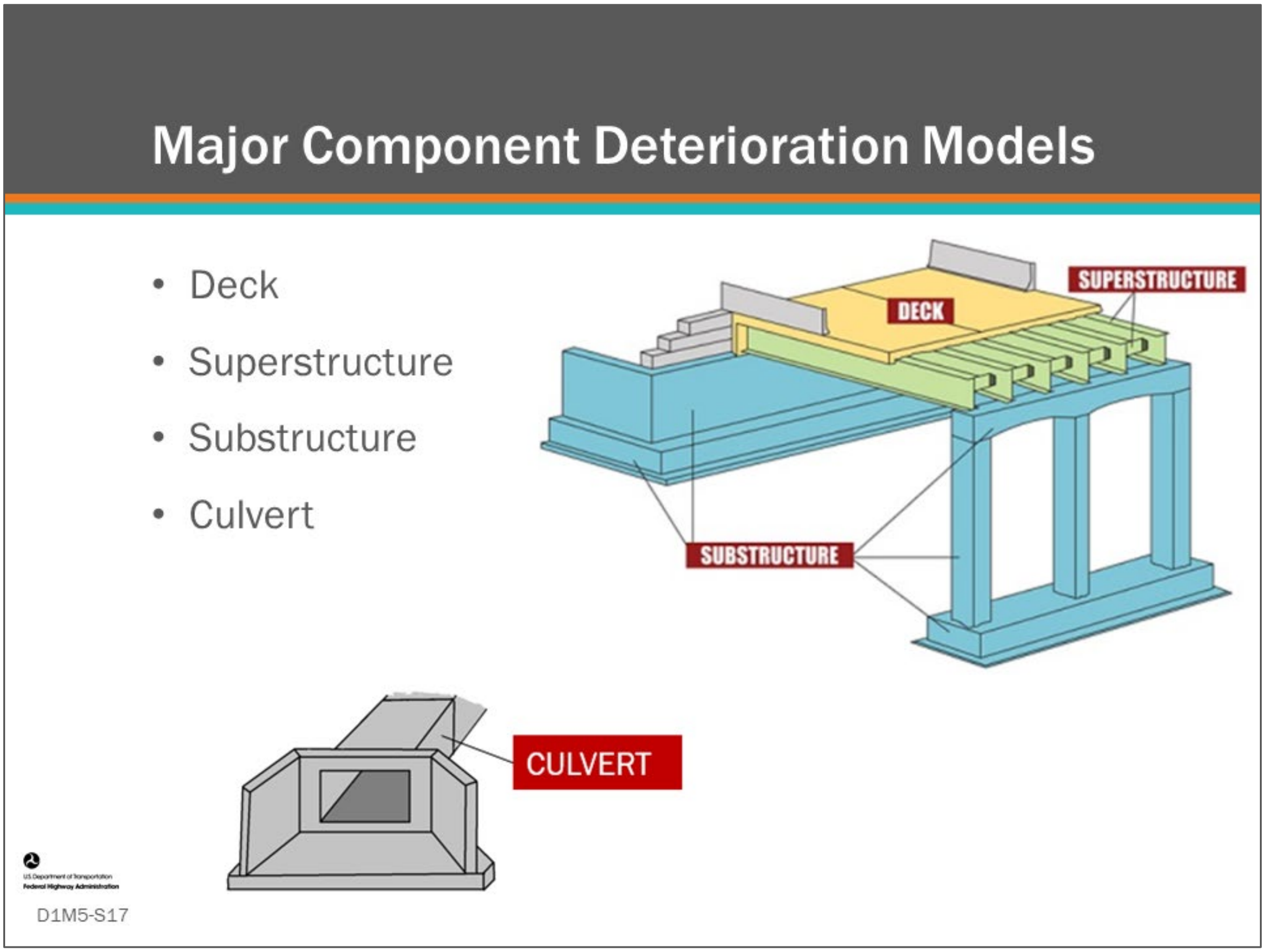
This chart shows a stacked area chart showing the change in percent in each of the condition states, Condition State 1 (CS1), Condition State 2 (CS2), Condition State 3 (CS3), and Condition State 4 (CS4) for the Steel Girder / Beam example shown in the previous slides. Most often these charts are shown in the familiar Green for good, yellow for fair, orange for poor, and red for severe. Bridge owners need to become familiar with these charts and the unique way elements with units of measure of linear feet and square feet deteriorate, and how that information is used in a BMS.

D1M5-Slide 16

Key Message

The next topic focuses on what should be modeled. Owners need to decide how detailed the actions are desired from their bridge management system. For example, an action could be "preserve the bridge deck" which could be determined by the general condition rating for the bridge deck, or an action could be “patch 25 square feet of the bridge deck, and replace the strip seal expansion joint," which would need element condition ratings for deck area and lineal feet of expansion joints.

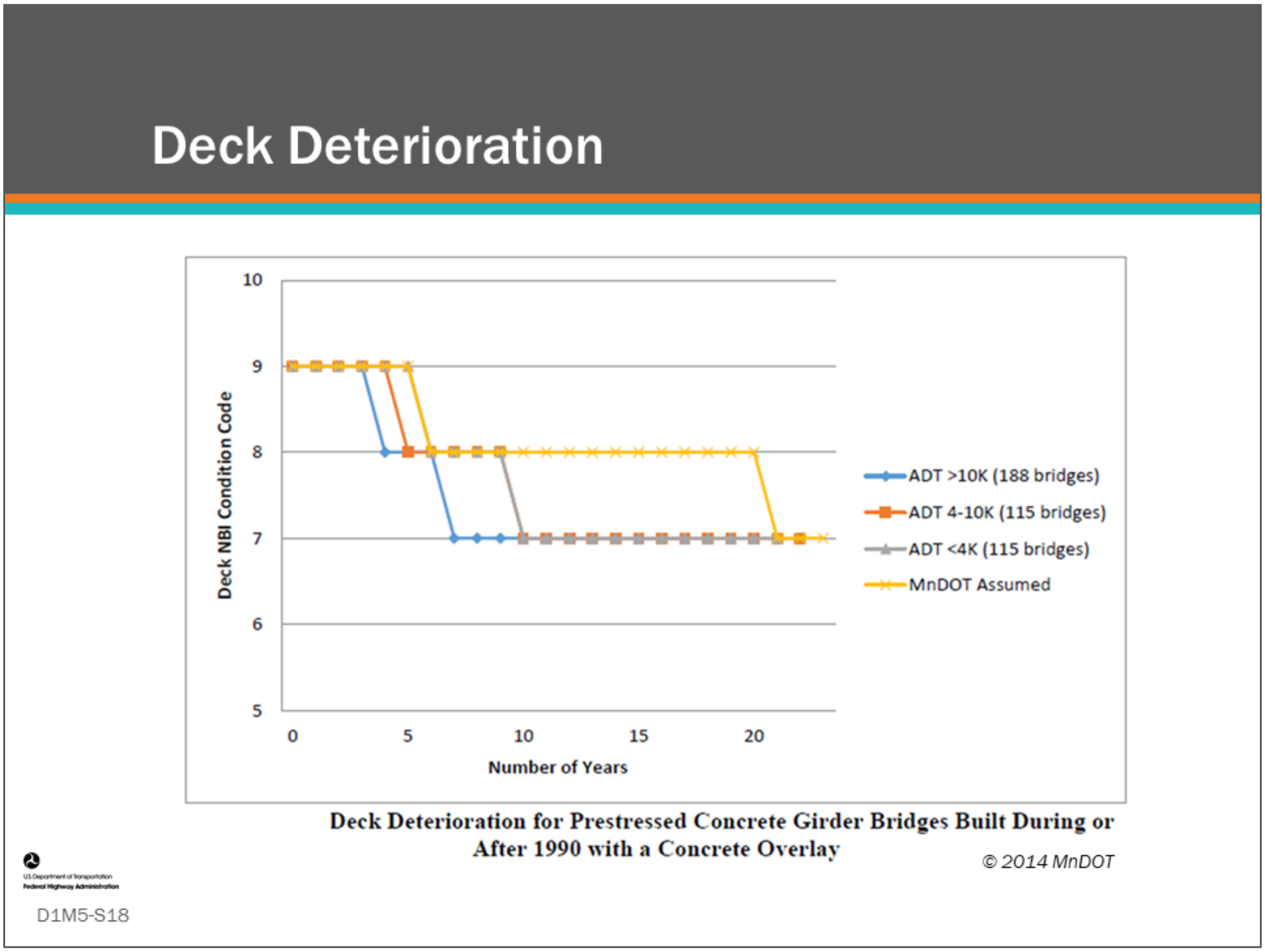
D1M5-Slide 17



Key Message

Major bridge components, deck, superstructure, substructure, and culverts are often studied for deterioration rates. BMS software allows parameters to be input in order to model deterioration of these individual components.

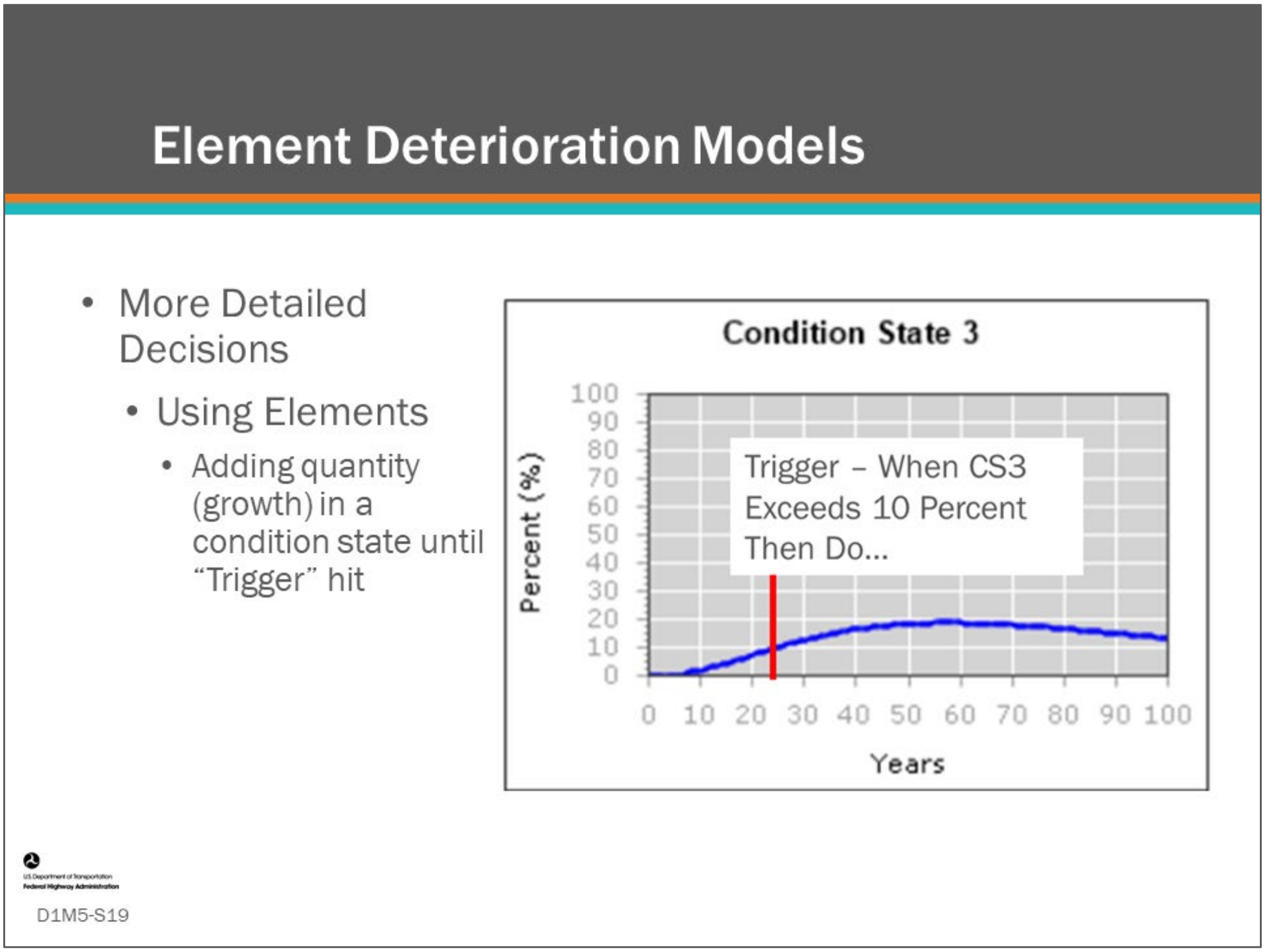
D1M5-Slide 18



Key Message

This slide shows the results of a component deterioration modeling study performed for the Minnesota DOT. It shows deck deterioration over time for prestressed concrete bridges built during or after 1990 with a concrete overlay.

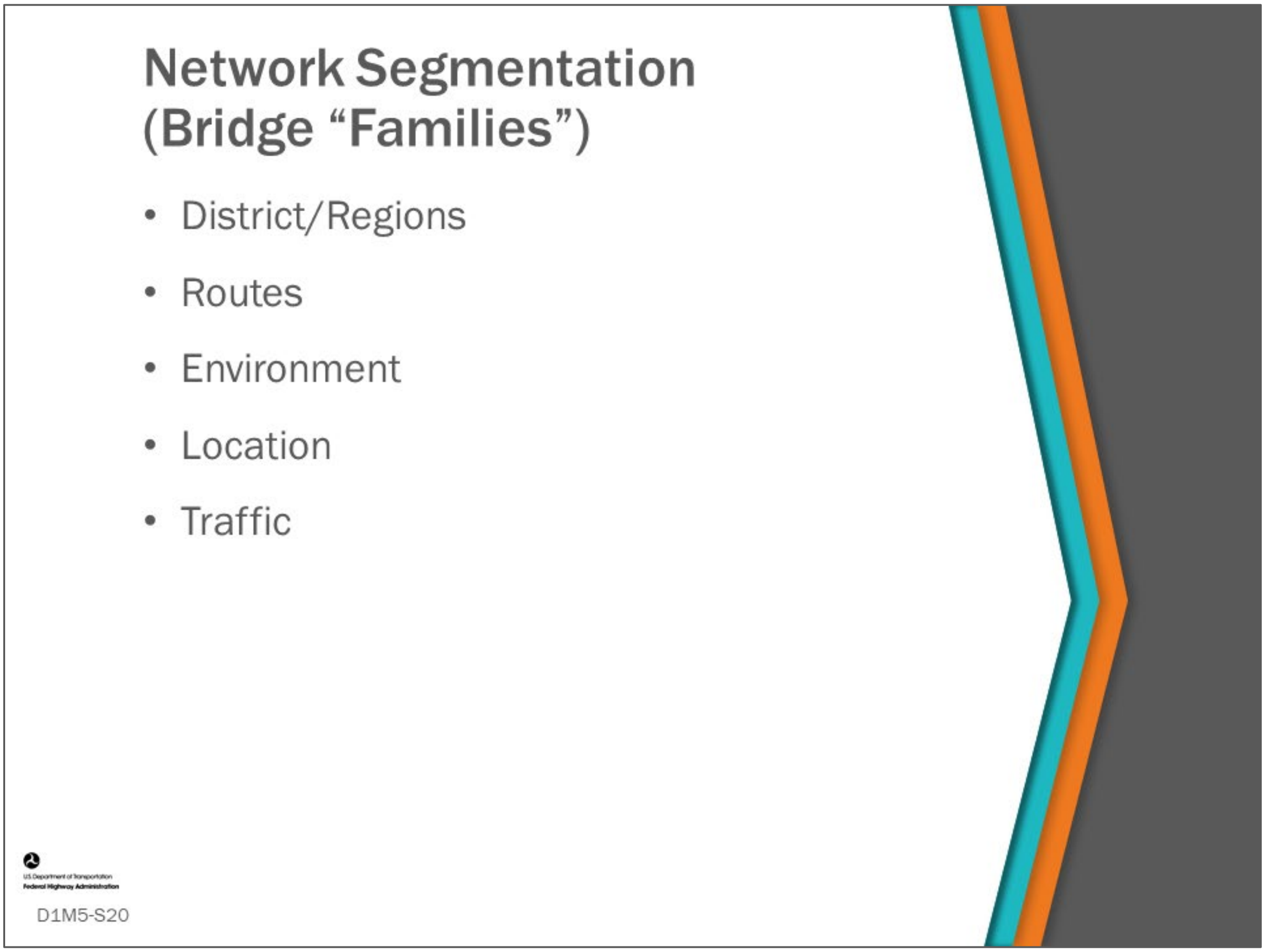
D1M5-Slide 19



Key Message

All advanced BMS software support management using bridge elements, so element-level deterioration modeling is becoming more and more important. Deterioration modeling for elements is a challenging new area that many are working to understand better. On the second day of the workshop, we will learn how to do element level deterioration modeling.

D1M5-Slide 20



Key Message

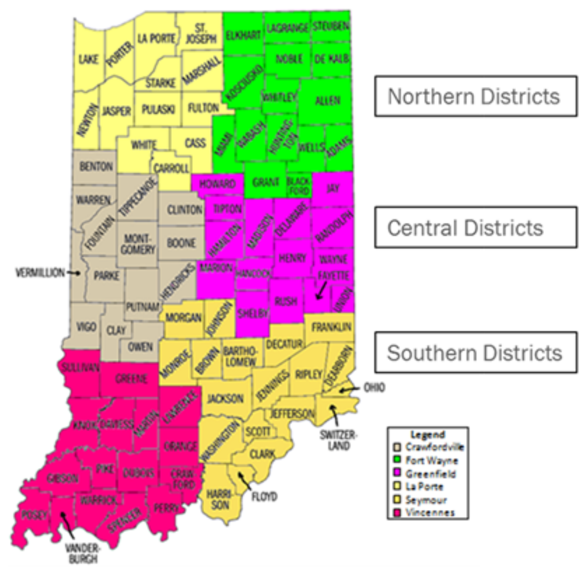
Experience and intuition tells us that all bridges do not deteriorate at the same rate.
When developing deterioration models and setting up your BMS, Agencies need to decide how their population of bridges is divided into network segments or "families."

Several possible types of network segmentation are outlined on this slide.

D1M5-Slide 21

Network Segmentation (Bridge "Families"): Location and Route

- Location
  - District / Regions
- Route
  - NHS or non-NHS
  - Freeway or non-freeway



Indiana's highway adminstrative districts

Source: This image was found at https://bit.ly/2Dw0isW and is being used under license terms available at https://bit.ly/1kvyKWi

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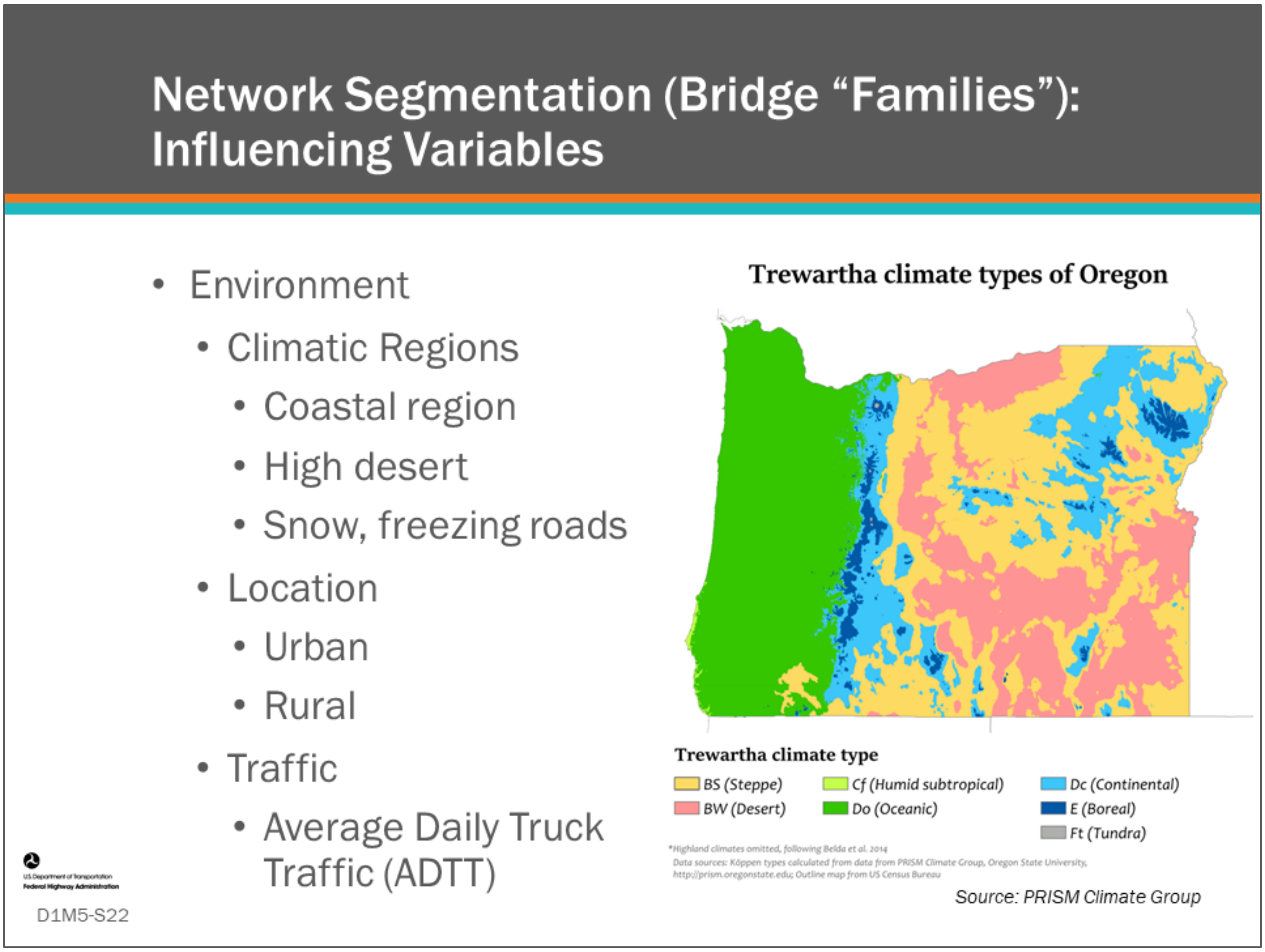
D1M5-S21

Key Message

Bridge families can be divided by district or region, by highway routes, or any other category that the owners deem relevant.

Shown on this slide are the districts for the Indiana DOT.

D1M5-Slide 22



Key Message

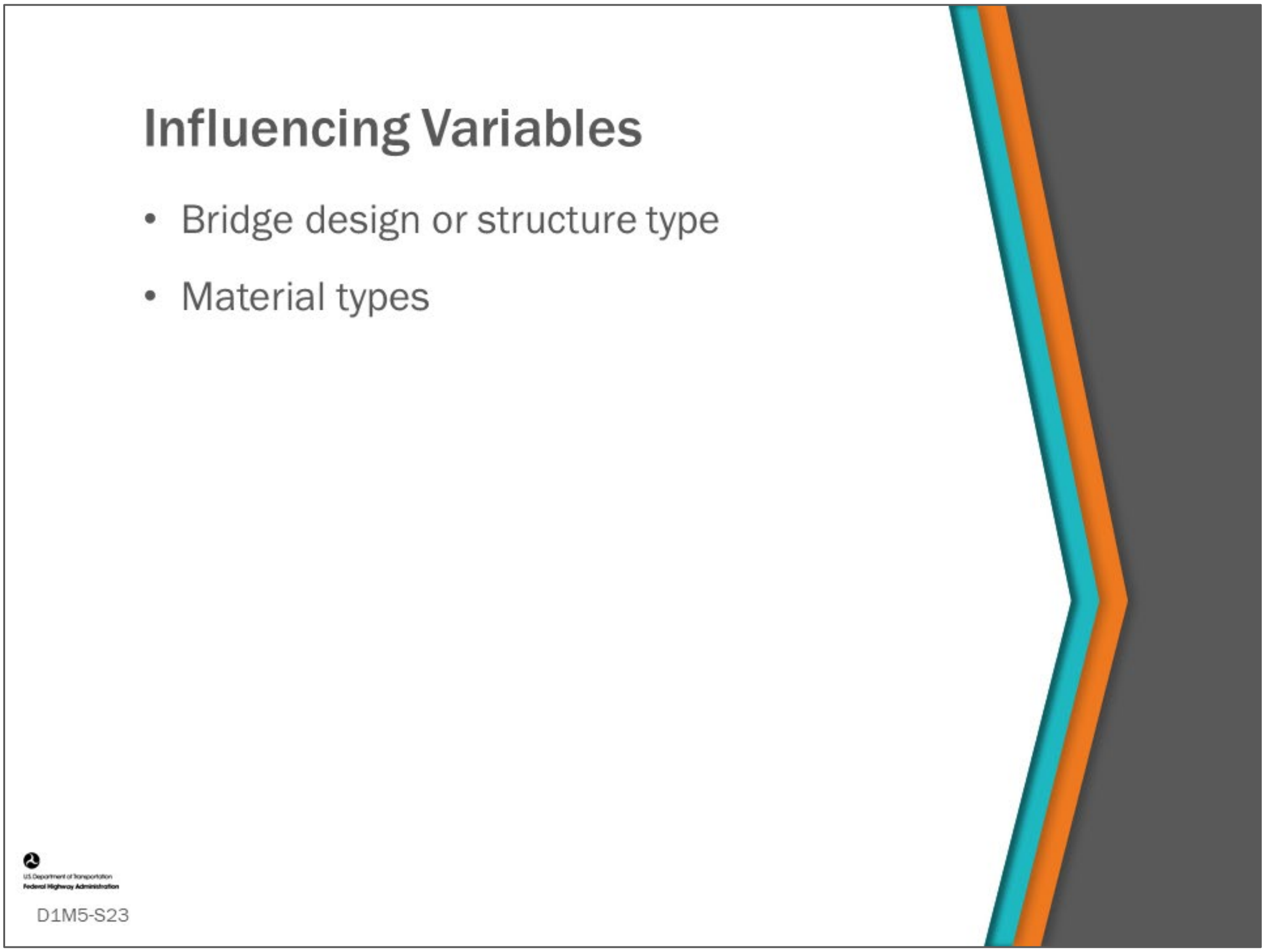
The climate in which the bridge resides is a very important consideration when setting deterioration families.

For example, Oregon DOT knows that bridges in their coastal region deteriorate very differently than bridges in the arid inland portions of the state.

The use of salt as a deicing material in states having a snow climate greatly affect deterioration rates. Bridges in urban locations are known to deteriorate differently than bridges in rural regions, and traffic, particularly truck traffic, is known to have an influence on bridge deterioration.

Traffic, such as Average Daily Traffic (ADT) and Average Daily Truck Traffic (ADTT) have been also shown to affect deterioration rates.

D1M5-Slide 23

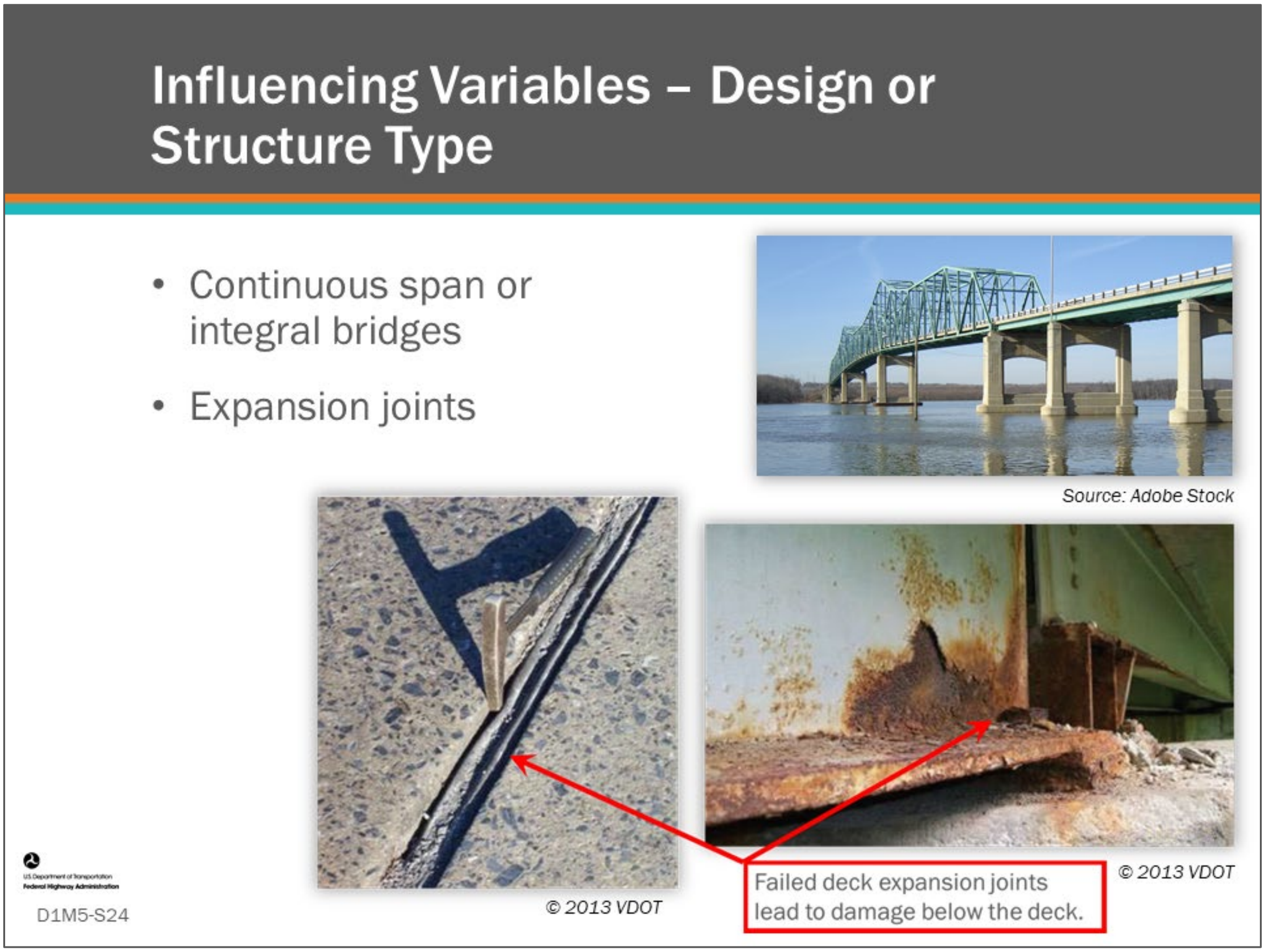


Key Message

Design, structure type, as well as components and elements consisting of different materials can each have their own deterioration models.

This section provides examples of these influencing variables, as well as opportunities to discuss how these different factors influence bridge deterioration.

D1M5-Slide 24



Key Message

Deterioration models need to account for different design and structure types, as they will have their own modes and rates of deterioration. For example, continuous span and integral abutment bridges deteriorate differently than bridges with expansion joints. In fact, failed bridge expansion joints are well known to be a leading cause of accelerated deterioration of the components and elements below them by allowing, and even directing, salt-laden moisture to make contact with them. One solution for this is remove expansion joints by designing bridges with continuous spans.

D1M5-Slide 25

Influencing Variables – Material Factors

- Example Deck Materials
  - Reinforced concrete deck with black rebar
  - Reinforced concrete deck with epoxy coated, galvanized, or other non-corroding rebar
- Example Superstructure Materials
  - Painted steel beams
  - Reinforced concrete beams
  - Prestressed concrete beams
- Example Substructure Materials
  - Reinforced concrete piers
  - Timber abutments

Source: Adobe Stock

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D1M5-S25

Key Message

Influencing variables include the materials that make up bridge elements and components. Reinforced concrete bridge decks with unprotected "black" rebar are known to deteriorate quicker than reinforced concrete decks with epoxy coated or stainless-steel rebar. Painted steel beams deteriorate differently than weathering steel beams. Influencing variables include combinations of environment, design type, and materials.

D1M5-Slide 26

Protective Systems

- Wearing Surface
- Steel Protective Coatings
- Concrete Reinforcing Steel Protective Systems
- Concrete Protective Coating

Source: FHWA

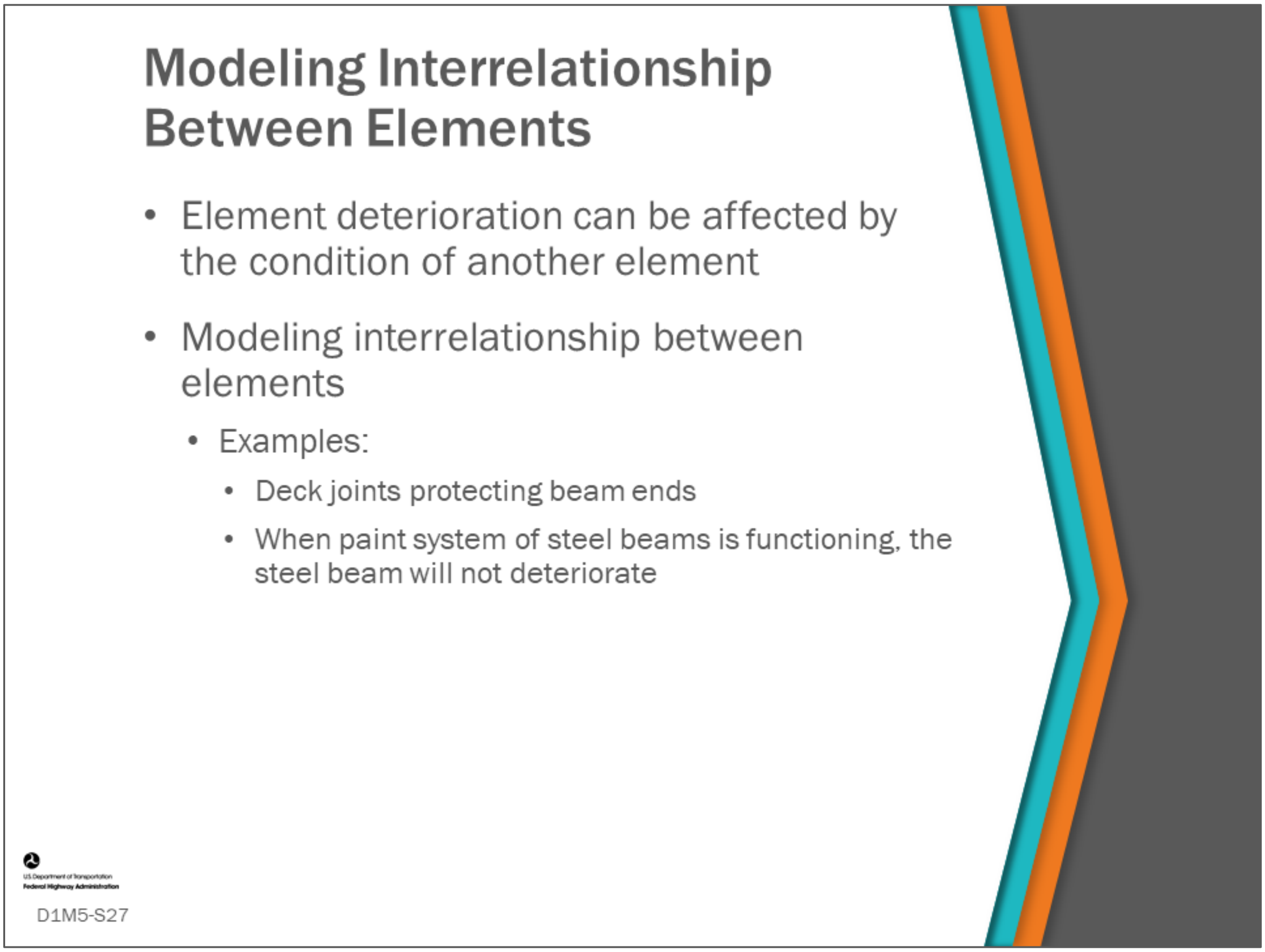
Source: FHWA

D1M5-S26

Key Message

Protective systems are special child elements that protect the parent element. Examples of these include wearing surface, steel protective coatings, corrosion resistant reinforcing steel, and concrete protective coating. The presence and effect of protective systems are important to include in BMS models so that the benefit of preservation can be considered in benefit-cost analysis. When modeling deterioration, if a protective system is in place and in good condition, the BMS software can reduce or even eliminate deterioration to the parent element.

D1M5-Slide 27



Key Message

Modeling the interrelationship between elements is the state of the art for deterioration modeling. It is an important area of study, but at this time there is little research to provide guidance, although some BMS provide a framework for modeling the interrelationship.

D1M5-Slide 28

Interrelationship Between Elements - Example - Failed Deck Joints

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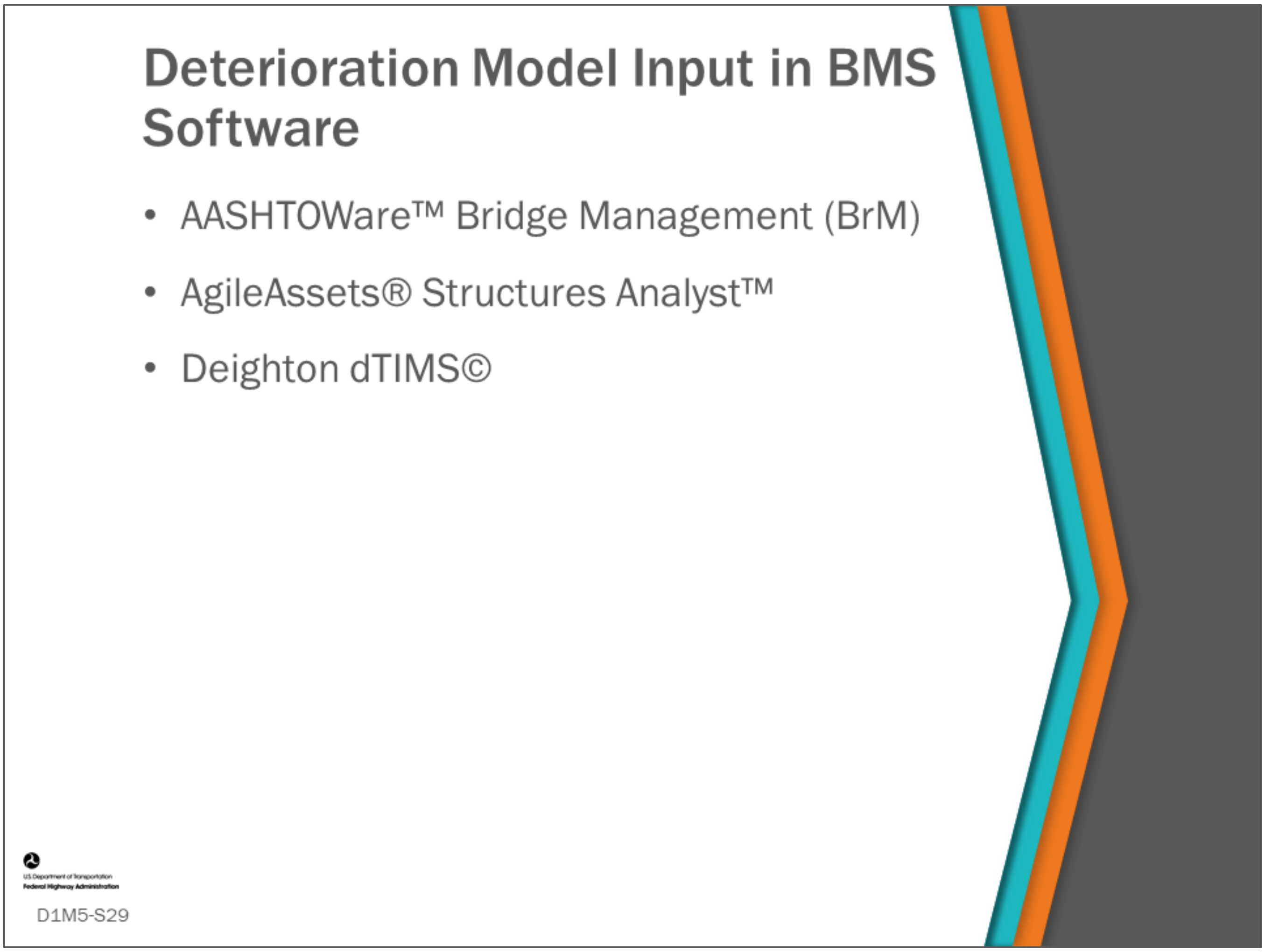
D1M5-S28

Key Message

The best known example of this is bridge deck expansion joints. When these elements fail, it exposes the bridge superstructure and substructure to water and chlorides. To better account for this, some agencies provide a sub-element (or child element) of the beam end to capture the faster deterioration that occurs here.

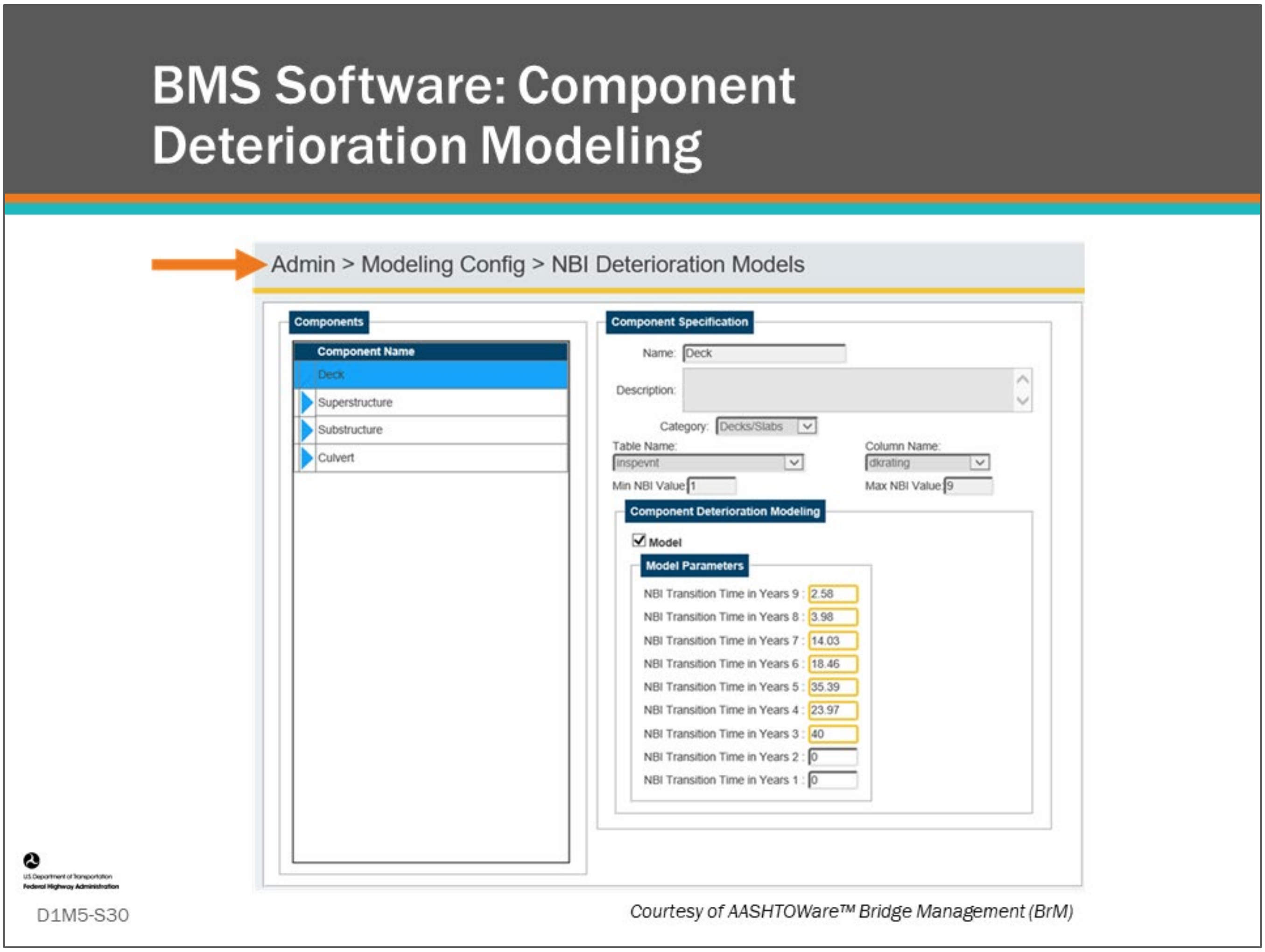
D1M5-Slide 29



Key Message

In this section, we will look at examples from some bridge management systems: AASHTOWare™ Bridge Management (BrM), AgileAssets® Structures Analyst™ and Deighton dTIMS©.

D1M5-Slide 30

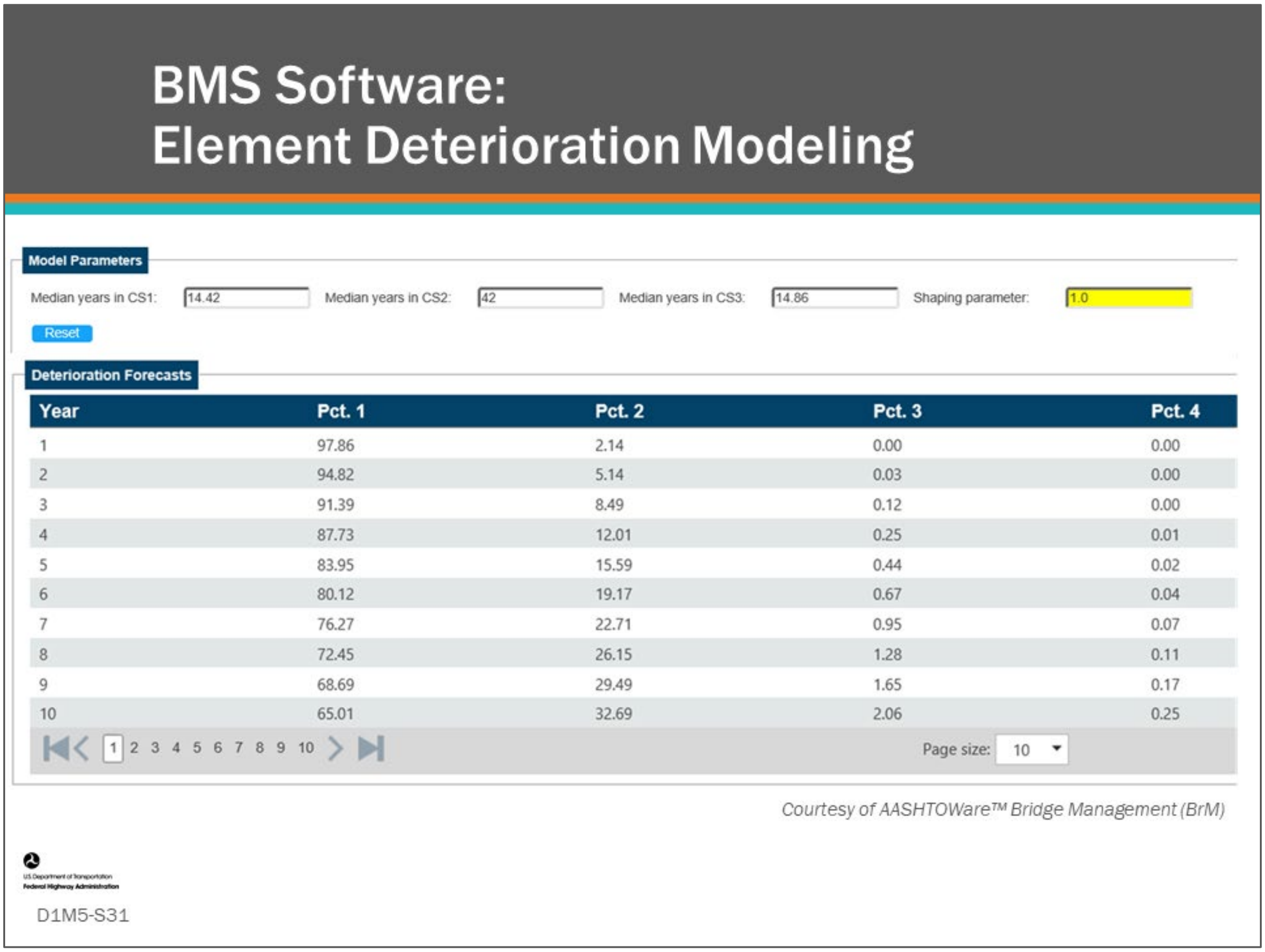


Key Message

In the AASHTOWare™ Bridge Management (BrM) software, Administration – Modeling Configuration – NBI Deterioration Models screen, you can input deterioration model parameters for components (deck, superstructure, substructure, and culvert). These values are input as NBI GCR Transition Time in Years for each condition rating (0 – 9).

The parameters define a deterministic "piecewise linear" model of the deterioration of NBI GCR over time. A piecewise linear model is one where straight line deterioration occurs over the transition time for each condition rating. When estimating the number of bridges in each condition rating in the future, BrM will look back when the component entered the condition and then calculate when it is expected to deteriorate to the next lower condition rating, and then follow the NBI GCR transition times for subsequent ratings.

D1M5-Slide 31



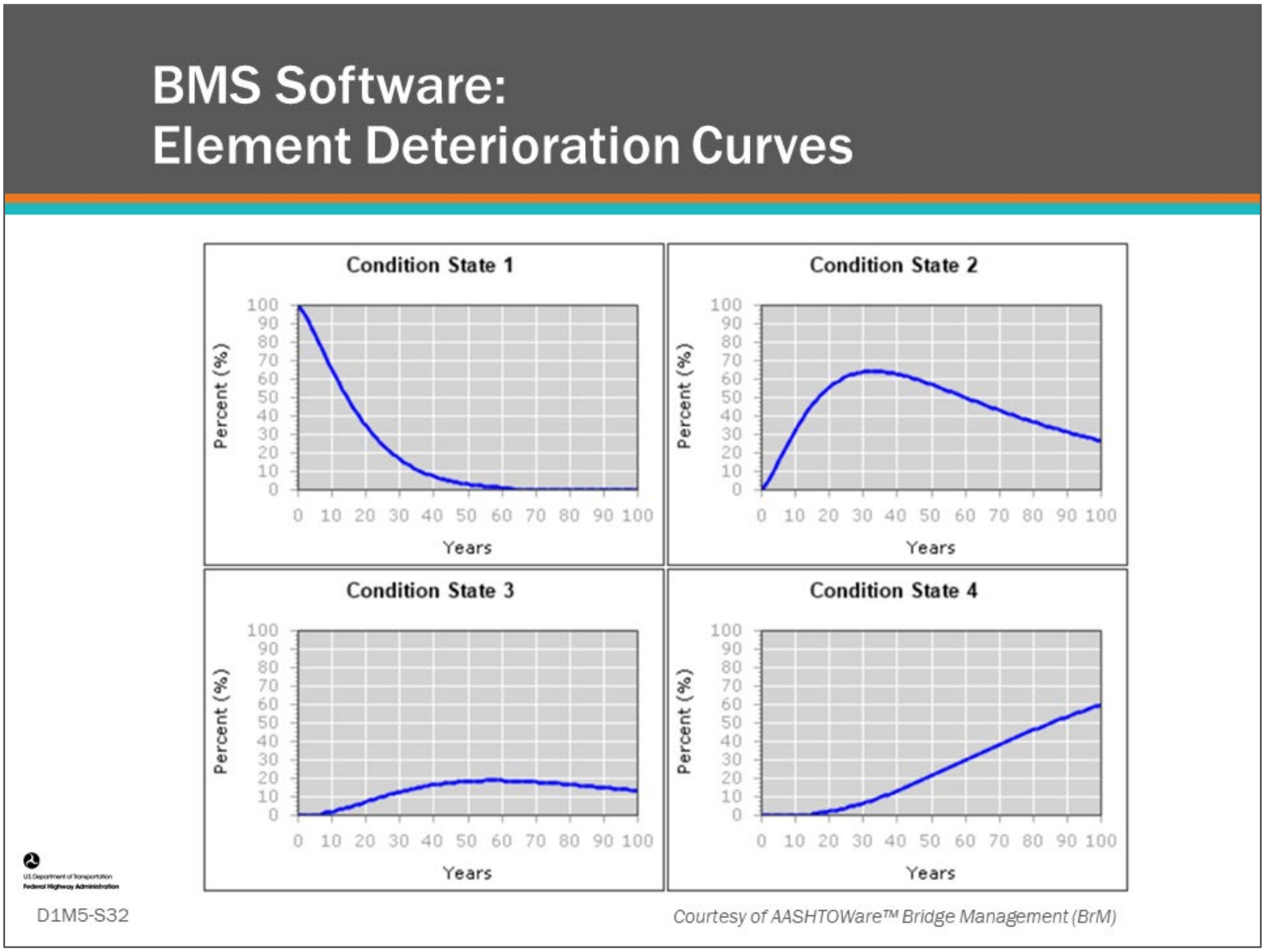
Year	Pct. 1	Pct. 2	Pct. 3	Pct. 4
1	97.86	2.14	0.00	0.00
2	94.82	5.14	0.03	0.00
3	91.39	8.49	0.12	0.00
4	87.73	12.01	0.25	0.01
5	83.95	15.59	0.44	0.02
6	80.12	19.17	0.67	0.04
7	76.27	22.71	0.95	0.07
8	72.45	26.15	1.28	0.11
9	68.69	29.49	1.65	0.17
10	65.01	32.69	2.06	0.25

Key Message

For bridge elements, deterioration modeling parameters are input as “median years” in each of the condition states shown. These are converted to transition probabilities which are used to move that percentage of quantity to the next lower condition state each year. AASHTOWare™ BrM also allows for use of a “shaping parameter” to be input that effects only Condition State 1.

The shaping factor is a parameter of the Weibull cumulative distribution function, which determines the initial slowing effect of deterioration. If the shaping parameter is set to 1.0, then the CS1 deterioration curve is identical to the Markov method. Values greater than one will produce a slowing effect to deterioration initially but will result in greater deterioration later in the life of the element.

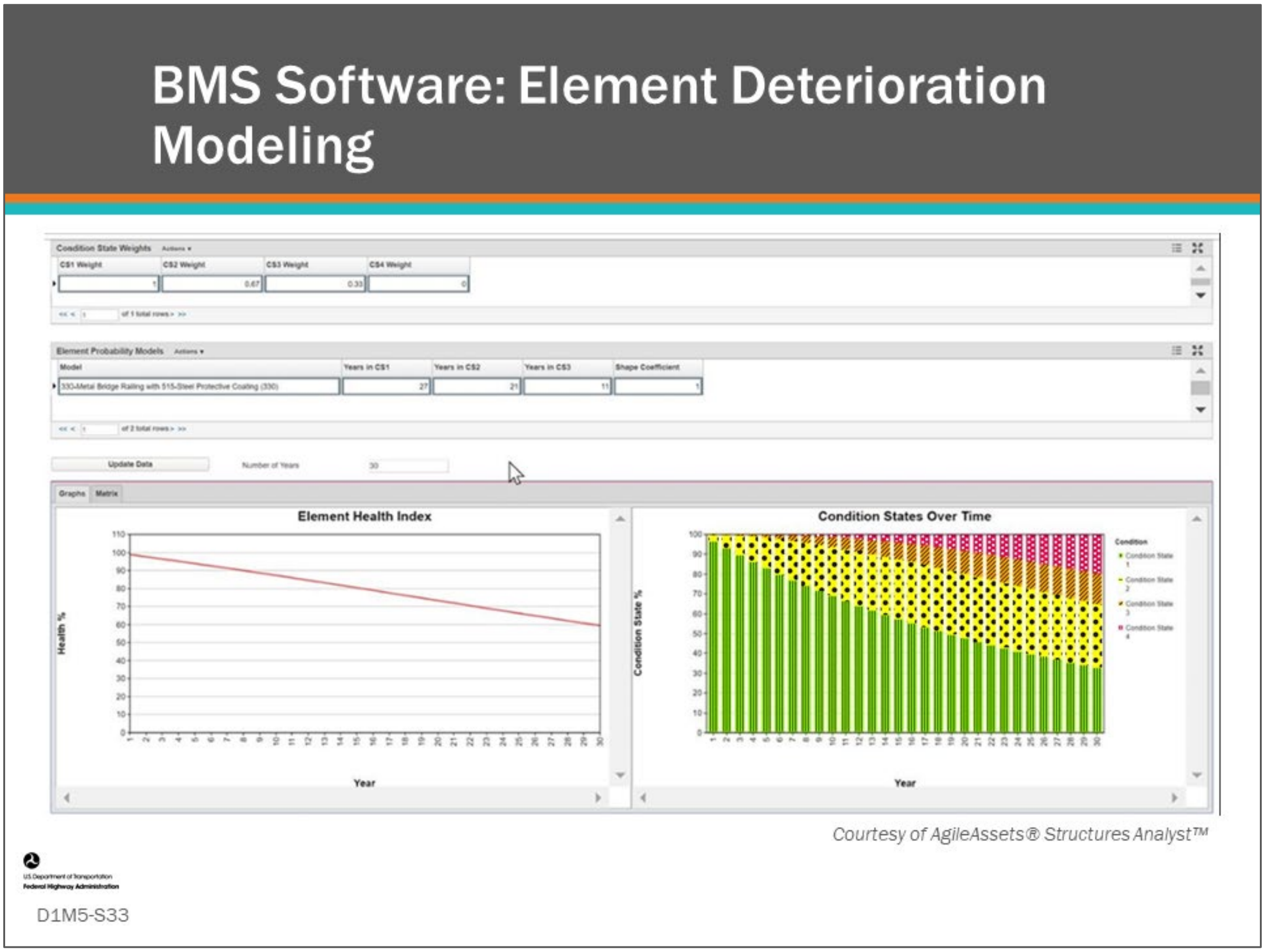
D1M5-Slide 32



Key Message

Deterioration curves are shown for each condition state. These are very important because agency rules set "triggers" when action is to be taken on an element based upon the percentage of the quantity in a given condition state.

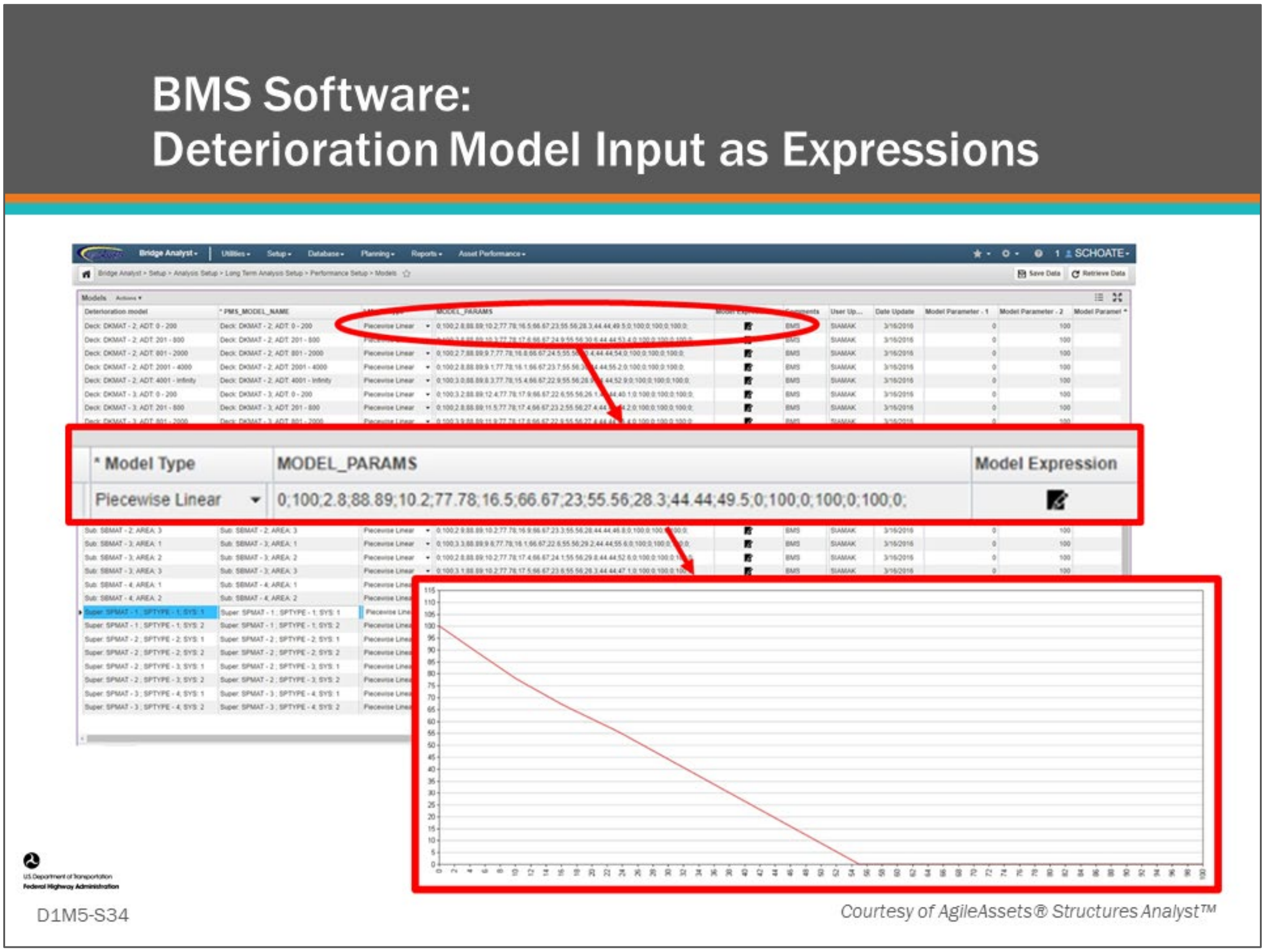
D1M5-Slide 33



Key Message

For element level modeling, AgileAssets® Structures Analyst™ allows input of element deterioration parameters as Years in CS1, CS2, and CS3, and a shape parameter. This is similar to BrM. The screen shown in this slide also provides input for Condition State Weights for CS1, CS2, CS3, and CS4. These are used to calculate a health index. In the element Probability Models area, for a selected element, after years in CS1, CS2, CS3, and a shape factor are entered, the software will calculate and show in a stacked area chart percent quantity in condition state over time for CS1, CS2, CS3, and CS4. The resulting Health Index over time is shown in the lower left of the screen.

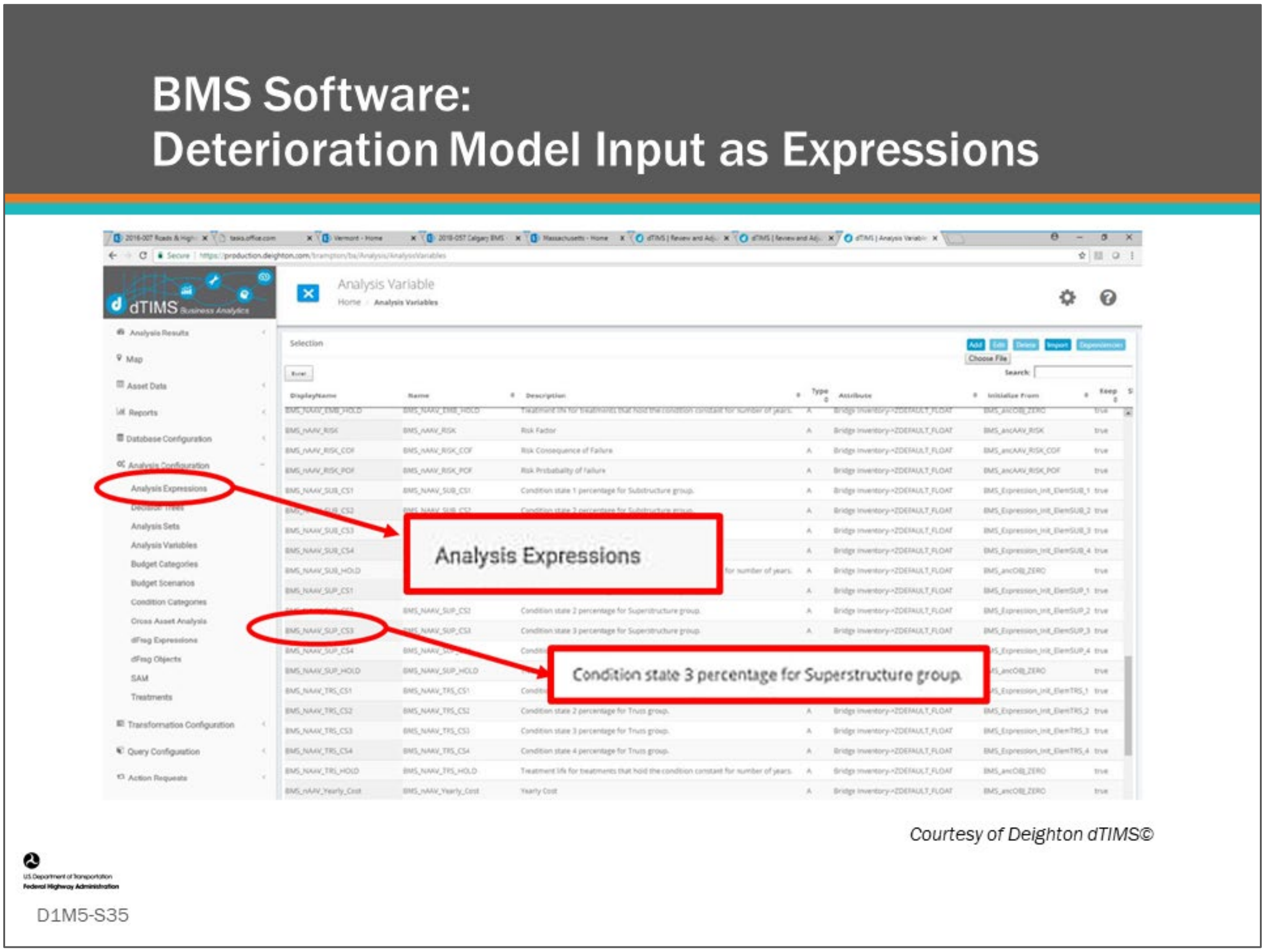
D1M5-Slide 34



Key Message

AgileAssets® Structures Analyst™ models component deterioration using a model describing the deterioration curve input into the software as an expression. This can be performed for all bridge families and influencing variables. A great deal of flexibility is given as to what type of expression is used to describe the deterioration curve.

D1M5-Slide 35

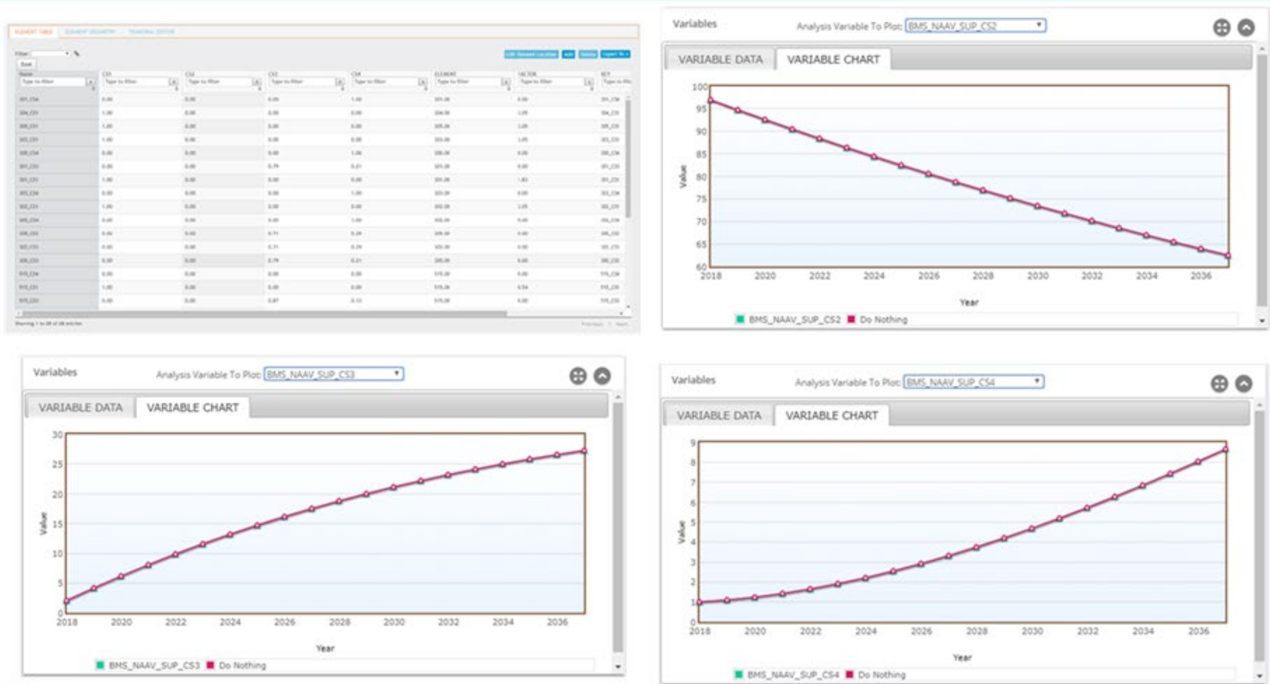


Key Message

The Deighton dTIMS© software models deterioration curves for components and elements using what are termed “analysis expressions.” Because Deighton dTIMS© is a software platform that can model deterioration for all types of assets, the user is not constrained in modeling the deterioration of either component NBI GCR values, or element-level condition states.

D1M5-Slide 36

BMS Software: Element Deterioration Models



Courtesy of Deighton dTIMS©

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D1M5-S36

Key Message

Deighton dTIMS© provides a built-in Markov function to create mathematical expressions for Markov transitions for bridge elements.

D1M5-Slide 37

Key Message

This concludes Module 5: Deterioration models.

D1M5-Slide 38

Slide #	Image Description	Source Information
5	A column chart is shown for a forecast of condition distribution of Utah bridges.	UDOT. Utah DOT 2015–2040 *Long-Range Transportation Plan Transportation in Utah's Rural Areas*, 2015.
6	A chart is shown for NBI condition rating for steel bridges and prestressed concrete superstructures.	Morcous, G. *Developing Deterioration Models for Nebraska Bridges*. Page 44. University of Nebraska-Lincoln.
7	A schematic chart is shown for bridge condition versus time.	FHWA. *Bridge Preservation Guide: Maintaining a Resilient Infrastructure to Preserve Mobility*. Publication No. FHWA-HIF-18-022. Washington, DC, 2018. Page 12.
8	A chart is shown for MDOT Deck Deterioration Trends.	Kelley, R. *A Process for Systematic Review of Bridge Deterioration Rates*. Page 6. Michigan Department of Transportation. March 2016.
10	A chart is shown with NBI value shown on the y axis (0 to 9) and year on the x axis (1992 to 2018).	This Workshop.
11	A chart is shown for Example State Highway Bridges Compare Deterioration Methods.	This Workshop.

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D1M5-S38

D1M5 Figure Source List

D1M5-Slide 39

Slide #	Image Description	Source Information
13	Table demonstrating that the Markov transition probability.	This Workshop.
14	The chart shows an x-y line chart with Percent Element in CS1 on the y axis and Years on the x axis.	This Workshop.
15	A chart is shown titled, "Markov Element Condition Curves. Element 107 Steel Girder / Beam"	This Workshop.
16	Photo showing the entire Golden Gate Bridge in San Francisco, CA.	Adobe Stock.
16	Photo showing the tower, or superstructure, on the Golden Gate Bridge in San Francisco, CA.	Adobe Stock.
16	Photo showing a close-up a few bridge elements on the Golden Gate Bridge in San Francisco, CA.	Adobe Stock.
17	A drawing shows a culvert.	This Workshop.
17	A drawing shows the major components of a bridge including the deck, superstructure, and substructure.	This Workshop.

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D1M5-S39

D1M5 Figure Source List

D1M5-Slide 40

Slide #	Image Description	Source Information
18	A chart is shown for deck deterioration for prestressed concrete girder bridges built during or after 1990 with a concrete overlay.	Nelson, S. *Deterioration Rates of Minnesota Concrete Bridge Decks*. Minnesota Department of Transportation. St. Paul, MN. October 2014. Page 24.
19	Graph showing deterioration model for element percent growth in Condition State 3 with a trigger.	This Workshop.
21	Map showing Indiana's highway administrative districts.	This image was found at https://bit.ly/2Dw0isW and is being used under license terms available at https://bit.ly/1kvyKWi.
22	A graphic showing a colored map of Oregon with climatic regions of the state	Koppen types calculated from data from PRISM Climate Group, Oregon State University.
24	Right upper photo shows a continuous span bridge.	Adobe Stock.
24	Left photo shows failed bridge deck joint.	VDOT. Joint Maintenance and Best Practices in Deck Joint Replacement. 2013 Virginia Concrete Conference.
24	Right lower photo shows beam end damage below joint.	VDOT. *Joint Maintenance and Best Practices in Deck Joint Replacement*. 2013 Virginia Concrete Conference.
25	Photo of bridge pier showing spalling of the concrete and corrosion of the steel rebar.	Adobe Stock.

D1M5-S40

D1M5 Figure Source List

D1M5-Slide 41

Slide #	Image Description	Source Information
26	Photo showing crew placing epoxy overlay on bridge deck.	FHWA.
26	Photo showing painted steel beam and bearing.	FHWA.
28	Photo showing failed bridge deck expansion joint.	VDOT. *Joint Maintenance and Best Practices in Deck Joint Replacement*. 2013 Virginia Concrete Conference.
28	Photo showing badly corroded beam end.	VDOT. *Joint Maintenance and Best Practices in Deck Joint Replacement*. 2013 Virginia Concrete Conference.
30	A screenshot of the AASHTOWare™ Bridge Management software screen showing major components (deck, superstructure, substructure, or culvert), component specification, and component deterioration modeling	AASHTOWare™ Bridge Management (BrM) software.
31	A screenshot shows deterioration forecasts with percent element in CS1, CS2, CS3, and CS4 for one to ten years.	AASHTOWare™ Bridge Management (BrM) software.
32	A screenshot is shown of the AASHTOWare Bridge Management software showing four charts. One each for deterioration curves for CS1, CS2, CS3, and CS4.	AASHTOWare™ Bridge Management (BrM) software.

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D1M5-S41

D1M5 Figure Source List

D1M5-Slide 42

Slide #	Image Description	Source Information
33	A screenshot of the AgileAssets Structures Analyst™ software is shown.	AgileAssets® Structures Analyst™ software.
34	A screenshot from AgileAssets Structure Analyst showing deterioration model entry as expressions is shown.	AgileAssets® Structures Analyst™ software.
35	A screenshot of the Deighton dTIMS© Analysis Configuration > Analysis Variables screen with a magnification box showing the Analysis Expressions option and Condition State 3 is shown.	Deighton dTIMS© software.
36	A screenshot of the Deighton dTIMS© Element Table and element deterioration charts is shown.	Deighton dTIMS© software.

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D1M5-S42

D1M5 Figure Source List

Module Title: D1M6 – Modeling Actions, Triggers, Costs and Effects

Module Time: 45 minutes

Module Summary

Having discussed modeling the deterioration of condition and performance measures in the previous module, we will now see how to model the effects that MR&R actions have on improving bridge elements and components and the effect preservation has on slowing deterioration.

MR&R Actions have several general properties that need to be defined in a BMS, including the following:

- Triggers – when and under what conditions should MR&R actions be taken
- Costs – how are costs calculated
- Effects – what beneficial effects do MR&R actions have, specifically on performance measures

The most basic asset management program takes condition data, identifies a work action that could address any deficiencies in condition and then calculates the benefits and cost of the action based on the quantity to be repaired.

Cost Models are developed for these actions and may include direct costs (those costs that are determined by a quantity of an element/component in a given condition state) and indirect costs (those costs that are not directly dependent upon an element or component condition state; e.g., maintaining traffic and mobilization).

The benefit, or effectiveness, of the action needs to be defined in the BMS software and later verified by inspection. Benefit can be measured by showing increase in element or component condition, slowing deterioration, or improvement to one or more performance measures.

Expected Outcome

Participants will be able to define types of actions, triggers to initiate these actions, how to calculate cost, and show benefit for various actions.

Resource List

Slide	Reference Information
4	AASHTO. *AASHTOWare™ Bridge Management (BrM) User's Manual*, version 5.2.3, Washington, DC, 2016.
8-10	FHWA. *Bridge Preservation Guide: Maintaining a Resilient Infrastructure to Preserve Mobility*. Publication No. FHWA-HIF-18-022. Washington, DC, 2018.
11	FHWA. *Hydraulic Engineering Circular No. 18. Evaluating Scour at Bridges.* Publication No. FHWA-HIF-12-003. Fifth Edition, Washington, DC, 2012.
23,26	MDOT. Cost Estimating Worksheet.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D1M6-Slide 1

Key Message

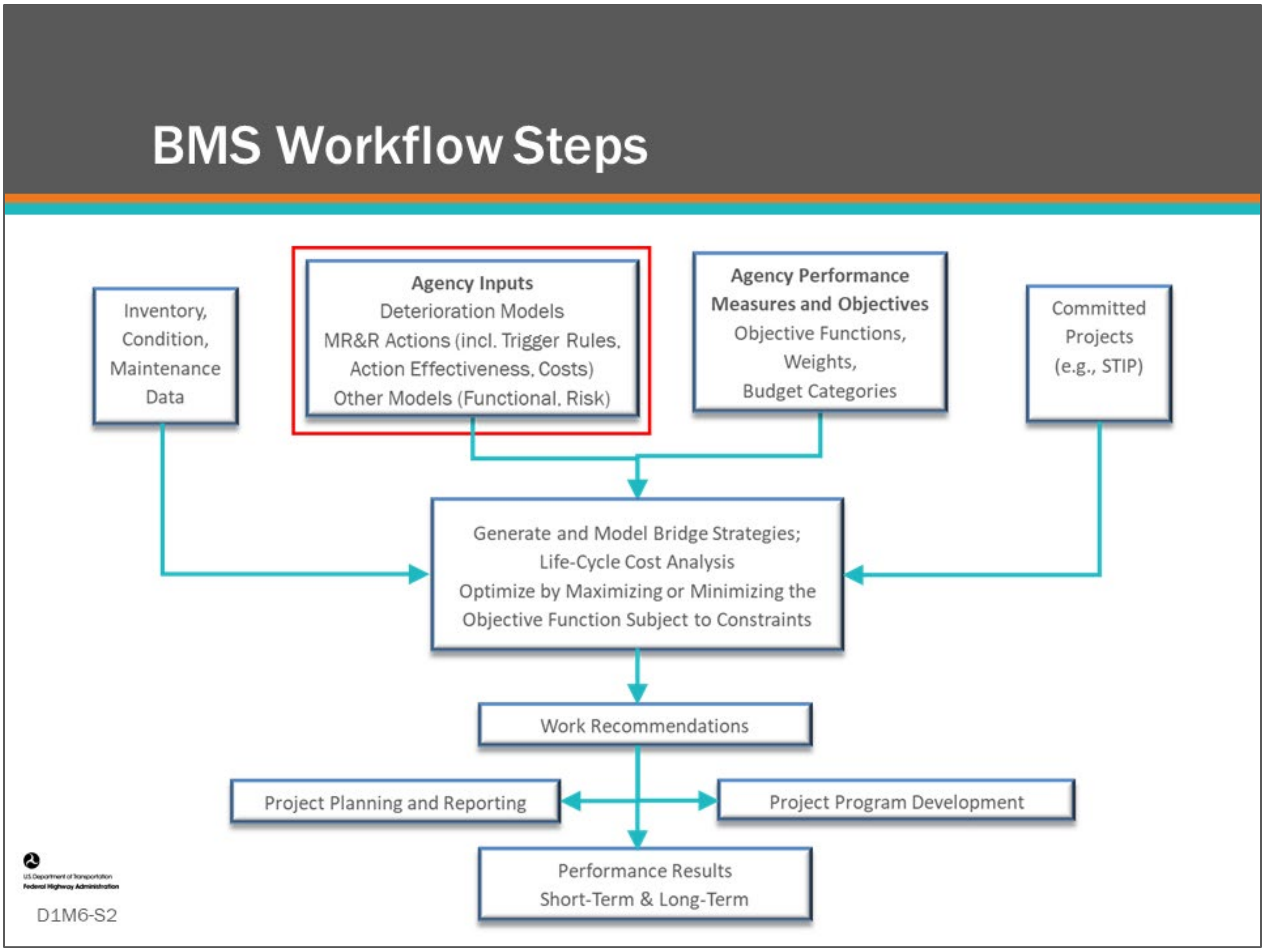
The most basic asset management program takes condition data for the asset inventory, identifies potential work actions that can address condition deficiencies, then calculates the benefits and costs of each action based on the action types and quantity. Having discussed modeling the deterioration of condition and performance measures in the previous modules, we will now see:

- How to model the effects that preservation, rehabilitation, and replacement actions have on improving bridge elements and components
- The effect preservation has on slowing deterioration

Disclaimer

FHWA does not promote or endorse patented and proprietary products. Bridge management software is largely proprietary. Workshop content pertaining to proprietary software is included only to illustrate how bridge management system concepts and analyses are applied in practice. The included content shall not be construed as promotion or endorsement of specific software.

D1M6-Slide 2



Key Message

Common workflow steps and features are shown on the slide. In this first section of this module, we will review Agency Inputs.

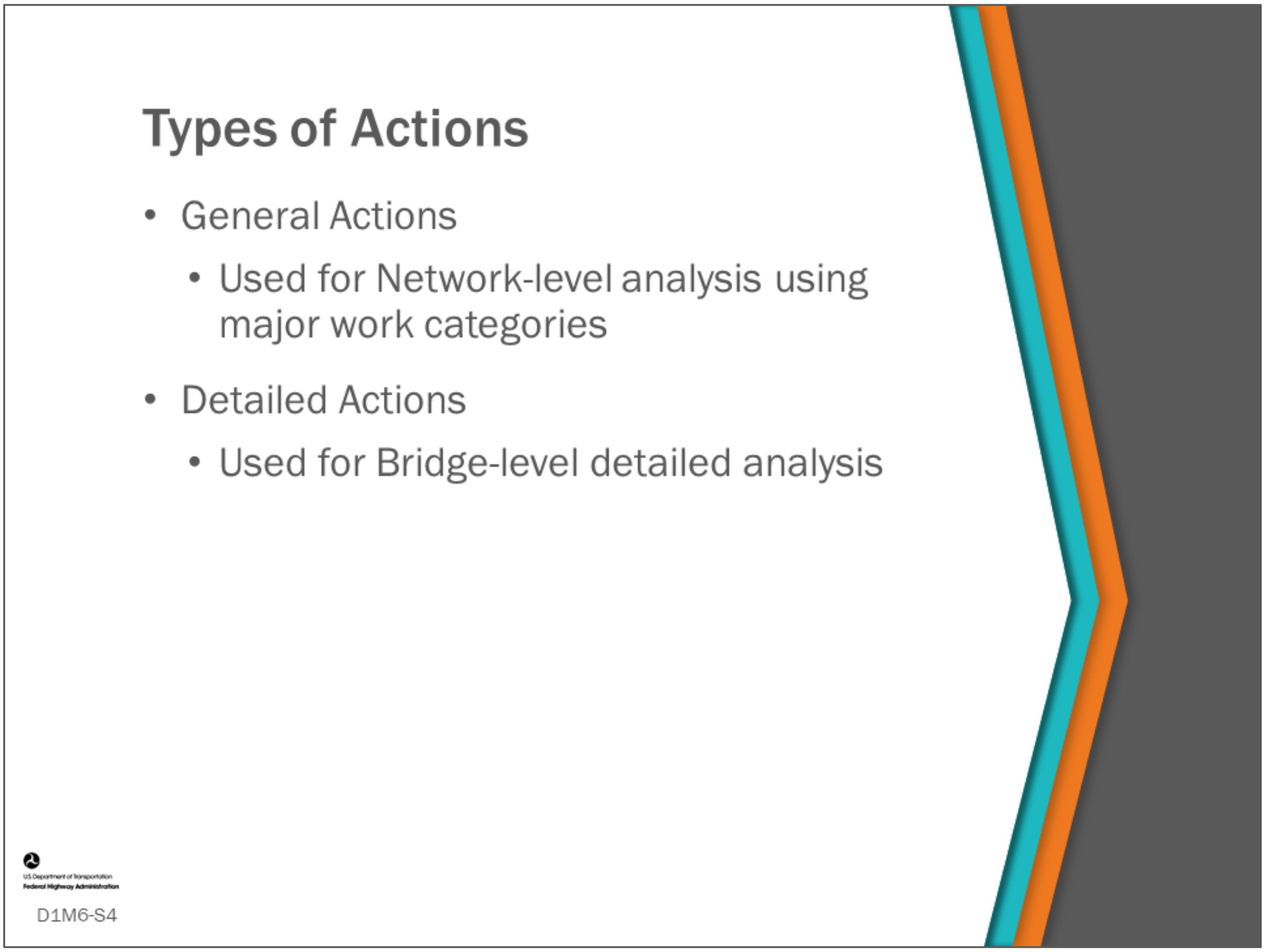
D1M6-Slide 3

Key Message

Topics covered in this module include:

- Types of actions
- Action trigger rules
- Action costs
- Action effects

D1M6-Slide 4

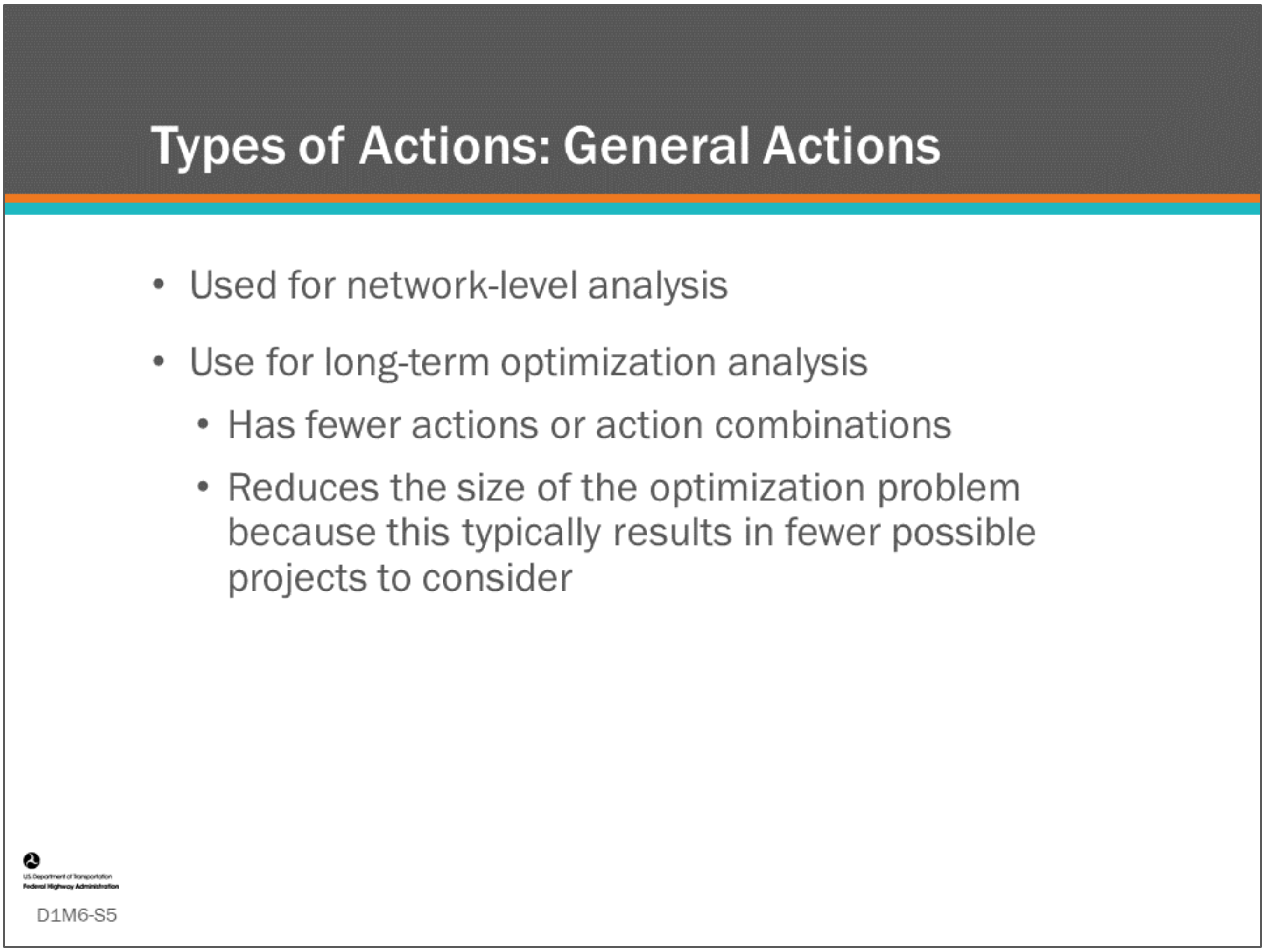


Key Message

- Actions are any activity done to a bridge to improve or preserve the structure.
- Actions can be general such as replace bridge or preserve superstructure, or they can be more detailed such as repair five lineal feet of expansion joint.
- We will discuss two approaches to analysis that are often included in bridge management literature.
  - "Top-Down" which begins with network goals and objectives and develops high-level strategy to meet these goals and objectives. A top-down approach can use bridge-level, component-level, or element-level actions
  - "Bottom-Up" approach finds the optimal solution for each bridge individually, which then adds up to a network program. A bottom-up approach is best done with element-level actions.

Network-level analysis can be associated with long-term analysis by some BMS software. A more detailed component or element analysis can be associated with a short-term analysis for the purpose of project and program development or can be associated with in-depth bridge-level analysis.

D1M6-Slide 5



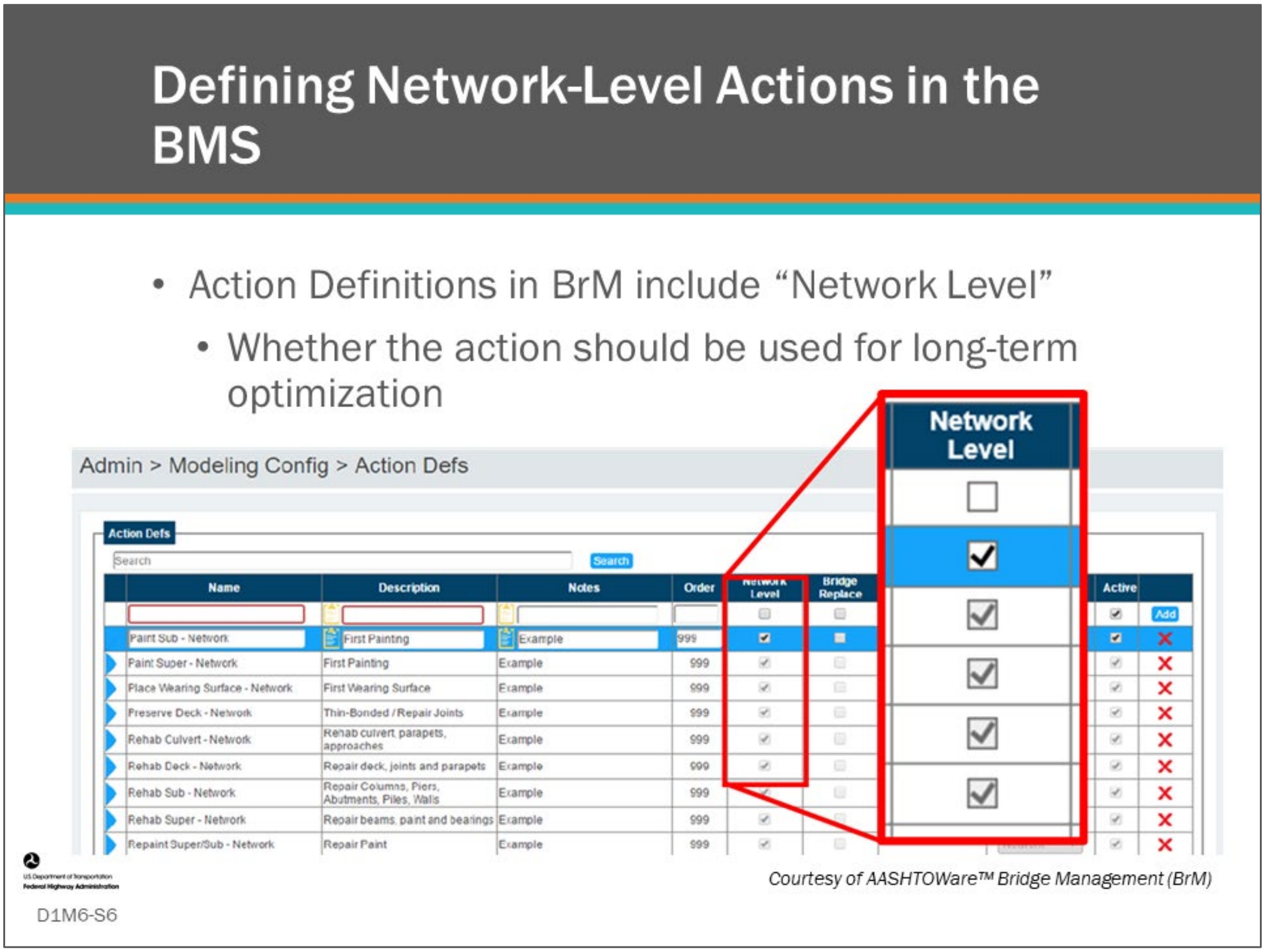
Key Message

General actions are used in network-level analysis for efficiency and full network-level optimization.

- Because this is a very large problem to solve where different strategies over time are competing for the most optimum network strategy, these actions are typically not extremely detailed and are typically defined for the bridge as a whole.
- For example, instead of detailing if parapet work should or should not be included with the deck rehab, these actions are more intended to answer questions like if this should be a deck rehab or a replacement.

For network analysis, the trick is to define decision rules for the actions to limit the number of possible actions for a bridge in any one year.

D1M6-Slide 6

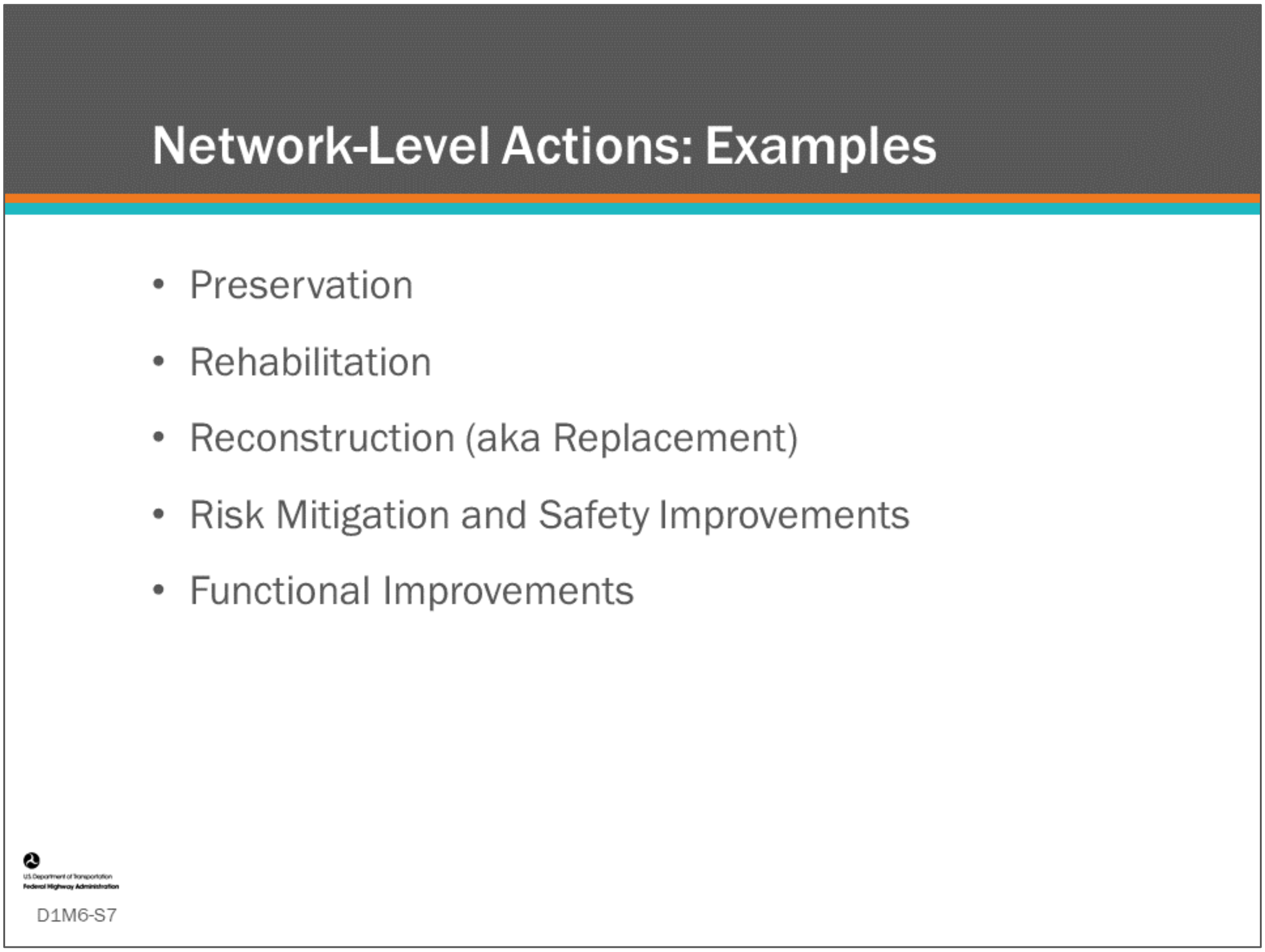


Key Message

Some BMS software allow the user to differentiate network-level actions that are included in long-term optimization.

- Note, we will learn more about optimization in Module 11.
- This slide shows a checkbox in the AASHTOWare™ Bridge Management (BrM) software used to identify an action as a network-level action.

D1M6-Slide 7

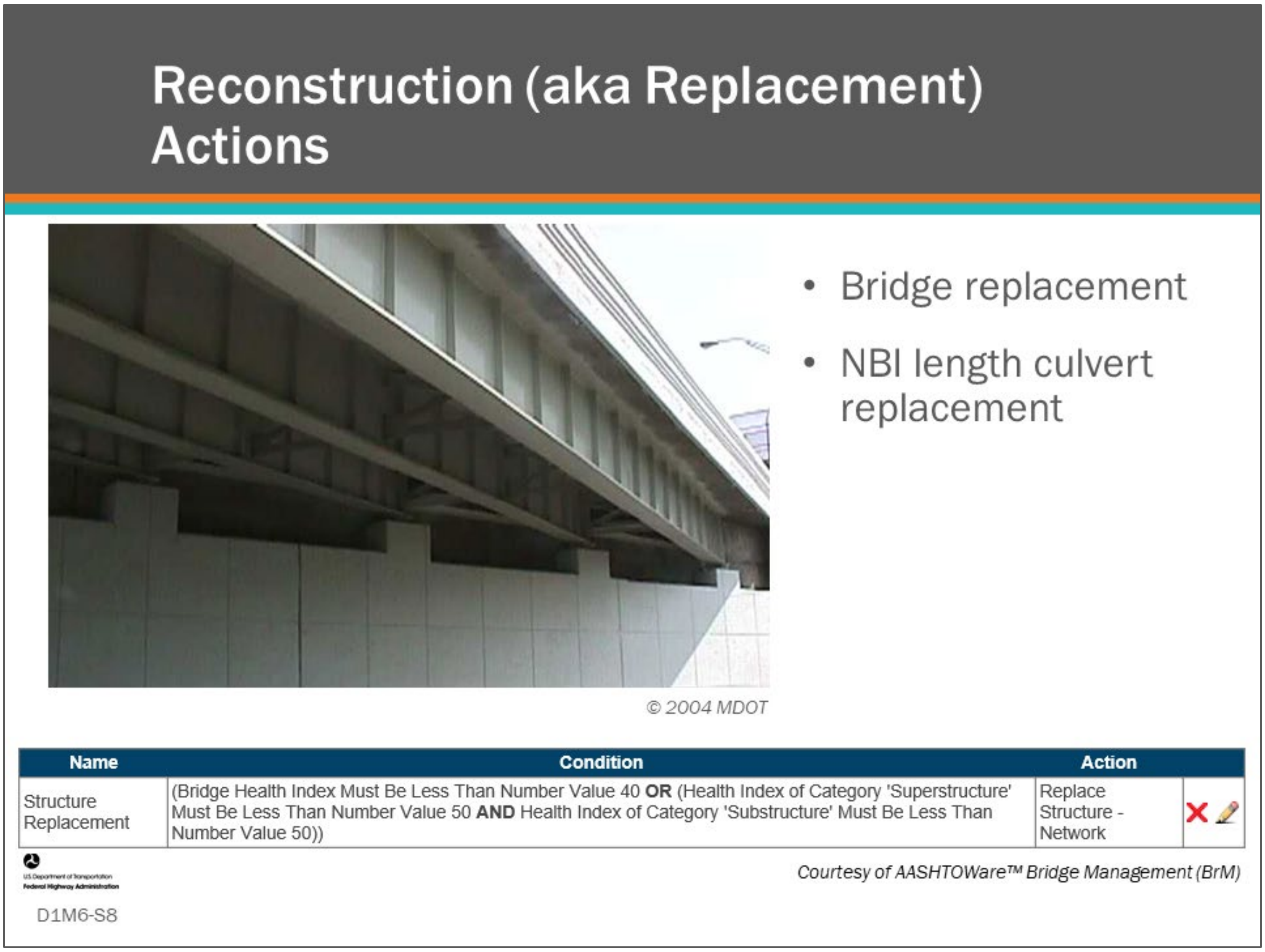


Key Message

Network-level actions made in your BMS are generic actions as shown on the slide.

- Network-level actions typically relate to a strategy or budget defined in the BMS once your Agency has set objectives, performance measures, and trends for those measures.
- Network-level actions are most often described in broad terms and apply to the whole bridge, major components, or major elements.
- The bridge manager will define these actions in more detail when planning and scoping the project.
- The network-level model provides a decision-making tool that optimizes bridge actions for multiple performance criteria, such as condition, safety, and functional improvements as shown on the slide.

D1M6-Slide 8



Key Message

As per FHWA's *Bridge Preservation Guide*, reconstruction actions include replacement of an existing bridge with a new facility constructed in the same general traffic corridor.

- A bridge or culvert is replaced when it reaches such a poor condition state that it no longer can be rehabilitated at a competitive cost, or no longer meets the functional needs for the roadway it carries.
- The replacement structure must meet the current geometric, construction, and structural standards required for the types and volume of projected traffic on the facility over its design life.
- Reconstruction includes a nominal amount of approach work sufficient to connect the new facility to the existing roadway or to return the grade line to an attainable touchdown point.
- In a BMS, a simple network action for replace bridge could be as shown on the slide; replace bridge when the bridge health index is less than 40 or when the bridge health index is less than 50 and the substructure health index is less than 50.

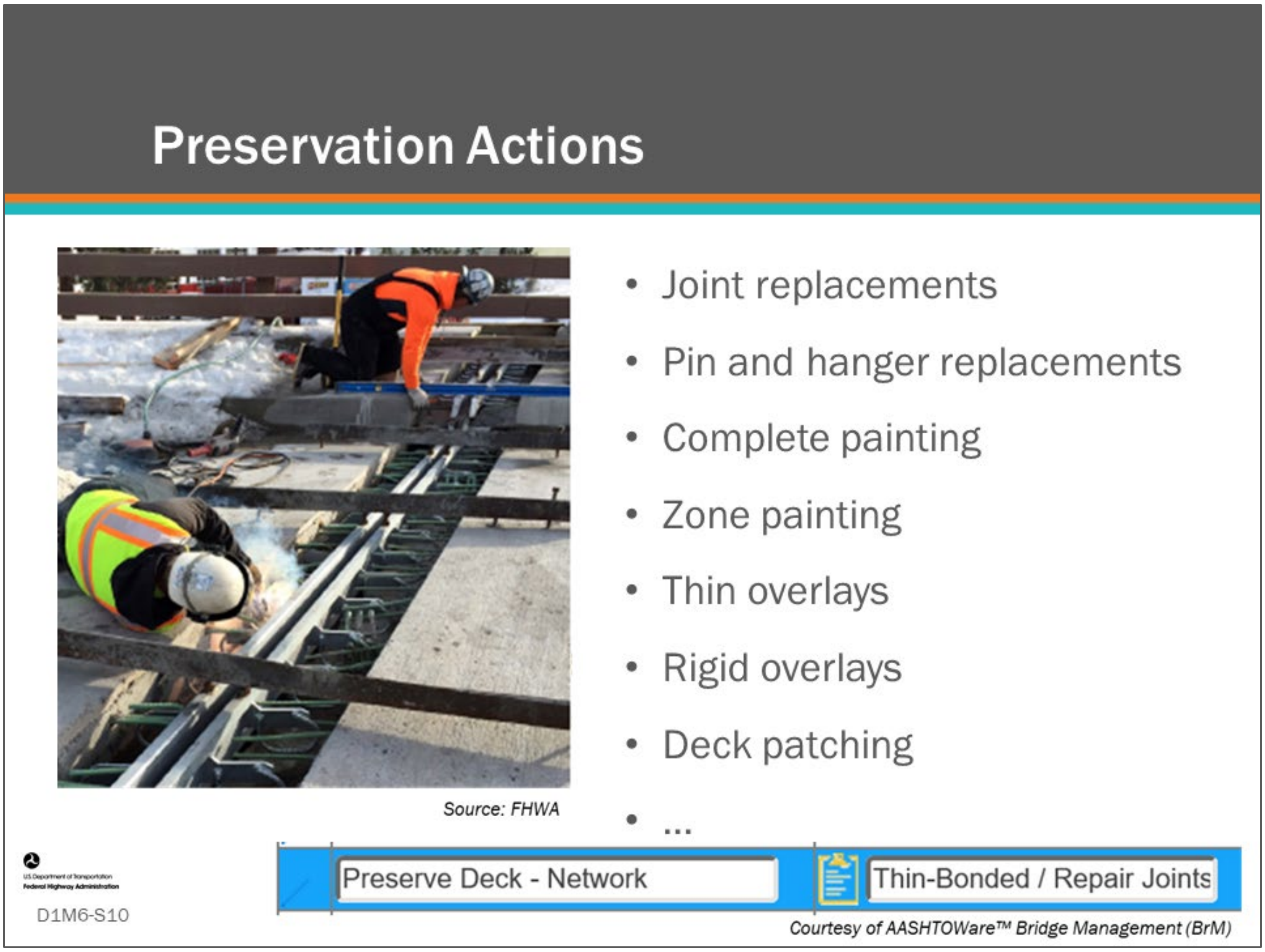
D1M6-Slide 9

Key Message

Rehabilitation involves major work required to restore the structural integrity of a bridge, as well as work necessary to correct major safety defects.

- Bridge rehabilitation actions provide complete or nearly complete restoration of bridge elements or components. Rehabilitation work can be done on one or multiple elements and/or components of a structure.
- A BMS will allow you to enter a threshold when bridge major components need to be rehabilitated or replaced, such as replace bridge deck when the General Condition Rating (GCR) for deck is rated 4 (poor) or below.
- The blue outlined text boxes at the bottom of the slide show the AASHTOWare™ Bridge Management (BrM) input for the network level action; Rehab Deck – Network. The second text box provides a description of the included work which is useful for clarity when assigning action costs and effects which will be discussed later.

D1M6-Slide 10



Key Message

Condition-based preservation actions are performed on bridge components or elements in response to known defects. Preservation improves the condition of that portion of the element, but it may or may not result in an increase in the component condition rating. Some examples of preservation actions are shown on this slide.

- A bridge preservation network-level action could be as simple as “preserve bridge” when one or more of the major components are rated in NBI GCR 5 or 6 (fair condition) and none of the major components are poor.
- Elements, however, allow the user to provide much more detailed actions, for example, a bridge preservation action could be described as; replace 82 lineal feet of strip seal expansion joint that is in Condition State 3, patch 248 square feet of reinforced concrete bridge deck in CS3 and CS4, and apply epoxy overlay to 1,550 square feet of bridge deck after the deck is patched.
- BMS software provides many tools to organize and categorize these actions that can be taken.
- The blue outlined text boxes at the bottom of the slide show the AASHTOWare™ Bridge Management (BrM) input for the network level action; Preserve Deck – Network. The second text box provides a description of the included work which is useful for clarity when assigning action costs and effects which will be discussed later.

D1M6-Slide 11

Key Message

Risk mitigation actions are those actions that improve one or more inventory items that increase the resilience of the bridge making it less susceptible to damage during extreme events.

- Examples include those listed on the slide.
- Objectives and performance measures can be set for these types of actions, and network level actions can be taken to make progress towards these objectives.

D1M6-Slide 12

Functional Improvement Actions

- Bridge widening and adding lanes
- Improve horizontal and vertical clearances
- Strengthening

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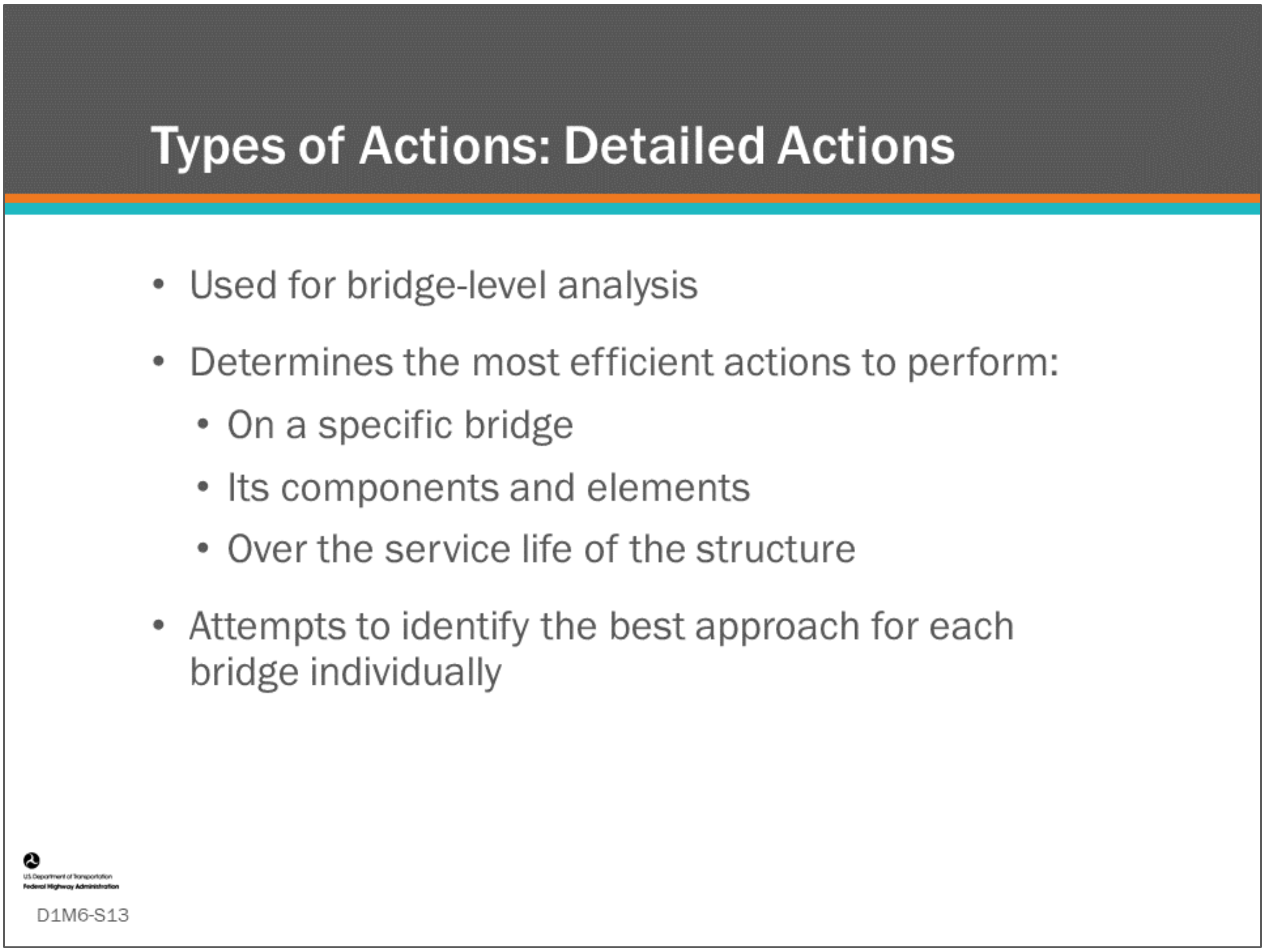
D1M6-S12

Key Message

Functional improvements bring a bridge up to modern standards and enhances the ability of the bridge to carry traffic over and under the structure.

- This includes actions such as widening the bridge to make the shoulders safer for disabled vehicles or adding lanes to improve the level of service for the roadway the bridge carries.
- It can include increasing the horizontal and/or vertical clearances for marine, train, or vehicular traffic.
- It can include strengthening to increase load capacity.
- Objectives and performance measures can be set for these type of items, and network-level actions can be taken to make progress towards these objectives.

D1M6-Slide 13

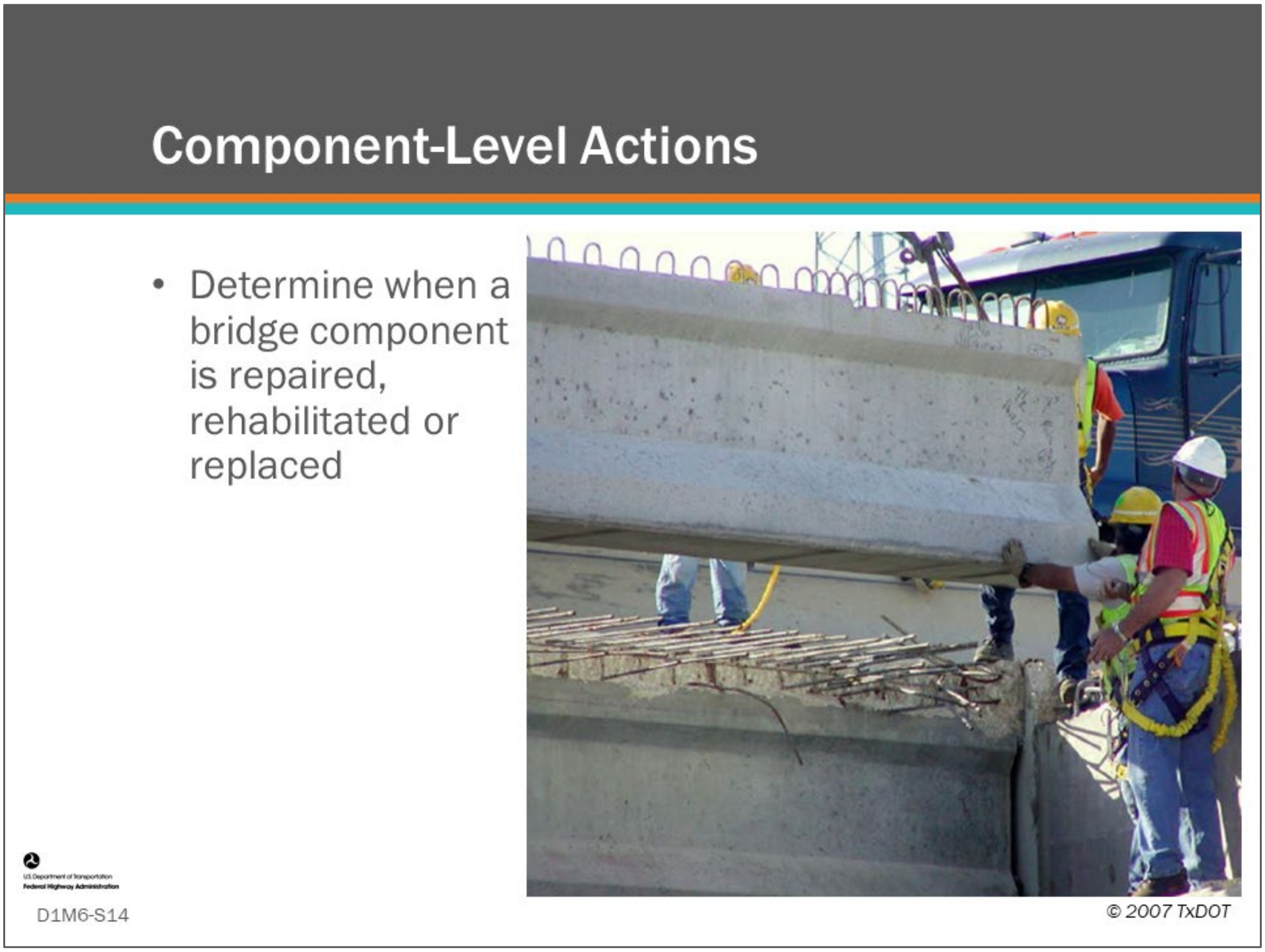


Key Message

A more detailed component or element level action approach looks to find the optimal approach for each bridge individually. A review and comparison of component- and element-level actions determine what are the most efficient activities to do to a bridge over its service life.

- We will learn more about bridge/component/element level actions in Modules 7 and 10.

D1M6-Slide 14

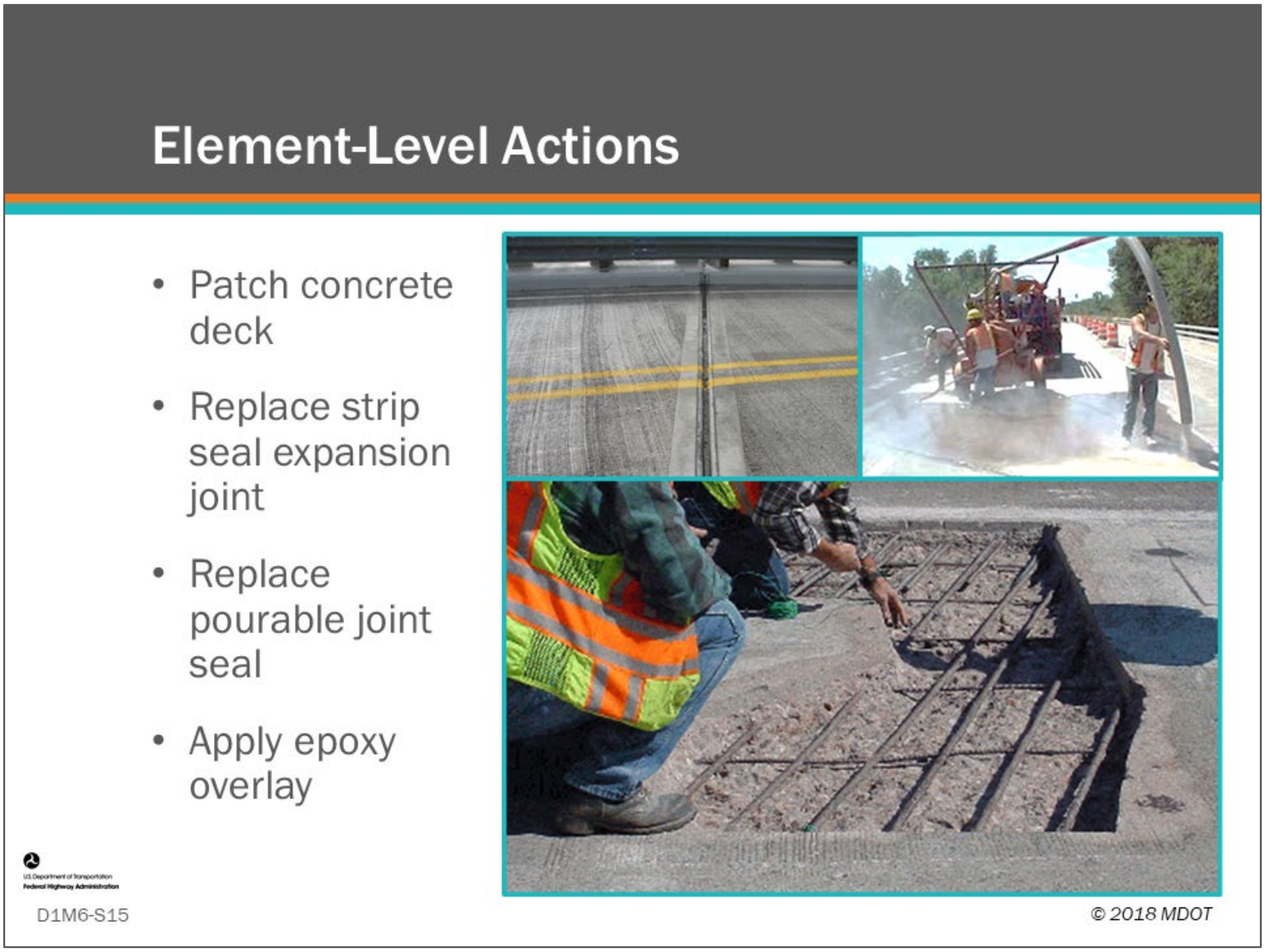


Key Message

Detailed component-level actions also include major component preservation, rehabilitation, and replacement.

- The difference with network-level actions is that bridge- or component-level actions may not necessarily be defined for use in network-level analysis but are used to identify detailed project-level actions to be taken on a bridge based on element-level inspections.
- If there are multiple possible actions (treatments) that meet the Agency rules, determining the value of taking these actions may be based upon cost/benefit comparison of these multiple actions for the specific structure.
- For example, BMS can use the deck General Condition Ratings (GCRs) and associate each GCR with several actions (treatments) which are compared to find the optimal action using life-cycle cost or another performance measure such as area under the condition versus time curve. Modern BMS software are designed to do this more detailed analysis.

D1M6-Slide 15

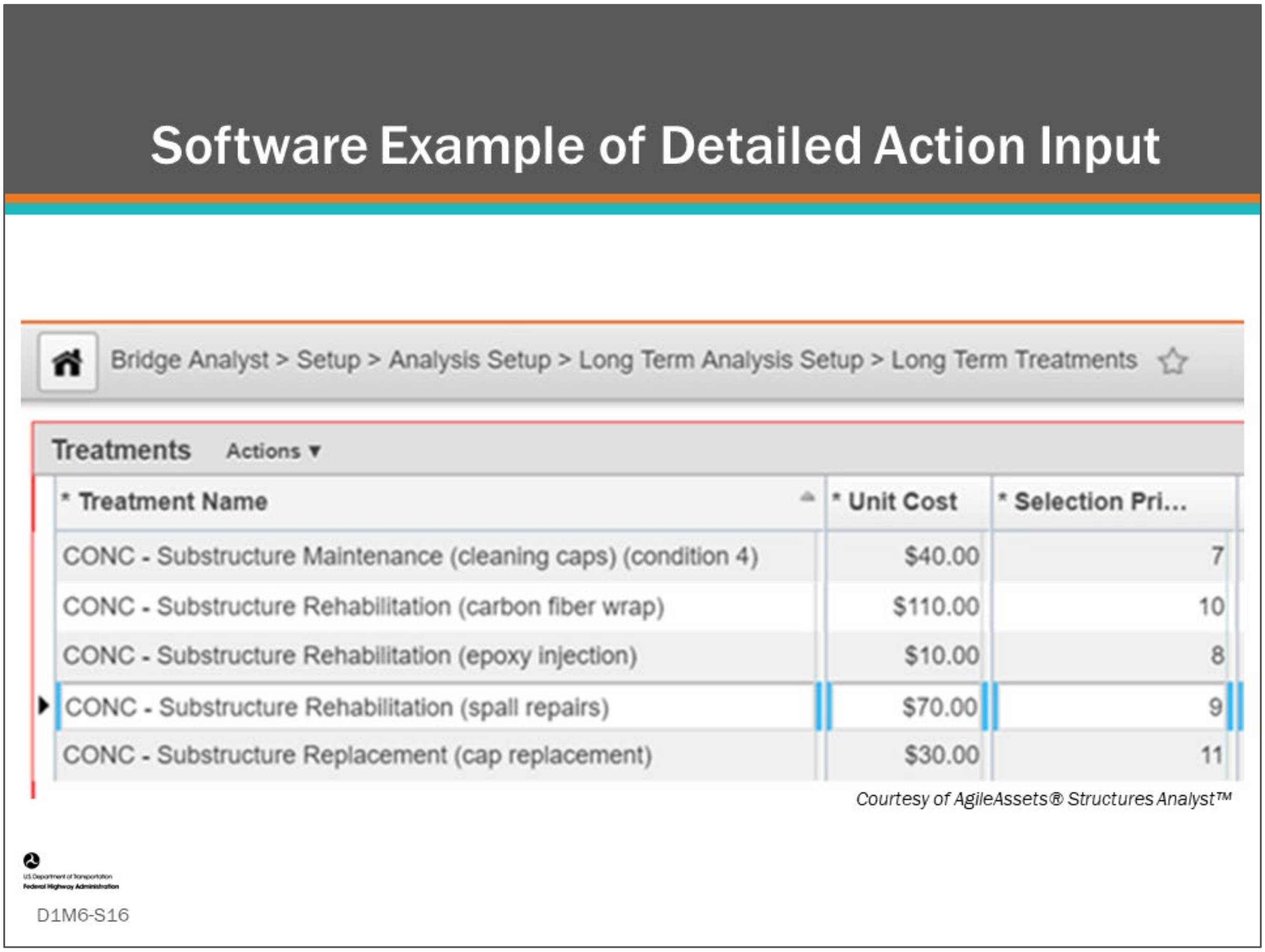


Key Message

When element level data is collected analysis can become much more detailed.

- With elements, instead of recommending “preserve bridge,” the bridge preservation action could be described as; replace 82 lineal feet of strip seal expansion joint, patch 248 square feet of concrete deck, and apply thin overlay to 1,550 square feet of bridge deck.
- The slide shows examples of element level actions that can be taken. There are many more.

D1M6-Slide 16

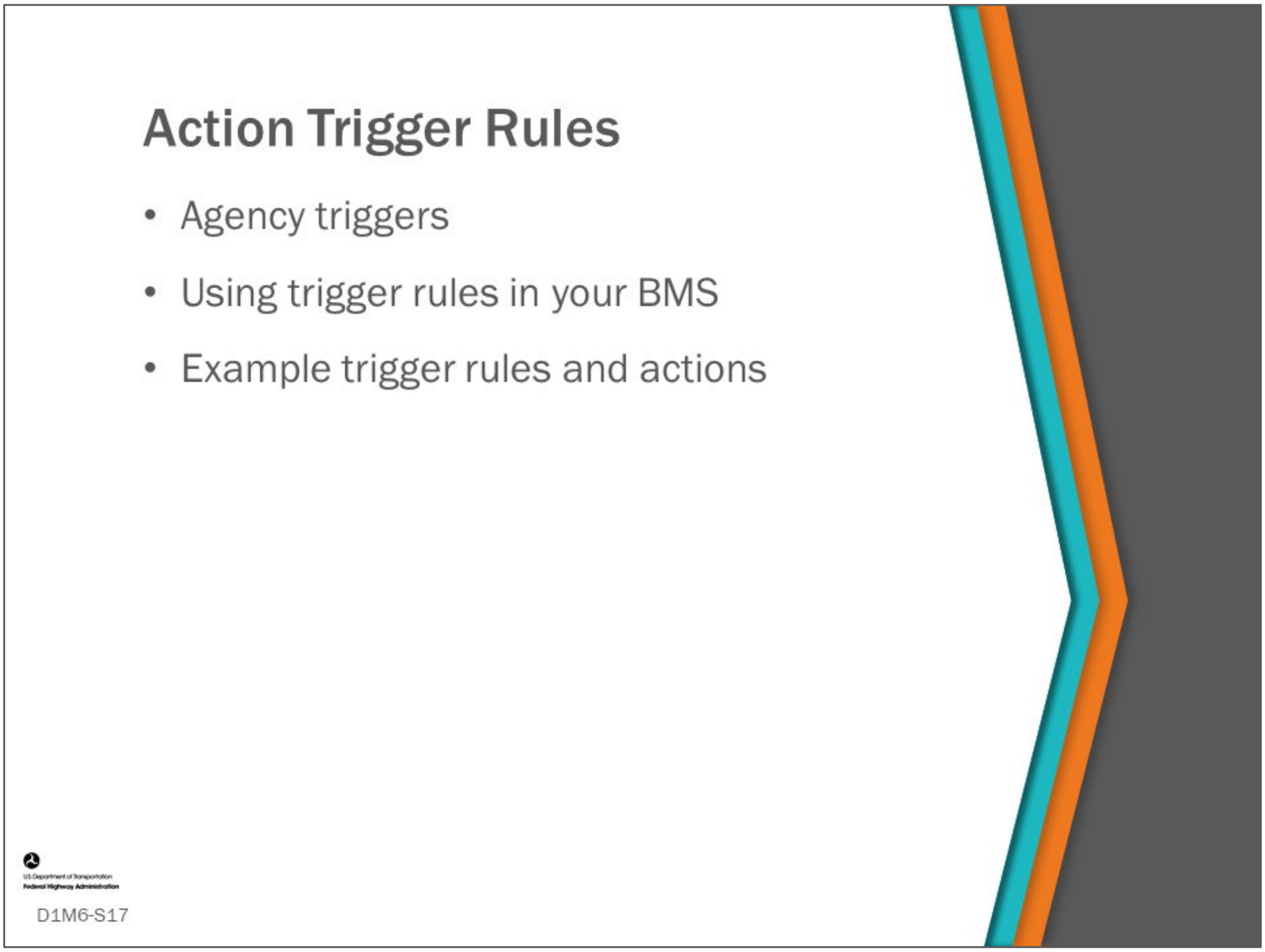


Key Message

BMS software can accommodate detailed bridge-level, component-level, and element-level actions.

- Shown on the slide are specific concrete substructure actions (treatments) from an example Agency.
  - For example, for concrete substructure maintenance there is cleaning “pier” caps.
  - For concrete substructure rehabilitation, there is carbon fiber wrap, epoxy injection, and spall repair actions.
  - For concrete substructure replacement, there is “pier” cap replacement.

D1M6-Slide 17



Key Message

This topic reviews Action Trigger rules in a BMS.

- To reduce the number of possible actions that need to be evaluated, especially when doing optimization encompassing a long analysis period, a BMS typically needs to limit the number of candidate actions compared to all of the Agency entered network-level and detailed actions. Action triggers link the different conditions of a component or element to specific candidate actions.
- Developing action trigger rules gives an Agency a great opportunity to review their business process for managing their bridges.

D1M6-Slide 18

Key Message

Action triggers are instructions to your BMS to consider an action on a bridge, major component, or element. They are often "triggered" when a condition index such as a general condition rating (major component), condition-state (element), or inventory item attribute exceeds a threshold value (or are between 2 values).

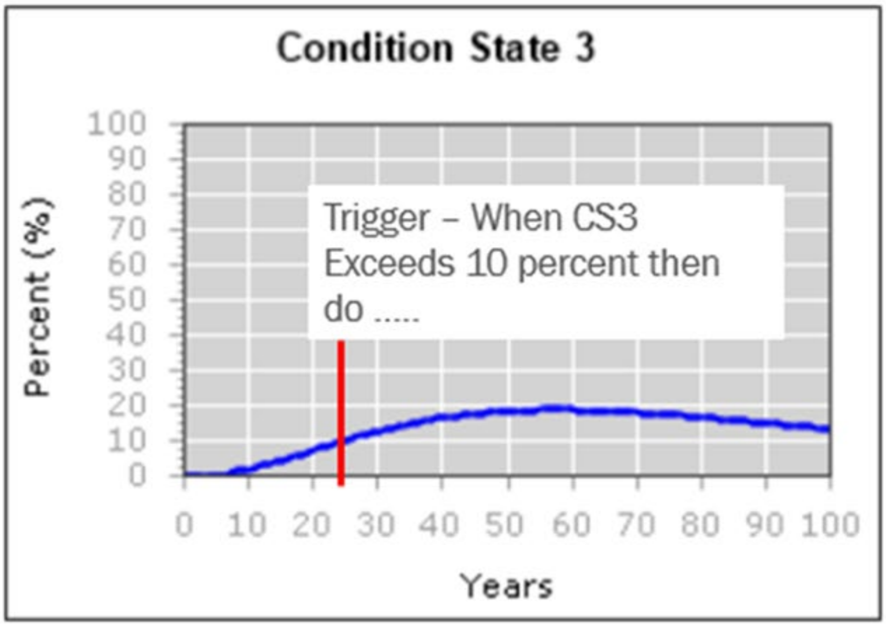
- Trigger rules can include much more than just element level condition. They include bridge/component type, ADT, road over river vs road over road, scour vulnerability rating, detour length, etc.
- Trigger rules can combine multiple indicators, such as: "replace bridge when the superstructure and substructure become poor, the bridge is rated scour critical (NBI Item 113 </= 3), and the bridge carries vehicular traffic exceeding an average daily traffic (ADT) count of over 10,000 vehicles per day."
- In some BMS software, these decisions are defined through decision trees (AgileAssets® Structures Analyst™), decision matrices (AgileAssets® Structures Analyst™), or written out as a formula (AASHTOWare™ Bridge Management (BrM) software and Deighton dTIMS©).

Note, that "rules" does not denote a Federal requirement.

D1M6-Slide 19

Example Element Trigger

- Perform substructure repair when 10% of the pier cap is in CS3



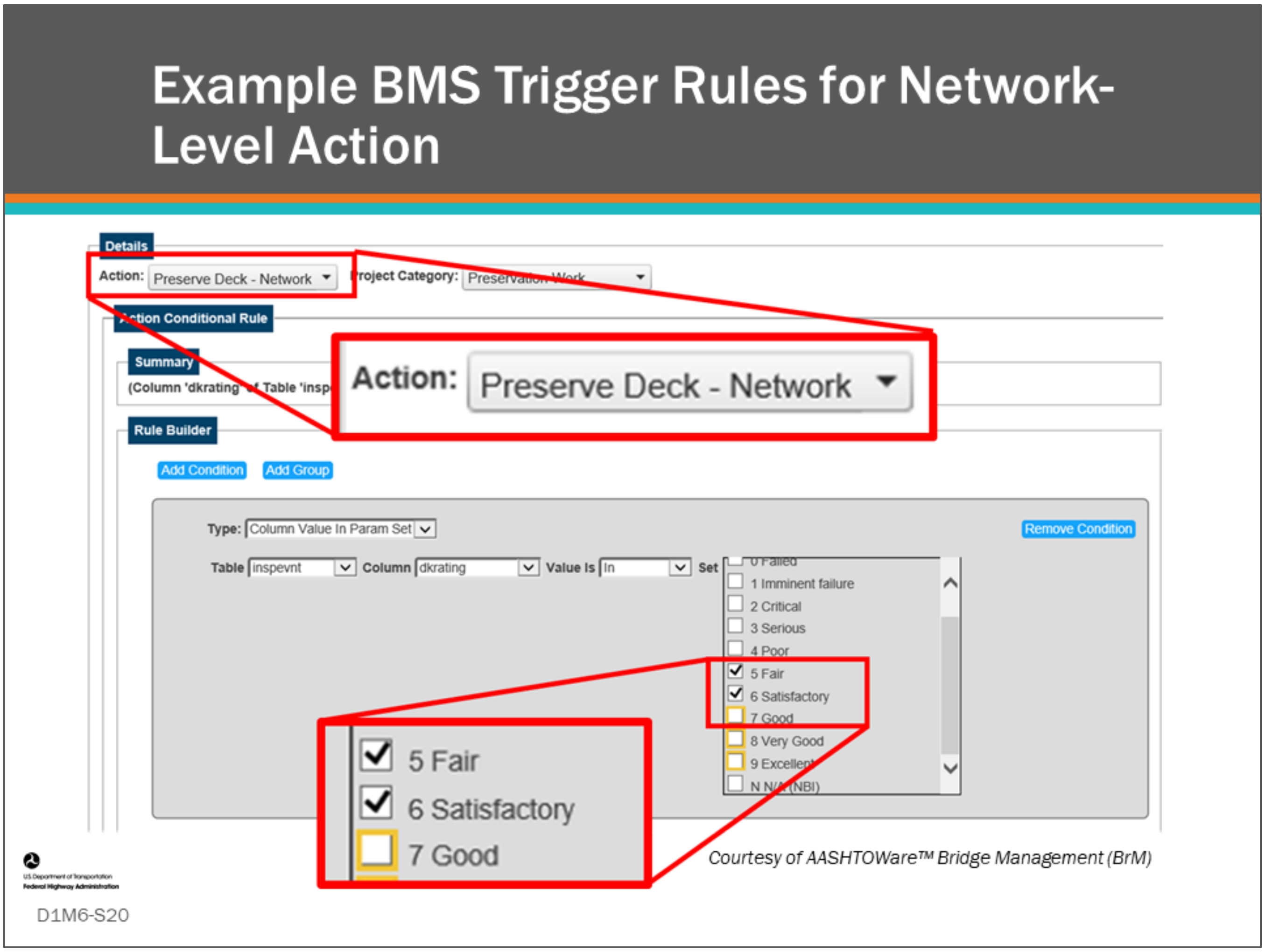
Courtesy of AASHTOWare™ Bridge Management (BrM)

D1M6-S19

Key Message

Element condition state deterioration curves are important to the development of trigger rules. Trigger rules are set in the BMS to take an action when the quantity or percent of element reaches a certain condition state.

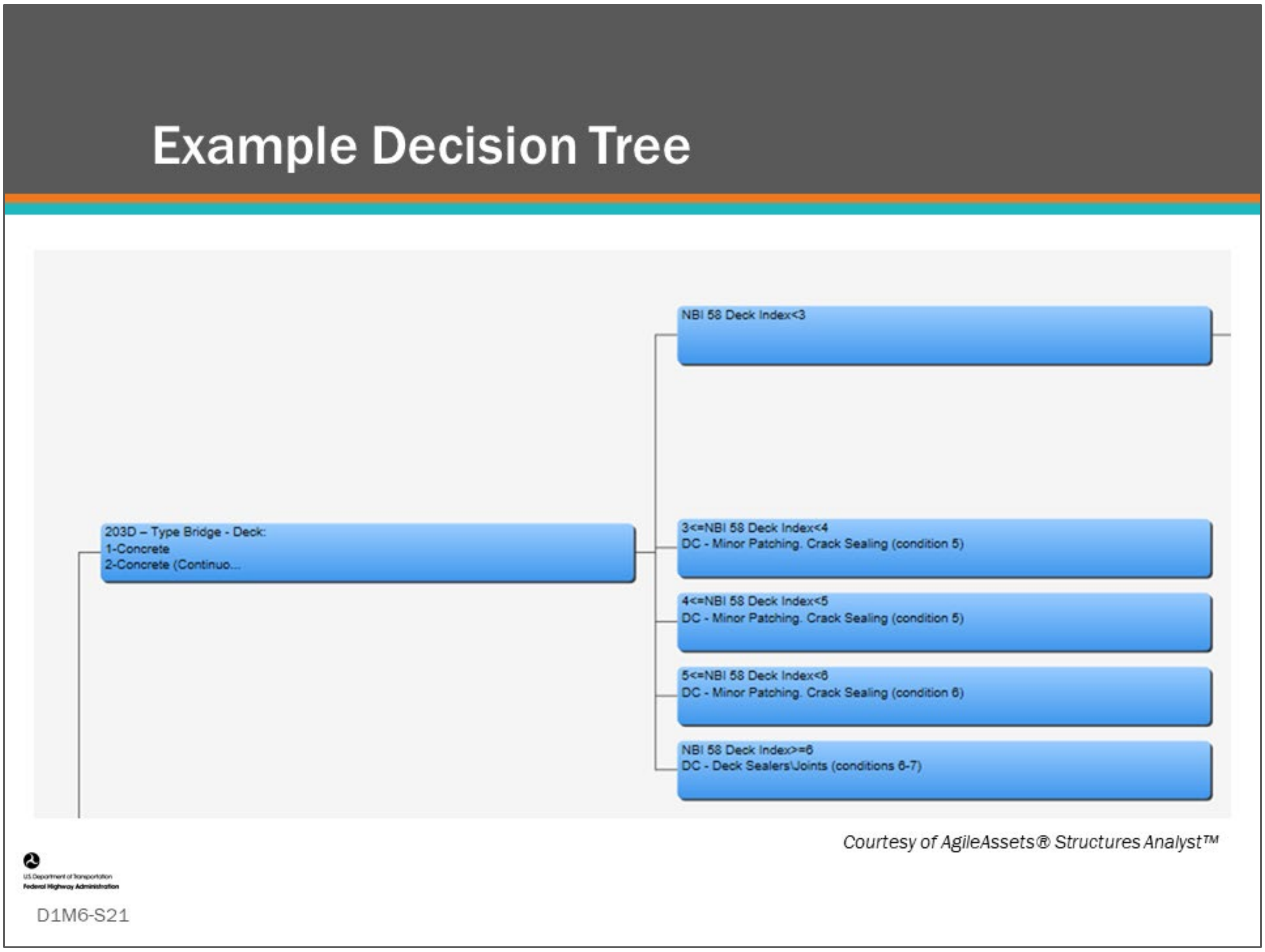
D1M6-Slide 20



Key Message

This slide shows a network-level action trigger rule to "preserve" the deck when the NBI GCR for the deck is rated 5 or 6.

D1M6-Slide 21



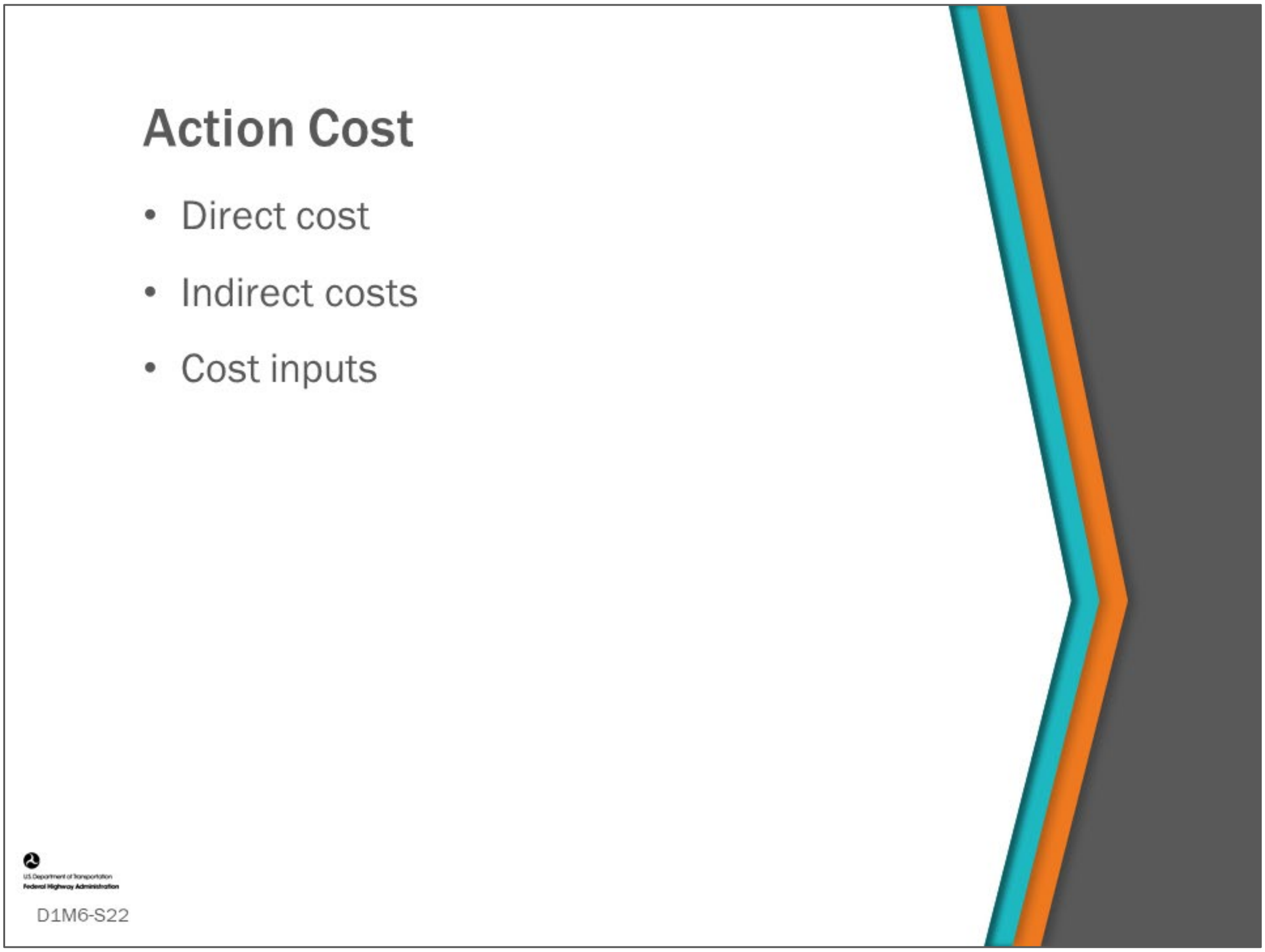
Key Message

The following AgileAssets® Structures Analyst™ decision tree provides trigger rules for a concrete bridge deck action based upon the condition of the deck.

Shown here is just a portion of a much larger decision tree for a concrete bridge deck, which is indicating:

- To replace the deck when the deck NBI rating is 3 or less
- Perform minor patching and crack sealing when the deck NBI rating is greater than or equal to 3 and less than 4
- Do minor patching and crack sealing when the NBI deck rating is greater or equal to 4 and it is less than 5
- Do minor patching and crack sealing when the NBI deck rating is greater or equal to 5 and it is less than 6
- Seal deck and repair/replace joints when the NBI deck rating is greater than or equal to 6

D1M6-Slide 22



Key Message

In order to perform cost/benefit analysis, a BMS must be able to calculate the cost of bridge actions. It is important to input reasonable action cost data into the BMS so that costs can be accurately estimated.

D1M6-Slide 23

Direct Cost

REGION: FISCAL YEAR:
ENGINEER: DATE: STRUCTURE ID: (3-5 digits)
LOCATION: DECK AREA: SFT BRIDGE ID: XXX-XXXXX
PRIMARY WORK ACTIVITY: DECK DIM: STR. TYPE:

WORK ACTIVITY		QUANTITY	UNIT	UNIT COST	TOTAL
NEW BRIDGE					
Multiple Spans, Concrete	(add demo, approach, MOT)		SFT	$220.00 /SFT	
Multiple Spans, Steel	(add demo, approach, MOT)		SFT	$245.00 /SFT	
Over Water or Single Span	(supplement to replacement cost)		SFT	$85.00 /SFT	
Precast Culvert 3 or 4 sided	(incl. single span supplement; add demo, approach, MOT)		SFT	$350.00 /SFT	
Other					
NEW SUPERSTRUCTURE					
Concrete	(incl. remove exist super, new railing; add MOT & approach)		SFT	$140.00 /SFT	
Steel	(incl. remove exist super, new railing; add MOT & approach)		SFT	$190.00 /SFT	
Over Water	(add to new superstructure cost)		SFT	$40.00 /SFT	
Other					
WIDENING					
Added portion only. _______ ft of width	(add approach transition)		SFT	$270.00 /SFT	
Other					
NEW DECK					
Includes remove exist deck & new railing	(add approach, MOT)		SFT	$70.00 /SFT	
Other					
DEMOLITION					
Entire bridge, grade separation			SFT	$32.00 /SFT	
Entire bridge, over water			SFT	$42.00 /SFT	
Other					

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D1M6-S23

Key Message

Direct costs are those that can be attributed directly to components and elements in their unit of measure.

- For example, this slide shows a portion of an Agency cost estimating worksheet. This can be as simple as providing unit costs per element quantity (Cost/Sq. Ft.)
- In BMS software, a cost expression formula can be used where the cost can be made dependent on various fields from the database.

D1M6-Slide 24

BMS Software Example of Direct Cost Input

ID	Element Name	Cost Per Unit	Unit
12	Re Concrete Deck (Condition improved)	$ 25	sq.ft
13	Pre Concrete Deck (Condition improved)	$ 25	sq.ft
15	Pre Concrete Top Flange (Condition improved)	$ 25	sq.ft
16	Re Conc Top Flange (Condition improved)	$ 25	sq.ft
28	Steel Deck - Open Grid (Condition improved)	$ 100	sq.ft
29	Steel Deck - Conc Fill Grid (Condition improved)	$ 100	sq.ft
30	Steel Deck - Orthotropic (Condition improved)	$ 100	sq.ft
38	Re Concrete Slab (Condition improved)	$ 25	sq.ft
54	Timber Slab (Condition improved)	$ 100	sq.ft
300	Strip Seal Exp Joint (Replace)	$ 65	ft
301	Pourable Joint Seal (Replace)	$ 15	ft

Courtesy of AASHTOWare™ Bridge Management (BrM)

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Federal Highway Administration

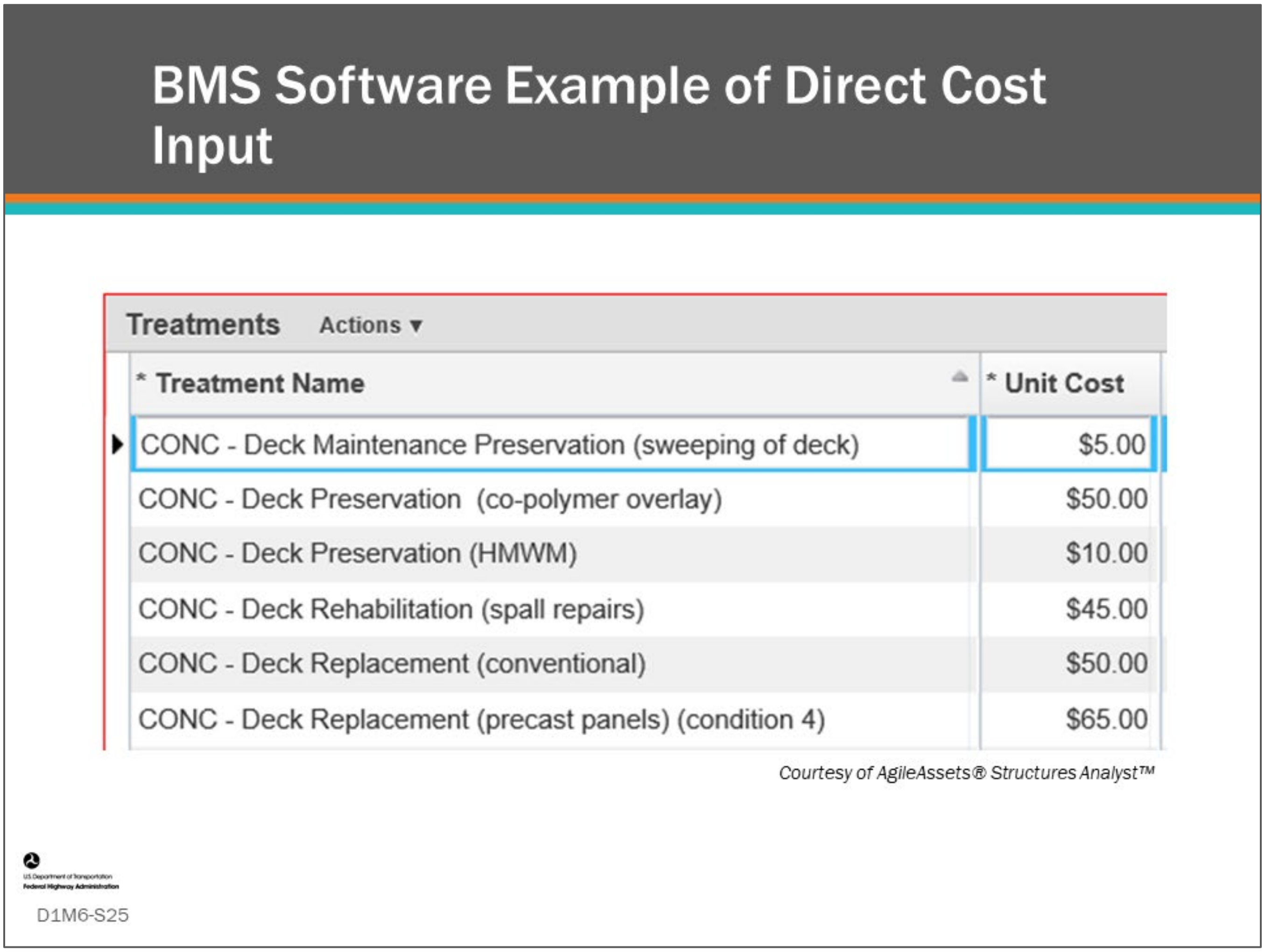
D1M6-S24

Key Message

BMS software provides ability to enter cost per unit for all identified actions.

- Shown here is a screenshot of the AASHTOWare™ BrM software, Action Definitions screen; where cost is input for all element-level actions.
- The unit cost can be calculated based on the portion of an element that changes due to the action, not necessarily the entire quantity of the element.

D1M6-Slide 25

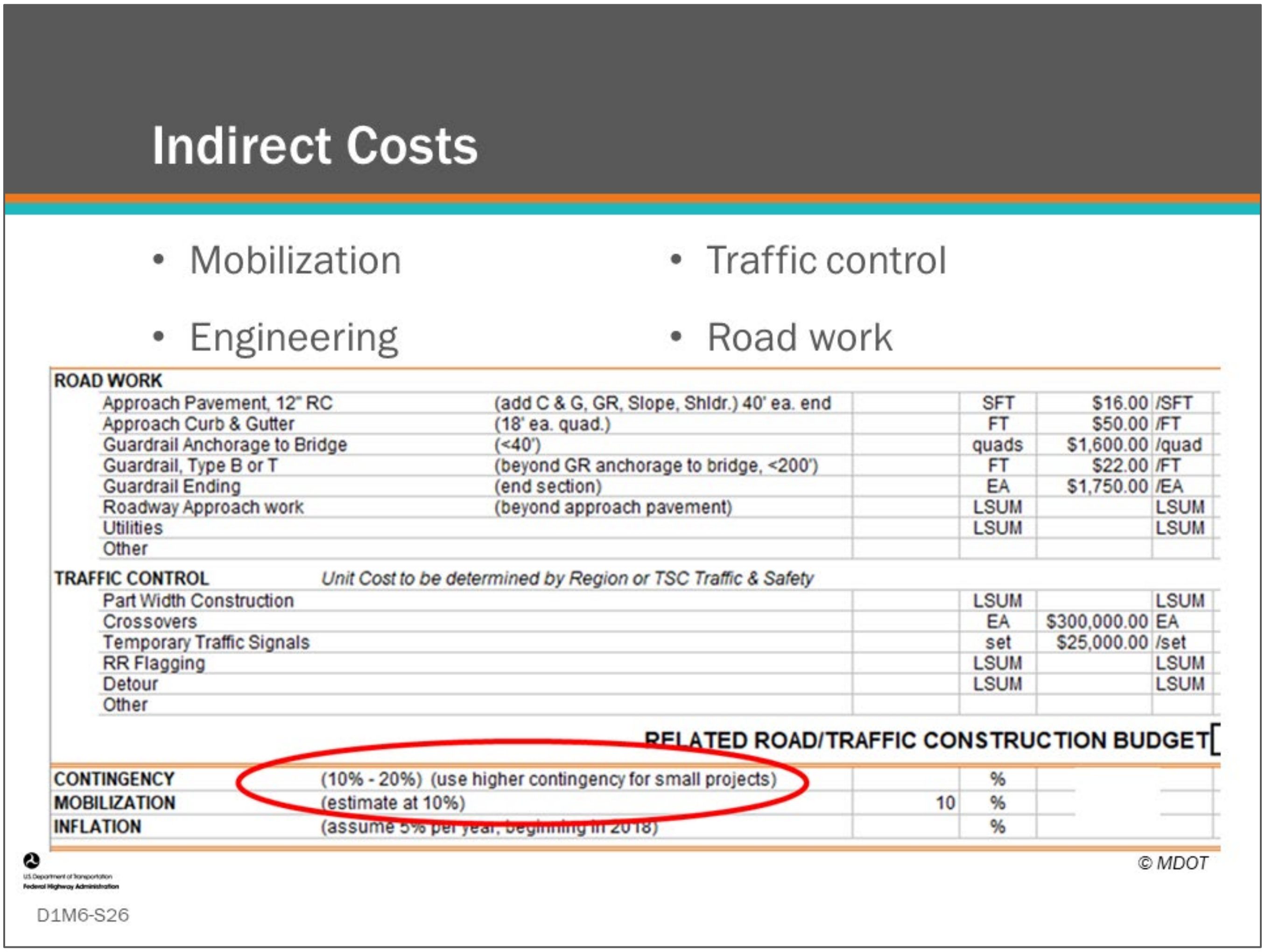


* Treatment Name	* Unit Cost
CONC - Deck Maintenance Preservation (sweeping of deck)	$5.00
CONC - Deck Preservation (co-polymer overlay)	$50.00
CONC - Deck Preservation (HMWM)	$10.00
CONC - Deck Rehabilitation (spall repairs)	$45.00
CONC - Deck Replacement (conventional)	$50.00
CONC - Deck Replacement (precast panels) (condition 4)	$65.00

Key Message

Similarly, AgileAssets® Structures Analyst™ allows entry of cost (total of direct and indirect) as Cost/Unit of measure. Both Deighton dTIMS© and AgileAssets® Structures Analyst™ also allow the use of a more detailed cost expression formula that can treat direct and indirect cost separately.

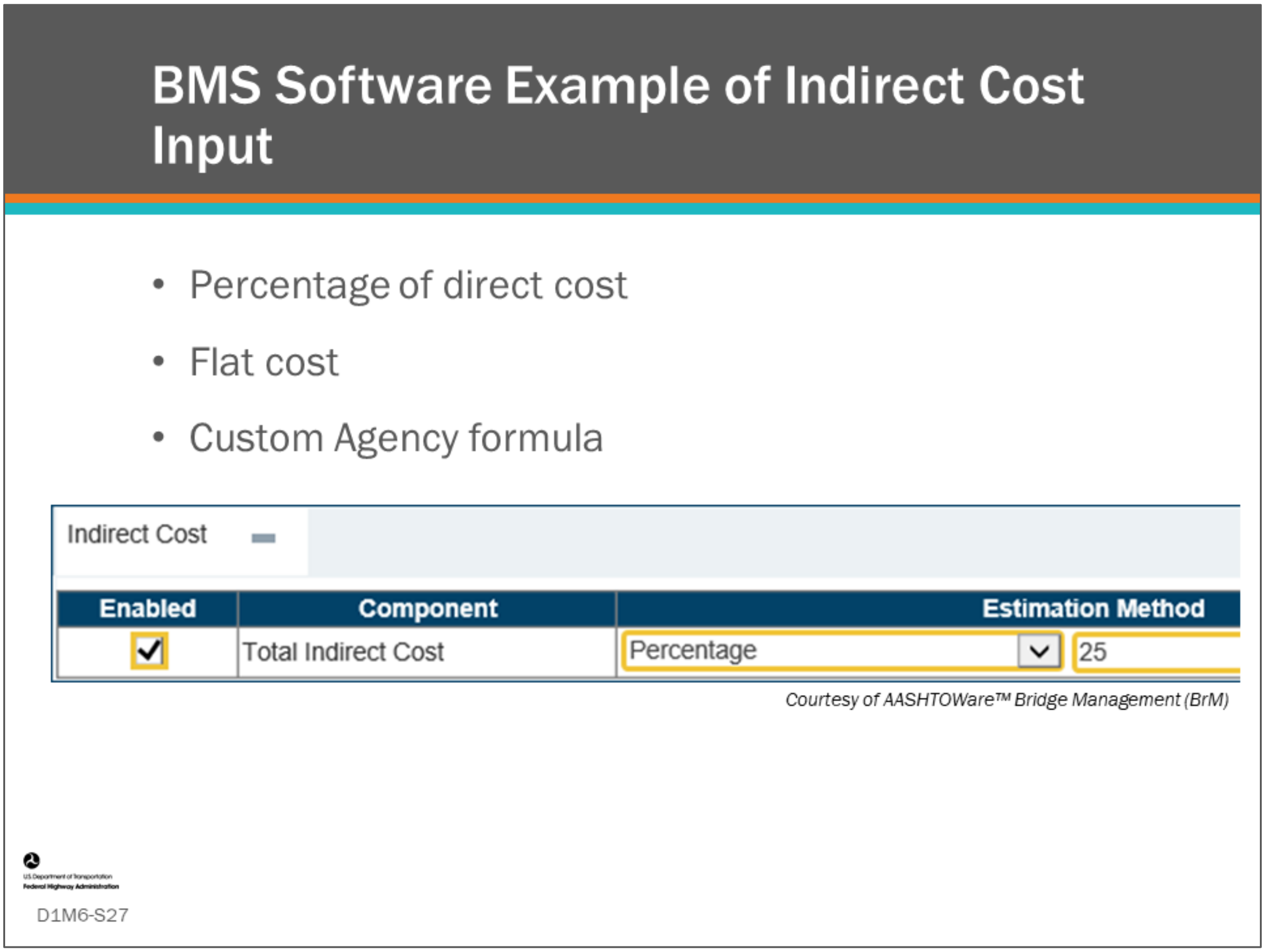
D1M6-Slide 26



Key Message

All bridge projects also have indirect costs that need to be accounted for. These include mobilization, traffic control, engineering (design and construction), and road work (Road work can also be input as a direct cost). Value for indirect costs is often determined by the location of the structure. For example, indirect costs for a highway bridge in a congested urban location will be much more than one in a rural location.

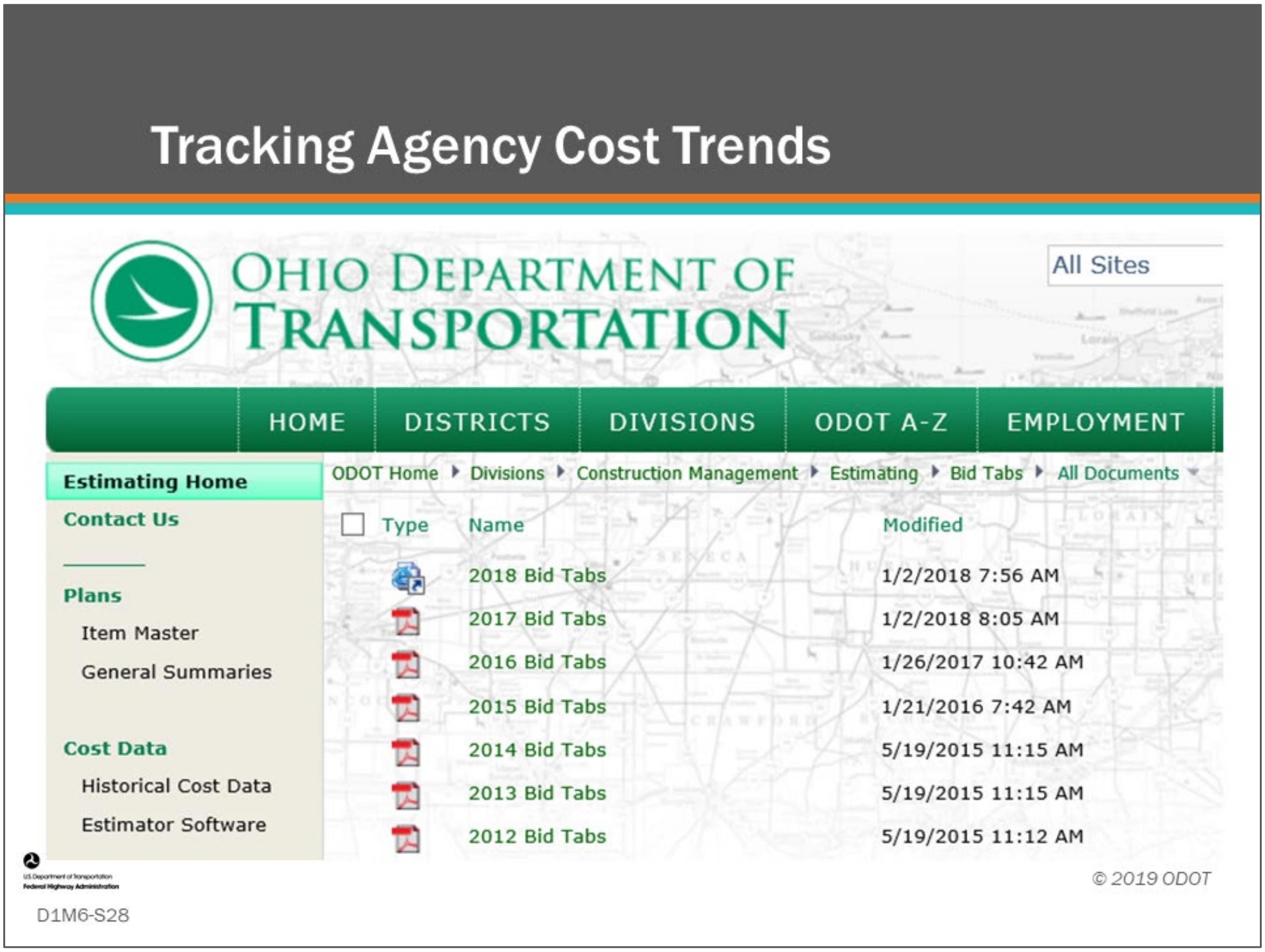
D1M6-Slide 27



Key Message

Indirect cost can be estimated as a percentage of the direct cost, flat cost, or using a custom Agency formula.

D1M6-Slide 28

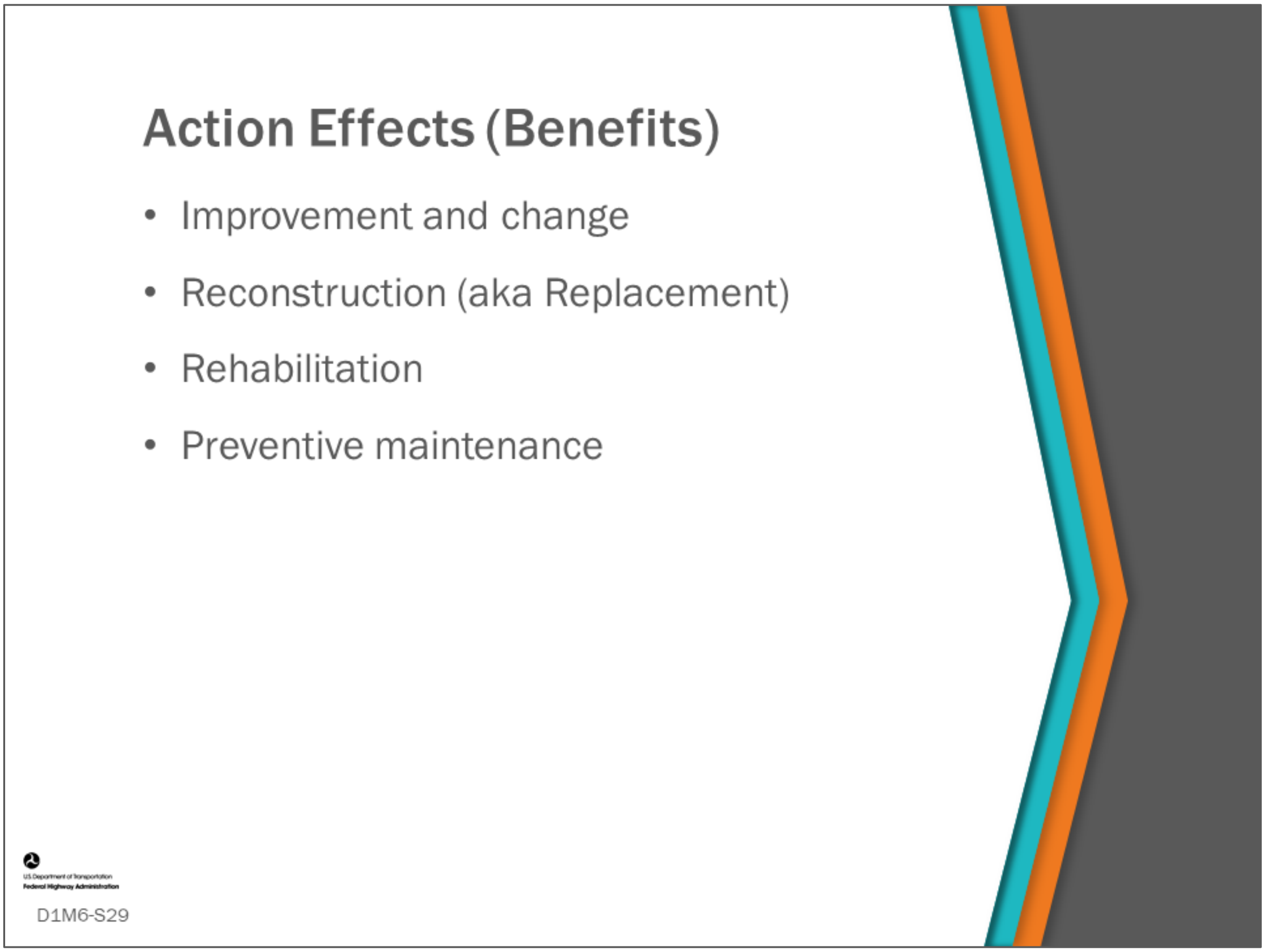


Key Message

It is important that an Agency tracks project direct and indirect cost on an annual basis. This can be done by reviewing and itemizing state Department of Transportation bid tabs for let construction projects.

- Shown on this slide is the Ohio DOT “Bid Analysis and Review Team” website for providing historic costs for construction projects by pay items.
- Because pay items often differ from BMS element quantities, there is some conversion needed to equate bid tab costs to BMS component and element unit costs.
- Agencies building a BMS should set up a systematic process to do this at a regular frequency.
- Agency cost trends can also be a performance measure. The cost-effectiveness of various actions can be tracked, possibly leading to changes in decision trees. Impacts to costs due to changes in Agency materials and/or specifications can be monitored.

D1M6-Slide 29



Key Message

Action effects or benefits are the improvement in both the condition and inventory items resulting from the activity.

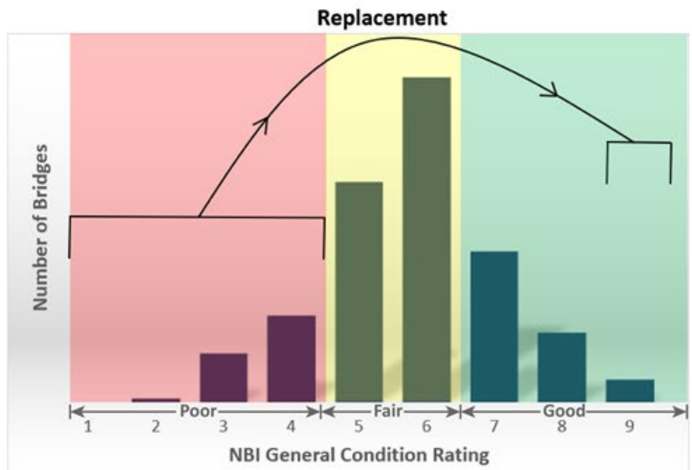
- This includes improvement in major component condition ratings, element condition states, as well as improved operation and function as represented by inventory items.
- Action effects also include changes to the elements resulting from the activity, such as a reconstruction action changing a bridge with a reinforced concrete beam superstructure to superstructure having prestressed concrete beams or changing a bridge to a precast concrete culvert.

When using deterioration curves, action effects may also include delaying the deterioration curve for a specified time and modifying or changing the deterioration curve to a different curve (whether this results in a steeper or shallower deterioration curve).

- You need to tell a BMS what the effect is for each action taken to each bridge component or element.

D1M6-Slide 30

Action Effect (Benefit) of Reconstruction (Replacement)



Element	Parent	Grandparent	Origin State	CS1	CS2	CS3	CS4
102 Steel Clsd Box Gird							
102 Steel Clsd Box Gird	None	None	CS2	100%			
102 Steel Clsd Box Gird	None	None	CS3	100%			
102 Steel Clsd Box Gird	None	None	CS4	100%			

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Courtesy of AASHTOWare™ Bridge Management (BrM)

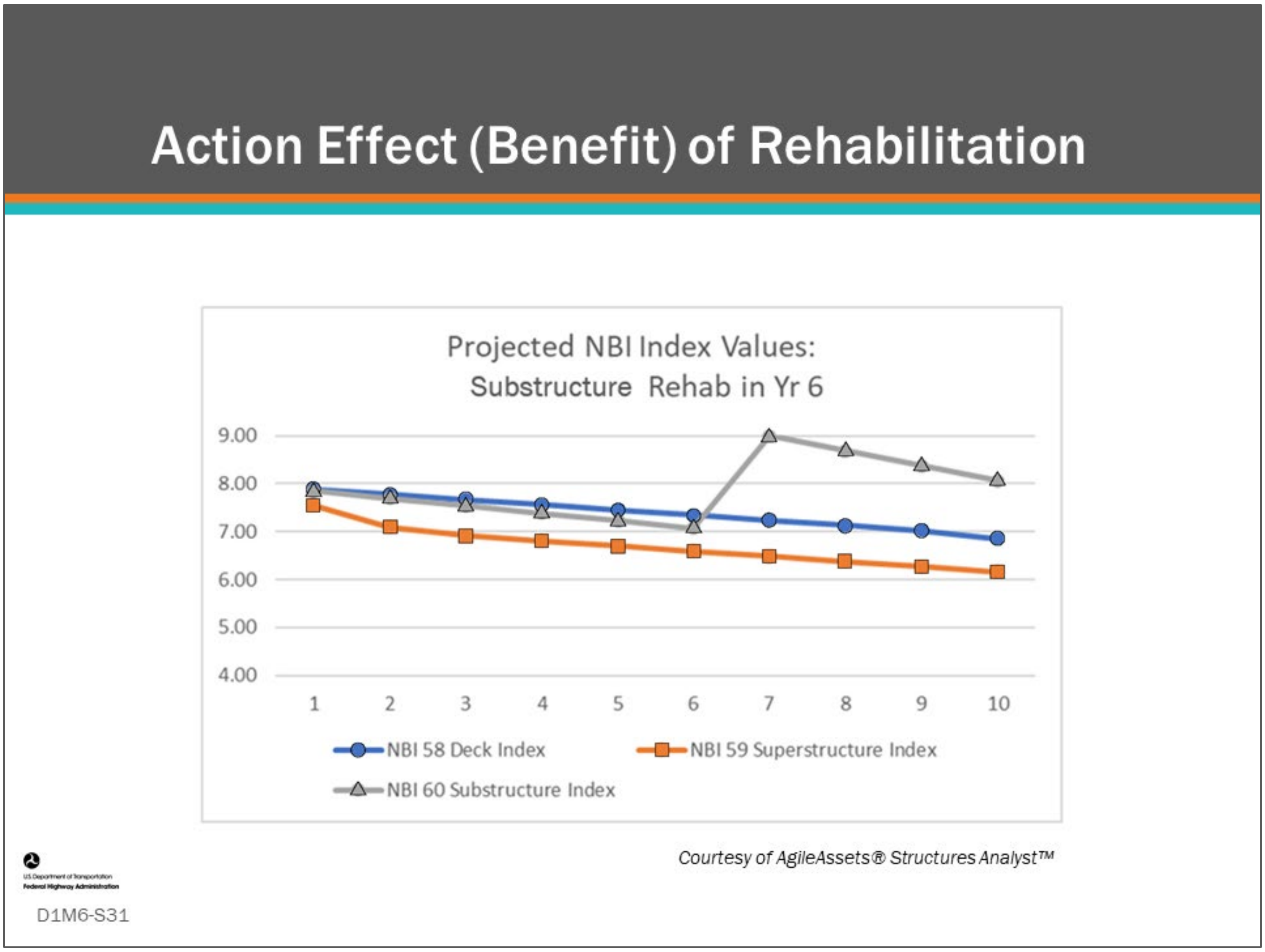
D1M6-S30

Key Message

The bar chart shows an example number of bridges in each NBI GCR.

- Reconstruction (Replacement) actions are most often done to bridges in poor condition (GCR 4 or below) resulting in improvement of the bridge to excellent condition (GCR 9) as shown in the chart.
- Also shown on the slide are instructions for Element 102 - Steel Closed Box Girder telling the software that all existing quantities in CS2, CS3, and CS4 will move to CS1 (Good) following a replacement project.

D1M6-Slide 31

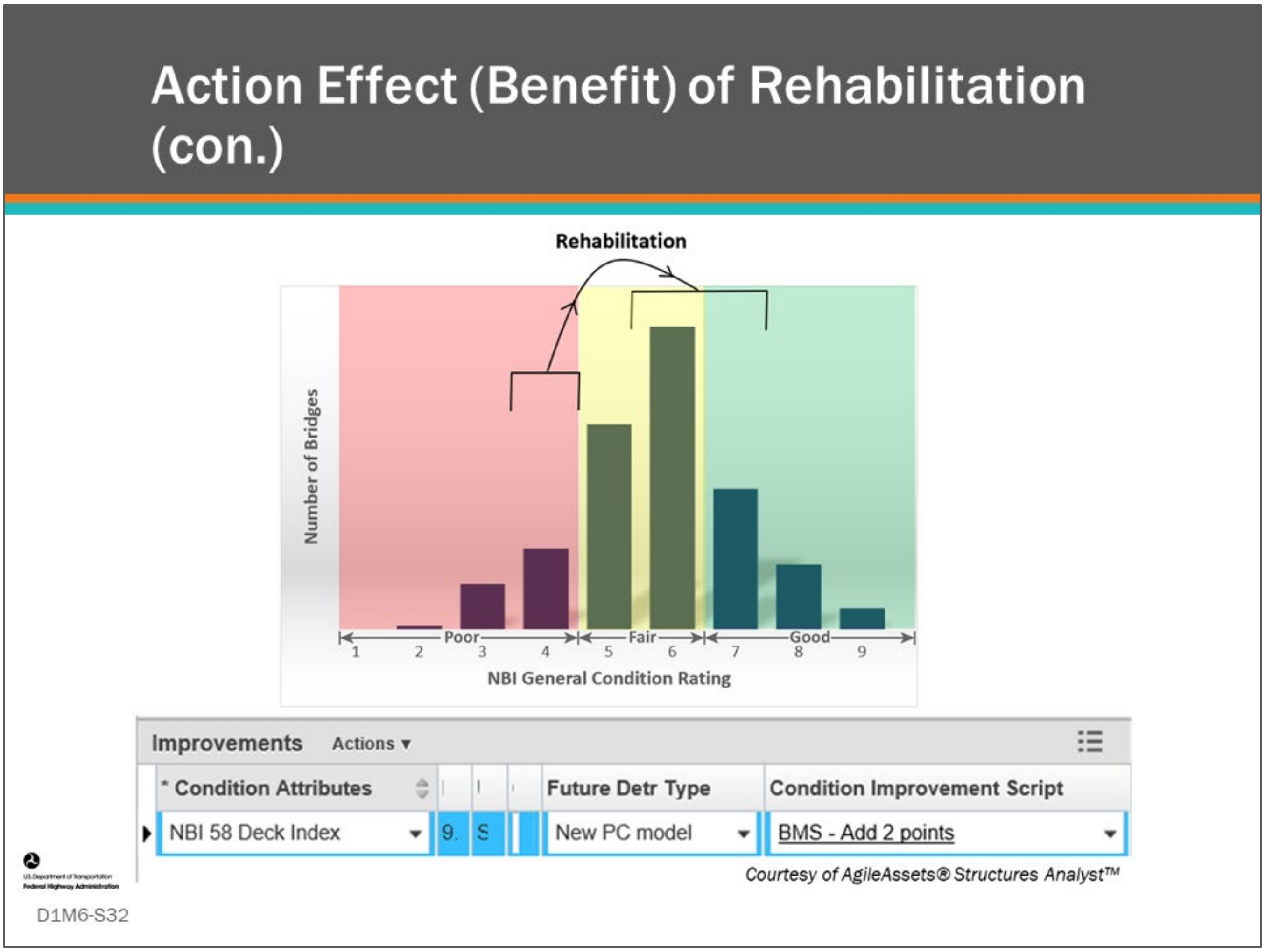


Key Message

The graph on this slide is showing that after a "Substructure Rehabilitation" in year 6, the substructure increased to a GCR of 9, but the deck and superstructure GCR did not improve.

- If you track projects and the type of work that was done, you can use the NBI GCRs to track the "action effect" of projects.
- Note, it may take a year or even two to show the improvement because after a project is programmed, it takes time to design, build, and finally inspect the bridge and input the new condition ratings.

D1M6-Slide 32

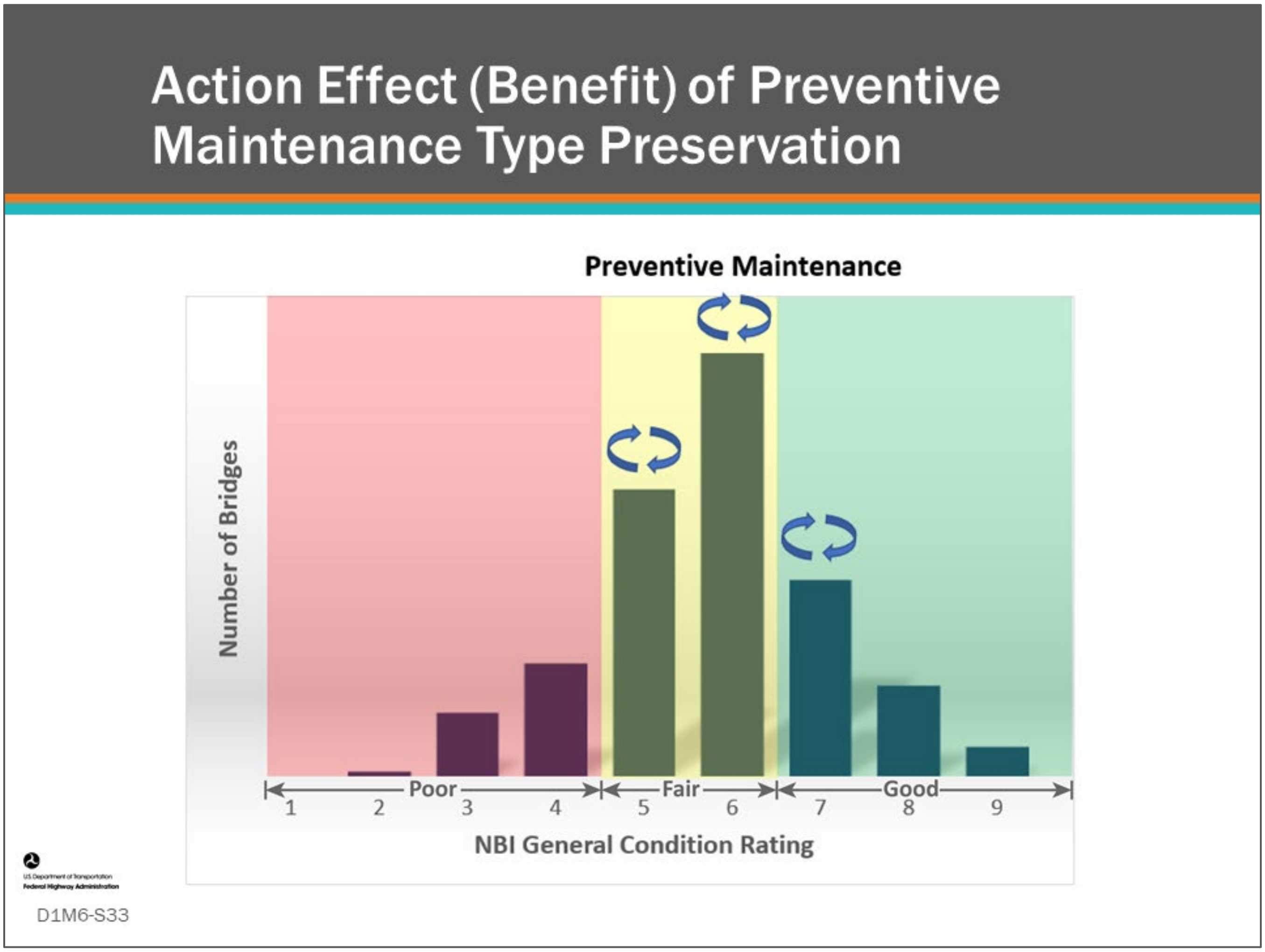


Key Message

Rehabilitation actions are often done to bridges when one or more of the major components are in poor condition.

- The chart on this slide shows that rehabilitation actions typically take a bridge rated with a "poor" condition and move that structure into the fair to good category.
- The improvements in condition as a result of rehabilitation actions need to be input into the BMS.
- Also shown on the slide, are instructions to the AgileAssets® Structures Analyst™ software that the bridge GCR will increase by two condition ratings after rehabilitation.

D1M6-Slide 33

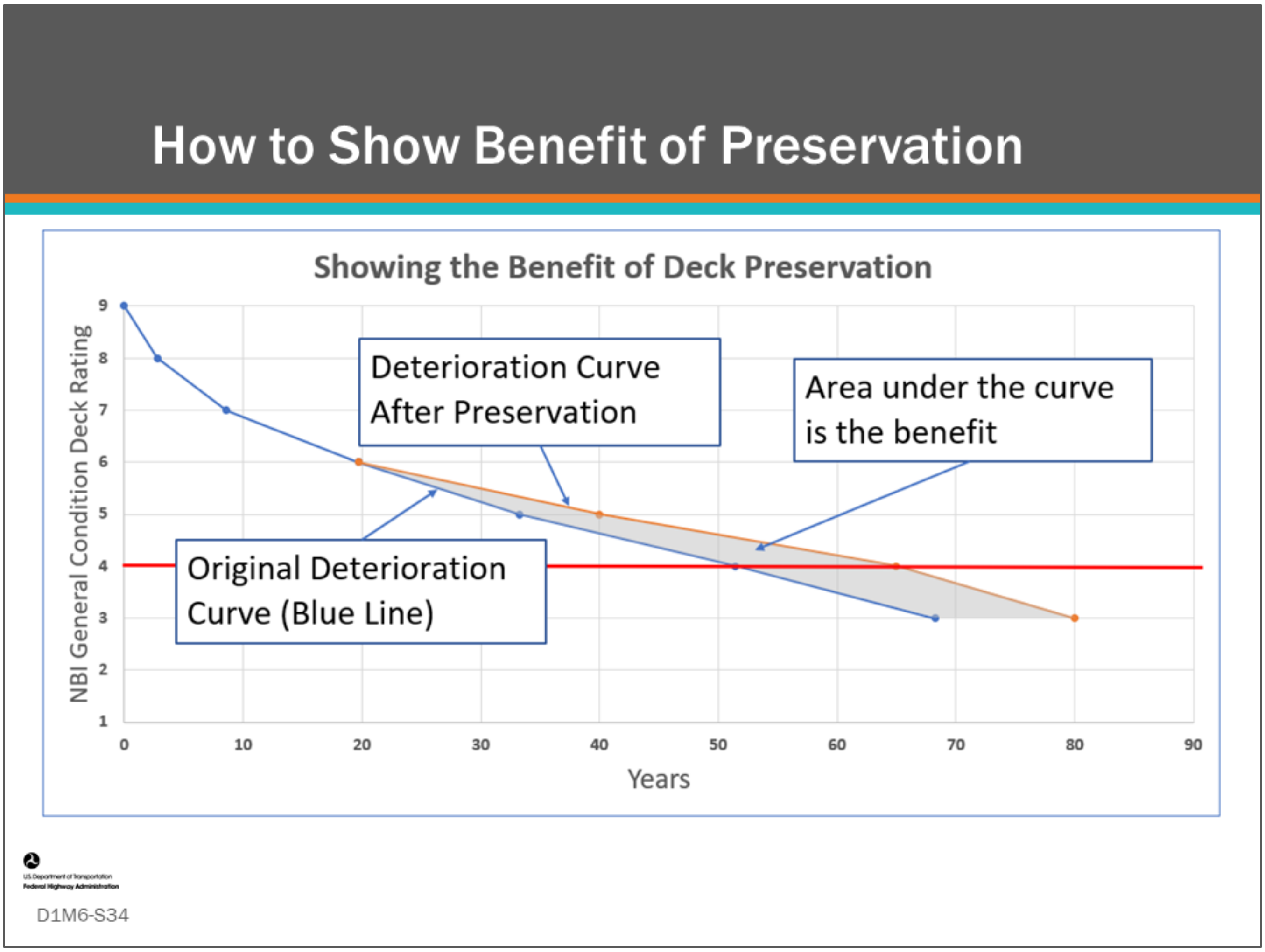


Key Message

Preventive maintenance actions slow down the deterioration of a bridge.

- As shown in the chart, bridge preventive maintenance is most often done to bridges in fair and good condition, with the objective of extending the time at which rehabilitation or replacement are needed.
- Modeling the action effect of preventive maintenance is a little more challenging than modeling rehabilitation or replacement.

D1M6-Slide 34

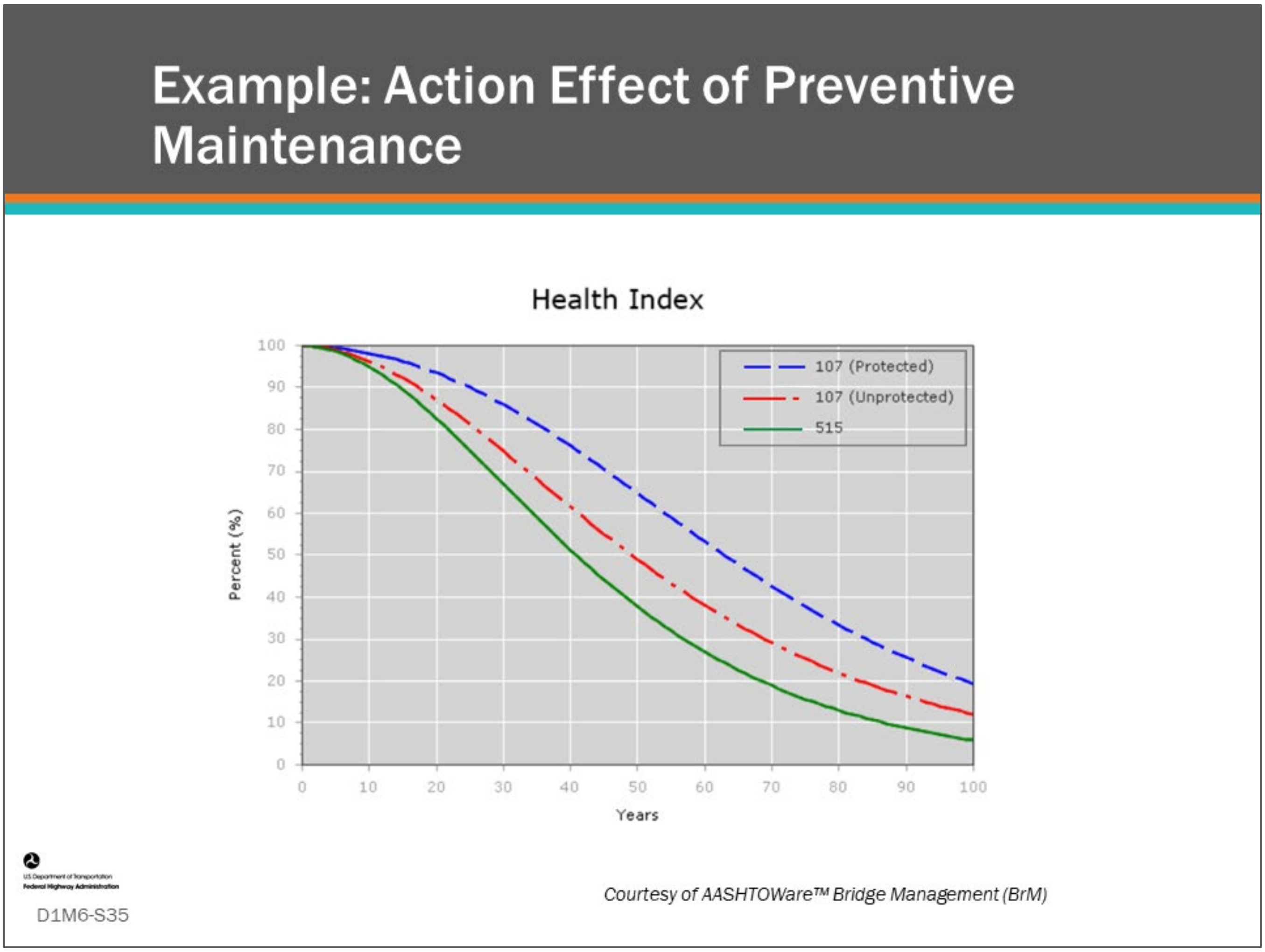


Key Message

Preservation benefit can be shown using bridge elements, but its benefit can also be shown using major component ratings by tracking change in deterioration curves.

- This slide shows the benefit of preservation as the area under the original deterioration cures and the new curve after preservation is done.
- Preservation actions that may not improve the rating of the major component include, deck sealing, concrete patching, or painting over a steel element with minor section loss (The section loss will still exist, thus preventive raising the GCR.)
- BMS software sometimes shows the benefit of preservation by allowing the user to slow or even eliminate deterioration of that element for a period after preservation was done.

D1M6-Slide 35



Key Message

This chart shows the effect of applying a protective system, Element 515 Steel Protective Coating, on the Parent Element 107, Steel Open Girder/Beam.

- The red line shows the deterioration curve for the unprotected beam, the green line shows the anticipated deterioration rate of element 515 Steel Protective Coating, and the blue line shows the deterioration curve for the steel beam with the application of the steel protective coating.
- Note, the slower deterioration rate of the protected beam; action effect (benefit) is improvement of the deterioration curve.

D1M6-Slide 36

Element Condition State Increase after Preservation

Element Number	Element Name	Total Quantity	Units	CS1	CS2	CS3	CS4	ω_e	Element Health Index
12	Concrete Deck	300	SFT	0	300			600	75.00%
107	Steel Girder/Beam	100	LFT	61	34	5		3500	89.00%
215	Concrete Abutment	24	LFT	24				7700	100.00%
300	Strip Seal Expansion Joint	24	LFT	0			24	560	0.00%
515	Steel Protective Coating	1200	SFT	0	600	400	200	300	54.17%

Bridge Health Index
75.9%

Element Number	Element Name	Total Quantity	Units	CS1	CS2	CS3	CS4	ω_e	Element Health Index
12	Concrete Deck	300	SFT	0	300			600	75.00%
107	Steel Girder/Beam	100	LFT	66	34	0		3500	91.50%
215	Concrete Abutment	24	LFT	24				7700	100.00%
300	Strip Seal Expansion Joint	24	LFT	0			24	560	0.00%
515	Steel Protective Coating	1200	SFT	1200	0	0	0	300	100.00%

Bridge Health Index
91.9%

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Federal Highway Administration

D1M6-S36

Key Message

Whereas major component ratings will typically only substantially increase after major rehabilitation or replacement, element condition states can increase after preservation activities.

- Shown here is 5 lineal feet of steel/girder beam improvement and 1200 square feet of steel protective coating following a beam end repair project and painting of the superstructure.
- Note also the increase in the bridge's health index resulting from the project.

D1M6-Slide 37

Action Effects of Risk-based and Functional Improvements

- Widening improving Level of Service (LOS) of roadway
- Reducing scour critical bridges
- Functional improvement
- Upgrade bridge rail and guardrail

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D1M6-S37

Key Message

Rules can be written in a BMS to update inventory items associated with safety and functional improvement projects.

- For example, when a bridge is retrofitted with scour revetment, the scour vulnerability rating (NBI item 113) may be upgraded from 3 to 7.
- If a bridge rail or guardrail is protected or upgraded, the inventory item in the BMS is modified accordingly. Sometimes a project results in a new element being created, such as when a bridge rail is modernized to the latest standard.
- Action effect rules are provided in the BMS to make these changes. In addition to only updating inventory, if for instance a mobility LOS performance measure was being modeled over time, this could be improved by widening and the benefit calculated.

D1M6-Slide 38

Key Message

This concludes Module 6: Modeling Actions, Triggers, Costs and Effects.

D1M6-Slide 39

Slide #	Image Description	Source Information
6	Screenshot of the AASHTOWare™ Bridge Management (BrM) software with a call-out box of network level check boxes.	AASHTOWare™ Bridge Management (BrM) software.
8	A picture of a new bridge superstructure	MDOT.
8	A screenshot of the AASHTOWare(TM) Bridge Management (BrM) software showing a sample structure replacement rule.	AASHTOWare™ Bridge Management (BrM) software.
9	Picture of concrete deck after hydro-demolition and before it will receive a concrete overlay.	MDOT.
9	Screenshot of AASHTOWare BrM software showing selection box for Rehab Deck - Network and Repair deck, joints and parapet.	AASHTOWare™ Bridge Management (BrM) software.
10	Photo showing workers replacing a bridge joint.	FHWA. *Bridge Preservation Guide: Maintaining a Resilient Infrastructure to Preserve Mobility*. Publication No. FHWA-HIF-18-022. Washington, DC, 2018.
10	Screenshot of the AASHTOWare™ BrM software showing the selection for Preserve Deck - Network and Thin-Bonded / Repair Joints.	AASHTOWare™ Bridge Management (BrM) software.
11	Picture showing guardrail retrofit of bridge parapet.	MDOT.

U.S. Department of Transportation Federal Highway Administration

D1M6-S39

D1M6 Figure Source List

D1M6-Slide 40

Slide #	Image Description	Source Information
11	Picture of scour example.	FHWA.
13	Picture showing beams being placed to widen a bridge.	Bettis, P.E., Alanna. *Bridge Widening Issues.* Presentation. Texas Department of Transportation. Bridge Division. August 2007.
14	Picture of construction workers placing a prestressed concrete beam.	Bettis, P.E., Alanna. *Bridge Widening Issues.* Presentation. Texas Department of Transportation. Bridge Division. August 2007.
15	Collage including three pictures: Picture showing a new concrete deck with new strip seal expansion joint. Picture of engineers examining a deck that will receive a concrete patch. Picture of engineers examining a deck that will receive a concrete patch.	MDOT.
16	Screenshot showing AgileAsset® Structures Analyst Long Term Treatments screen.	AgileAssets® Structures Analyst™ software.
19	Screenshot of CS3 deterioration curve with red line at 25 years.	AASHTOWare™ Bridge Management (BrM) software.
20	Screenshot of AASHTOWare™ BrM software showing network policy screen.	AASHTOWare™ Bridge Management (BrM) software.
21	Screenshot showing AgileAssets® Decision Tree.	AgileAssets® Structures Analyst™ software.

U.S. Department of Transportation
Federal Highway Administration

D1M6-S40

D1M6 Figure Source List

D1M6-Slide 41

Slide #	Image Description	Source Information
23	Screenshot of example cost estimating worksheet showing bridge work activities, quantity, unit, unit cost, and total cost.	MDOT. *Cost Estimating Worksheet.*
24	Screenshot from AASHTOWare™ Bridge Management (BrM) showing element ID, list of work activities, cost per unit, and unit of measure.	AASHTOWare™ Bridge Management (BrM) software.
25	Screenshot showing AgileAssets® Structures Analyst™ screen showing treatments and unit cost.	AgileAssets® Structures Analyst™ software.
26	Screenshot of example cost estimating worksheet showing bridge work activities for road work and traffic control, showing work item, quantity, unit, unit cost, and total cost. Also shown are rows for inputting contingency, mobilization, and inflation.	MDOT. *Cost Estimating Worksheet.*
27	Screenshot showing AASHTOWare™ BrM screen showing Indirect Cost selection enabled, and total indirect cost selected as percentage of 25 percent.	AASHTOWare™ Bridge Management (BrM) software.

U.S. Department of Transportation
Federal Highway Administration

D1M6-S41

D1M6 Figure Source List

D1M6-Slide 42

Slide #	Image Description	Source Information
28	Screenshot of Ohio DOT Bid tabs website page.	Ohio DOT. *Bid Tabs Website.*
30	Screenshot of column chart with Number of Bridges on the y-axis and NBI General Condition Rating on the x-axis.	This Workshop.
30	Screenshot of AASHTOWare™ BrM software showing Benefits Group Screen.	AASHTOWare™ Bridge Management (BrM) software.
31	Screenshot of AgileAssets® Structures Analyst™ screen showing a line chart with NBI GCR condition ratings on the y-axis and years on the x-axis.	AgileAssets® Structures Analyst™ software.
32	Column chart with Number of Bridges on the y-axis and NBI General Condition Rating on the x-axis.	This Workshop.
32	Screenshot showing AgileAssets® Improvement screen showing the deck condition rating will increaser 2 points after rehabilitation.	AgileAssets® Structures Analyst™ software.
33	Column chart with Number of Bridges on the y-axis and NBI General Condition Rating on the x-axis.	This Workshop.
34	Line chart showing NBI GCR for bridge deck on the y-axis and Years on the x-axis.	This Workshop.
35	Line chart showing Health Index as Percent on the y-axis and Years on the x-axis.	AASHTOWare™ Bridge Management (BrM) software.
37	Picture showing new construction of scour mitigation project showing rip-rap, revetment, and low flow channel.	MDOT.

D1M6-S42

D1M6 Figure Source List

Module Title: D1M7 – Life-Cycle Agency Costs and Life-Cycle Modeling

Module Time: 40 minutes

Module Summary

This module will introduce life-cycle agency costs and life-cycle modeling. It will define agency cost which will be compared to user costs in a later module. Bridge Life-Cycle Cost Analysis (LCCA) will be introduced and participants will learn how to convert a future value to present value considering the time value of money. Participants will get an overview of how LCCA variables are input into BMS software and how this software can be used to evaluate life-cycle strategies.

Expected Outcome(s)

Participants will understand how Agency costs can be evaluated over the service life of a bridge to compare preservation, rehabilitation and replacement strategies for determining project work actions and programs of projects that minimize life cycle agency costs.

Resource List

Slide	Reference Information
4,8, 11,12 18,20	NCHRP. Report 483 *Bridge Life-Cycle Cost Analysis*. Washington, DC, 2003.
4, 9, 10,14, 15	FHWA. *Using a Life Cycle Planning Process to Support Asset Management*. Washington, DC, 2017.
15,25, 26	AASHTO. *AASHTOWare™ Bridge Management (BrM) User's Manual*, version 5.2.3, Washington, DC, 2016.
15	Ohio DOT. *Cost Index and Forecasting.* Office of Estimating, Bid Analysis Review Team.
16,17	FHWA. *Life-Cycle Cost Analysis Primer*, Office of Asset Management USDOT. Washington, DC, 2002.
26	Johnson, J. *AASHTOWare BrM 5.2.3. Deterioration and LCCA*. Presentation. April 2017.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D1M7-Slide 1

Key Message

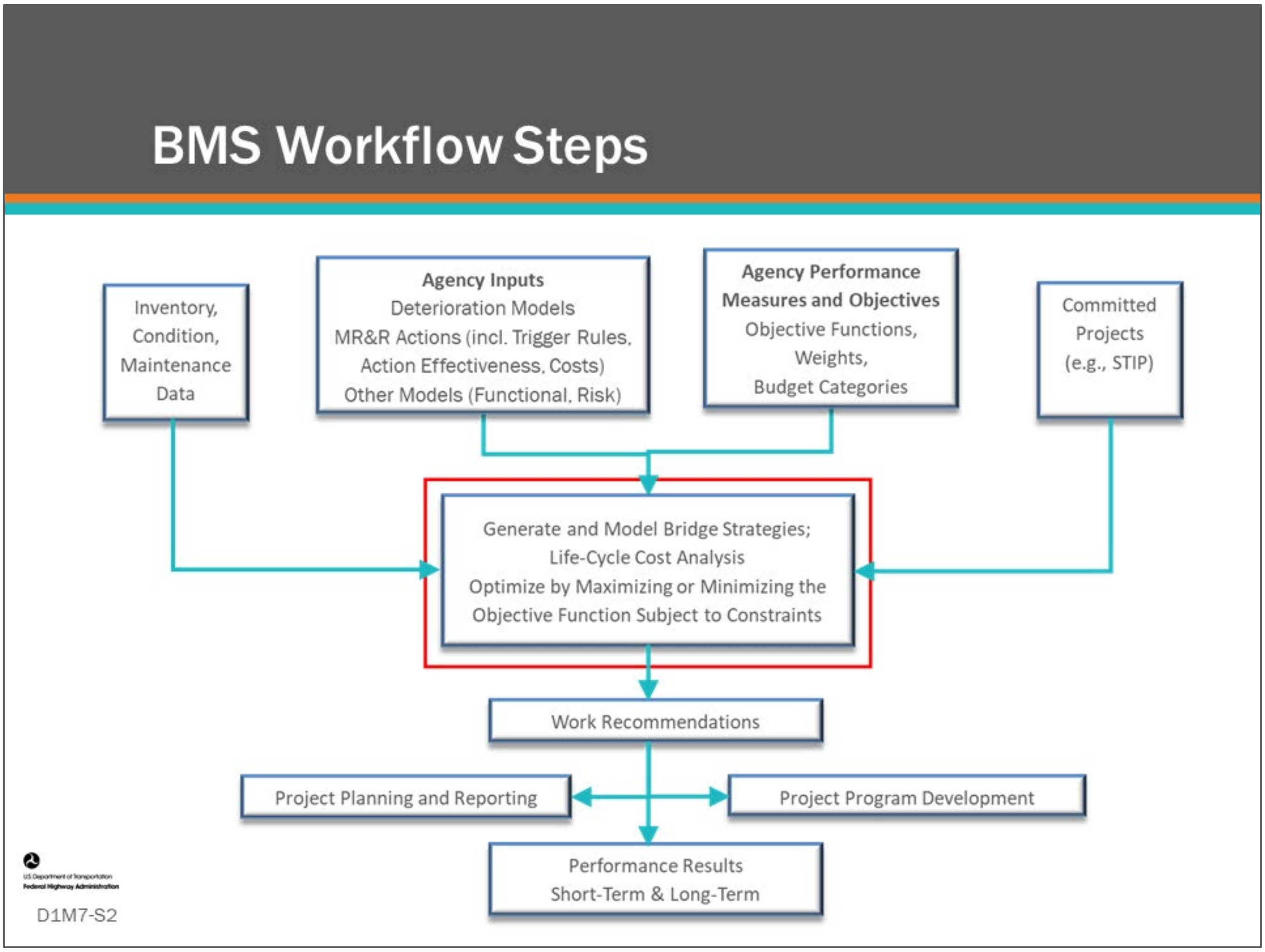
At this point, we have discussed all the various inputs into a BMS, and we have reviewed deterioration models and the concepts of action, trigger, cost, and action effect. We will now explore how these fit together to create a life-cycle plan for the service life of a network of bridges.

- Another way to think of it is that life-cycle encompasses the many stages of a bridge's life. Performing work on bridges influences the duration of the stages which ultimately effects bridge performance and long-term cost to maintain.

Disclaimer

FHWA does not promote or endorse patented and proprietary products. Bridge management software is largely proprietary. Workshop content pertaining to proprietary software is included only to illustrate how bridge management system concepts and analyses are applied in practice. The included content shall not be construed as promotion or endorsement of specific software.

D1M7-Slide 2



Key Message

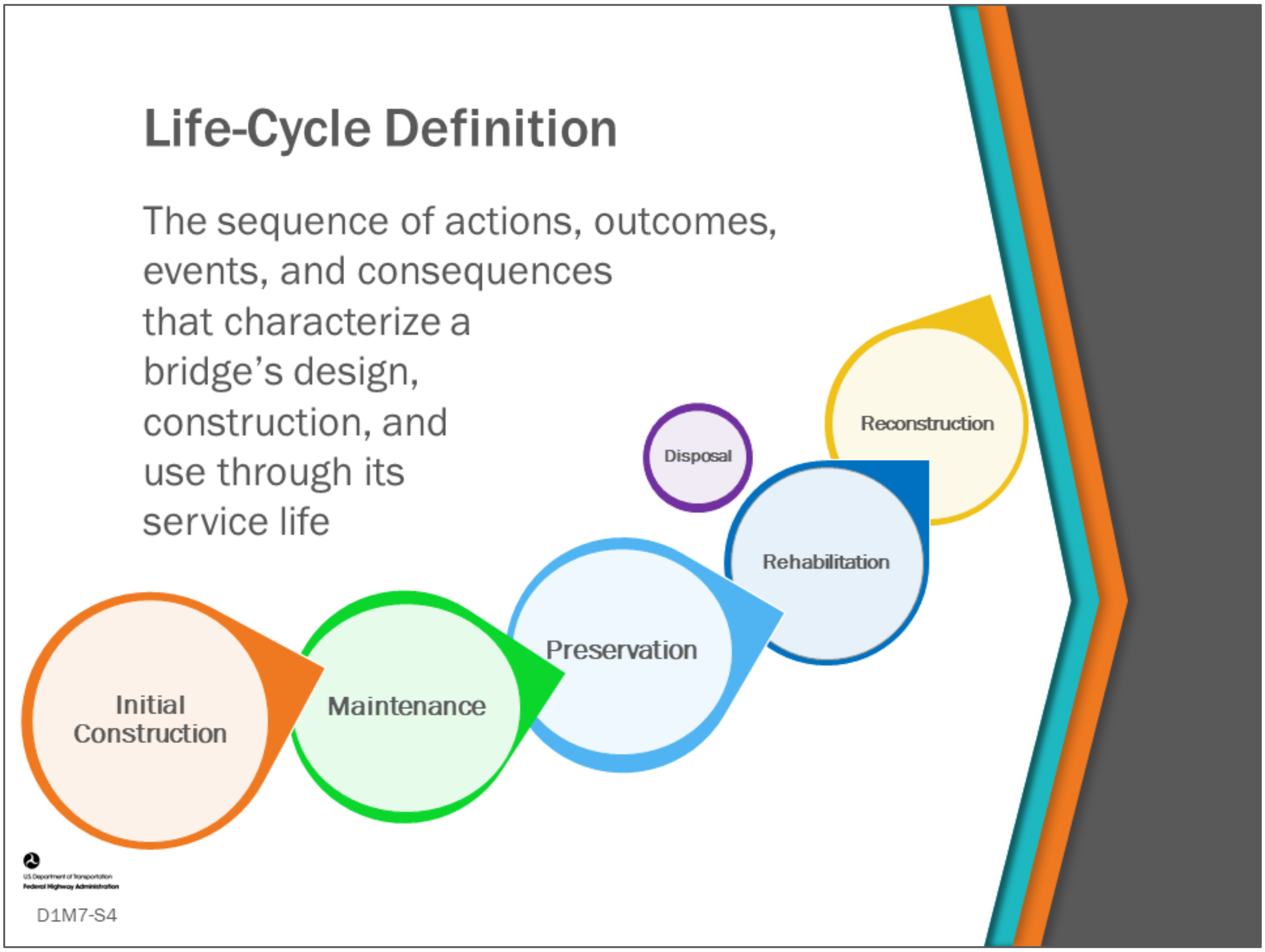
BMS workflow steps are shown on the slide. Life-Cycle Cost Analysis (LCCA) is highlighted by the red box.

D1M7-Slide 3

Key Message

This module will introduce life-cycle agency costs and life-cycle modeling which includes Life-Cycle Cost Analysis (LCCA). It will provide an overview how life-cycle modeling is input into several BMS software models.

D1M7-Slide 4



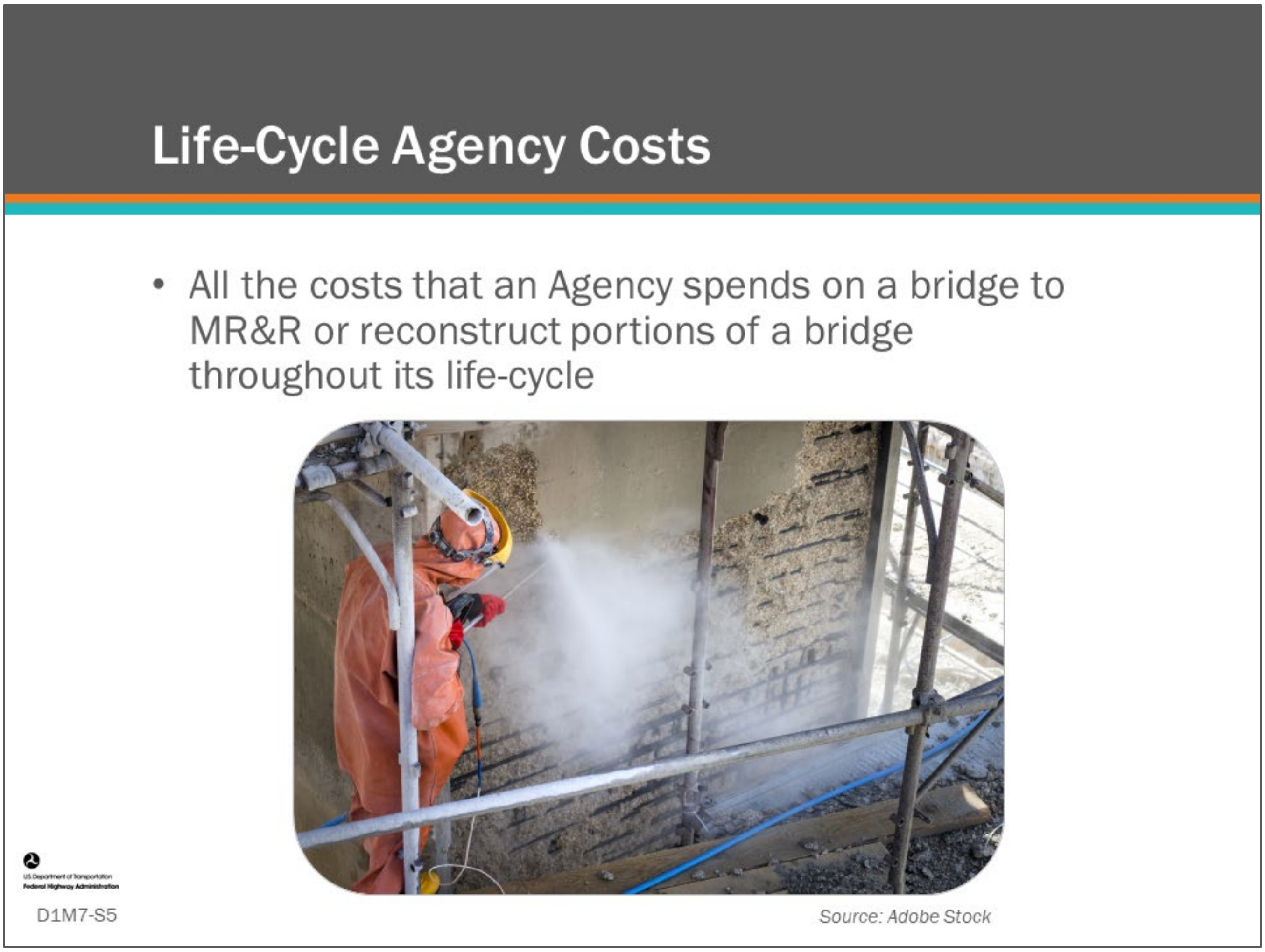
Key Message
Before we define life-cycle agency costs, let's first define life-cycle.

As shown on the slide, a life-cycle is a sequence of actions, outcomes, events, and consequences that characterize a bridge's design, construction, and use through its service life. Another way to think of it is life-cycle encompasses the many stages of a bridge's life. Performing work on bridges influences the duration of the stages which ultimately effects bridge performance and long-term cost to maintain.

Life-cycle isn't limited to a bridge; major components or elements can also have a life-cycle.

Note: In a BMS, actions are also called treatment options, and this sequence of actions and their timing is also called a strategy.

D1M7-Slide 5



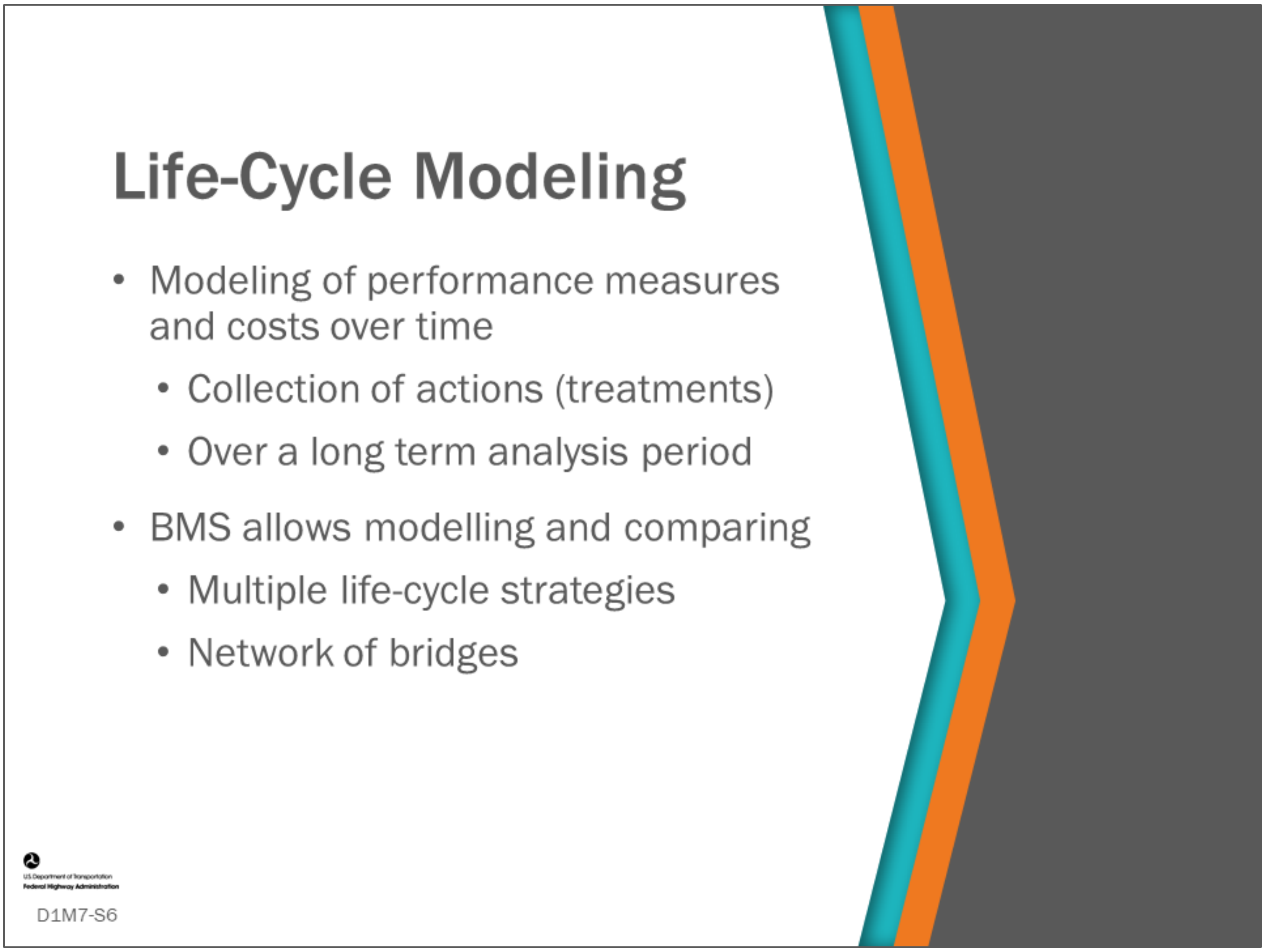
Key Message

Define life-cycle agency costs, which are all the costs during the life-cycle that an Agency spends on a bridge to:

- Maintain
- Repair
- Rehabilitate
- Reconstruct portions

Note: The word "agency" differentiates between life-cycle "agency" costs and life cycle "user" costs, as discussed in the next module.

D1M7-Slide 6

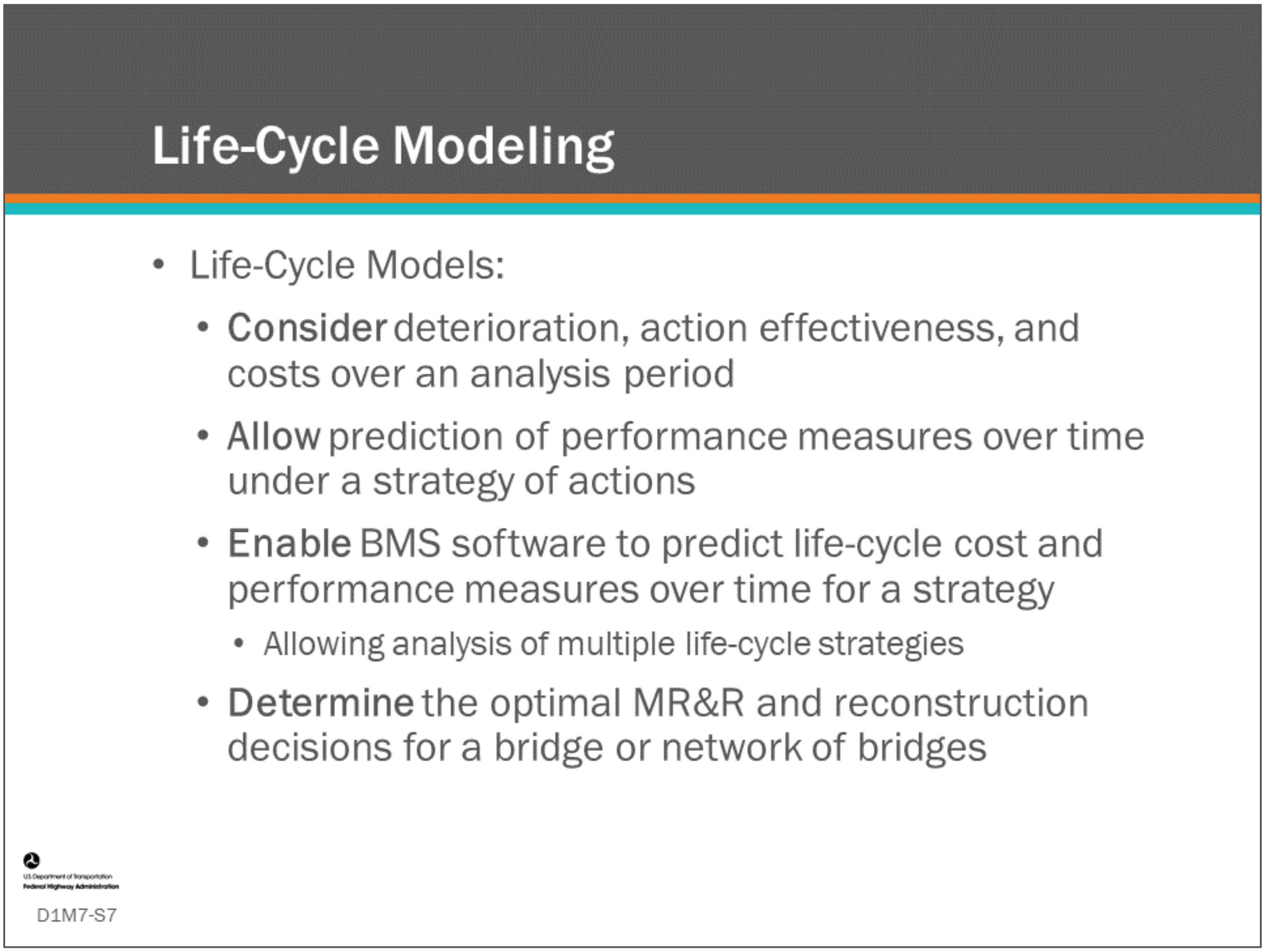


Key Message

Life-cycle modeling is often a bridge level analysis rather than generalized for all bridges or subsets of bridges.

- Each bridge's unique elements/components, element/component costs, conditions, and deterioration rates dictate that a life-cycle strategy of actions and timing is specific to a bridge.
- The interrelation of elements makes it essential to take a wholistic view when determining the most cost-effective actions to take.
- For example, it is not cost effective to replace a deck if the superstructure will not last sufficiently long to recoup the investment.
- LCCA computations can be used to assist in the wholistic determination.

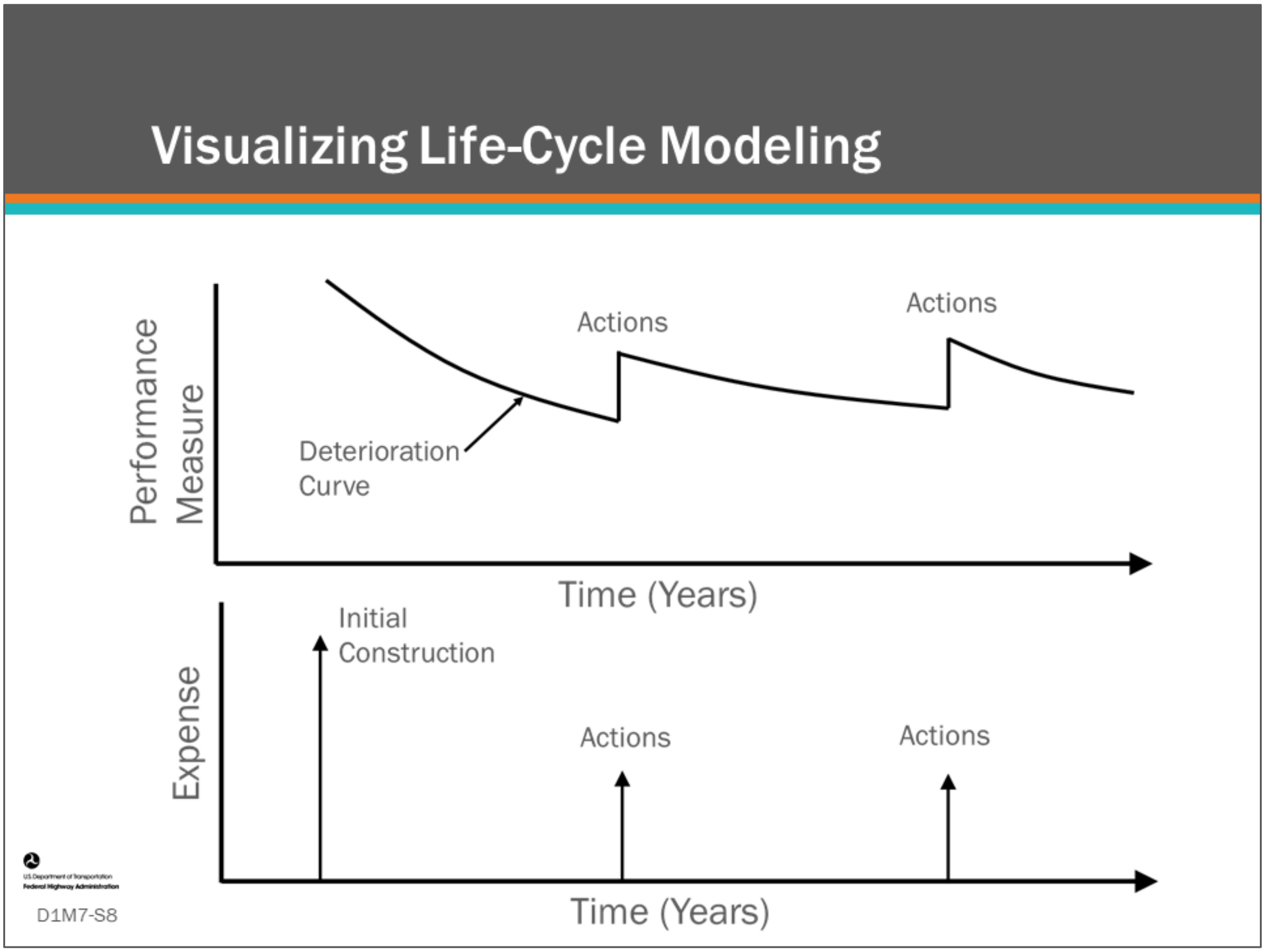
D1M7-Slide 7



Key Message

This slide provides a general description of life-cycle modeling as it is used in a BMS. The definition is meant to convey the processes which a BMS strives to achieve.

D1M7-Slide 8

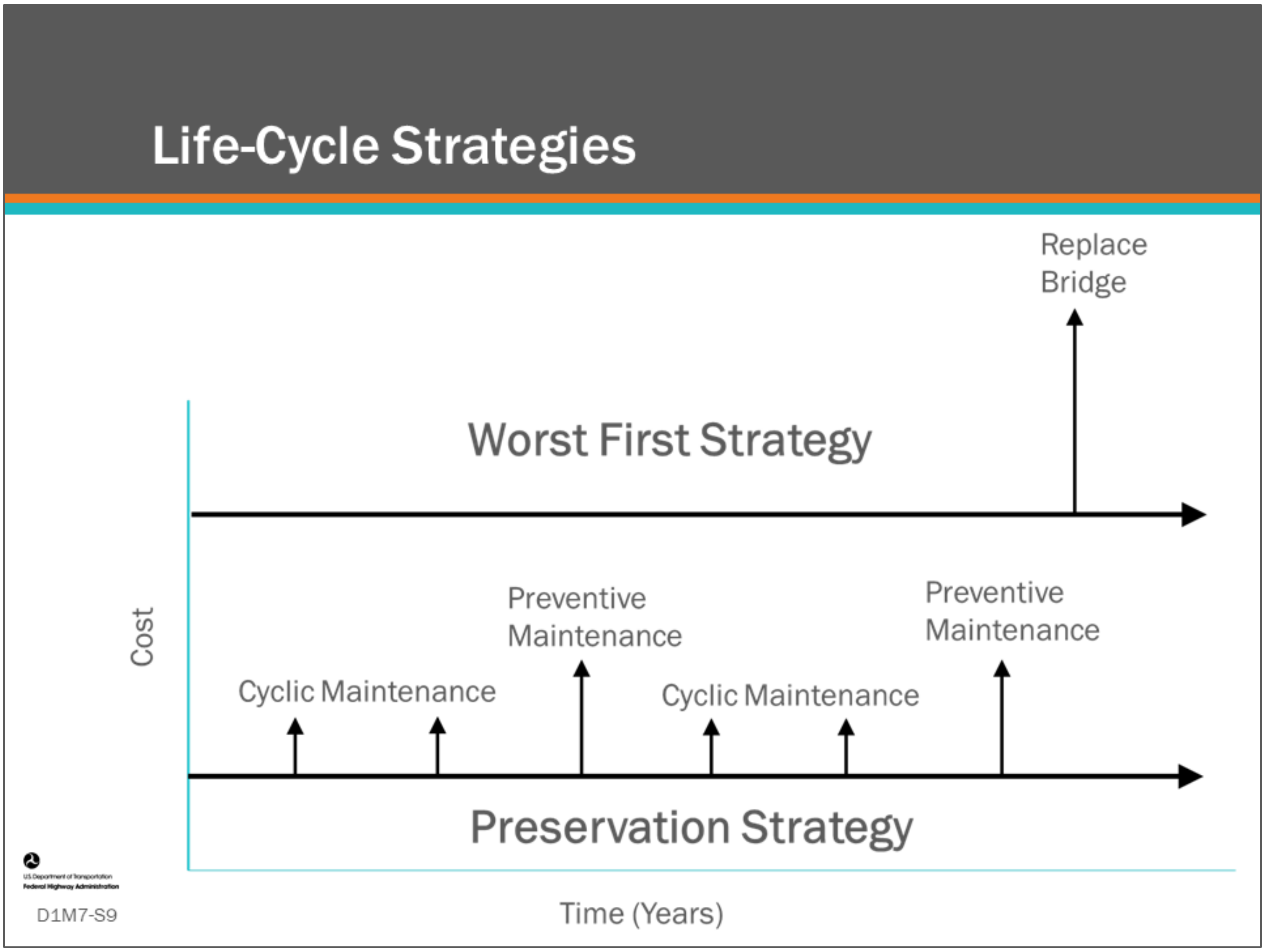


Key Message

A bridge life-cycle model can be shown using bridge deterioration curves shown for any strategy of actions that improve the condition of the bridge over its service life.

- A schematic of this concept is shown in the top chart on the slide, where it is observed that actions increase performance.
- The lower schematic shows action costs are plotted as a function of the time (i.e., a life-cycle activity profile) when they are made.

D1M7-Slide 9

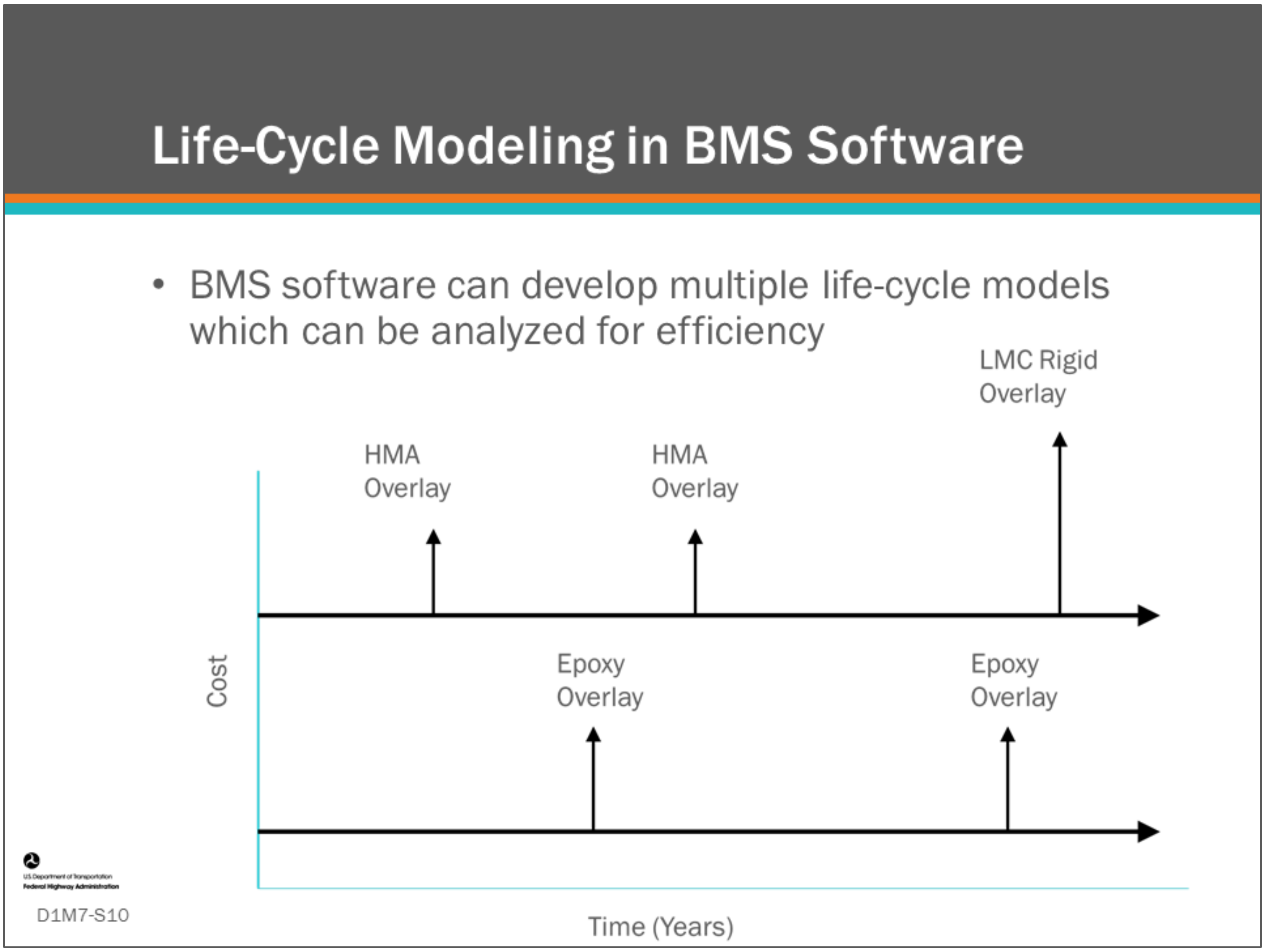


Key Message

In BMS software you can compare multiple life-cycle strategies for a bridge which can be analyzed and compared based on their life-cycle cost.

- Many Agencies followed a "worst-first" strategy where the worst bridges in the network were replaced and very little maintenance actions were taken. This slide shows the effect of this strategy at the project level.
- Two life-cycle activity profiles are shown, the top life-cycle activity profile shows a classic worst-first strategy where a bridge is left alone and then replaced when it deteriorates to a poor condition. The bottom activity profile shows a preservation strategy where an Agency does cyclic and preventive maintenance to maintain the structure in good or fair condition to extend its service life.

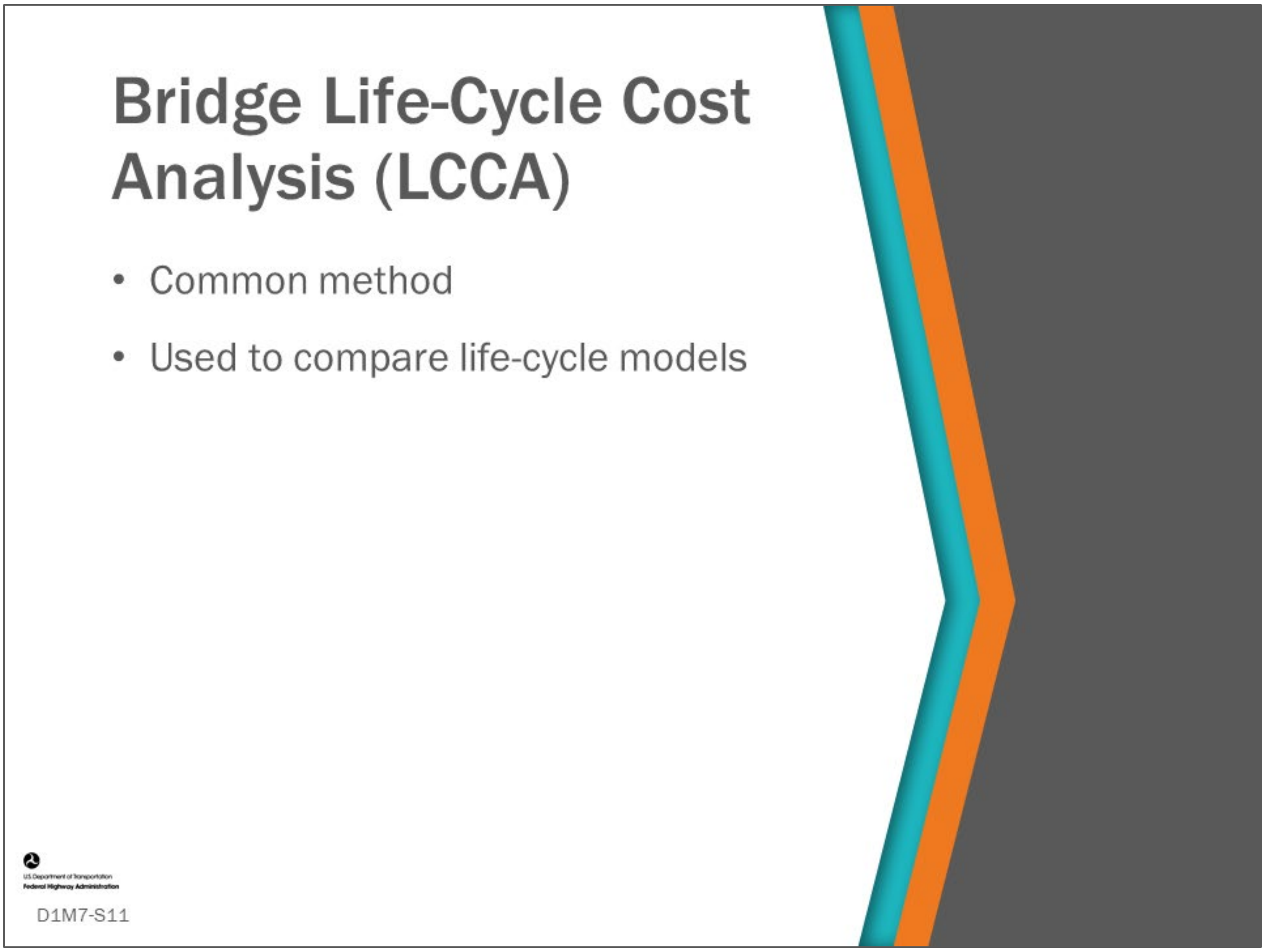
D1M7-Slide 10



Key Message

In BMS software, action strategies are compared to find the best strategy to minimize life-cycle cost. In this slide two life-cycle activity profiles for a deck are shown, the top one showing two Hot Mix Asphalt (HMA) overlays applied to the bridge deck and a Latex-Modified Concrete (LMC) Rigid overlay applied in a later year. The bottom life-cycle activity profile shows two epoxy overlays placed on the bridge deck.

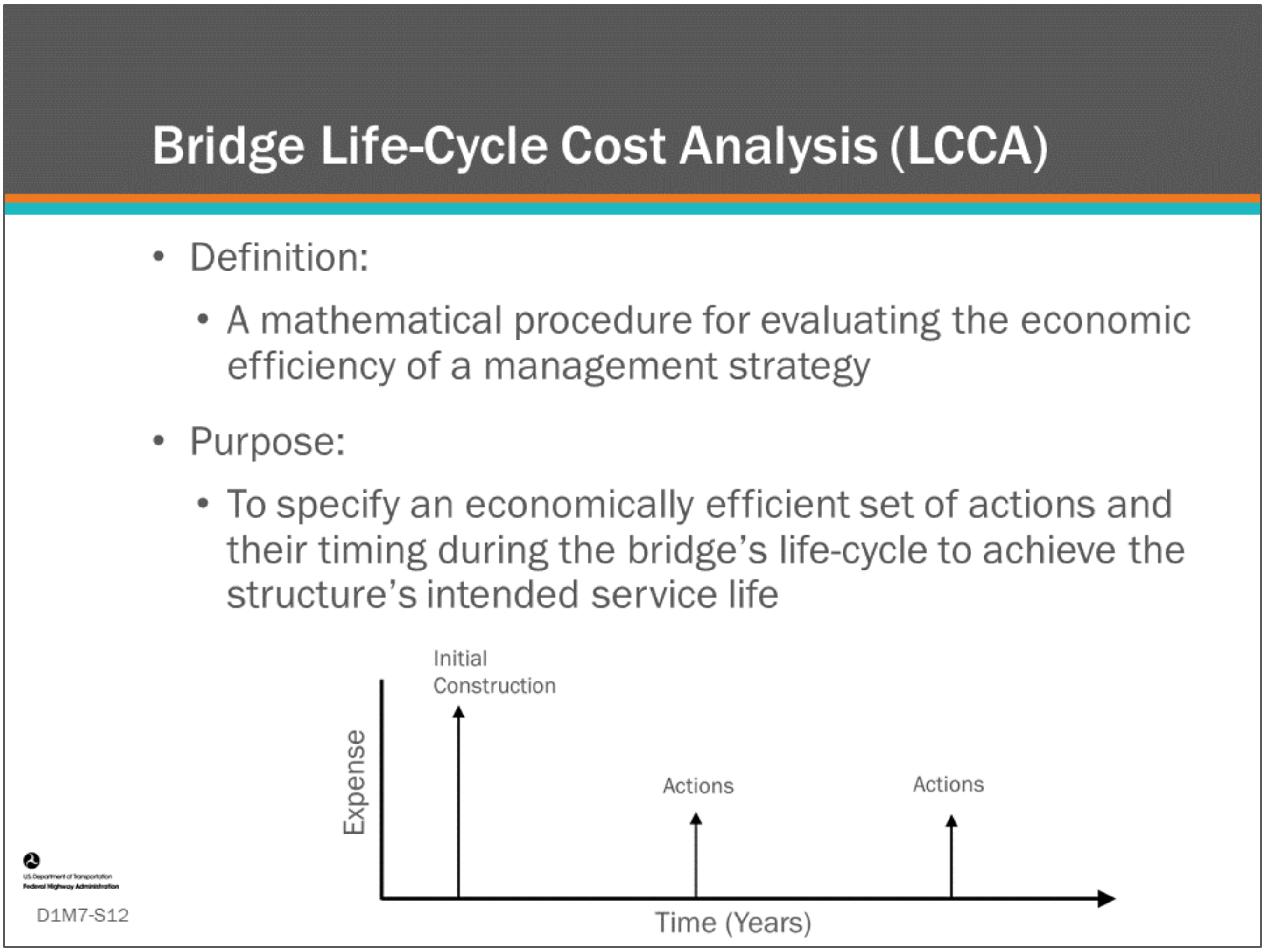
D1M7-Slide 11



Key Message

This topic will provide an overview of bridge LCCA which is a common method for comparing the multiple life-cycle models.

D1M7-Slide 12

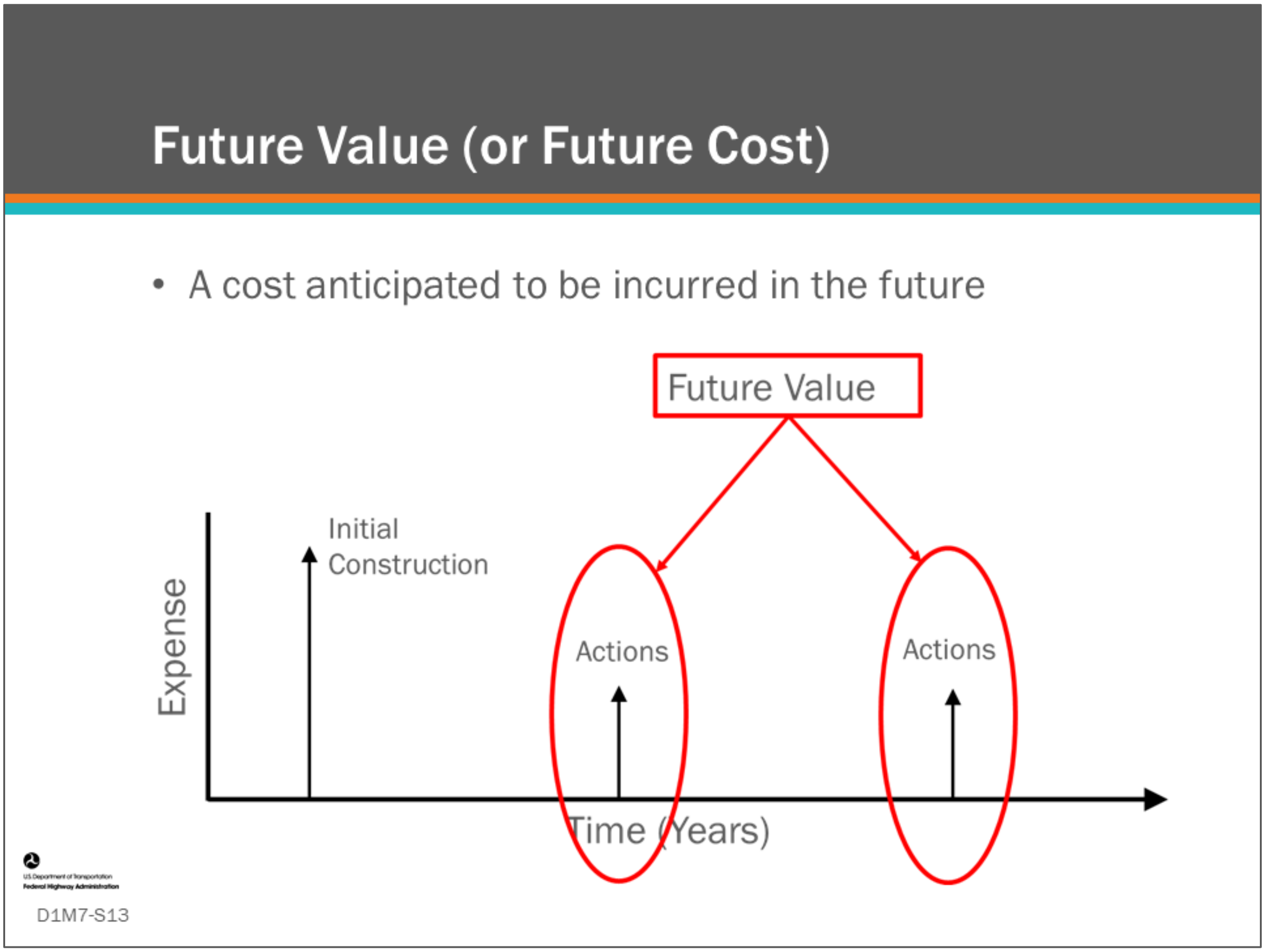


Key Message

Definition for bridge LCCA:

- A mathematical procedure for evaluating the economic efficiency of a management strategy or preservation model.
- It is a way of comparing preservation strategies or other strategies for rehabilitation or replacement projects to find the most cost-efficient strategy.

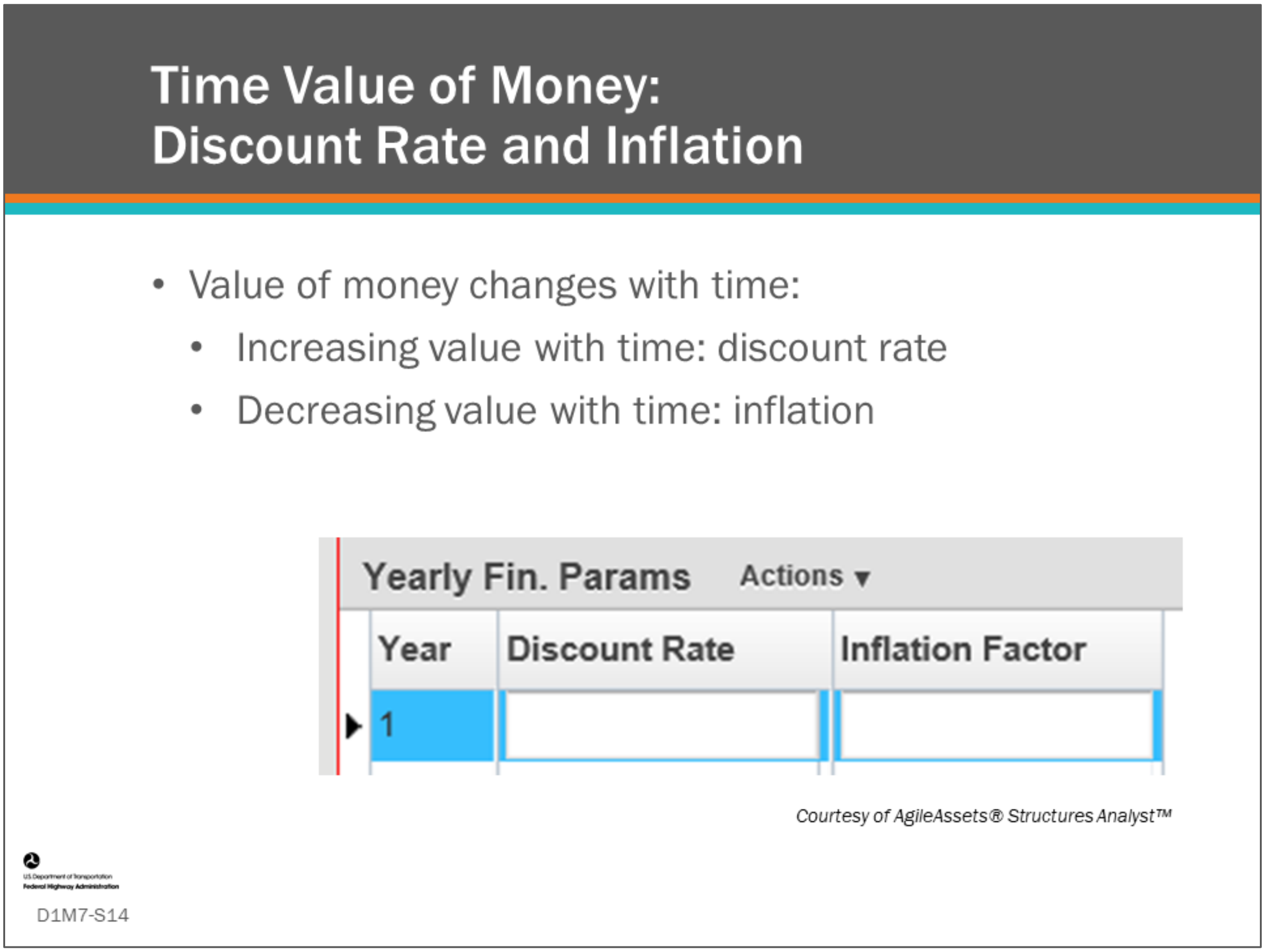
D1M7-Slide 13



Key Message

Future value is the cost incurred for an action at some time in the future.

D1M7-Slide 14



Key Message

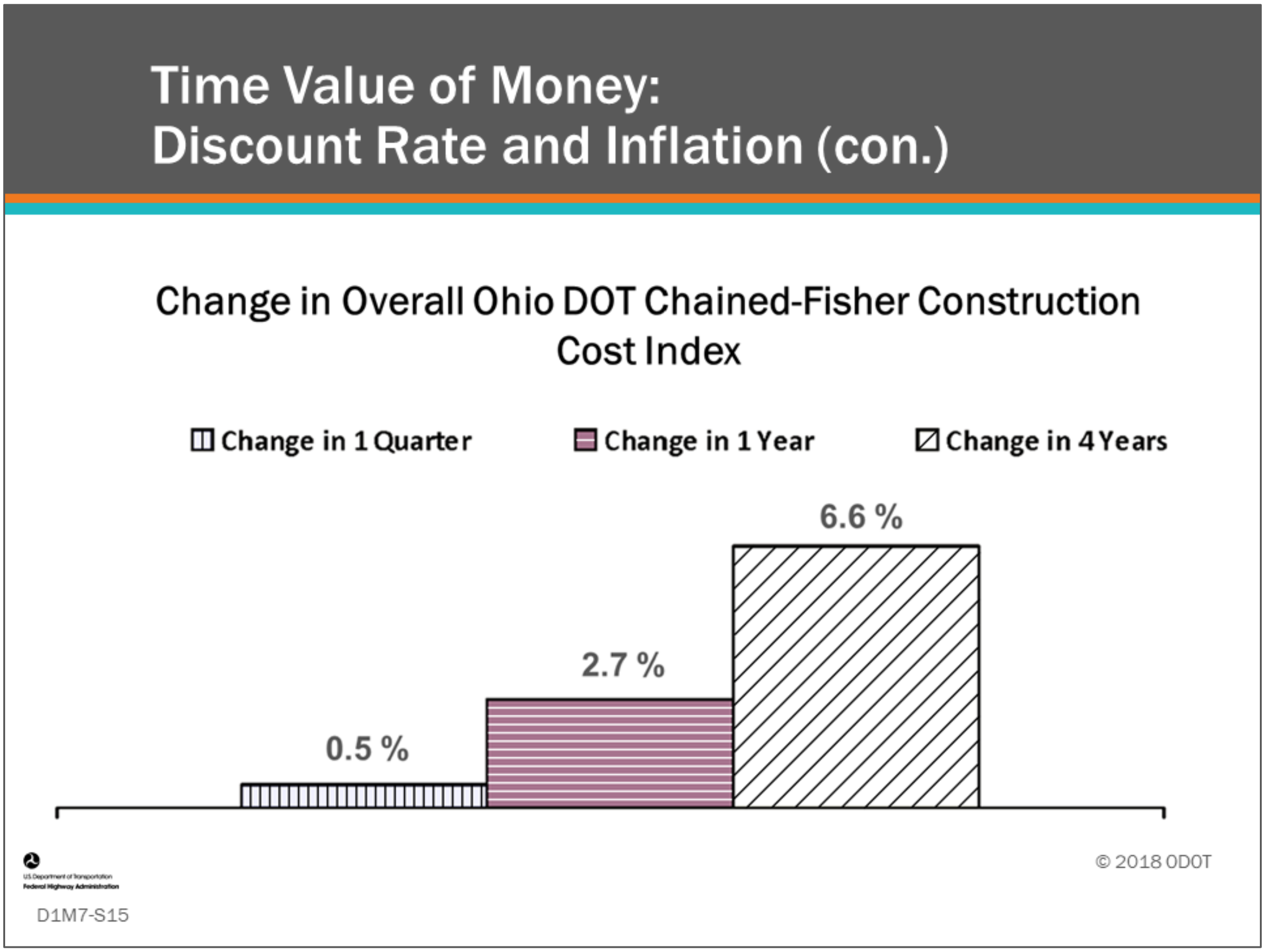
The time value of money is a concept that explains why money available today is worth more than an identical sum of money made available in the future (Investopedia 2018).

Money's increase in value is due to its potential to grow in value over time because of dividend payments and capital appreciation (discount rate). However, at the same time, material and labor costs often increase over time, which may more than offset the increase in value (inflation).

Some BMS software allow input of both discount rate and inflation rates as shown on the slide (screenshot from AgileAssets® Bridge Analyst™ software).

When setting up life-cycle models and LCCA in a BMS, remember that discount rate and inflation rate directly oppose each other.

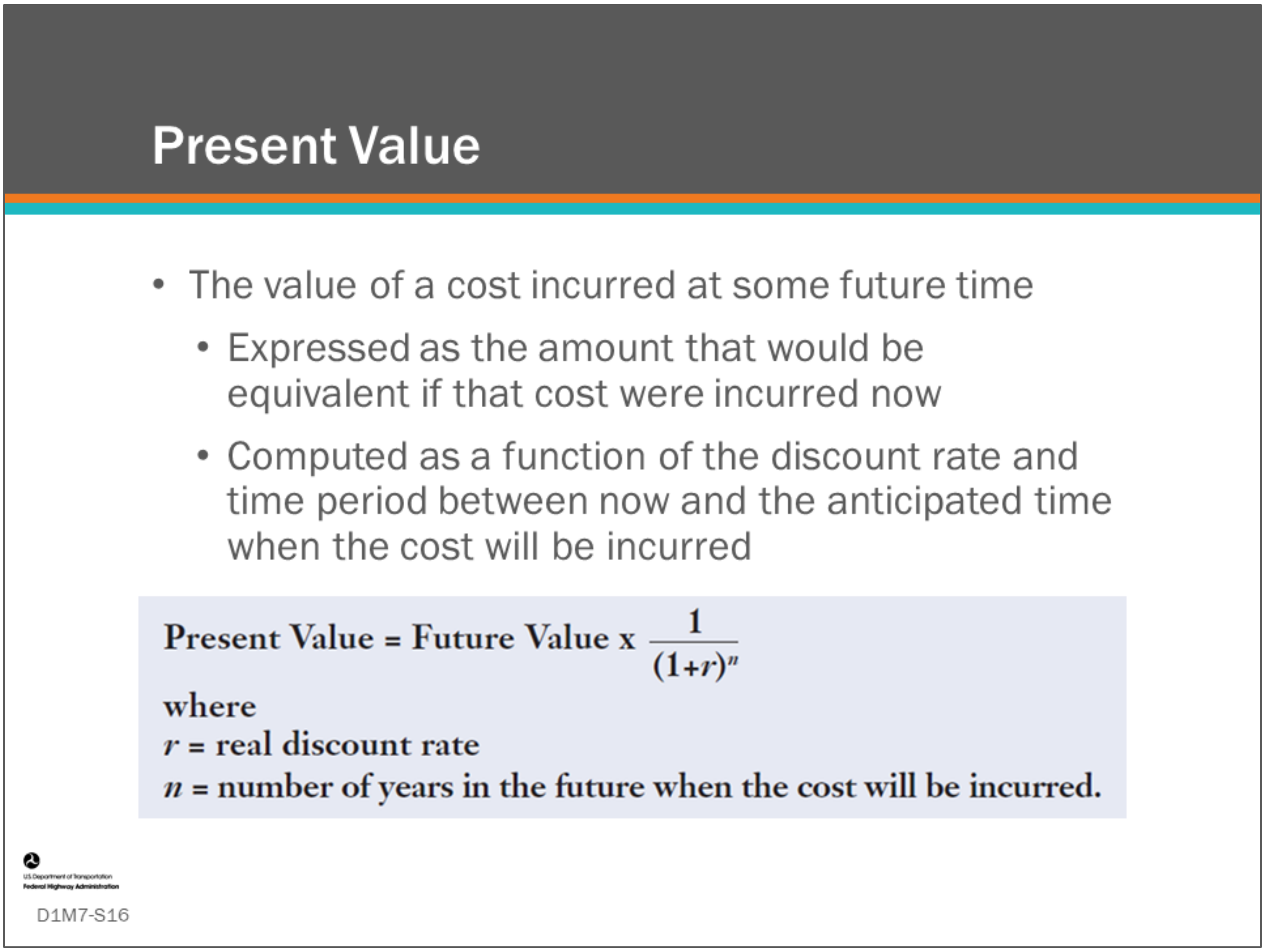
D1M7-Slide 15



Key Message

Many Agencies track the cost of doing construction. For example, this slide shows the change in construction cost in Ohio for a four-year period.

D1M7-Slide 16



Key Message

The slide shows the definition for present value.

Typically, in a BMS, present value is the equivalent performance measure for comparing life-cycle cost of alternatives.

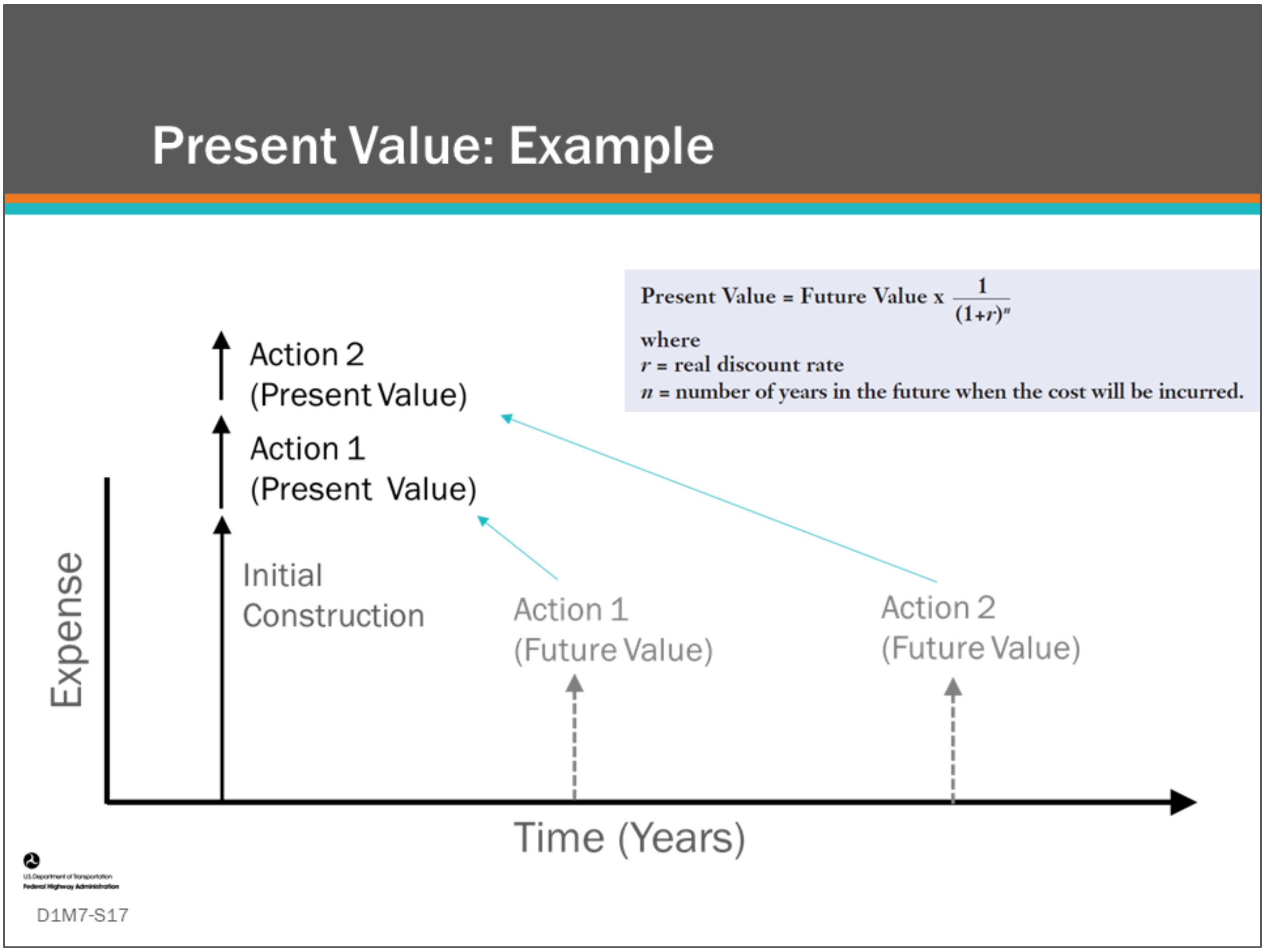
- The formula to discount future value cost to present value is shown on the slide.
- The term $1/(1+r)^n$ is called the "discount factor" and is always less than or equal to one.

Discount rate is the value used to compute the equivalent present value of a future cost; the real discount rate accounts for inflation (most Agencies do not consider inflation), the relative financial risk of an investment, and the time value of money.

- The discount rate is key to determining the economic efficiency of a life-cycle strategy and Agency policy normally determines the appropriate discount rates to be used.

Defining the analysis period extends beyond life-cycle cost analysis. When forecasting the outcome of alternative investment strategies, the analysis period should be long enough to discern the long-term differences between investment strategies.

D1M7-Slide 17



Key Message

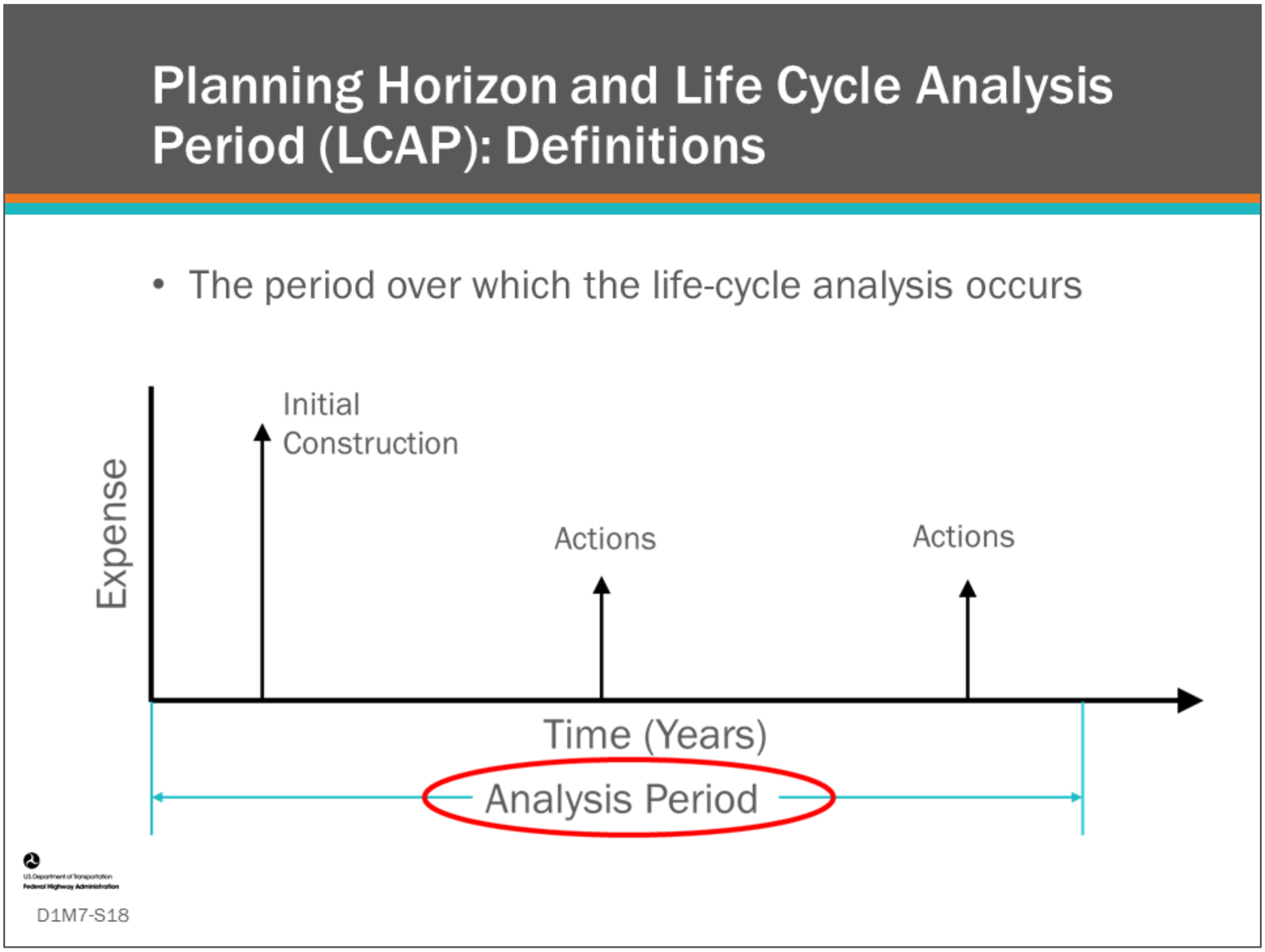
Using the present value formula, the two future values shown on the slide can be presented as Present Values.

For example:

- If Action 1 has a future value (cost) of $10,000 incurred in year 20, discounted to the present (year zero) at 4 percent real discount rate (r equal to 0.04), would have a net present value of $4,563.
- Action 2 has a future value (cost) of $10,000 incurred in year 40, discounted to the present (year zero) at 4 percent real discount rate (r equal to 0.04), would have a net present value of $2,083.
- If the initial construction of the bridge is $100,000, the total present value of this life-cycle strategy is the sum of $100,000 and $4,563 and 2,083 equal to $106,646.

Converting all future values to a present value allows comparison of multiple life-cycle strategies.

D1M7-Slide 18



Key Message

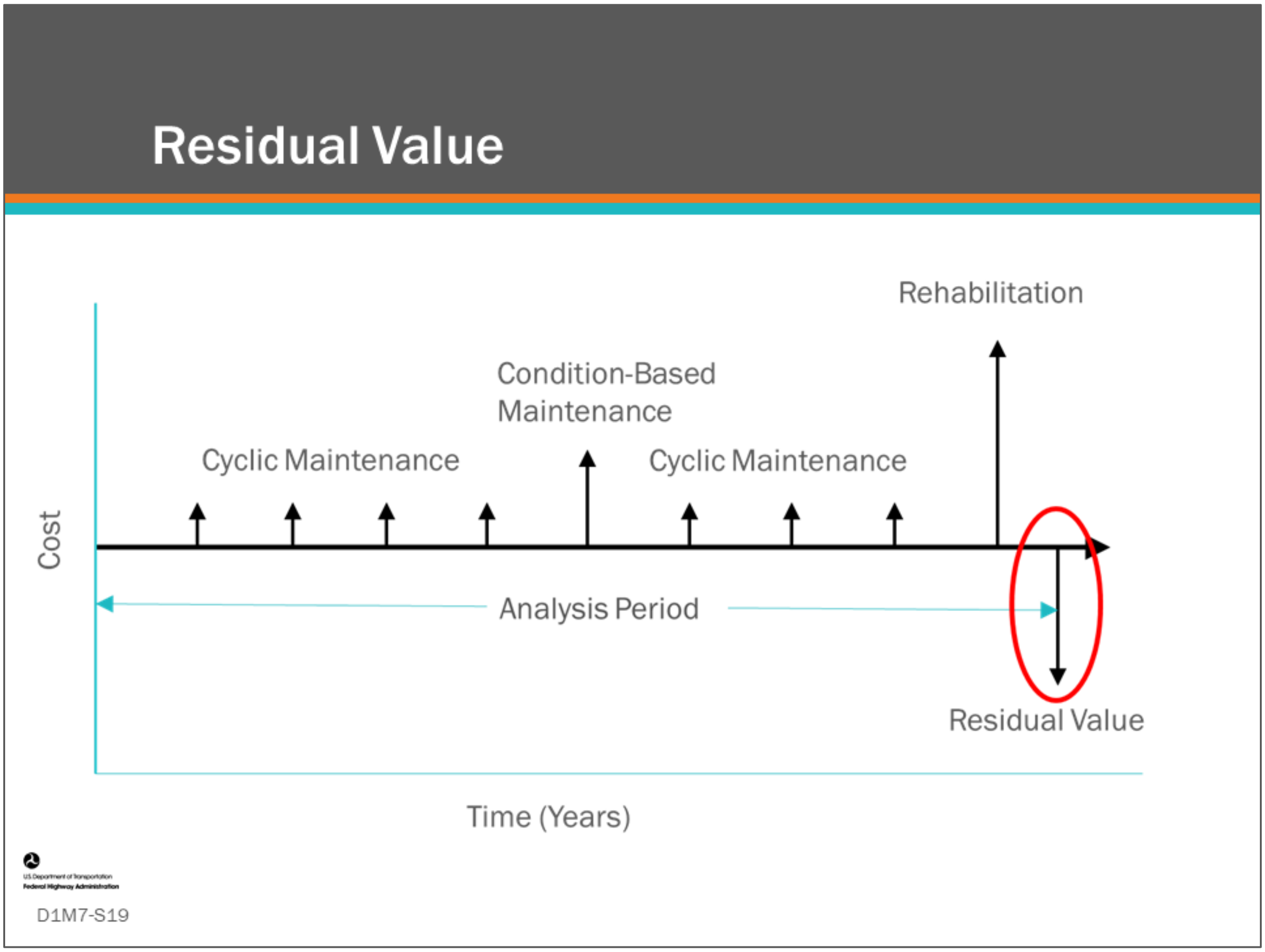
When comparing multiple life-cycle strategies, a fixed analysis period needs to be selected. The life-cycle analysis period should not be confused with the planning horizon.

The three terms are defined as follows:

- Planning horizon is the period of work program simulation.
- Life Cycle Analysis Period (LCAP) is the entire period over which costs of a strategy are evaluated.
- Planning period is the period covered in a strategic plan such as a Transportation Asset Management Plan or Long Range Transportation Plan or the period of a planned program of projects such as a Transportation Improvement Plan.

The LCAP for a bridge should capture all major actions including replacement and therefore will exceed the planning horizon.

D1M7-Slide 19

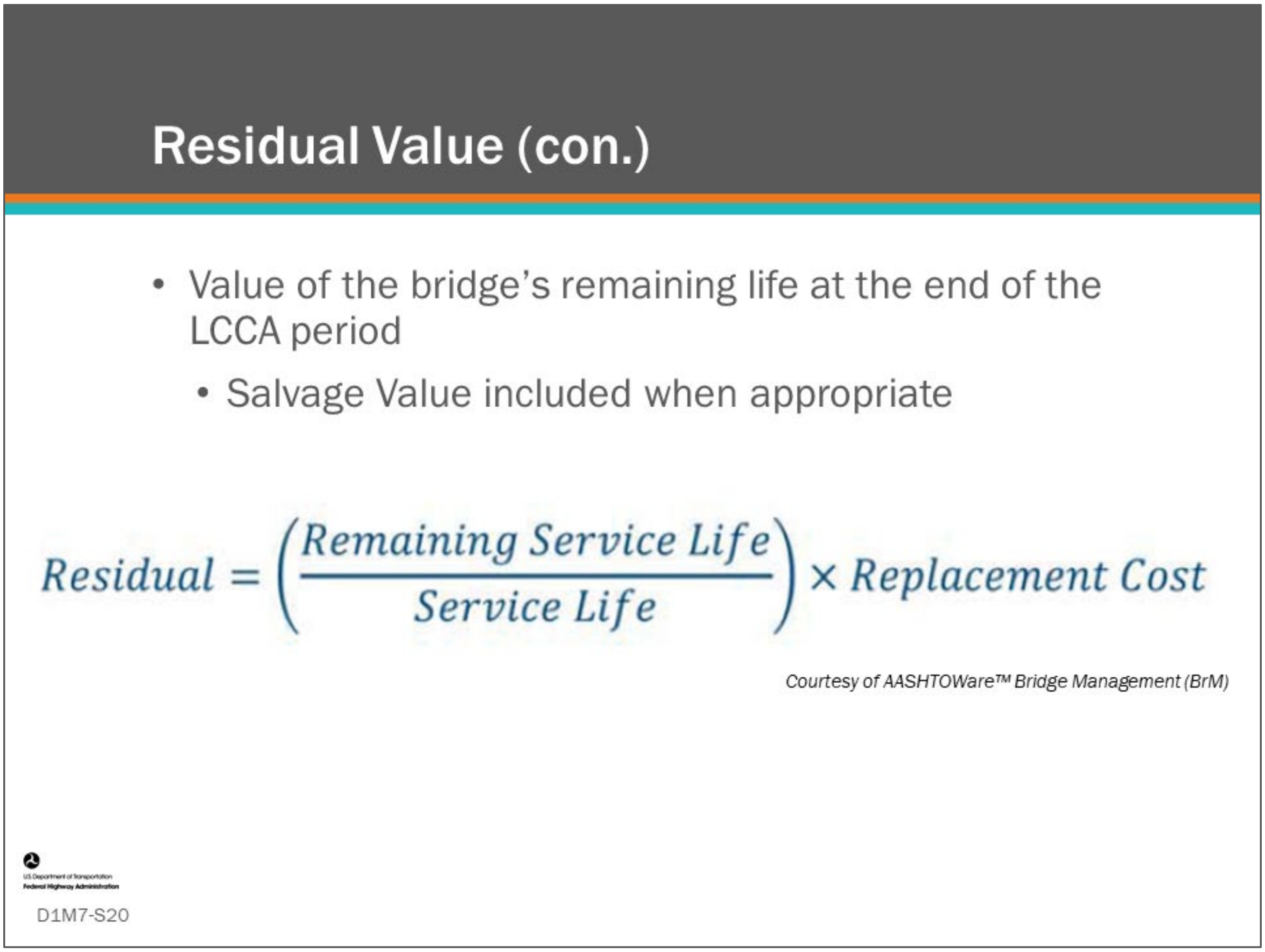


Key Message

The Life-Cycle Activity Profile (LCAP) for Maintenance, Repair, Rehabilitation (MR&R) candidates in a BMS most often are bridges that are already in service at the beginning of the analysis period, and they will remain in service either in their present form or as replacement bridges after the analysis period.

As a result, an initial construction cost may not be shown in the life-cycle activity profile. At the end of the analysis period, a "residual value" or "extended benefit" for the bridge needs to be provided for in some way.

D1M7-Slide 20



Key Message

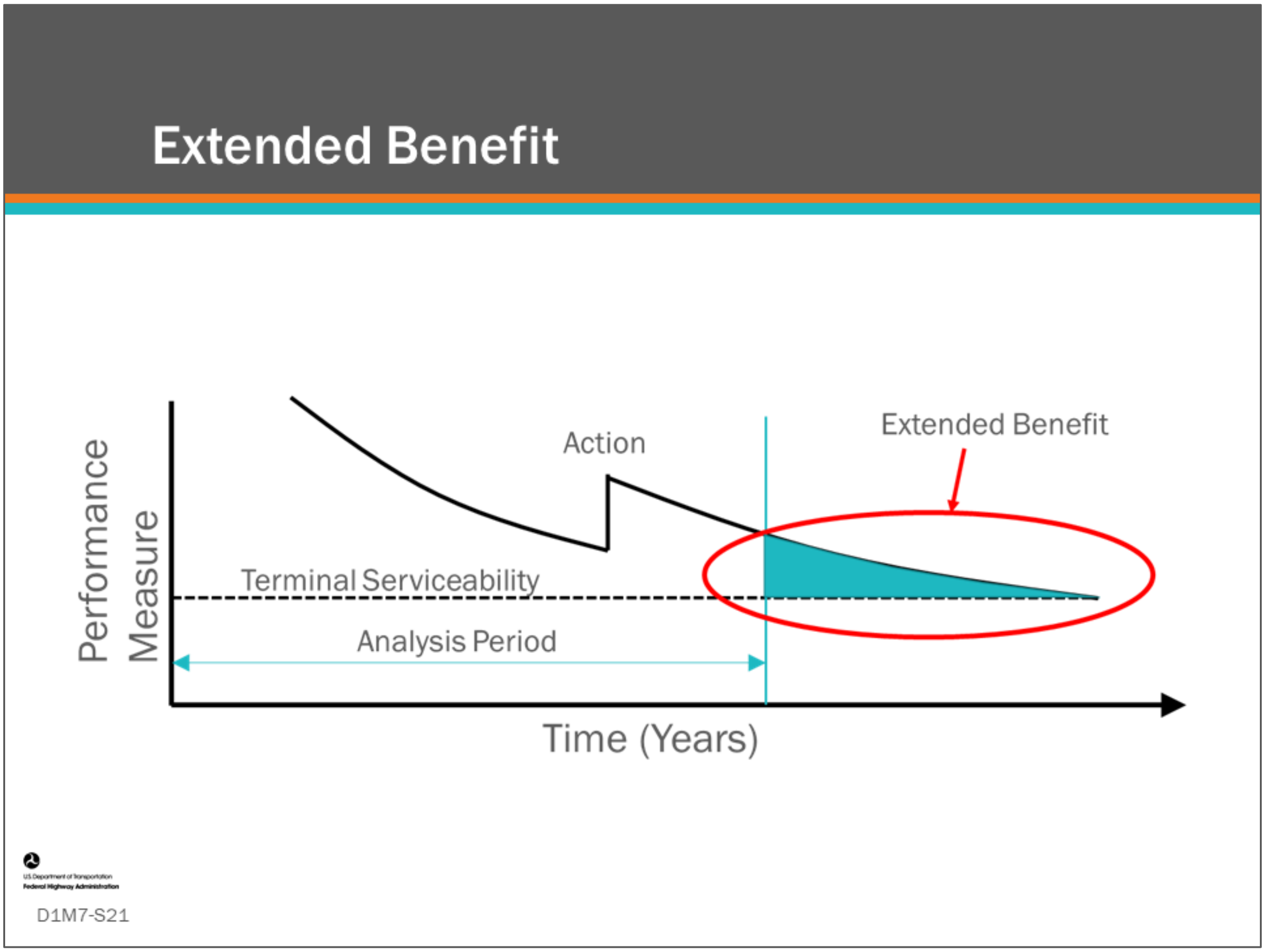
Residual value is the value of the structure at the end of the analysis period.

- This variable is an important part of a life-cycle cost analysis as it equates treatments that will produce different residual value of the bridge at the end of the analysis period.

BMS software have several different ways to account for this.

- For example, the AASHTOWare™ Bridge Management (BrM) software calculates residual value using the equation shown on the slide.

D1M7-Slide 21

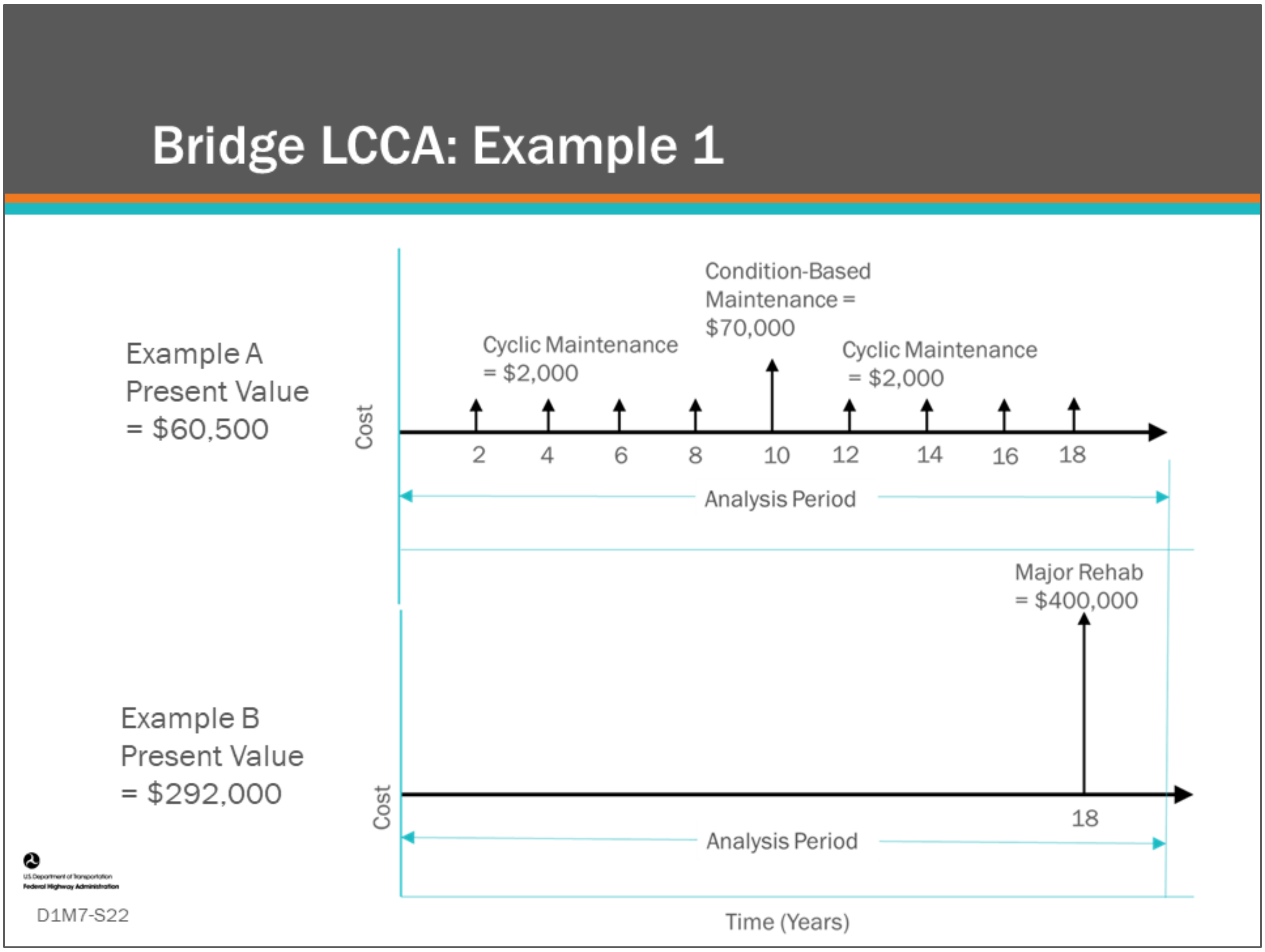


Key Message

Adding a calculated residual value to the net present value of the cost in life cycle cost analysis is one way to account for the remaining value of the asset at the end of the analysis period. However, if the benefit of a strategy is being calculated as the area under the performance curve; then, another way to account for remaining value at the end of the analysis period, is to calculate the additional area under the performance curve until the performance curve reaches a terminal serviceability.

- This additional “extended benefit” (the area indicated in the chart) can then be added to the benefit value calculated during the analysis period.

D1M7-Slide 22



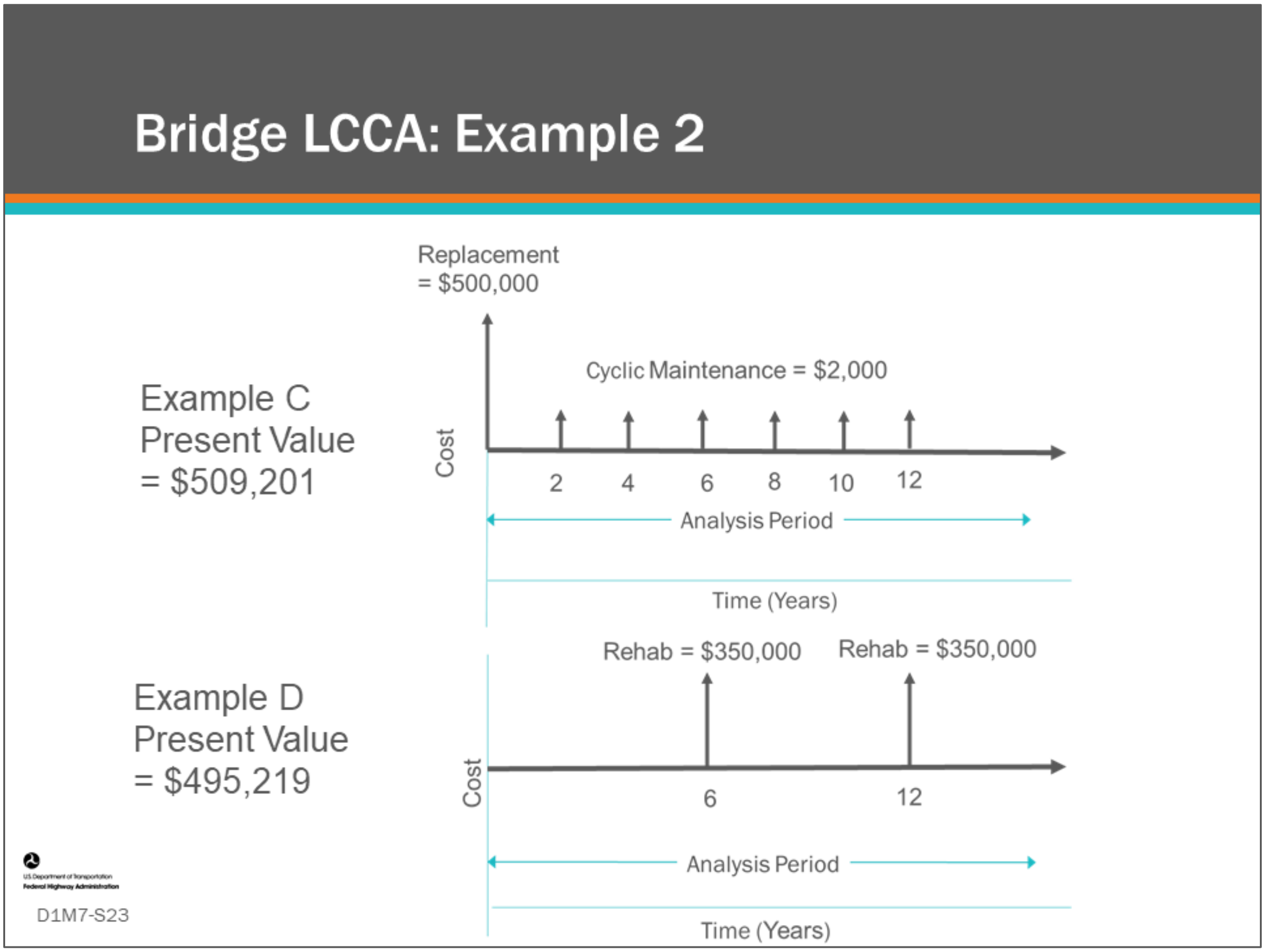
Key Message

This slide shows two Life-Cycle Activity Profiles and resulting Present Value for each. Discount rate for the example is 4 percent.

- Example A shows a series of cyclic maintenance done every two years at a cost of $2,000 each and a condition-based maintenance project done at year 10 for a cost of $70,000. The resulting present value using the equation for Present Value in Example A is $60,500.
- Example B shows a single major rehabilitation project at 18 years with a cost of $400,000. The resulting present value using the equation on Slide 18 for present value in Example B is $292,000.

Example A is the more efficient strategy, as demonstrated by its lower Present Value of the future activities.

D1M7-Slide 23



Key Message

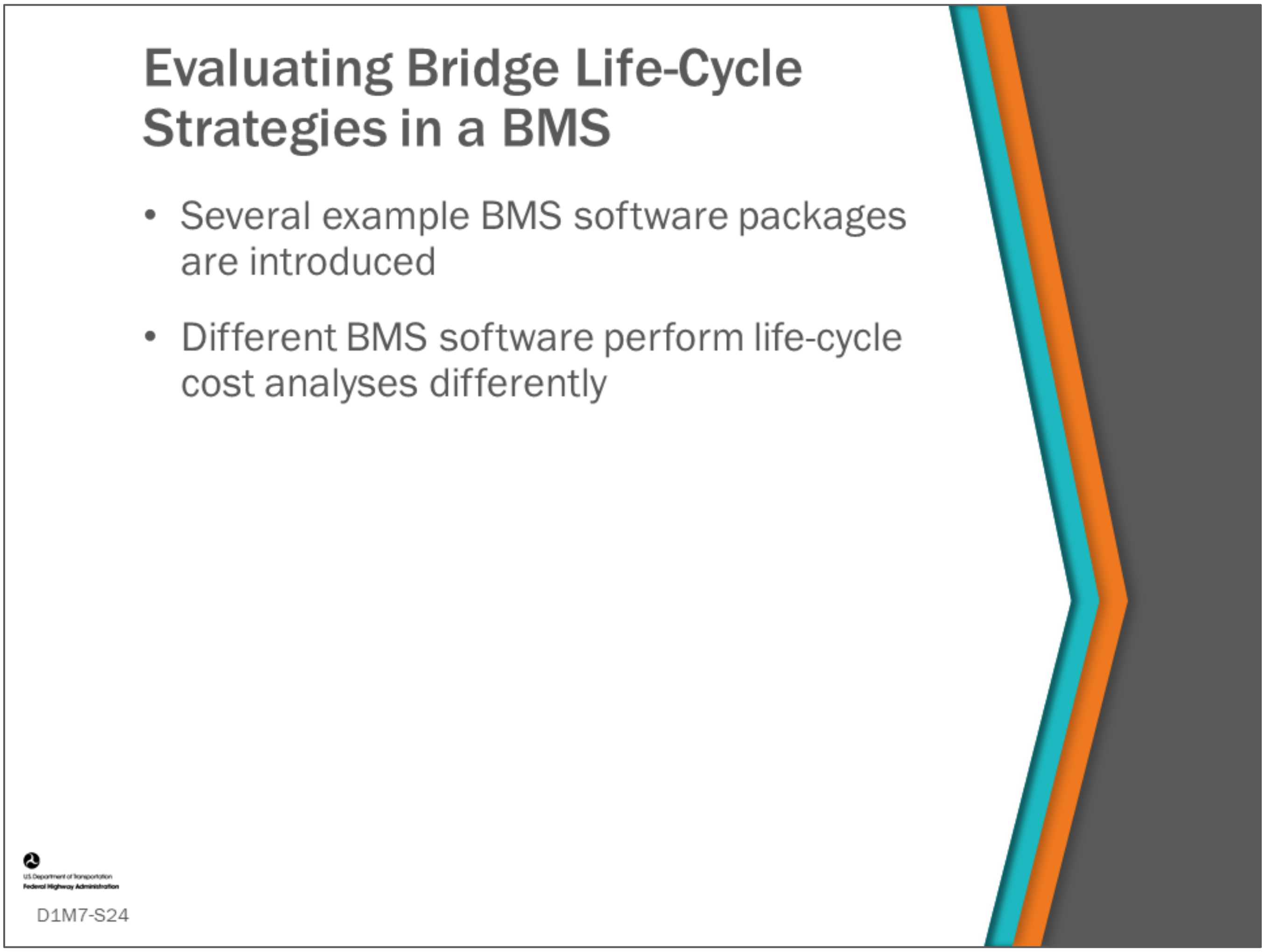
This slide shows two Life-Cycle Activity Profiles and resulting Present Value for each. Discount rate for the example is 4 percent (r=0.04).

- Example C shows a reconstruction (replacement) action with a cost of $500,000 in year 0 and a series of cyclic maintenance done every two years at a cost of $2000 each. The resulting present value using the equation for Present Value in Example A is $509,201.
- Example D shows major rehabilitation projects at 6 and 12 years with a cost of $350,000. The resulting present value using the equation for Present Value in Example B is $495,219.

Example D is the more efficient strategy, as demonstrated by its lower present value of the future activities without consideration of the Residual Value.

An important value of BMS LCCA computations is the ability to determine what is the least life-cycle cost action to take on a bridge in the current programming period. Expanding on the examples given here, each potential action that could be reasonably taken in the present day (including no action), and the resulting trailing actions, can be compared on the basis of life-cycle cost.

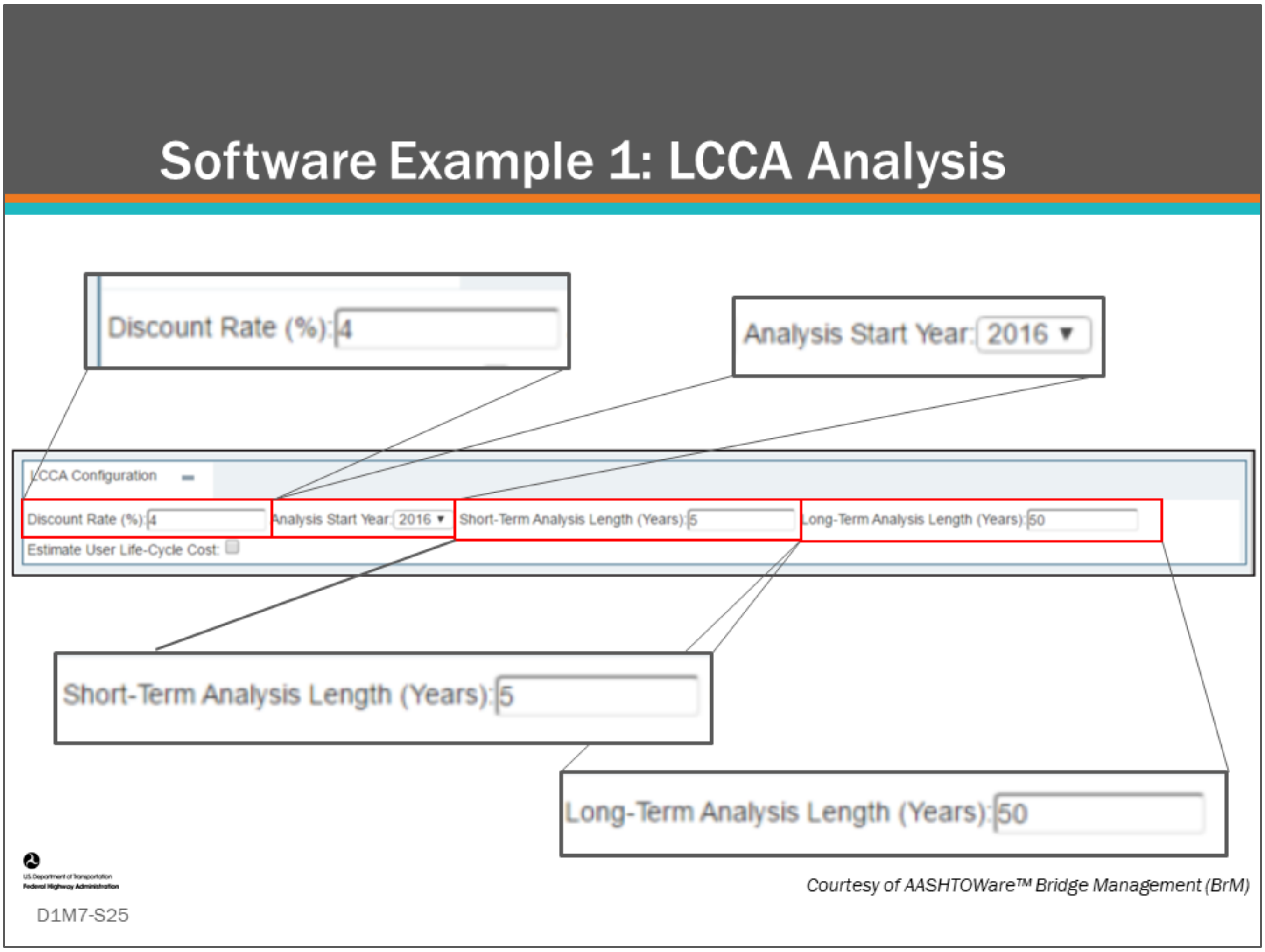
D1M7-Slide 24



Key Message

This topic will cover inputting life-cycle cost analysis values into several example BMS software packages and compares how the different BMS software perform LCCA.

D1M7-Slide 25

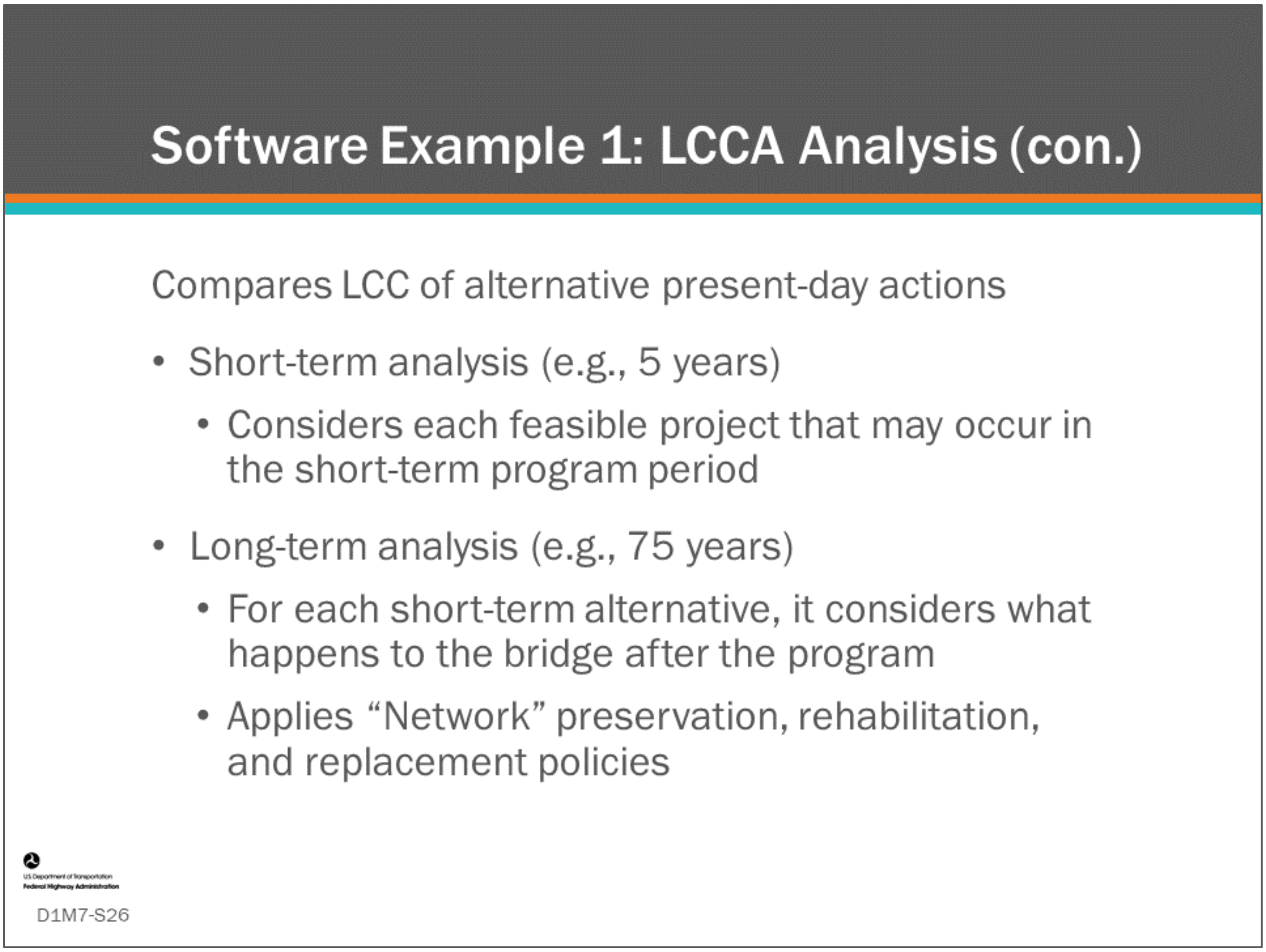


Key Message

In our first software example, the AASHTOWare™ Bridge Management (BrM) software provides a feature that does life-cycle cost comparison for multiple short-term actions for individual bridges.

- This slide shows a screenshot of the AASHTOWare™ Bridge Management (BrM) LCCA configuration screen which has inputs for discount rate, analysis start year, short-term analysis length, and long-term analysis length.

D1M7-Slide 26

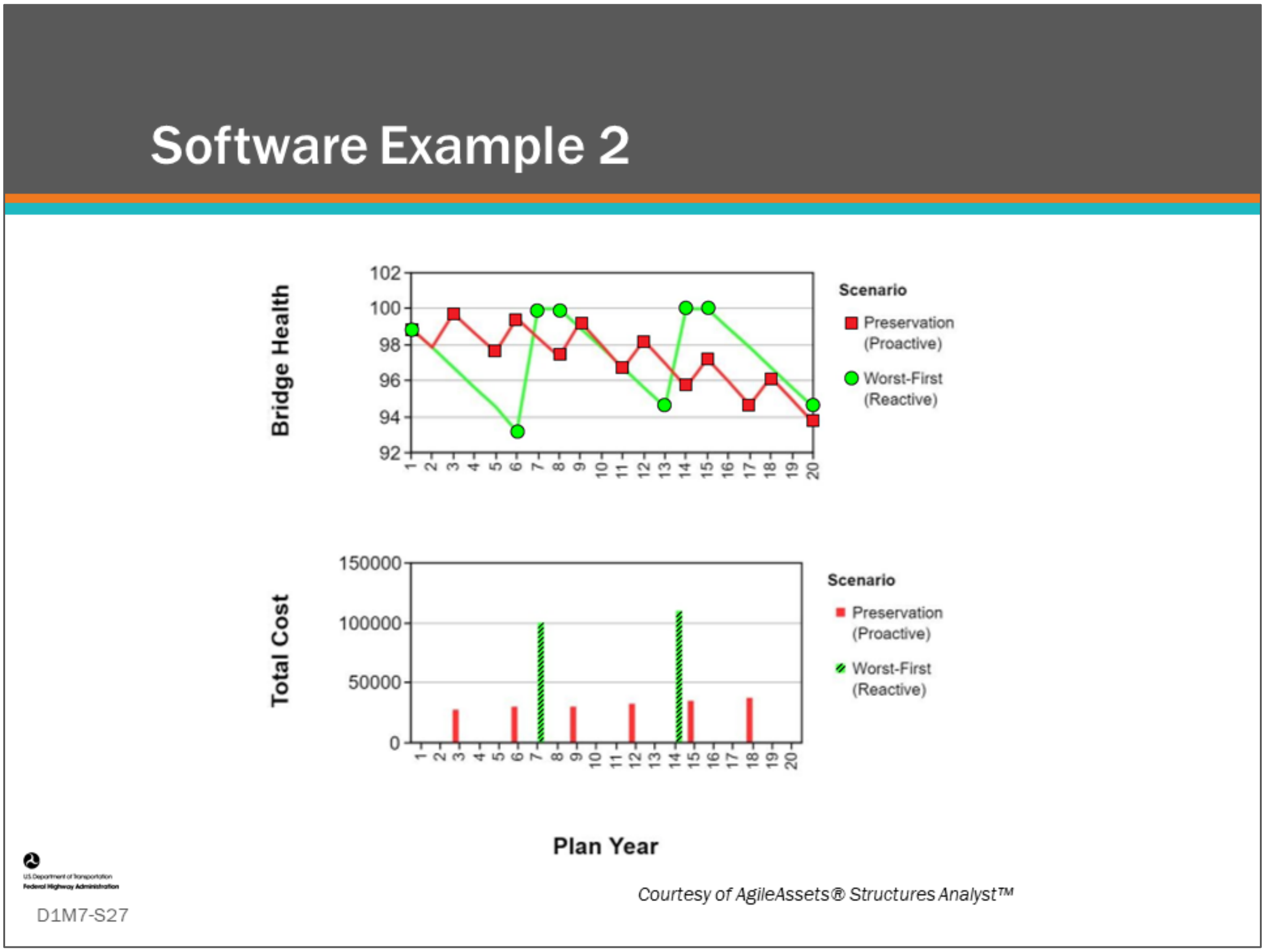


Key Message

The short-term analysis in AASHTOWare™ Bridge Management (BrM) provides a more detailed comparison of treatments in the near term (compared to long-term).

- The Analysis-LCCA screen will show a comparison of the treatments using LCCA, and the user can pick which option to set a work candidate which can be used for prioritization and optimization.
- The long-term analysis applies life-cycle policies to the structure over the long-term analysis period and returns a present value which is used to compare benefit cost of alternative actions on a bridge based on life-cycle cost and to compare other candidate bridges, allowing for prioritization and optimization of the program.

D1M7-Slide 27

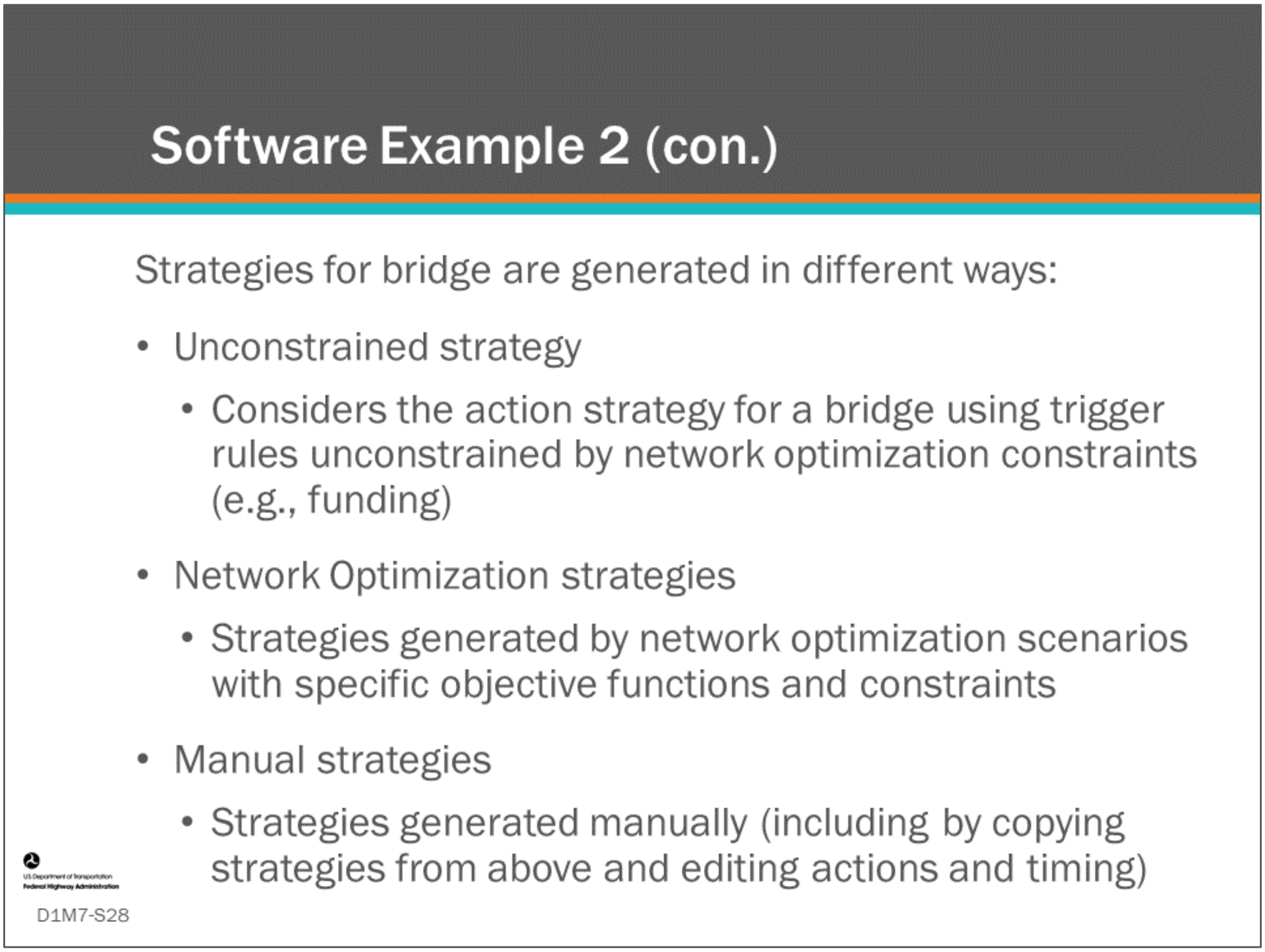


Key Message

Our second software example uses AgileAssets® Structures Analyst™ (Bridges>Analysis>Long Term Analysis>Structures Analysis).

- The screenshot shows comparison of two life-cycle strategies, a worst-first strategy and a preservation strategy.
- Bridge Health over Analysis Period is shown in the top chart and a life-cycle activity profile is shown in the bottom chart for each of the two strategies. AgileAssets® Structures Analyst™ can then report net present value (NPV) for any particular strategy.
- Note, however, that the software does not optimize strategies using NPV but rather uses cost/benefit ratio where benefit is calculated as area under the performance curve as noted earlier.

D1M7-Slide 28



Key Message

In AgileAssets® Structures Analyst™ software, different strategies (sequences of actions) for a bridge can be generated and compared.

Strategies can be compared on the basis of benefit (area under the deterioration curve of a performance index), cost (agency cost), and benefit/cost ratio.

D1M7-Slide 29

Software Example 3 Showing Present Value (PV)

Strategy Data | Efficiency Chart | Strategy Chart

Export to Excel | Select Strategy | Reset Strategy

Year	First Major	Benefit / Cost	PV Benefits
2022	Str_Bridge_Major_Rehab	0.029276001	$55,027.04
2026	Str_Bridge_Minor_Rehab	0.037593761	$33,991.14
			$0.00
2023	Str_Bridge_Major_Rehab	0.028286863	$52,656.63
2024	Str_Bridge_Major_Rehab	0.027321506	$50,370.56
2025	Str_Bridge_Major_Rehab	0.026379287	$48,165.84
2026	Str_Bridge_Major_Rehab	0.025459578	$46,039.56
2027	Str_Bridge_Major_Rehab	0.024561767	$43,988.93
2028	Str_Bridge_Replacement	0.006926759	$42,806.70
2018	Str_Bridge_Minor_Rehab	0.043631714	$42,620.75
2017	Str_Bridge_Minor_Rehab	0.043102055	$42,512.14
2028	Str_Bridge_Major_Rehab	0.023685259	$42,011.27

Courtesy of Deighton dTIMS©

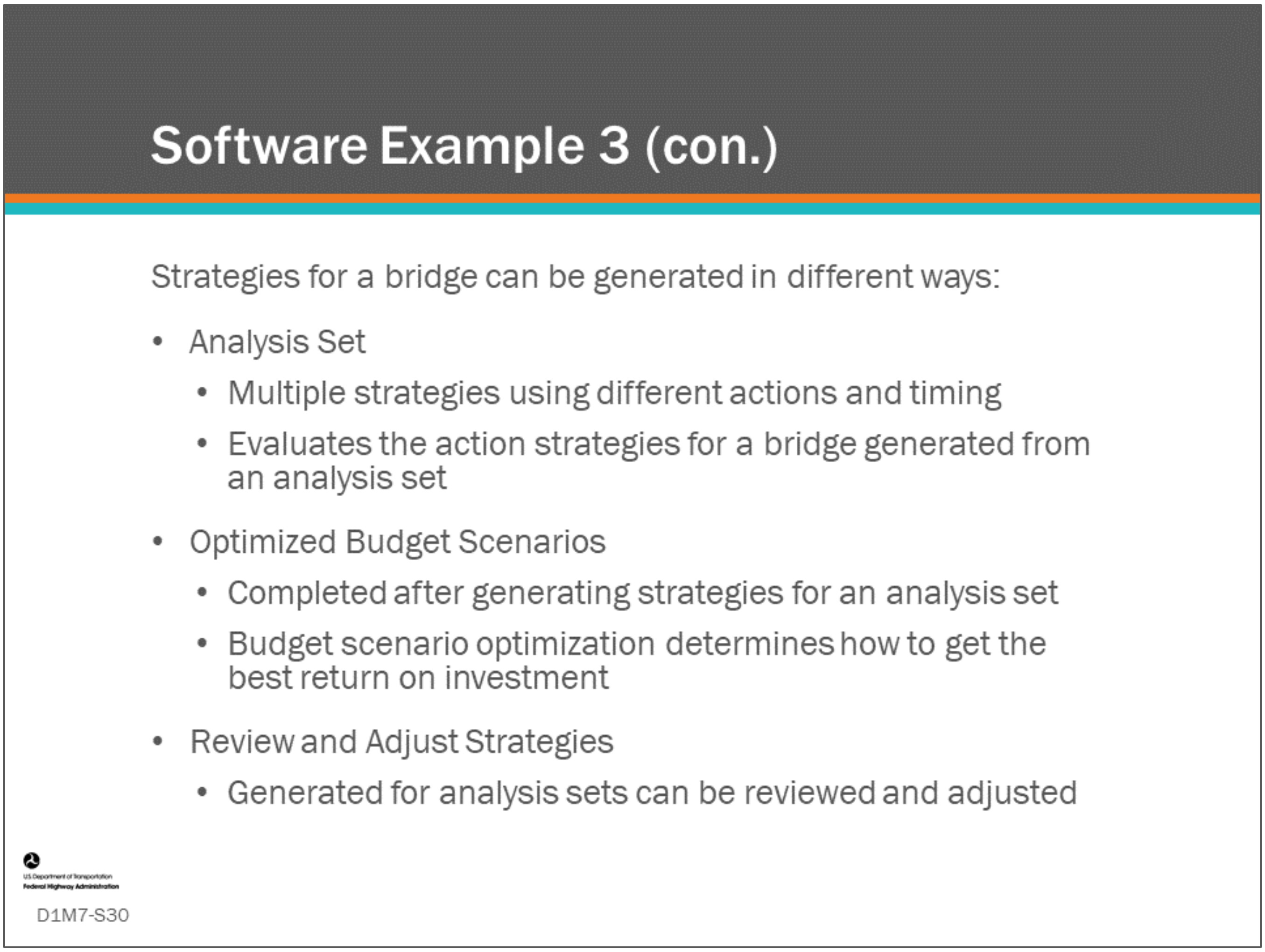
D1M7-S29

Key Message

In our third software example, we see a screenshot of the Deighton dTIMS© software, Export screen.

- In the far-right column, Present Value (PV) is shown for several actions (e.g., rehab and replacement) being compared for a single bridge for multiple strategies different years.
- In Deighton dTIMS©, the Present Value (PV) can represent the area under the curve for a bridge composite index, which is often a health index.

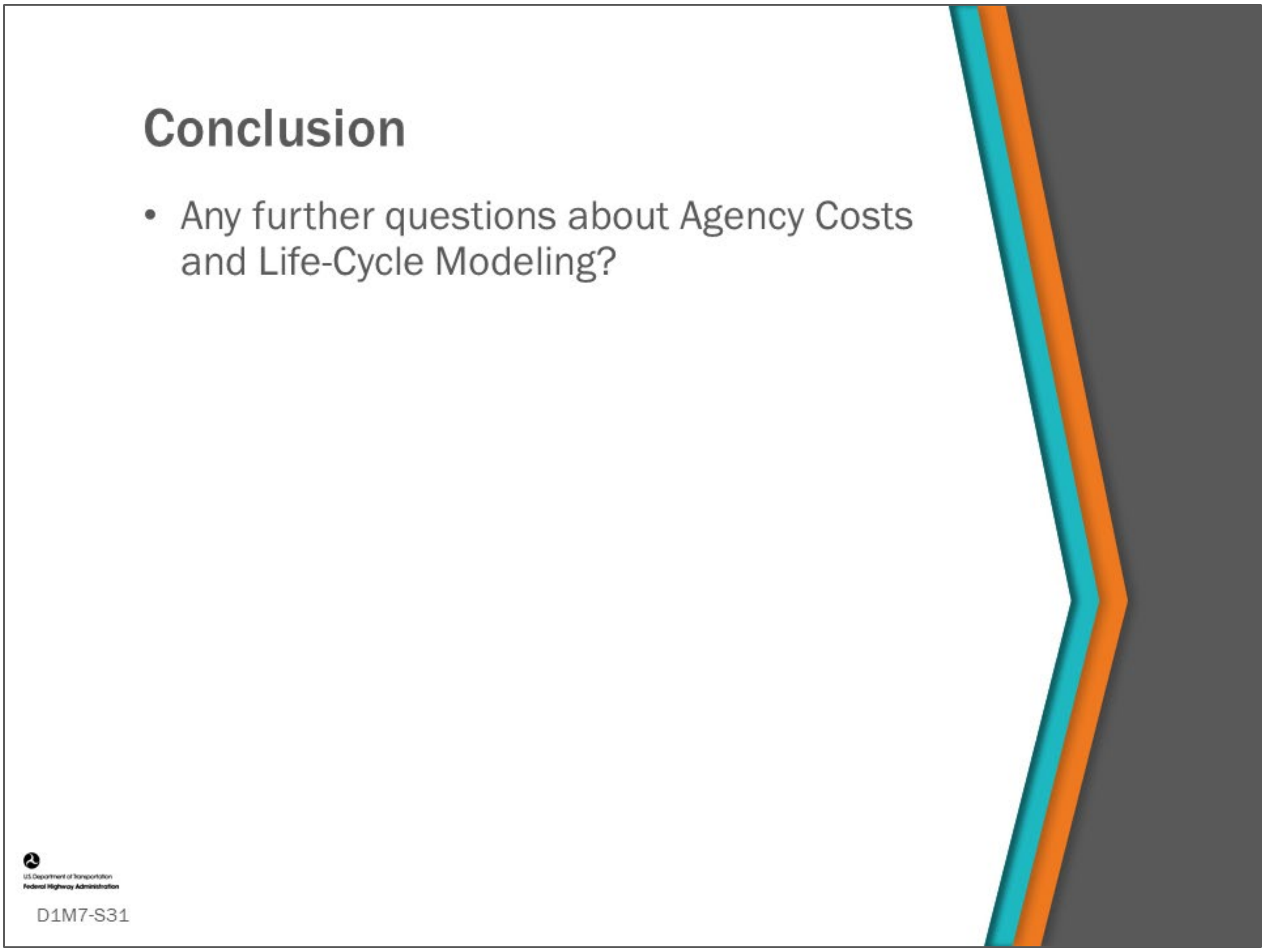
D1M7-Slide 30



Key Message

- In Deighton dTIMS©, after optimizing a budget scenario, the "Review and Adjust" step allows you to look at multiple optimization analysis strategies for each bridge. The strategies for comparison are listed from a chosen analysis set and compared on the costs and benefits.
- The strategy with the highest benefit to cost ratio is listed first.

D1M7-Slide 31



Key Message

This concludes D1M7: Agency Costs and Life-Cycle Modeling.

D1M7-Slide 32

Slide #	Image Description	Source Information
4	A life-cycle is a sequence of actions, outcomes, events, and consequences that characterize a bridge's design, construction, and use through its service life.	This Workshop.
5	Photo of bridge worker pressure washing exposed rebar on bridge pier.	Adobe Stock.
8	The top chart is a line chart having Performance Measure on the y-axis and time in years on the x-axis. The bottom chart shows a life-cycle activity profile which is a horizontal line representing time with vertical arrows representing expenditures.	This Workshop.
9	The top profile shows a tall arrow at right side of the profile for replace bridge. The bottom profile shows four short arrows for cyclic maintenance, and two medium tall arrows for preventive maintenance.	This Workshop.
10	The top chart showing two Hot Mix Asphalt (HMA) overlays applied to the bridge deck and a Latex-Modified Concrete Rigid overlay applied in a later year. The bottom life-cycle activity profile shows two epoxy overlays placed on the bridge deck.	This Workshop.
12	A life-cycle activity profile showing from left to right; tall arrow for initial construction, medium arrows for action, and action.	This Workshop.
13	A life cycle activity profile showing a cost anticipated to be incurred in the future.	This Workshop.
14	Screenshot from AgileAssets® Structures Analyst™ software showing input text boxes for discount rate and inflation rate.	AgileAssets® Structures Analyst™ software.

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D1M7-S32

D1M7 Figure Source List

D1M7-Slide 33

Slide #	Image Description	Source Information
15	A bar chart shows the change in overall ODT Chained-Fisher Construction Cost Index for 1 quarter, 1 year, and 4 years.	Ohio DOT. *Cost Index and Forecasting.* Office of Estimating, Bid Analysis Review Team.
15	An equation shows Present Value equals Future Value times 1 over (1 plus r) to the n power. r is real discount rate. n is number of years in the future when the cost will be incurred.	FHWA. *Life-Cycle Cost Analysis Primer*, Office of Asset Management USDOT. Washington, DC, 2002. Page 17.
17	A life-cycle activity profile shows from left to right; initial construction with Action 1 and Action 2 present value all at the same location (the present).	This Workshop.
17	An equation shows Present Value equals Future Value times 1 over (1 plus r) to the n power. r is real discount rate. n is number of years in the future when the cost will be incurred.	FHWA. *Life-Cycle Cost Analysis Primer*, Office of Asset Management USDOT. Washington, DC, 2002. Page 17.
18	A life-cycle activity profile shows from left to right, a tall arrow pointing up representing initial construction, a medium tall arrow pointing up representing action, and a medium tall arrow pointing up representing action.	This Workshop.

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D1M7-S33

D1M7 Figure Source List

D1M7-Slide 34

Slide #	Image Description	Source Information
19	A life-cycle activity profile shows from left to right; cyclic maintenance (four times) as short arrows pointing up, a medium tall arrow pointing up representing condition-based maintenance, three short arrow representing cycling maintenance, a tall arrow pointing up representing rehabilitation, and a medium tall arrow pointing down representing residual value.	This Workshop.
20	An equation shows residual equals (remaining service life divided by service life) times replacement cost.	AASHTOWare™ Bridge Management (BrM).
21	A deterioration curve with actions is shown with a vertical line shown after an action representing the analysis period.	This Workshop.
22	Top graphic shows a life-cycle activity profile shows from left to right four short arrows pointing up equally spaced representing cyclic maintenance, a medium tall arrow pointing up representing condition-based maintenance, then three short arrows pointing up equally spaced representing cyclic maintenance. Bottom graphic shows a life-cycle activity profile showing one tall arrow at the right side representing major rehab.	This Workshop.
23	Top graphic shows a two life-cycle activity profiles showing from left to right one long arrow pointing up representing replacement, six short arrows pointing up equally spaced representing cyclic maintenance. Bottom graphic shows a life-cycle activity profile showing two medium length arrows pointing up representing rehab.	This Workshop.
25	A screenshot from AASHTOWare™ Bridge Management (BrM) shows input text boxes for discount rate, analysis start year, short-term analysis length, and long-term analysis length.	AASHTOWare™ Bridge Management (BrM).

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D1M7-S34

D1M7 Figure Source List

D1M7-Slide 35

Slide #	Image Description	Source Information
27	Graphic showing a screen shot of the AgileAssets® Structures Analyst™ (Bridges>Analysis>Long Term Analysis>Structures Analysis) screen.	AgileAssets® Structures Analyst™ software.
29	Screen shot showing Deighton dTIMS© "Export to Excel" list showing Present Value (PV) Benefits column highlighted by a red circle.	Deighton dTIMS© software.

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D1M7-S35

D1M7 Figure Source List

Module Title: D1M8 – Life-Cycle User Costs and Functional Assessment and Improvement Models

Module Time: 15 minutes

Module Summary

Functional improvement and modernization of the infrastructure reduces risks of increased user costs by eliminating, mitigating or reducing bridge functional or operational deficiencies, and/or improving capacity. A BMS may account for these projects and coordinate this work with bridge condition-based work. Like the previous module for agency costs, different types of user costs (such as vehicle operating costs, delay, and accident costs) will be defined. The modeling of functional improvement will be introduced. This module will review different types of user costs, introduce utility as a surrogate for direct dollar values, and introduce the class to modeling user costs and benefits.

Expected Outcome

The expected outcome of this topic will be an understanding of how other factors beyond condition can affect a bridge program, and how these factors can be accounted for in a BMS.

Resource List

Slide	Reference Information
7	NCHRP. *Report 483 Bridge Life-Cycle Cost Analysis*. Washington, DC, 2003.
8	NCHRP. *Report 590 Multi-Objective Optimization for Bridge Management Systems.* Washington, DC, 2007.
9	AASHTO. *AASHTOWare™ Bridge Management (BrM) User's Manual*, version 5.2.3, Washington, DC, 2016.
11,12	Thompson, P., et al. *Development of Pontis User Cost Models for Florida,* FDOT, 1999.
11	Johnston, D.W., et al. *Developing User Costs for Bridge Management Systems,* Transportation Research Circular 423, TRB, National Research Council, Washington, DC, 1994.
11, 13-15	AASHTO. *Pontis Release 4.4 User's Manual*. Washington, DC, 2005.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D1M8-Slide 1

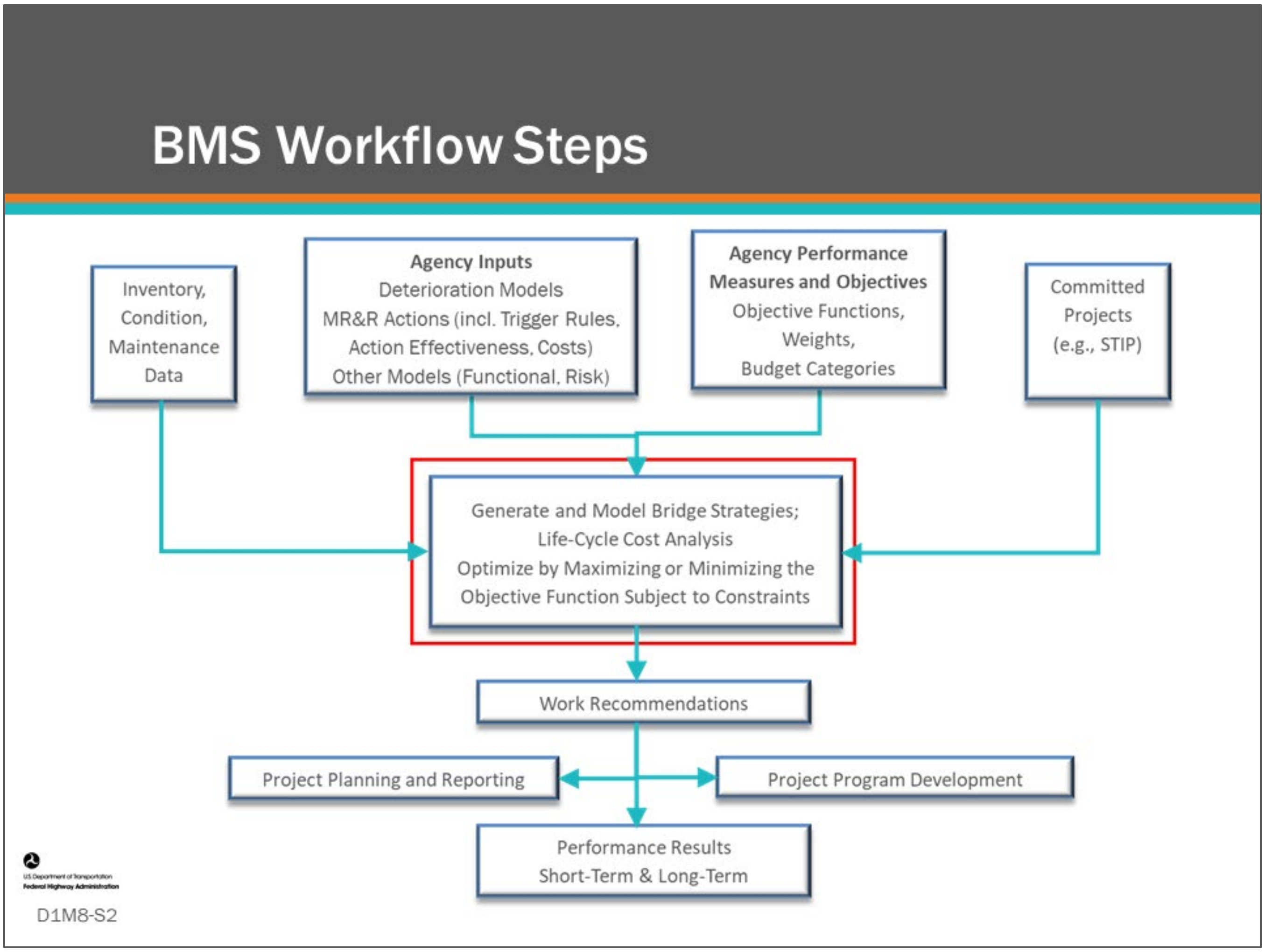
Key Message

Following the previous module on “agency costs”, this module will look at “user costs” and how they fit into a bridge management system. Functional assessment and improvement models will also be introduced.

Disclaimer

FHWA does not promote or endorse patented and proprietary products. Bridge management software is largely proprietary. Workshop content pertaining to proprietary software is included only to illustrate how bridge management system concepts and analyses are applied in practice. The included content shall not be construed as promotion or endorsement of specific software.

D1M8-Slide 2



Key Message

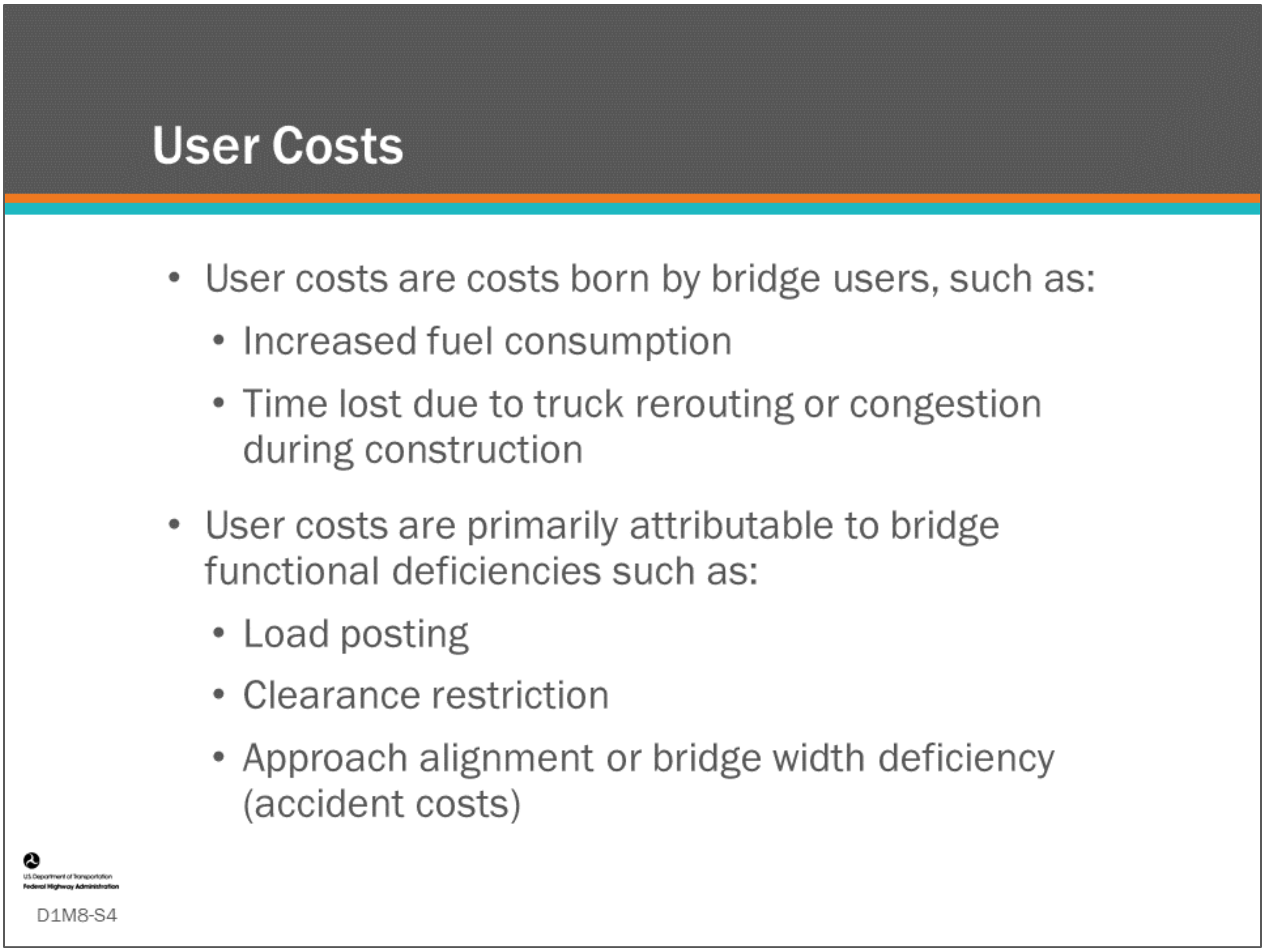
Common workflow steps and features are shown on the slide. In this first section of this module, we will review how to Generate and Model Bridge Strategies.

D1M8-Slide 3

Key Message

The topics covered in this module include life-cycle user costs, functional assessment, and improvement models.

D1M8-Slide 4



Key Message

This slide describes user costs. User costs can be in the form of delay costs, operating costs, and denial-of-use costs.

User costs are costs borne by bridge users, such as:

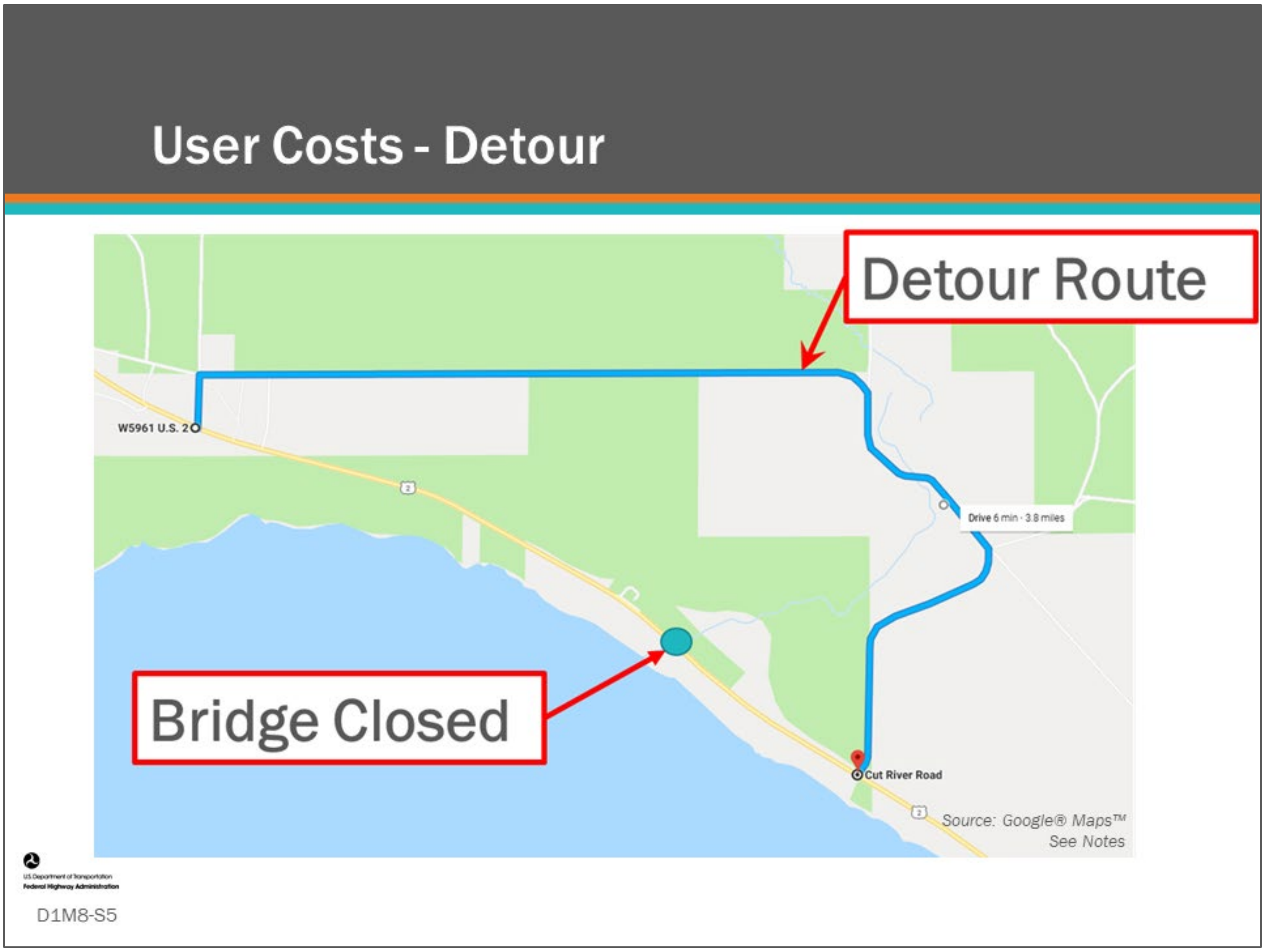
- Increased fuel consumption
- Time lost due to truck rerouting or congestion during construction

User costs are primarily attributable to the functional deficiency of a bridge

- Load posting
- Clearance restriction
- Approach alignment or bridge width deficiency (accident costs)

These functional deficiencies may cause higher vehicle-operating costs because of such factors as detours, lost travel time, and higher accident rates.

D1M8-Slide 5



Key Message
Detours produce user costs.

Vehicle take detours, either imposed by a restriction or self-imposed due to poor level of service, caused by:

- Narrow deck width
- Reduced lanes on the bridge as a result of poor condition
- Inadequate vertical clearance or load capacity

The detour costs consist of:

- Additional fuel consumption
- Vehicle wear and tear
- Value of the time lost

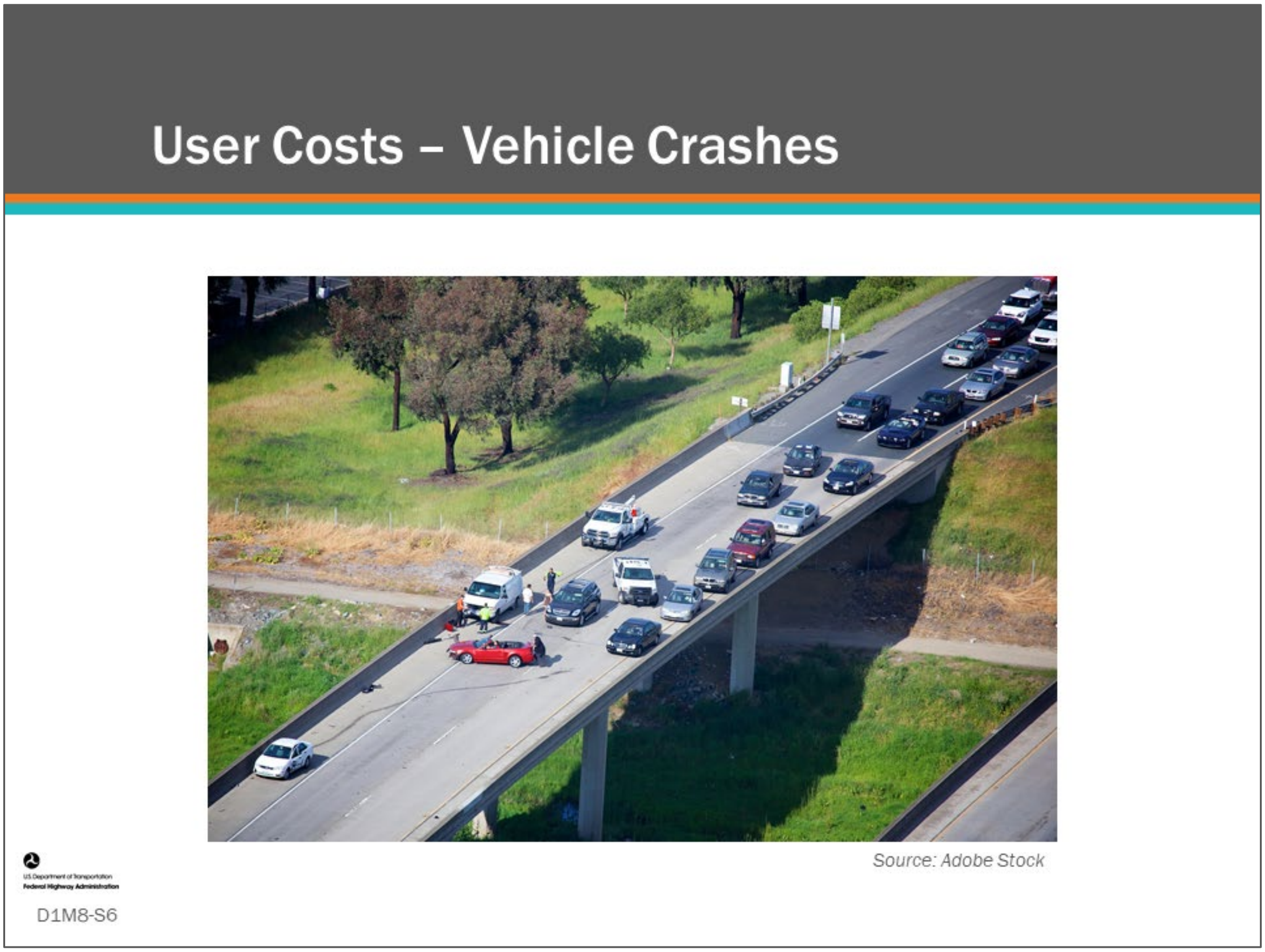
Variables that might be used when calculating user costs for detours are:

- Detour length
- Average Daily Traffic (ADT)
- Average Daily Truck Traffic (ADTT)
- Vehicle operating and labor cost as dollars per hour or dollars per mile

Notes

The original map is the copyright property of Google® Maps™ and can be accessed from https://www.google.com/maps. The map modifications showing a detour for a closed bridge were developed as part of this workshop. The modifications include a blue circle representing the location of the closed bridge, a blue line representing the associated detour route, and text boxes and arrows identifying both features.

D1M8-Slide 6



Key Message

Vehicle crashes contribute to user costs when the crashes are the result of bridge deficiencies.

Data that might be used to estimate user cost resulting from vehicle crashes includes:

- Vehicle crash data on or below the bridge
- Vehicle damage and personal injury costs
- Average daily traffic (ADT)

D1M8-Slide 7

User Costs - Construction Zone Delays

© 2007 TxDOT

$$UC = (\text{vehicles delayed}) \times (\text{average delay}) \times (\text{cost per unit delay time})$$

$$UC_{12} = 1{,}200 \times 0.50 \times \$8.00 = \$4{,}800.$$

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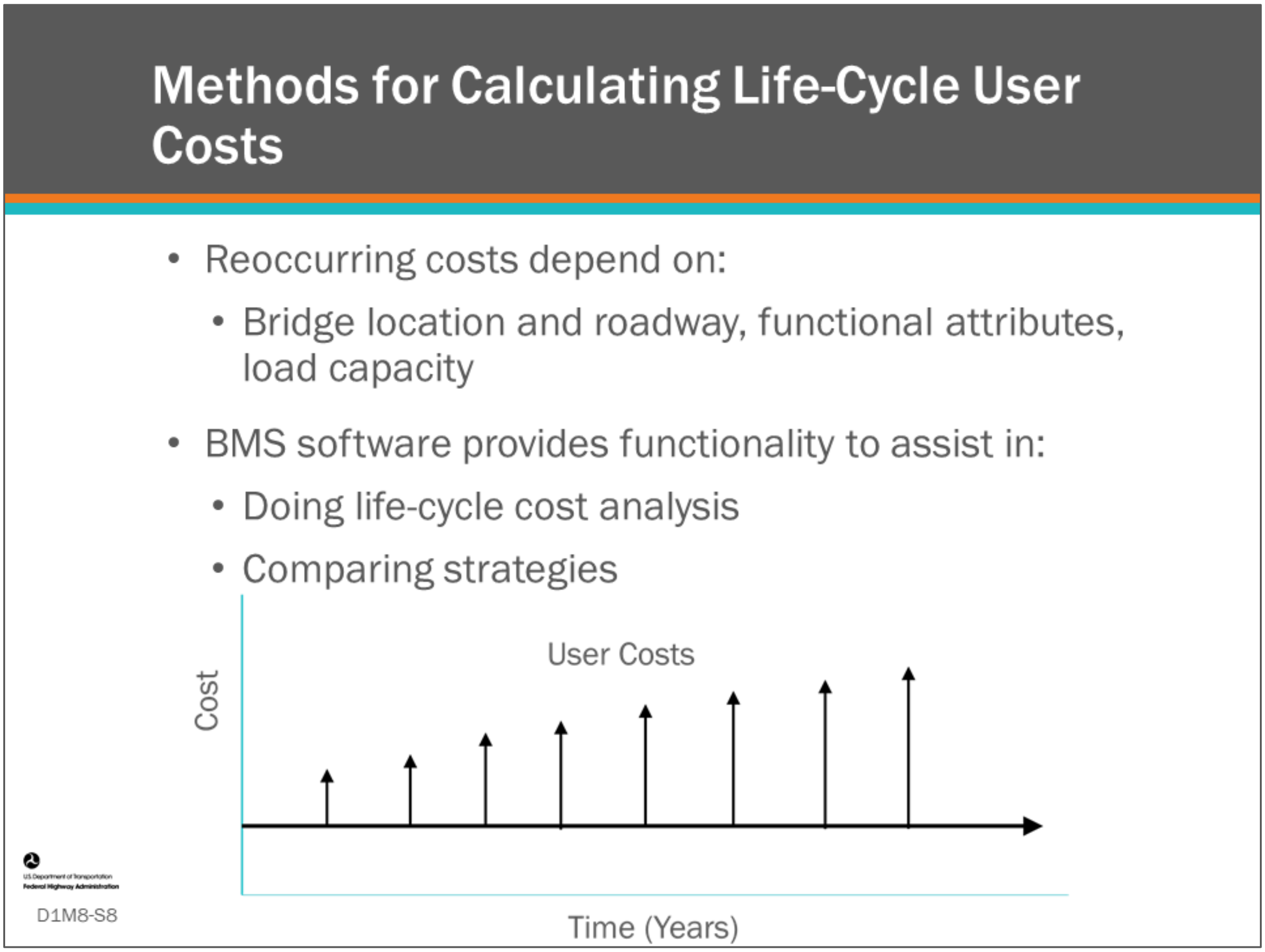
D1M8-S7

Key Message

- Bridge work (i.e., preservation, rehabilitation, or replacement work) often influences traffic flow both on the bridge, beneath the bridge, and on surrounding roads.
- When comparing construction methods, engineers may include user cost as a factor in deciding what type of construction methods are best for that location.
- Delays are different for replacement, rehabilitation, and preservation work types. When the delay costs are included in the models, they can be used to capture the different user costs associated with different work types in a bridge’s life cycle activity profile.
- This may influence the decision of which work type to perform and when.

A sample calculation for User Cost (UC) is shown.

D1M8-Slide 8

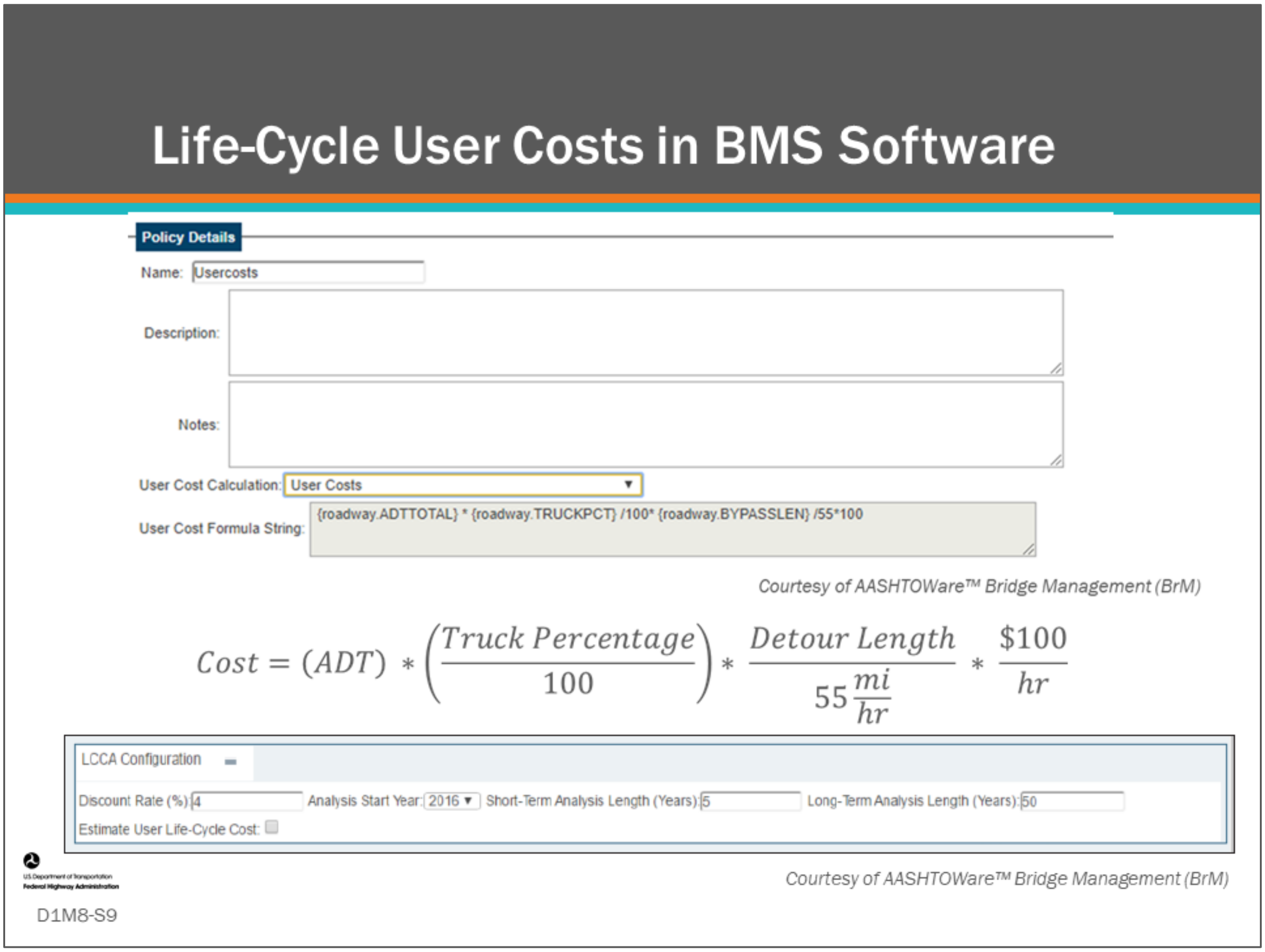


Key Message

- Since user costs from functional deficiencies are not one-time costs but extend over time (often many years), it is appropriate to convert them to life-cycle cost.
- Or, in the case of user construction impacts associated with different work types, since the work may be analyzed in both the present and future it is also appropriate to convert those costs to net present value. Life-cycle user costs are those user costs that you model in your BMS software.
- These can be annual expenditures that can increase with time as a bridge deteriorates or traffic levels increase.

From NCHRP, *Report 590,* Page 69, "When a functional deficiency is found to exist on a bridge, the effect on road users is represented as a user cost. This user cost is calculated for each year of the deficiency, discounted to present value, and added to life-cycle cost. Functional improvements may eliminate certain user costs, so that they do not occur in the year of the action or any following years. User costs are proportional to traffic volume, so they change each year because of traffic growth. In most cases, the model interpolates the traffic volume for any given year based on a constant growth rate between the most recent average daily traffic (ADT) and the future ADT provided in the roadway table of the bridge management system".

D1M8-Slide 9



Key Message

BMS software allow user costs to be input into the life-cycle cost analysis routines of the software.

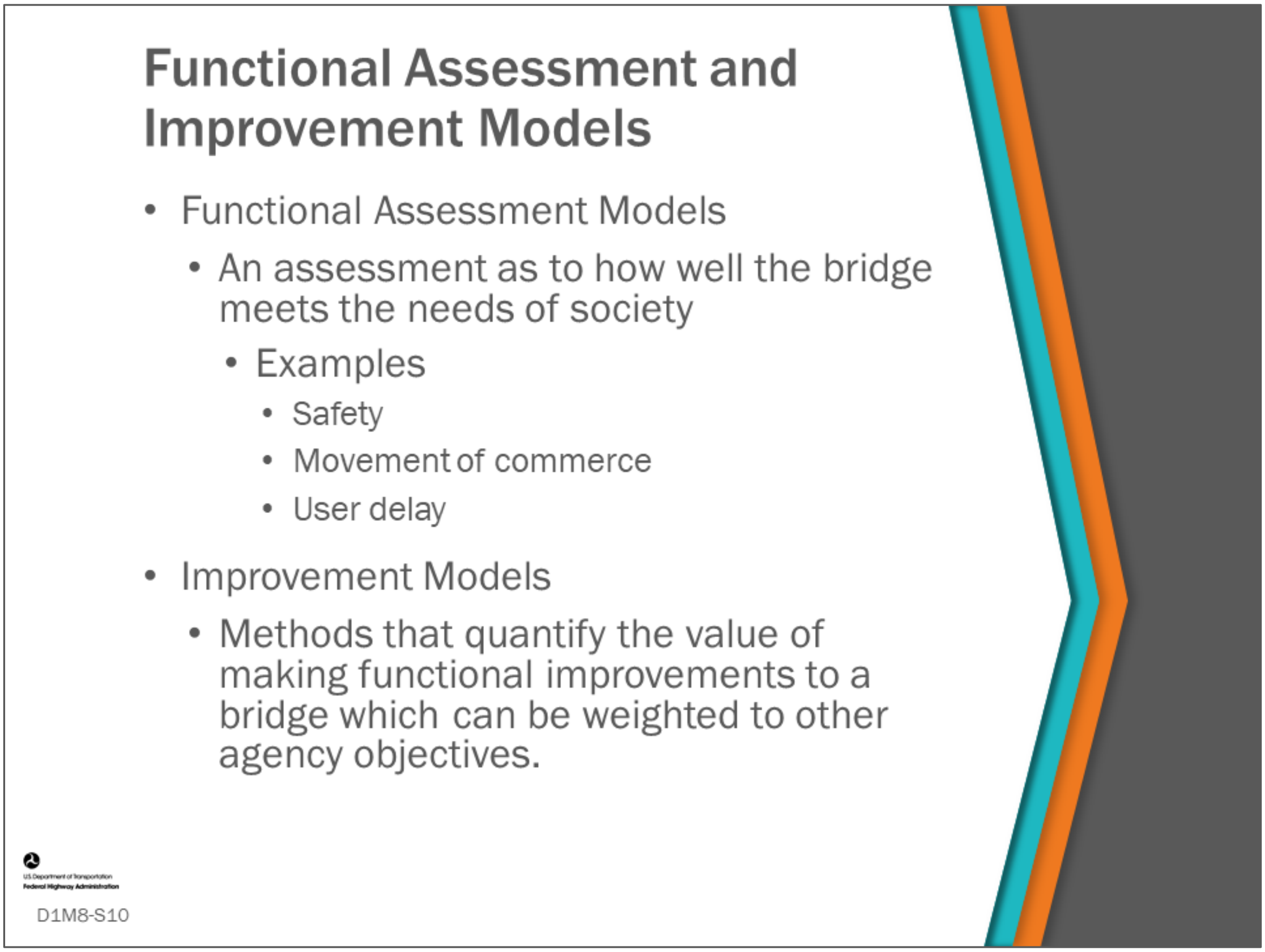
As shown on this slide, user cost can be included in AASHTOWare™ Bridge Management (BrM) life-cycle cost analysis by custom formula (i.e., the User Cost Formula String box).

- The User-Cost Calculation dropdown shown on the slide is used to select a formula that will calculate user cost per year of the LCCA.
- The formula string above assumes a truck operation and labor cost of $100 per hour and a speed of 55 mph over the length of the detour, as shown in the example calculation.

When the checkbox “Estimate User Life-Cycle Cost” is selected, the user may enter the user cost manually, overriding the formula(s) for user cost computation.

In AgileAssets® Structures Analyst™ and Deighton dTims™, user costs are input as a “Cost Expression.”

D1M8-Slide 10



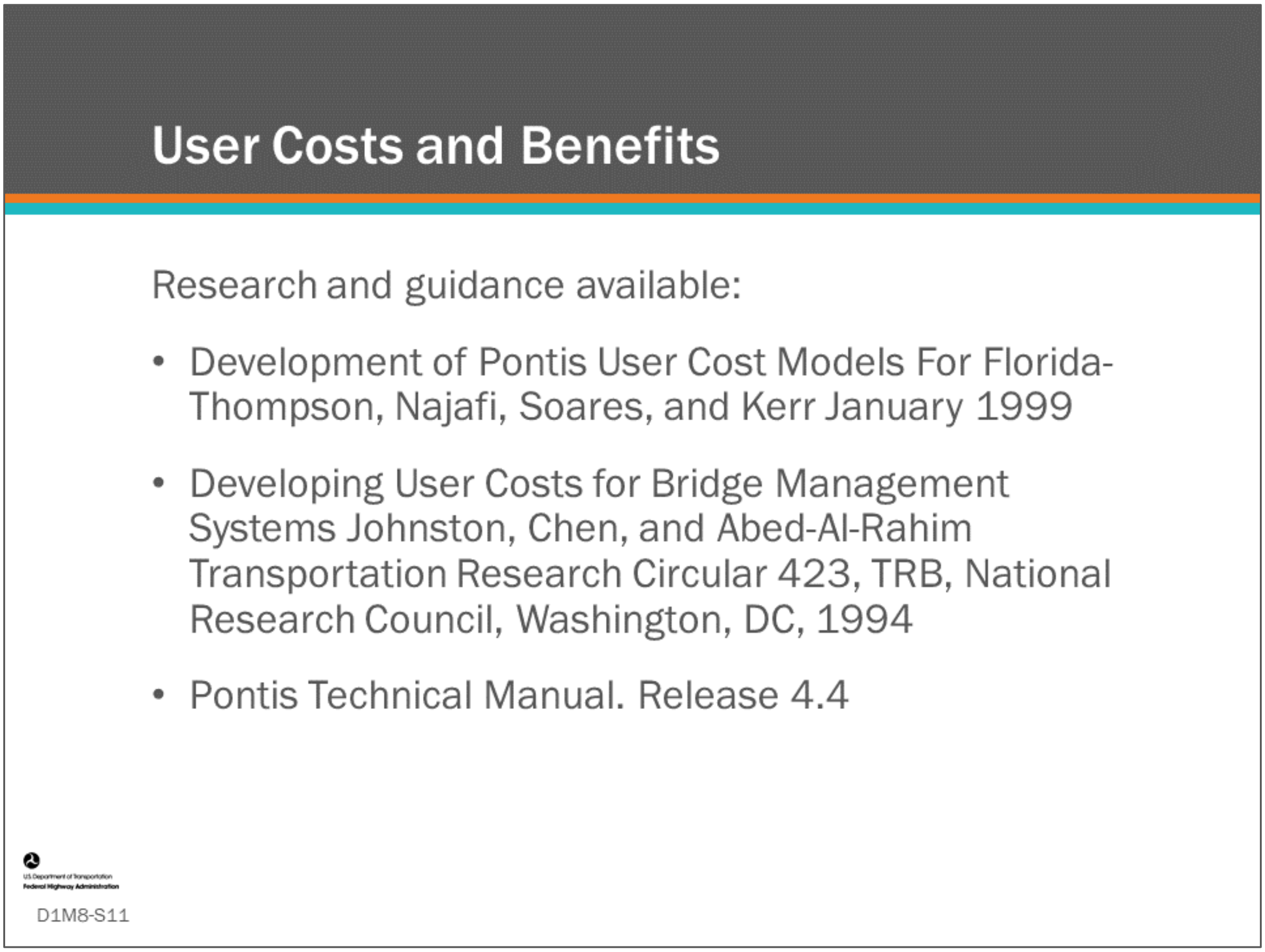
Key Message

This topic will cover functional assessment and improvement models for bridges as part of a BMS.

- A functional assessment model measures how well the bridge meets the needs of society. It can include measures of safety, movement of commerce (truck traffic), or decreased user delay.
- Improvement models quantify the value of making functional improvements to bridges, often in terms of a change in the functional assessment measure, which can be weighted to other Agency objectives.

Functional improvements can be included in a BMS by giving weight to the benefit it provides.

D1M8-Slide 11



Key Message

Including user costs and benefits in a BMS is a relatively new area for many of us, however there is some research available for quantifying user costs and benefits as shown on the slide. As an agency's BMS matures, they are encouraged to quantify user costs and benefits of making functional improvement.

We will look at an example where Florida DOT has done research to incorporate user costs and benefits in their BMS.

D1M8-Slide 12

User Benefits Of Addressing Functional Needs

$$B_r = \frac{W_c}{100} \, x \, V_{ry} \, (BW_r + BR_r + BS_r)$$

Where:

W_c is the weight given to user cost benefits, in percent

V_{ry} is the forecast average daily traffic volume for the program year

BW_r is the annual benefit of widening per unit average daily traffic

BR_r is the annual benefit of raising per unit average daily traffic

BS_r is the annual benefit of strengthening per unit average daily traffic

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D1M8-S12

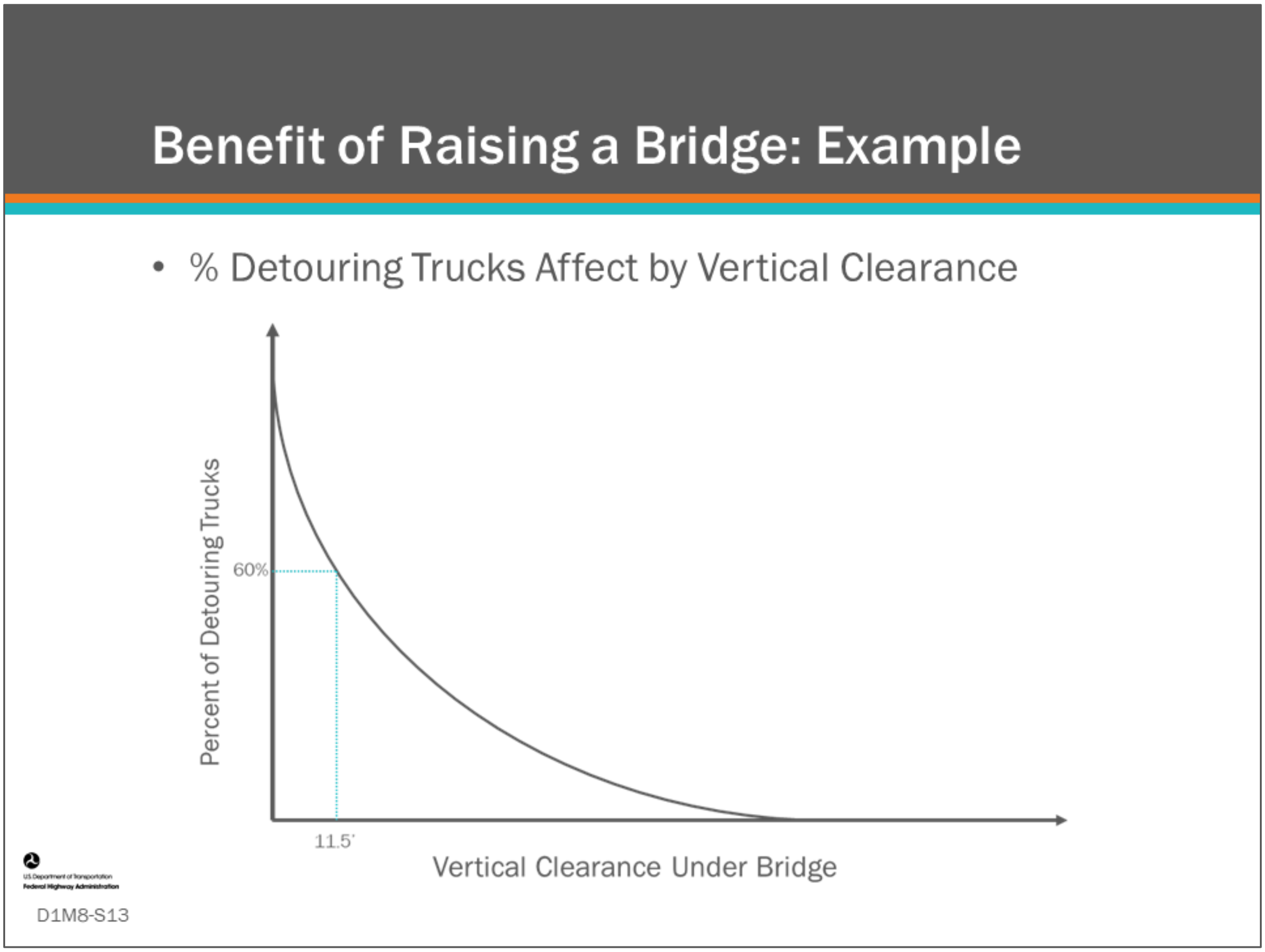
Key Message

The total user benefit of addressing functional needs, Br, can be calculated by considering individual benefits for widening, raising, and strengthening. The terms BW_r, BR_r, and BS_r can be calculated by equations shown in the Florida research. (Thompson, et al., 1999).

- W_c is the weight given to user cost benefits in percent.
- V_{ry} is the forecast average daily traffic volume for the program year.
- BW_r is the annual benefit of widening per unit average daily traffic.
- BR_r is the annual benefit of raising per unit average daily traffic.
- BS_r is the annual benefit of strengthening per unit average daily traffic and is equal to 365 multiplied by detour cost per truck multiplied by the percent of truck traffic multiplied by the percent of truck traffic that is detoured by the bridge.

Since many of the factors going into the user benefit are not NBI items, calculation of user costs and benefits will require detailed traffic and safety data.

D1M8-Slide 13



Key Message

There is an inverse relationship between the vertical clearance under a bridge and the percentage of trucks that must detour around it. This relationship can be established by conducting traffic surveys and compiling histograms of truck heights. In the example curve shown above, 60 percent of trucks would be detoured by a bridge with 11.5-foot underclearance.

The example shows how raising a bridge could reduce the amount of truck detours. Next we will show how to calculate the total annual user benefit of raising the bridge.

D1M8-Slide 14

Example – Benefit of Raising a Bridge: Example Equations

- Total annual user benefit of raising, $U_{raising}$:

$$Detour\ Cost\ per\ Vehicle = Hr\ Detour\ Cost\ * \frac{Bypass\ Length}{Detour\ Speed} + Detour\ Cost/km\ * Bypass\ Length$$

$$U_{raising} = 365.25\ *\ V_{ADT}\ *\ \frac{\tau}{100}\ *\ F_{VClrInv} *\ \text{Detour Cost per Vehicle}$$

- Where:
  - $U_{raising}$ = annual user benefit of raising
  - V_{ADT} = average daily traffic on the bridge (NBI Item 29)
  - τ = truck percentage (NBI Item 109)
  - $F_{VClrInv}$ = fraction of trucks that have to detour due to the current height of the bridge (percentage divided by 100)

D1M8-S14

Key Message

To determine the annual benefit of raising a bridge, we need to compute the detour cost per vehicle affected by the detour, then multiply that cost by the number for vehicles that are detoured.

The detour cost per vehicle has two components: the cost per hour reflecting driver costs and cost per mile reflecting fuel and vehicle costs.

The annual benefit of raising a bridge is found by multiplying the cost per vehicle by the number of vehicles affected by the detour.

D1M8-Slide 15

Example – Benefit of Raising a Bridge: Example Calculation

Example Calculation Assumptions:

- Detour cost per hour = $100
- Detour cost per km = $1.50
- Detour Length = 10 km
- Detour Speed = 35 mph = 56.3 kmph
- ADT = 15,000 with 8% trucks
- 60% of trucks detoured by bridge height

$$Detour\ cost\ per\ vehicle = \$100 * \frac{10\ km}{56.3\ km/hr} + (\$1.50/km * 10\ km) = \mathbf{\$32.76}$$

$$User\ Benefit = 365.25 * 15000 * \frac{8}{100} * \frac{60}{100} * \$32.76 = \$\mathbf{8,615,225}$$

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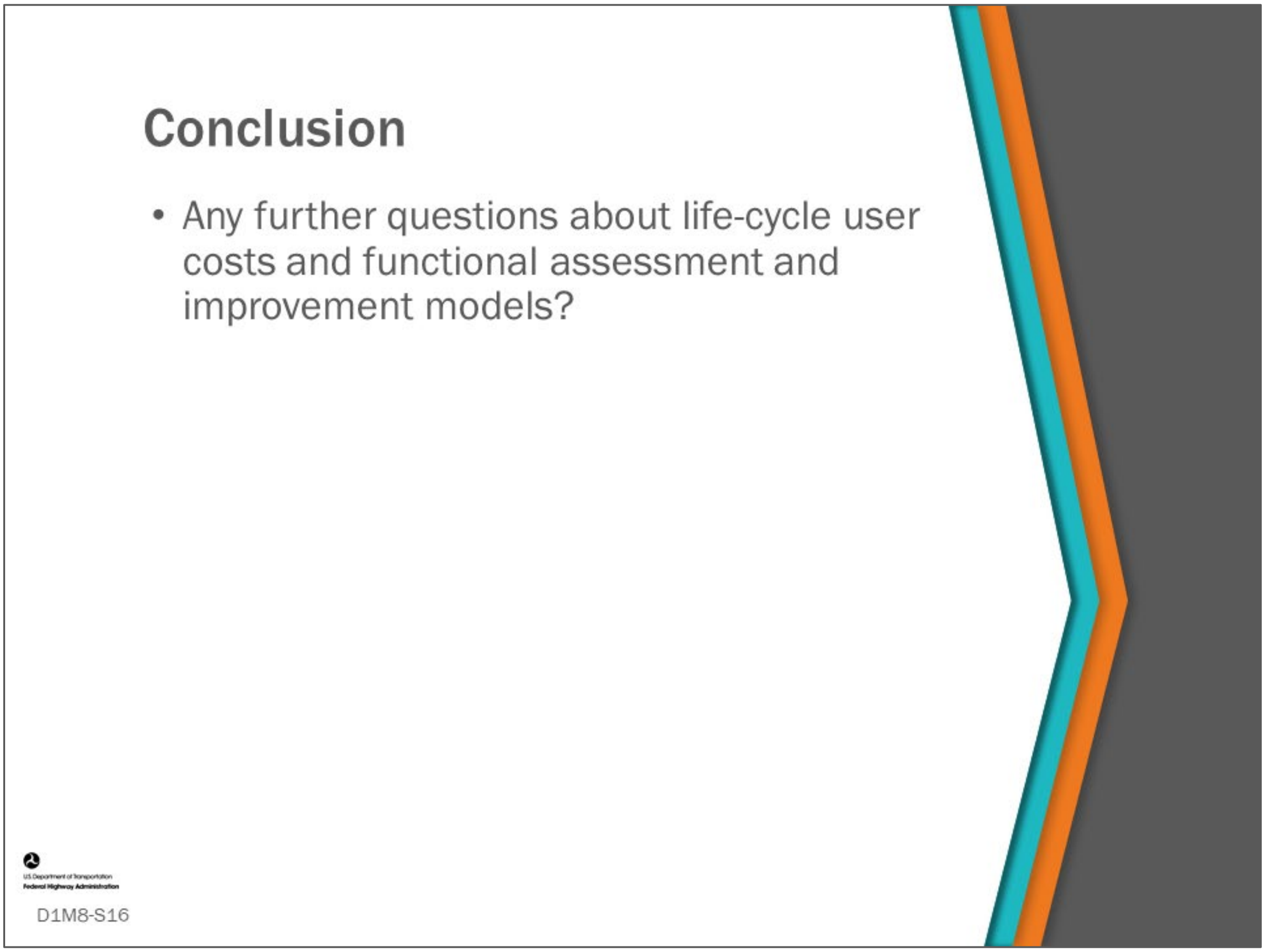
D1M8-S15

Key Message

An example is shown for calculating annual user benefit for raising a bridge. Assumed inputs are provided. The detour cost per vehicle is calculated and then used as an input for calculating the annual user benefit.

D1M8-Slide 16



Key Message

This concludes D1M8: Life-Cycle User Costs and Functional Assessment and Improvement Models.

D1M8-Slide 17

Slide #	Image Description	Source Information
5	Map showing an example detour bypassing a closed bridge.	The original map is the copyright property of Google® Maps™ and can be accessed from https://www.google.com/maps. The map modifications showing a detour for a closed bridge were developed as part of this workshop. The modifications include a blue circle representing the location of the closed bridge, a blue line representing the associated detour route, and text boxes and arrows identifying both features.
6	Picture showing traffic reduced to one lane on a bridge because of an accident.	Adobe Stock.
7	Picture showing a bridge work zone with construction workers placing a bridge beam and no traffic on the bridge.	TxDOT. 2007. Bettis, A. *Bridge Widening Issues.* Presentation. Texas Department of Transportation. Bridge Division. August 2007.
7	Equation showing UC equal vehicles delayed (1,200) times average delay (0.50) times cost per unit time ($8.00) for a total of $4,800.	NCHRP. *Report 483 Bridge Life-Cycle Cost Analysis*. Washington, DC, 2003, page 77.
8	A chart showing a life cycle activity profile with cost on the y-axis and time (years) on the x-axis. Upward points arrows represent annual user cost expenditures which are shown to increase each year.	This Workshop.

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D1M8-S17

D1M8 Figure Source List

D1M8-Slide 18

Slide #	Image Description	Source Information
9	Screen shot of AASHTOWare™BrM User Cost Calculation drop down list and user cost formula string	AASHTOWare™ Bridge Management (BrM) software.
9	Equation defining cost equal to average daily traffic multiplied by truck percentage divided by 100 multiplied by detour length divided by 55 miles per hour multiplied by 100 dollars per hour.	This Workshop.
9	Screen shot of AASHTOWare™ BrM screen showing LCCA Configuration area with Estimated User Life-Cycle Cost button unchecked.	AASHTOWare™ Bridge Management (BrM) software.
13	A schematic example of a graph showing the benefit of raising a bridge.	This Workshop.
14	Equation showing Detour Cost per Vehicle.	This Workshop.
14	Equation showing Annual User Benefit of Raising a Bridge.	This Workshop.
15	Example calculation for Detour Cost per Vehicle.	This Workshop.
15	Example calculation for Annual User Benefit of Raising a Bridge.	This Workshop.

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D1M8-S18

D1M8 Figure Source List

Module Title: D1M9 – Risk Assessment and Mitigation Models

Module Time: 20 minutes

Module Summary

This module naturally follows the previous module because risk is closely linked to user and agency costs (functional improvements affect both user and agency costs). Risk is the potential for an unplanned adverse event that can impact a bridge in a way that causes unacceptable consequences. In bridge management, the primary concern is disruption of expected or designed service levels, which may cause injuries or property damage, loss of mobility, and immediate expenditures or long-term excess costs. Risk assessment evaluates the likelihood and consequence of adverse events. NCHRP Report 20-07/Task 378 provides a risk assessment methodology that was developed to assist in estimating likelihood and consequences of service disruption per various types of hazards. This module will introduce methods of accommodating risk in different types of BMS.

Expected Outcome(s)

Participants will learn the definition of risk and types of risk, concepts of risk assessment, and examples calculations used in risk assessment models.

Resource List

Slide	Reference Information
4,16	AASHTO. *Manual for Bridge Evaluation.* Washington, DC, third edition, 2018.
7	Constable, D. and D. Blades. *National Performance Management Measures: Bridge Condition to Assess the National Highway Performance Program*. FHWA Office of Bridges & Structures. Washington, DC, 2017.
8,10-16	NCHRP. *Assessing Risk for Bridge Management*. AASHTO Standing Committee on Highways, NCHRP 20-07/Task 378. Washington, DC, 2017.
9	NCHRP. *A Guide for Vulnerability Assessment for Critical Asset Identification and Protection*, 20-07/Task 151B. Washington, DC, 2002.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D1M9-Slide 1

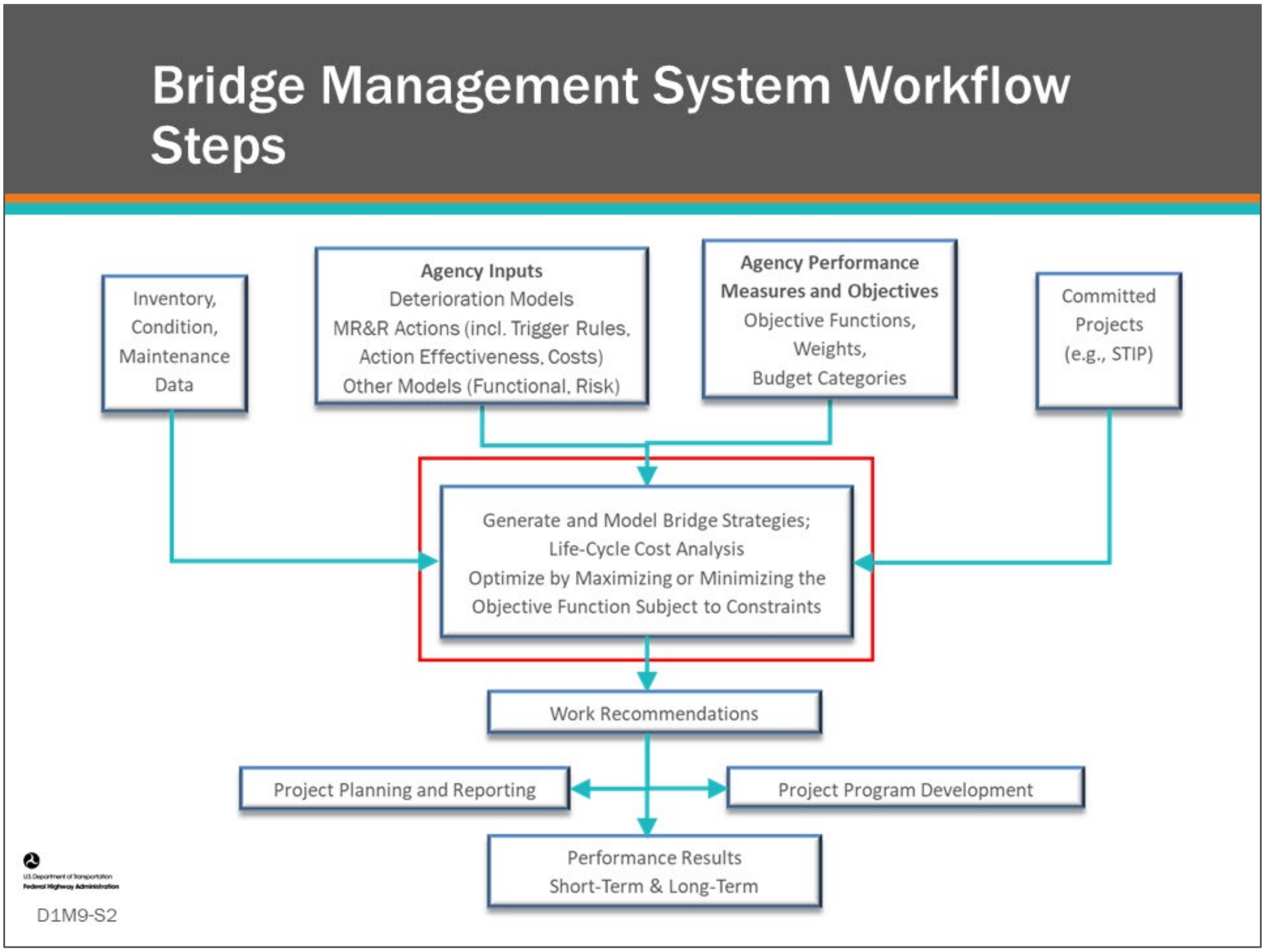
Key Message

This module naturally follows the previous module because risk is closely linked to user and Agency costs.

Disclaimer

FHWA does not promote or endorse patented and proprietary products. Bridge management software is largely proprietary. Workshop content pertaining to proprietary software is included only to illustrate how bridge management system concepts and analyses are applied in practice. The included content shall not be construed as promotion or endorsement of specific software.

D1M9-Slide 2



Key Message

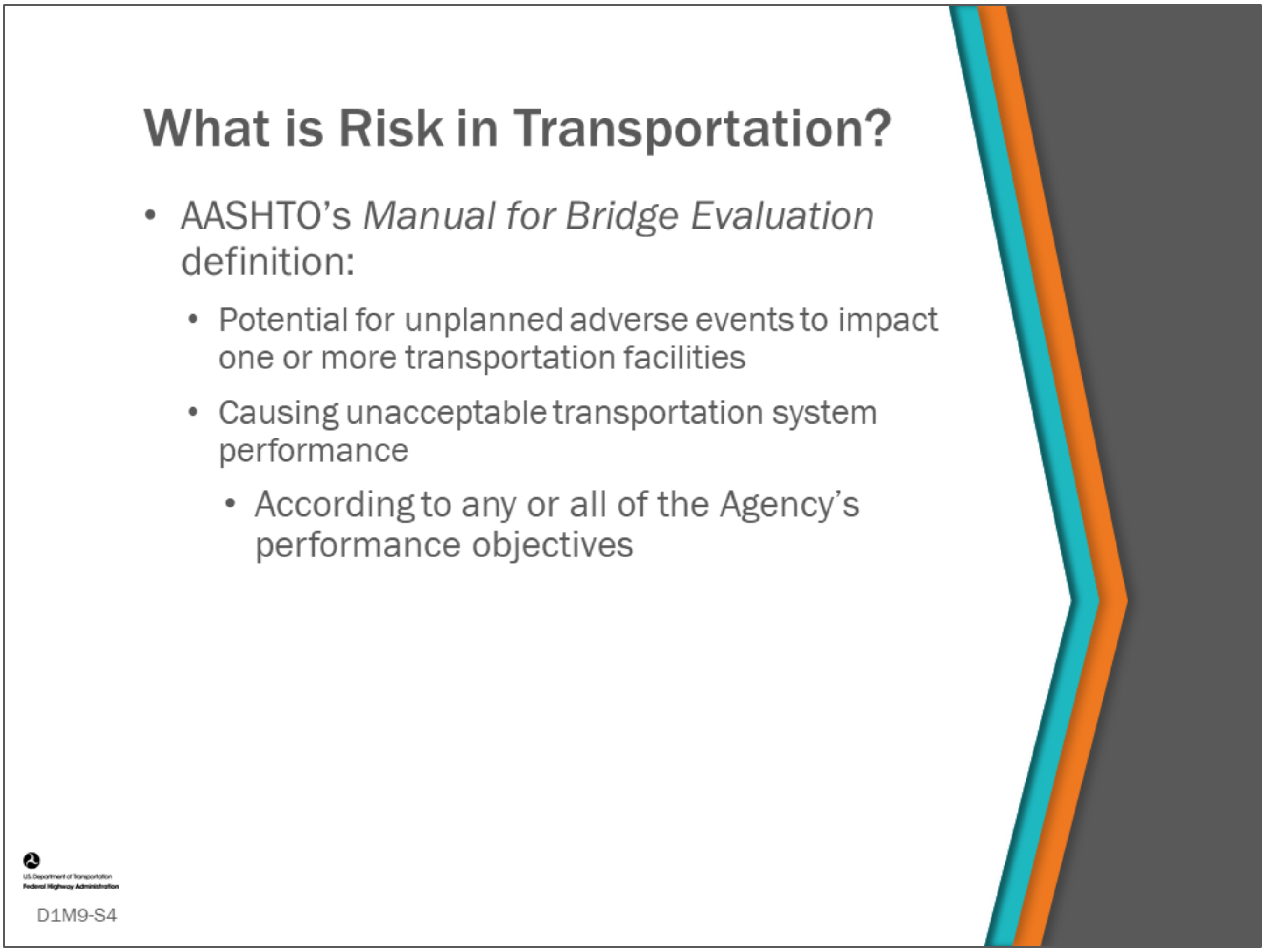
BMS workflow steps are shown on the slide. Risk assessment is highlighted by the red box.

D1M9-Slide 3

Key Message

In this module, we will define risk and cover risk assessment and mitigation models that can be incorporated into bridge management decisions.

D1M9-Slide 4



Key Message

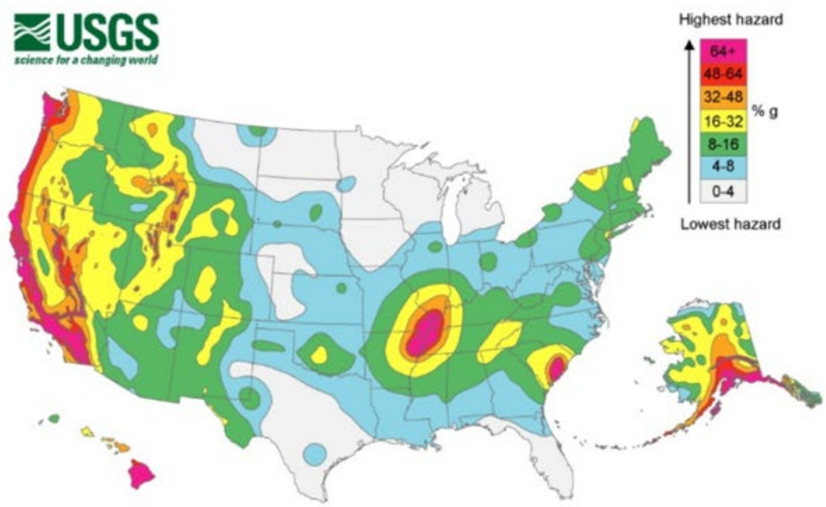
AASHTO's *Manual for Bridge Evaluation* defines *risk* as the potential for unplanned adverse events to impact one or more transportation facilities in a way that causes unacceptable transportation system performance according to any or all of the Agency's performance objectives.

- The manual also says, "In bridge management, the primary concern is disruption of expected or designed service levels, which may cause injuries or property damage, loss of mobility, and immediate expenditures or long-term excess costs.

D1M9-Slide 5

Types of Risk: Natural

- Earthquakes
- Landslides
- Storm surge
- High winds
- Floods and scour
- Wildfires



Source: USGS

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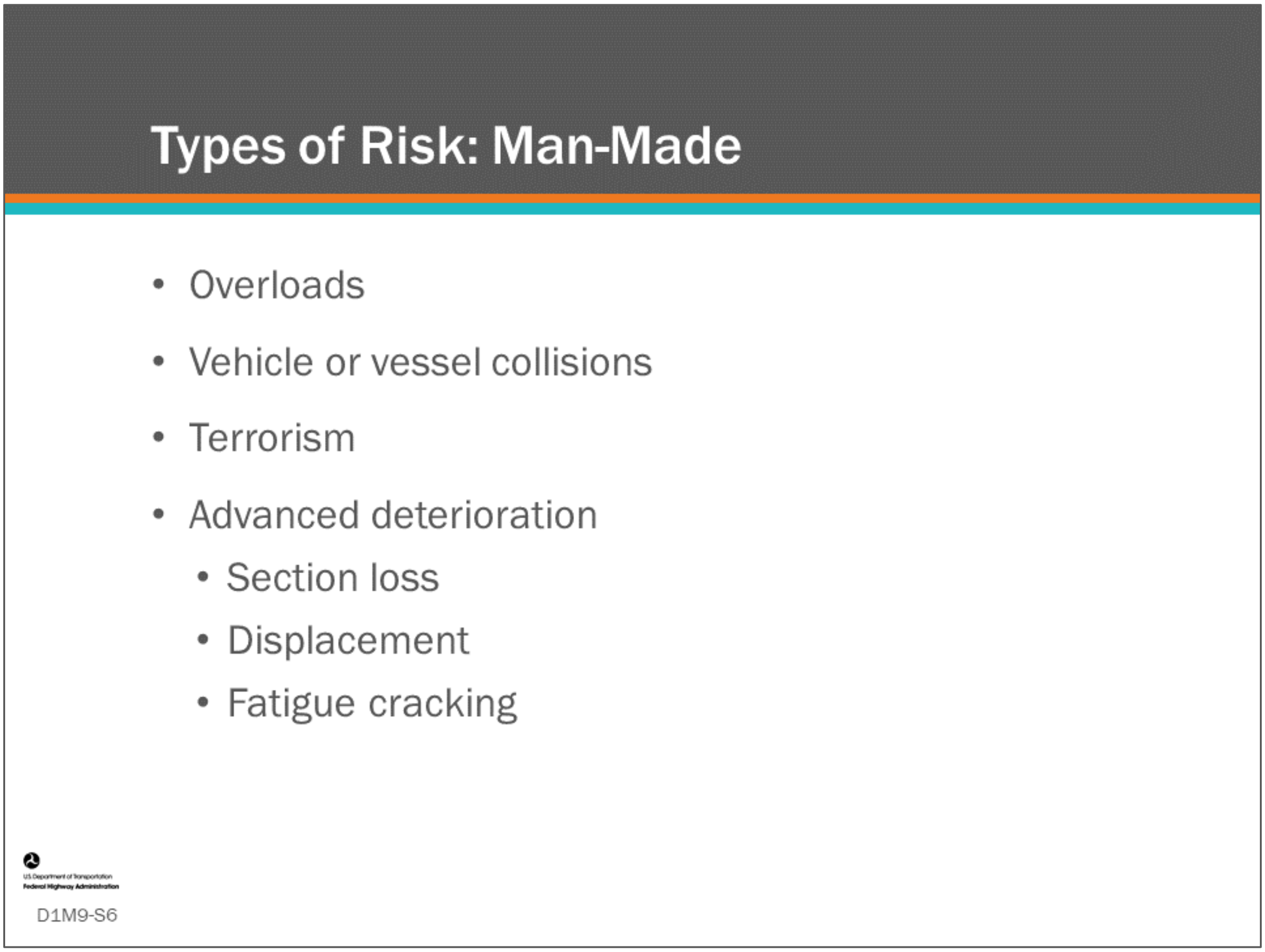
D1M9-S5

Key Message

Risk can come from natural sources, such as those listed here. The image shows a USGS Map of earthquake vulnerability in the U.S.

D1M9-Slide 6



Key Message

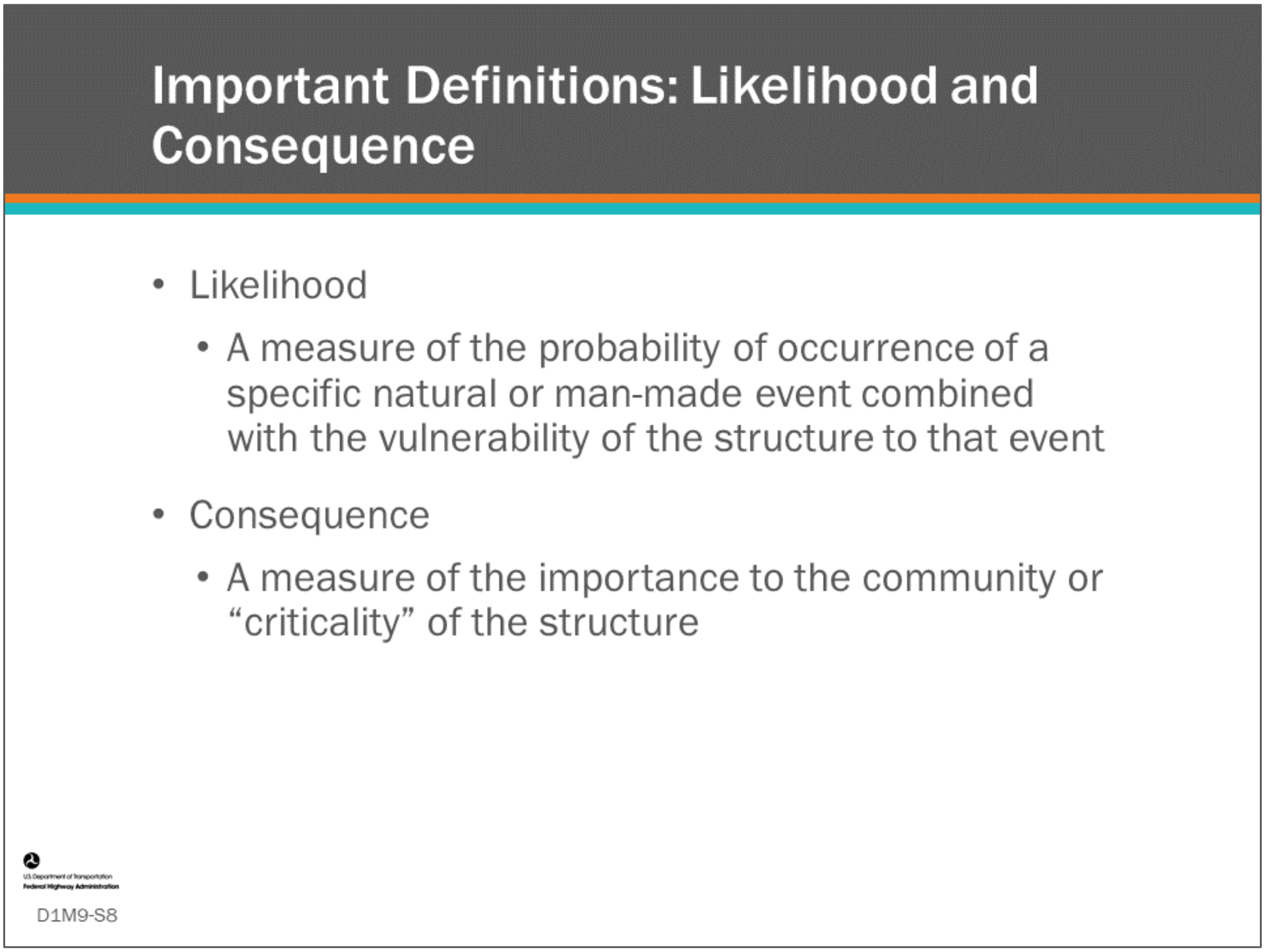
Risk can include man-made risks, such as those listed here, as well as slowly developing deterioration-related risks that decrease structural reliability.

D1M9-Slide 7

Key Message

Risk assessment includes identification of risks and assessment of likelihood of occurrence and impact of consequence. These can be incorporated into a BMS.

D1M9-Slide 8

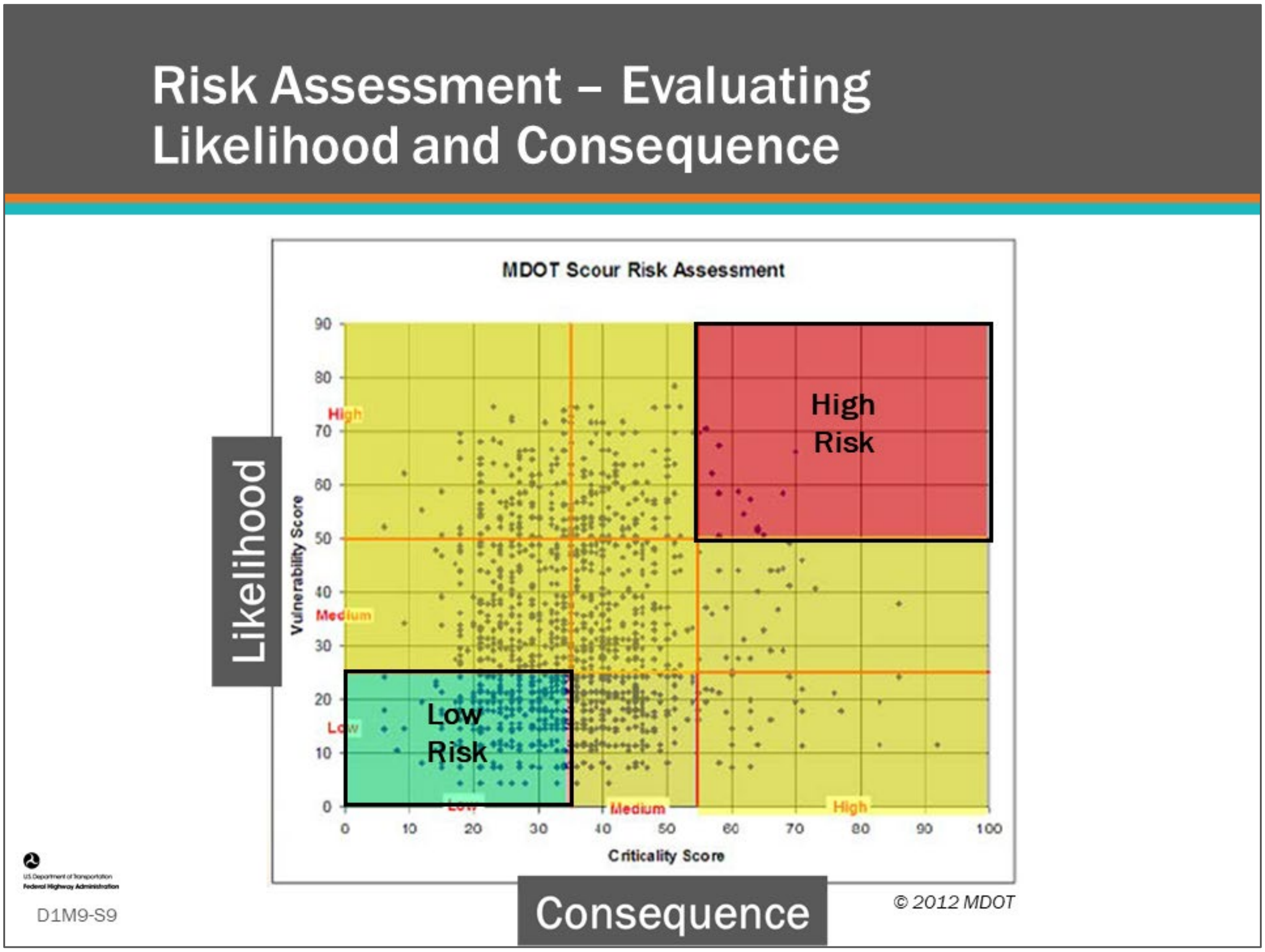


Key Message

According to AASHTO:

- Likelihood is the characterization of the probability of an extreme event and a service disruption
- Consequence is a summary measure of all impacts of an unexpected disruption in transportation service, as experienced by the agency, road users, non-users, and the environment.

D1M9-Slide 9



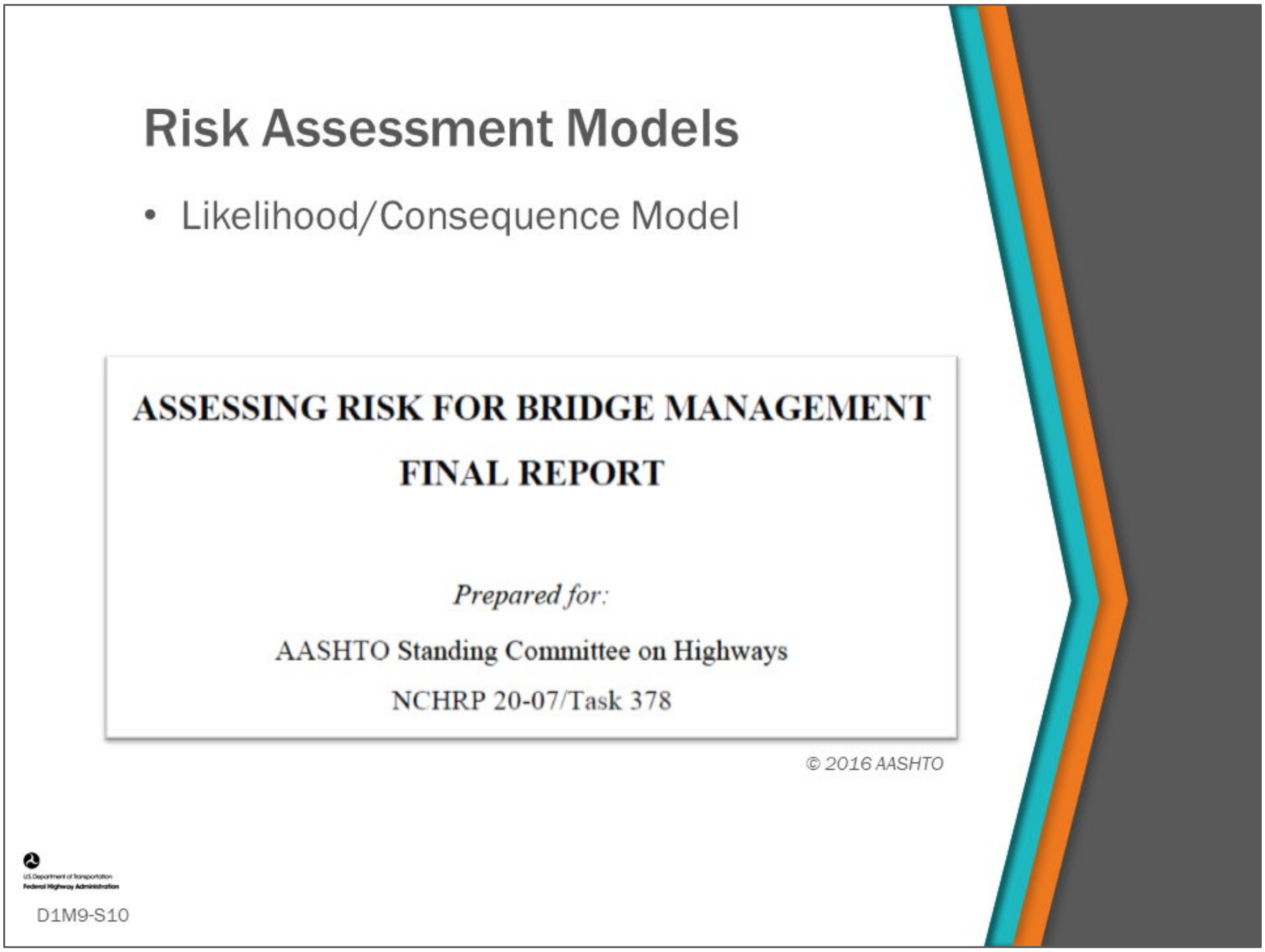
Key Message

A risk assessment involves evaluating the likelihood of a hazardous event happening and the consequence of the event. Likelihood is often treated as a combination of likelihood of extreme event along with likelihood of structural failure from the event.

Likelihood and consequence are often plotted with likelihood on the y-axis and consequence on the x-axis. Both can be rated on a numeric scale and categorized as low, medium, and high. This is often called a heat map.

The assessment on the slide was made by the Michigan Department of Transportation following the guidance provided in *A Guide for Vulnerability Assessment for Critical Asset Identification and Protection*. Structures that were deemed highly vulnerable and critical to the community (highlighted red region in the chart) were prioritized for action.

D1M9-Slide 10



Key Message

Risk assessment models are reviewed in a report titled, Assessing Risk for Bridge Management – Final Report. The report was prepared for the AASHTO Standing Committee on Highways, NCHRP 20-07/Task 378 with the purpose to incorporate risk assessment into bridge asset management so that risk concerns can be fully and appropriately considered in decisions about project priorities, resource allocation, and performance management. The report provides a guidance document for doing a risk assessment that will produce cost and utility value compatible with a BMS.

The report mentions several types of risk assessment models, including delay/detour models and recovery consequence models, but the method it teaches is likelihood/consequence models which are often incorporated into a BMS, however, any of these models could be used as part of a performance measure that could be used in an objective function.

D1M9-Slide 11

Risk Assessment Summary Spreadsheet

Hazard Scenarios						Likelihood			
ID	Scenario	Cost	Safety	Mobility	Environment	Extreme	Disruption	Weight	Risk ($k)
1	Eq-100	12,345	50	6,000	600	1.00%	5.00%	1.00	9.50
2	Fl-100a	12,345	50	6,000	600	1.00%	10.00%	1.00	19.00
3	Fl-100b	100	0	2,000	200	1.00%	20.00%	1.00	4.60
4	Fl-500	12,345	50	6,000	600	0.20%	50.00%	1.00	19.00
5	OH-13.5	100	70	200	40	--	5.00%	1.00	20.50
6	AD-0.9	50	0	200	40	--	10.00%	1.00	29.00
7	Fracture	12,345	0	6,000	600	--	0.50%	1.00	94.73
8								1.00	0.00
9								1.00	0.00
10								1.00	0.00

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Risk cost and vulnerability	Cost	Safety	Mobility	Environment
Struc weight	20,000	75,000	134,400	134,400
Criteria weight	1.00	1.00	1.00	1.00
Social cost ($k)	102.79	3.63	79.00	10.90
Vulnerability	5.1394	0.0483	0.5878	0.0811

Risk analysis results	
Maximum unit risk cost:	100
Vulnerability index:	0.0586
Utility:	**94.14**
Social cost of risk ($000):	**196.31**

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D1M9-S11

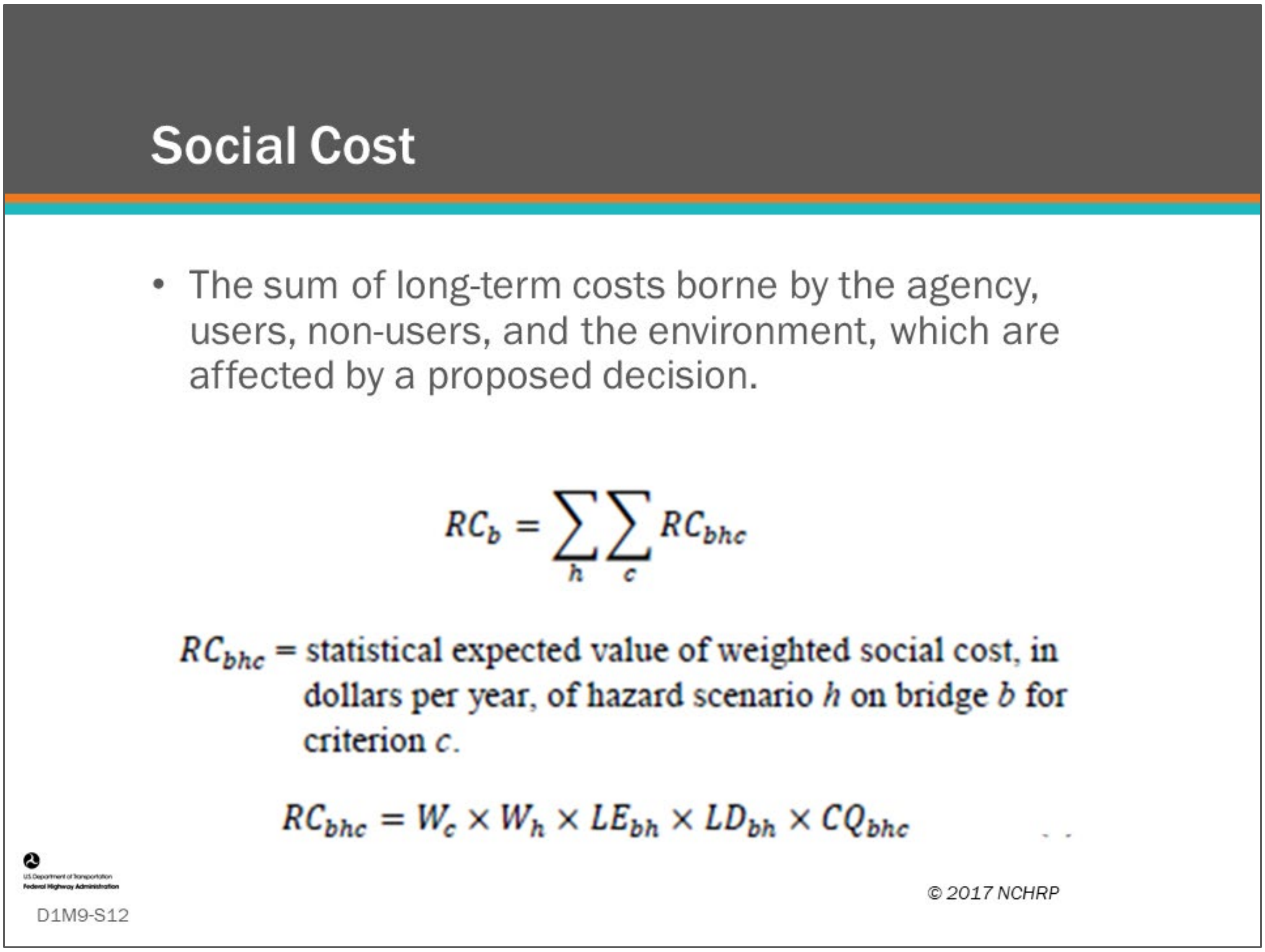
Key Message

If your BMS uses risk utility to measure risk and the benefits of risk mitigation actions, you will need to develop a quantitative risk assessment process to feed into it.

This slide shows the risk assessment summary spreadsheet from the *Risk Assessment Guidelines* found in Appendix B of NCHRP 20-07 Final Report, Task 378.

The end result of the spreadsheet is "Social Cost of Risk" and "Utility Value," which are shown at the bottom right of the spreadsheet example and discussed in the following slides.

D1M9-Slide 12



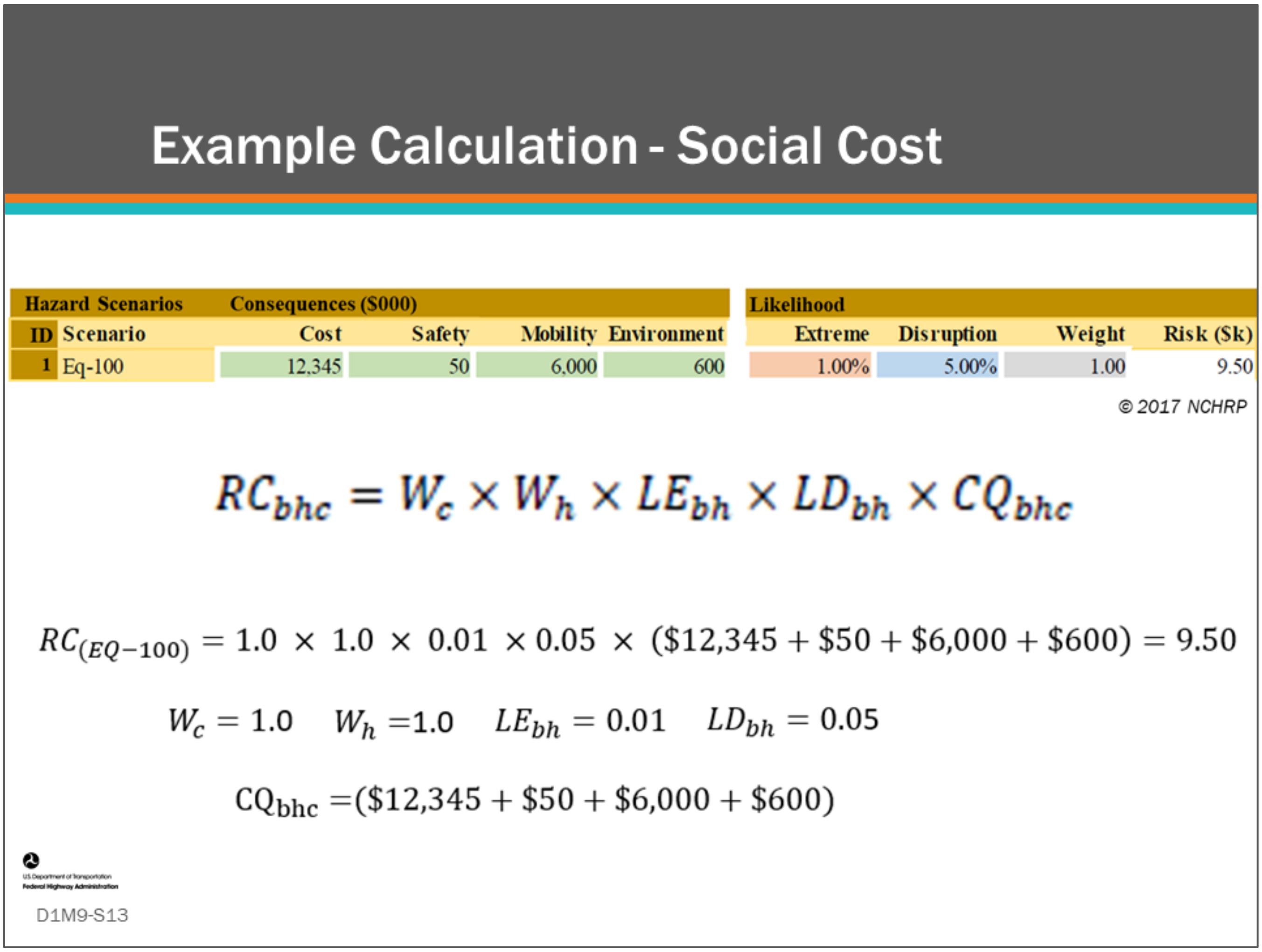
Key Message

Part of the risk assessment process is the computation of the social cost of risk.

Social cost is the sum of long-term costs borne by the Agency, users, non-users, and the environment, which are affected by a proposed bridge-level decision. The social cost of risk is the weighted average of all hazard scenarios and all performance criteria.

- RC_b is the social cost of risk for bridge b
- W_c is a weight given to each performance criterion c
- W_h is the weight given to hazard scenario h
- LE_{bh} is the likelihood of occurrence of the extreme event of hazard scenario h on bridge b
- LD_{bh} is the likelihood of a specific magnitude of service disruption caused by the event of hazard scenario h on bridge b
- CQ_{bhc} is the consequence in dollars per disruption event, to performance criterion c due to the service disruption caused by the event of hazard scenario h on bridge b

D1M9-Slide 13



Key Message

Shown on this slide is an example calculation of social cost for Eq-100, given the consequence cost (CQ_{bhc}) values, likelihood (LE_{bh} and LD_{bh}) values, and weight (W_h) shown in the spreadsheet.

The social cost for each hazard is added to get the total social cost for risk.

D1M9-Slide 14

Example Calculation- Vulnerability

Risk cost and vulnerability	Cost	Safety	Mobility	Environment
Struc weight	20,000	75,000	134,400	134,400
Criteria weight	1.00	1.00	1.00	1.00
Social cost ($k)	102.79	3.63	79.00	10.90
Vulnerability	5.1394	0.0483	0.5878	0.0811

Risk analysis results	
Maximum unit risk cost:	100
Vulnerability index:	0.0586
Utility:	**94.14**
Social cost of risk ($000):	**196.31**

$$UCR_b = \sum \frac{RC_{bhc}}{SW_{bc}}$$

$$= \frac{102{,}790}{1.0 \ x \ 20{,}000} + \frac{3630}{1.0 \ x \ 75{,}000} + \frac{79{,}000}{1.0 \ x \ 134{,}400} + \frac{10{,}900}{1.0 \ x \ 134{,}400}$$

$$= 5.1394 + 0.0483 + 0.5878 + 0.0811 = 5.8566$$

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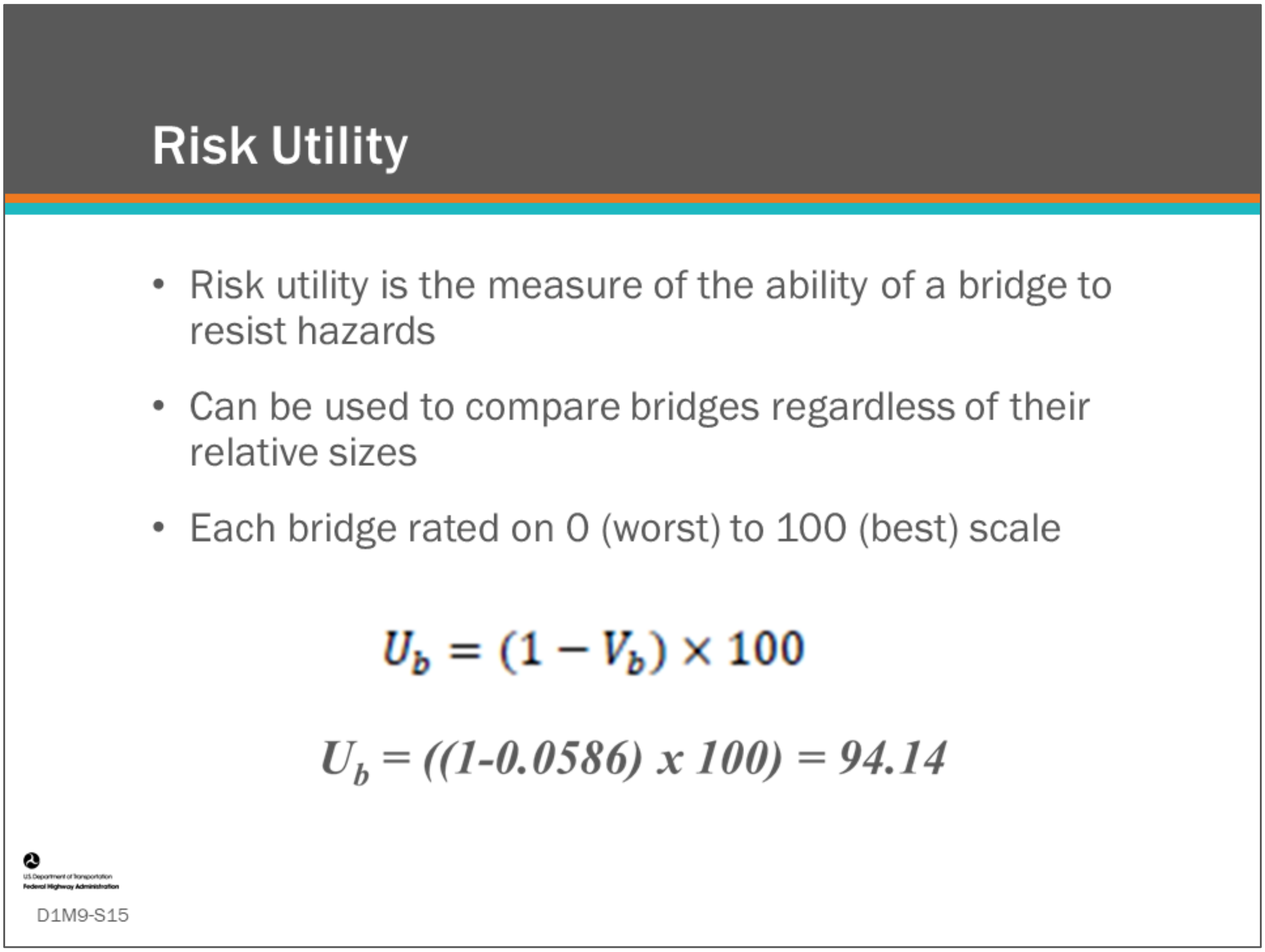
D1M9-S14

Key Message

Shown is an example calculation of vulnerability.

- The unit risk cost (UCR_b) for bridge "b" is the sum of the social cost divided by the structure weight for each criteria.
- In the equation, RC_{bhc} is the social cost for hazard scenario "h" on bridge "b" for criterion "c."
- SW_{bc} is the structure weight of structure "b" for criterion "c."
- The maximum unit risk cost is given as 100, thus the vulnerability index for this bridge is 0.0586.

D1M9-Slide 15



Key Message

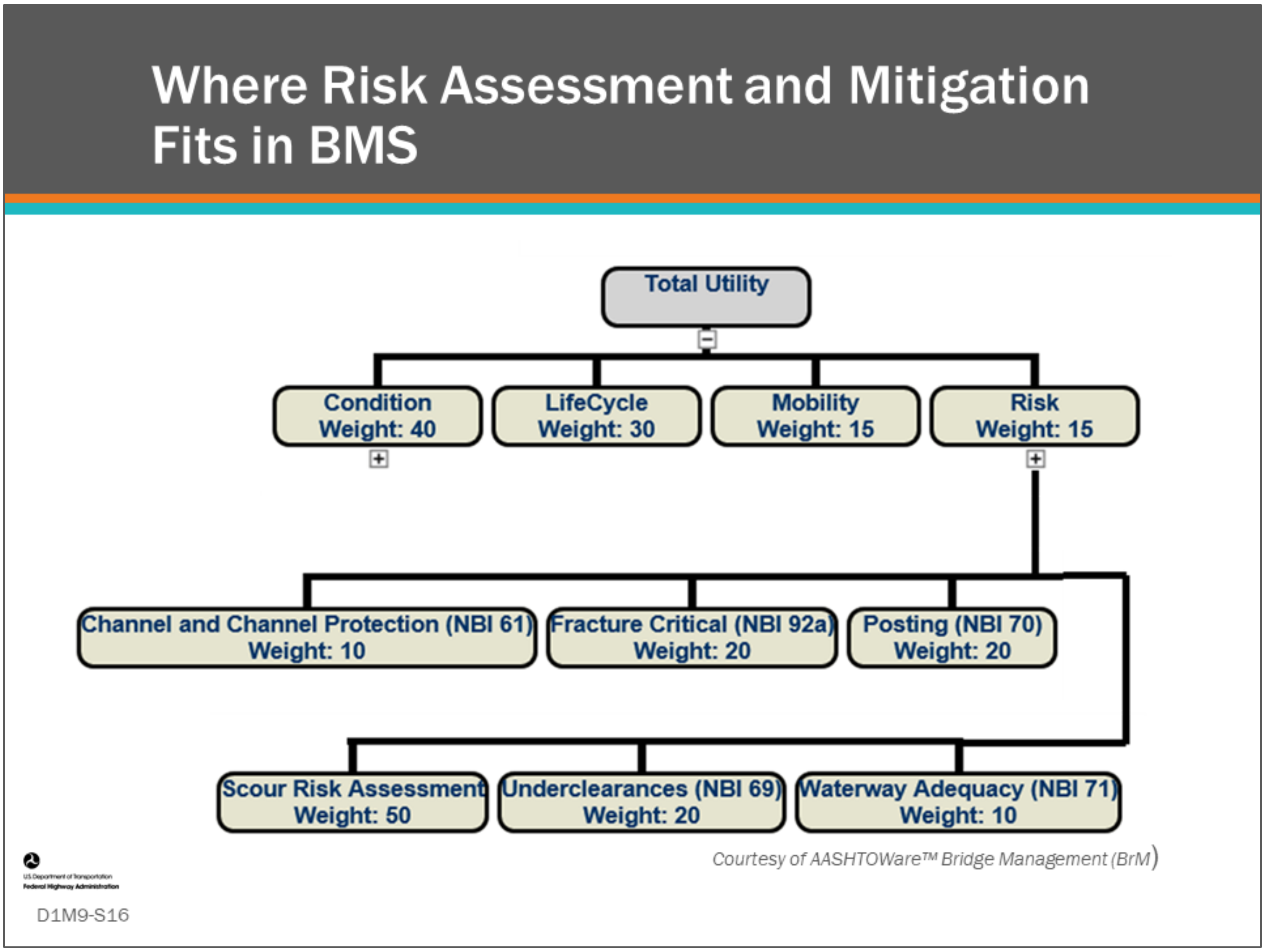
Risk utility is a measure of a bridge to resist risk hazards on a 0 to 100 scale.

Risk utility is related to social cost. It is common to compute utility by computing vulnerability first and then converting using the equation shown.

- U_b is the utility index for a bridge
- V_b is the vulnerability index for a bridge

The utility for the example shown in the previous slide is $((1\text{-}V_b) \times 100)$ equals 94.14.

D1M9-Slide 16



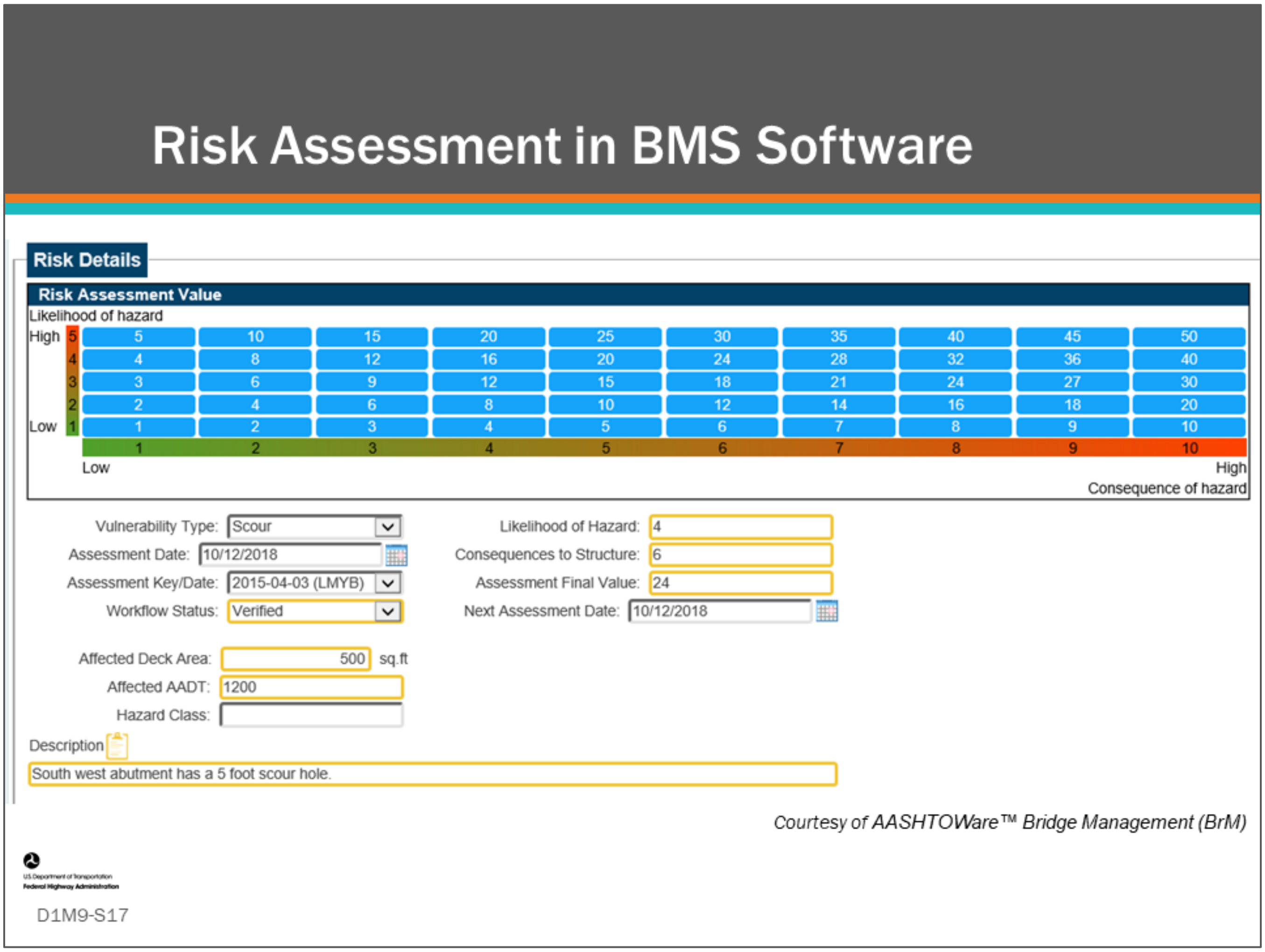
Key Message

This slide shows the utility weighting in the AASHTOWare™ Bridge Management (BrM) software.

As shown, risk can be incorporated into a BMS by including it as an objective (utility) function which we will learn more about in Module 10.

The objective function can be used at the project level, or you can set up a vulnerability reduction objective with performance measures and include a utility function at the network optimization level.

D1M9-Slide 17



Key Message

BMS software have several ways to incorporate risk. The AASHTOWare™ Bridge Management (BrM) software provides a specific way of evaluating risk at the bridge-level for inclusion in the objective function.

- Shown on this slide is the Inspection-Assessments screen where an inspector or bridge manager can:
  - Add a new risk (hazard class);
  - Identify the vulnerability;
  - Access the likelihood and consequence of a hazard; and,
  - Provide an assessment final value.
- The assessment final value can then be included as a utility function that is used in conjunction with mitigation actions in the prioritization/optimization module of the software. The utility value will be the assessment value divided by the greatest possible value.
- Theoretically, network-level risk mitigation action types can be assigned along with the expected improvement in risk assessment value. However, since risk is largely site specific, manual assignment of improvement in the same manner as manual assessment of risk as shown on the slide example is most common.
- Risk may change with condition or time. If you want to model change in risk with time, then you need to model risk-related items that change with time. It will be difficult to model change over time for some of the risk-related items. Before setting up a performance measure for risk, the bridge manager should identify which inventory items need to be modeled to monitor changes in risk.

- AgileAssets® Structures Analyst™ and Deighton dTIMS© do not provide a specific method to model risk, however, any method that evaluates a risk value for a strategy (sequence of treatments for a bridge) can be configured as an index (AgileAssets® Structures Analyst™) or analysis variable (Deighton dTIMS©).

D1M9-Slide 18

Key Message

This concludes D1M9: Risk Assessment and Mitigation Models.

D1M9-Slide 19

Slide #	Image Description	Source Information
5	Map of the United States showing a contour map of risk for earthquake.	USGS. *Seismic Hazard Maps and Site-Specific Data.*
9	A chart showing vulnerability score (likelihood) on the y-axis (0 to 90) and criticality (consequence) on the x-axis (0 to 100).	MDOT.
10	Screenshot of title page of the report reading; Assessing Risk for Bridge Management.	NCHRP. *Assessing Risk For Bridge Management*. AASHTO Standing Committee on Highways, NCHRP 20-07/Task 378. Washington, DC, 2017.
11	Spreadsheet for a risk assessment for a single bridge. Included are hazard scenarios and their consequences and likelihood.	NCHRP. *Assessing Risk For Bridge Management*. AASHTO Standing Committee on Highways, NCHRP 20-07/Task 378. Washington, DC, 2017.
11	Spreadsheet for a risk assessment for a single bridge showing summary risk assessment results including risk cost and vulnerability and risk analysis results.	NCHRP. *Assessing Risk For Bridge Management*. AASHTO Standing Committee on Highways, NCHRP 20-07/Task 378. Washington, DC, 2017.
12	Social Cost Equation.	NCHRP. *Assessing Risk For Bridge Management*. AASHTO Standing Committee on Highways, NCHRP 20-07/Task 378. Washington, DC, 2017. Page B-15, B-21.
13	Screenshot of consequence - likelihood spreadsheet.	NCHRP. *Assessing Risk For Bridge Management*. AASHTO Standing Committee on Highways, NCHRP 20-07/Task 378. Washington, DC, 2017.
14	Screenshot showing structure weight, criteria weight, social cost, and vulnerability for cost, safety, mobility, and environment criteria.	NCHRP. *Assessing Risk For Bridge Management*. AASHTO Standing Committee on Highways, NCHRP 20-07/Task 378. Washington, DC, 2017.

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D1M9-S19

D1M9 Figure Source List

D1M9-Slide 20

Slide #	Image Description	Source Information
16	Diagram for Total Utility, showing Total Utility box comprised of Condition Weight: 40; LifeCycle Weight: 30; Mobility Weight: 15, and Risk Weight: 15.	AASHTOWare™ Bridge Management (BrM) software.
17	Screenshot of AASHTOWare™ Bridge Management (BrM) software showing example screen for Risk Detail with selectable chart having likelihood on the y-axis (ranging from low or 1 to high or 5) and consequence on the x-axis (ranging from low or 1 to 10 or high).	AASHTOWare™ Bridge Management (BrM) software.

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D1M9-S20

D1M9 Figure Source List

Module Title: D1M10 – Benefit-Cost Analysis

Module Time: 40 minutes

Module Summary

Once an agency can identify work actions, estimate the cost for those actions, and show the benefit of the actions (as discussed in Module 6), they then can apply benefit-cost analysis. Benefit-cost analysis compares the benefits to costs of work candidates, which could be any combination of MR&R activity, or a "do-nothing" alternative. The work candidates can be evaluated using methods such as Benefit-Cost Ratio, Incremental Benefit-Cost Ratio (IBCR), or other optimizing techniques that have the objective of optimizing benefit subject to constrained cost.

Because the direct cost to a highway agency for owning a bridge is in fact a long-term, multiyear investment of a series of expenditures for maintenance, preservation, rehabilitation and replacement, a BMS should be able to model and compare multiple strategies over the life-cycle of a bridge.

Having laid out the building blocks in the previous modules, this module will bring all these together to show how the heart of a BMS is its ability to model both condition and costs for a great many different strategies for maintaining the various elements of a bridge over time, and most importantly to be able to compare these strategies.

Expected Outcome(s)

The expected outcome of this topic will be an understanding of benefit-cost analysis and life-cycle planning cost analysis, and knowledge of their limitations.

Resource List

Slide	Reference Information
4,24, 26	FHWA. *Life-Cycle Cost Analysis Primer*, Office of Asset Management USDOT. Washington, DC, 2002.
10-12,18, 28,29	NCHRP. *Report 590 Multi-Objective Optimization for Bridge Management Systems*. Washington, DC, 2007.
13, 15-17	Johnson, J. *AASHTOWare BrM 5.2.3. Deterioration and LCCA*. Presentation. April 2017.
14,24, 28	AASHTO. *AASHTOWare™ Bridge Management (BrM) User's Manual*, version 5.2.3. Washington, DC, 2016.
16	FHWA. *Using a Life Cycle Planning Process to support Asset Management: A Handbook on Putting the Federal Guidance into Practice*. Washington, DC, Final Draft. 2018. Page 18.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D1M10-Slide 1

Key Message

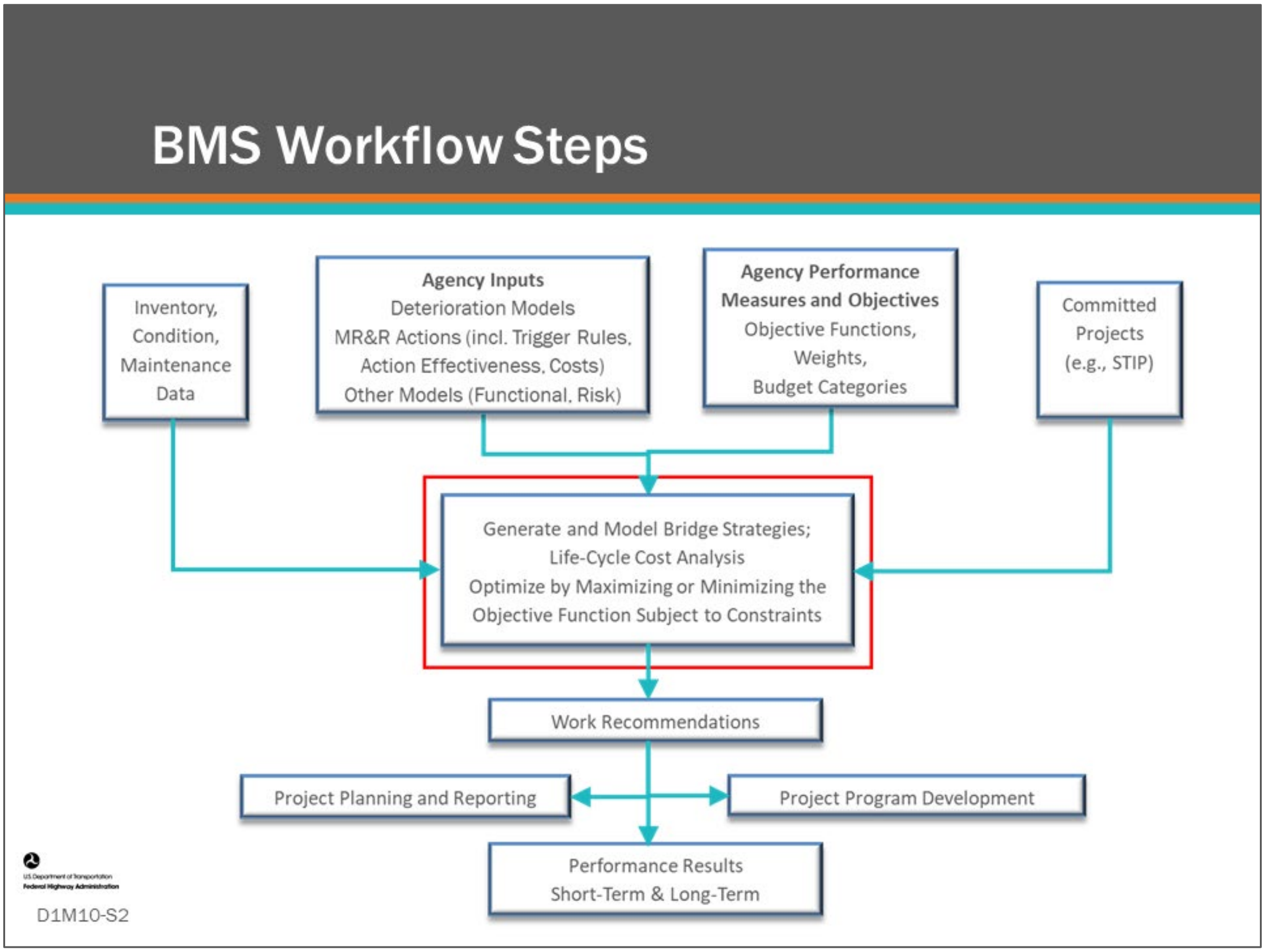
In the previous module, we presented the approach to multiple strategies containing various actions over an analysis period for each bridge across multiple bridges in a network.

Next, we present concepts for optimization at the network level so we can find the optimum strategy for each bridge under an array of constraints.

Disclaimer

FHWA does not promote or endorse patented and proprietary products. Bridge management software is largely proprietary. Workshop content pertaining to proprietary software is included only to illustrate how bridge management system concepts and analyses are applied in practice. The included content shall not be construed as promotion or endorsement of specific software.

D1M10-Slide 2



Key Message

BMS workflow steps are shown on the slide. Benefit-Cost Analysis is part of optimization that is used to generate and model bridge strategies as highlighted by the red box.

D1M10-Slide 3

Key Message

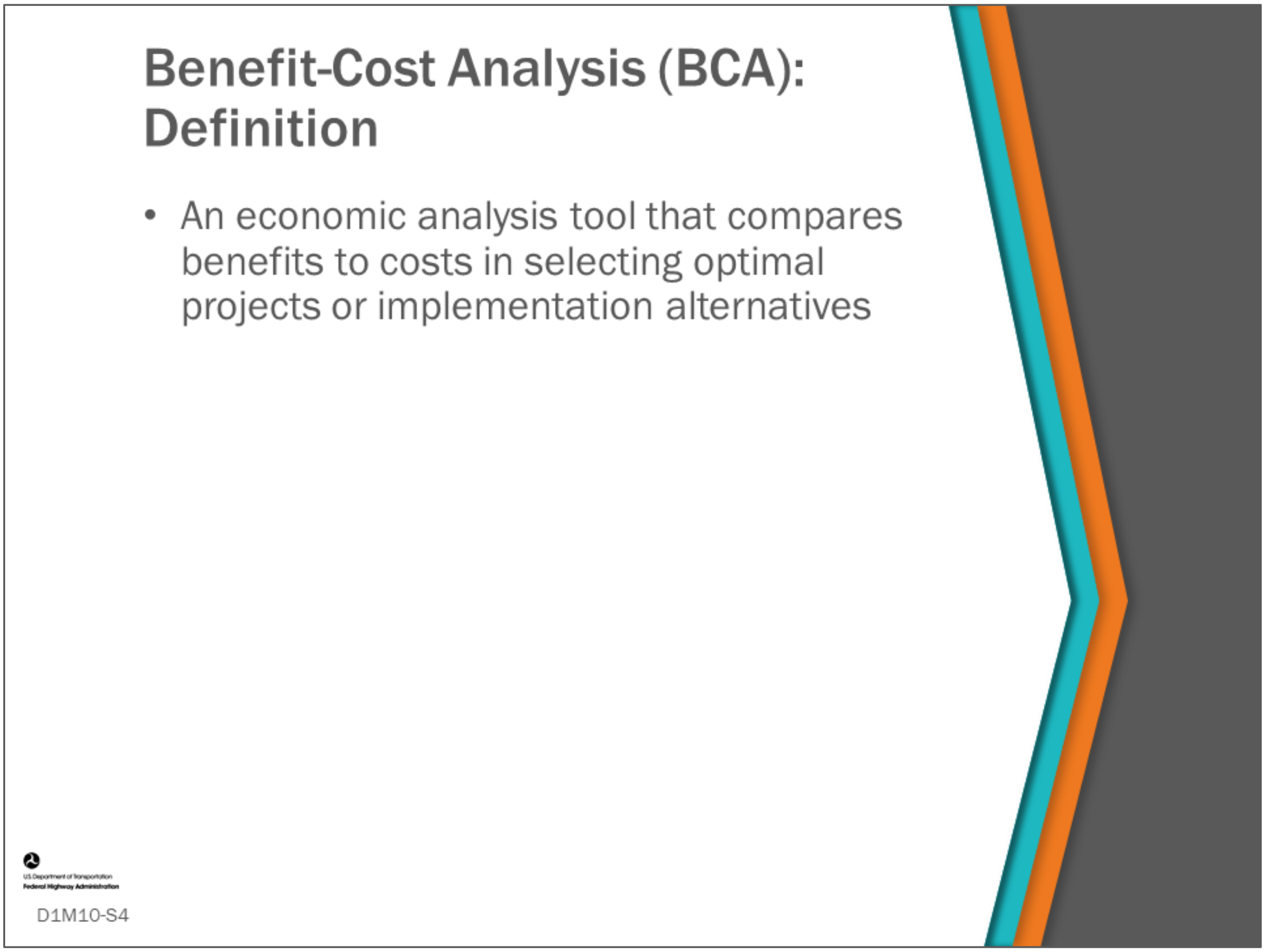
Benefit-Cost Ratio (BCR) compares the benefit to cost ratio of work actions or strategies, in any combination of preservation, rehabilitation or reconstruction activities.

The activity or combination of activities (strategy) with the highest BCR or Incremental Benefit to Cost (IBC) ratio would be the preferred course of action.

Because the direct cost to a highway Agency for owning a bridge is in fact a long-term, multiyear investment of a series of expenditures for maintenance, preservation, rehabilitation and replacement, as well as operational, functional, and safety improvements, a BMS should be able to model multiple strategies over the life-cycle of a bridge.

Having laid out the building blocks in the previous modules, this module will bring all these together to show how the highest level of functionality for an advanced BMS is its ability to model both benefits and costs for a great many different strategies for maintaining the various elements of a bridge over time, and most importantly to be able to compare these strategies, which is often done using incremental utility cost.

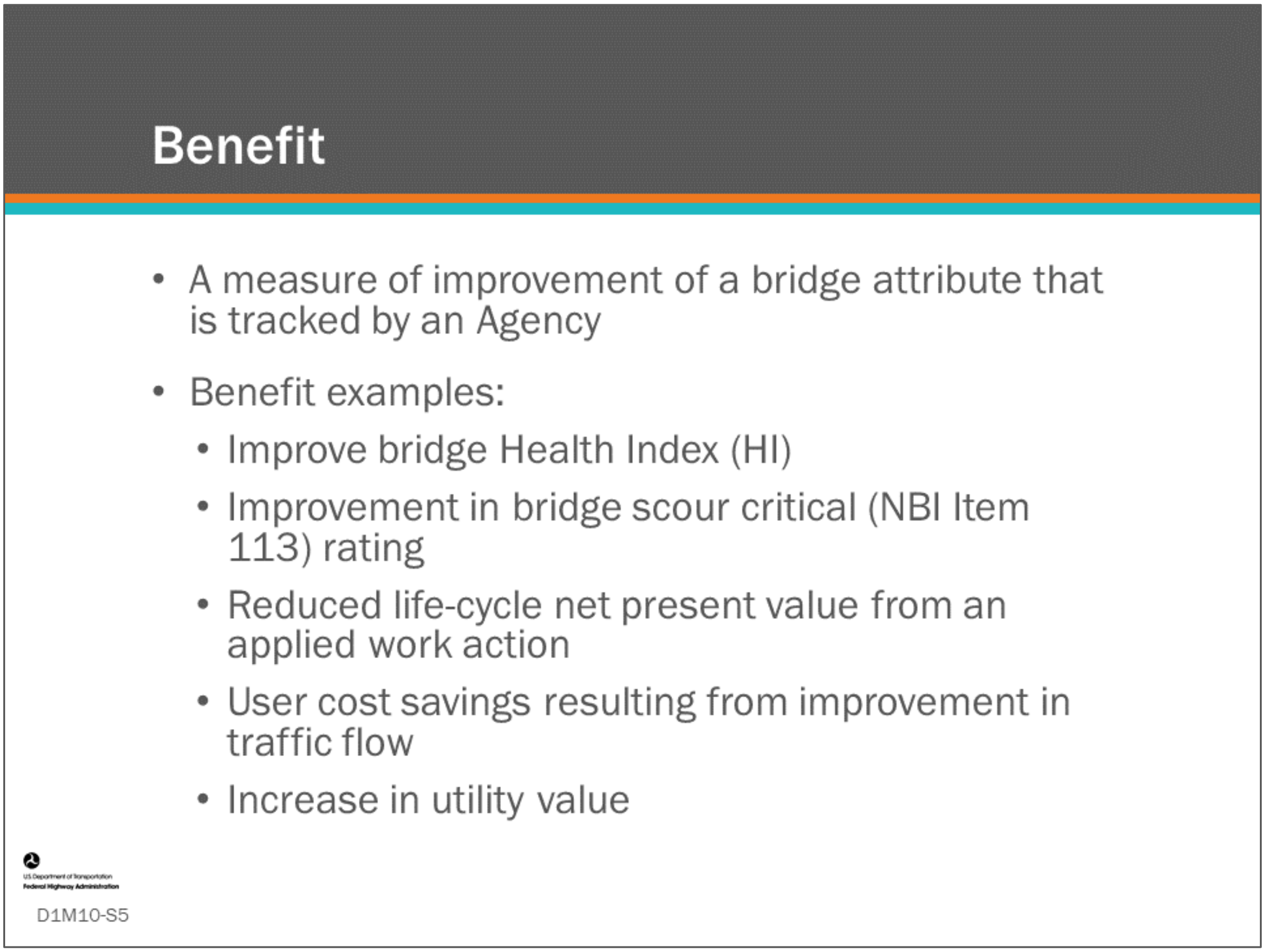
D1M10-Slide 4



Key Message

Review the definition of Benefit-Cost Analysis (BCA).

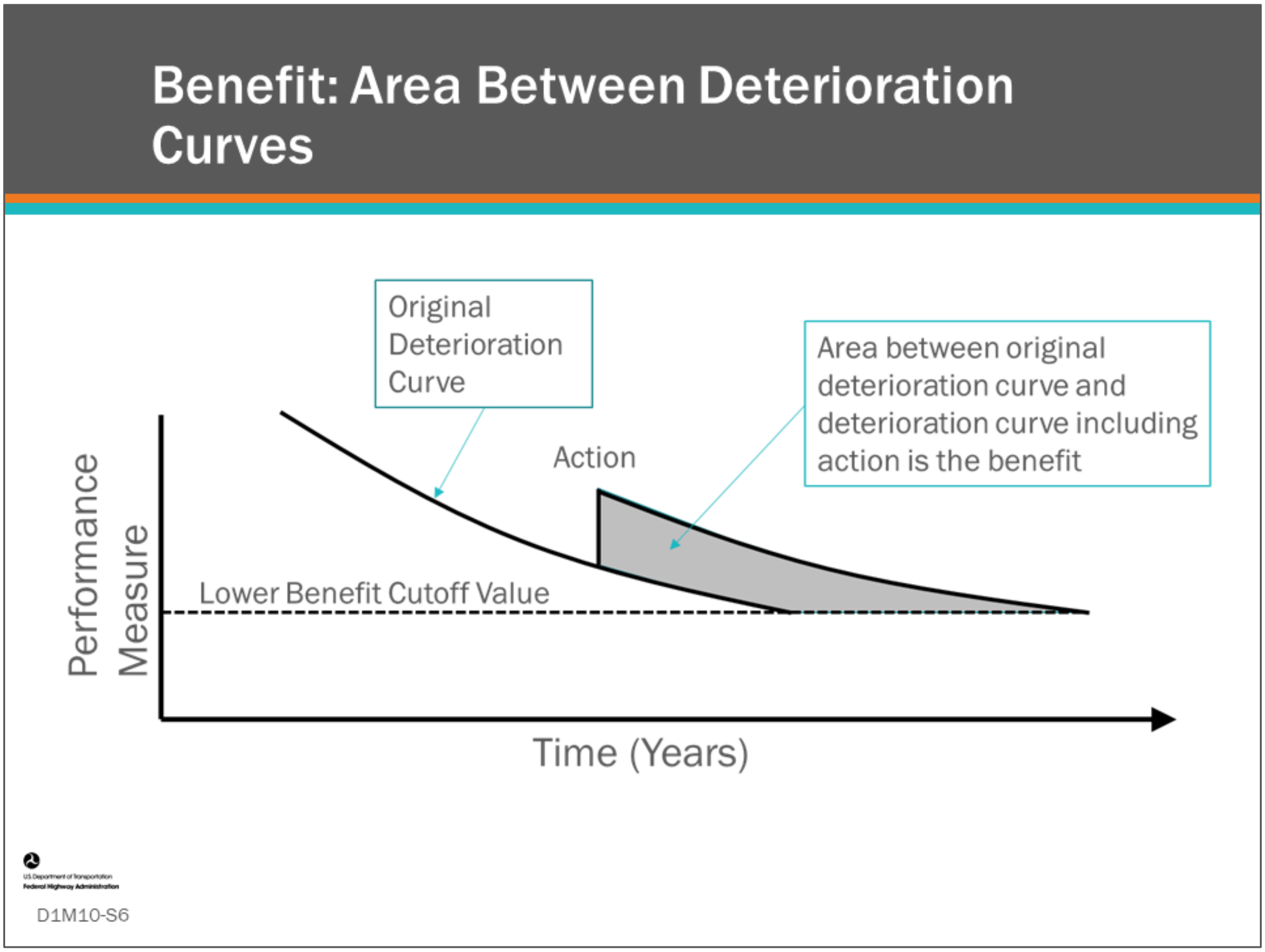
D1M10-Slide 5



Key Message

Shown on this slide is the definition of Benefit. There are many ways to show benefit. Several examples are included on the slide.

D1M10-Slide 6

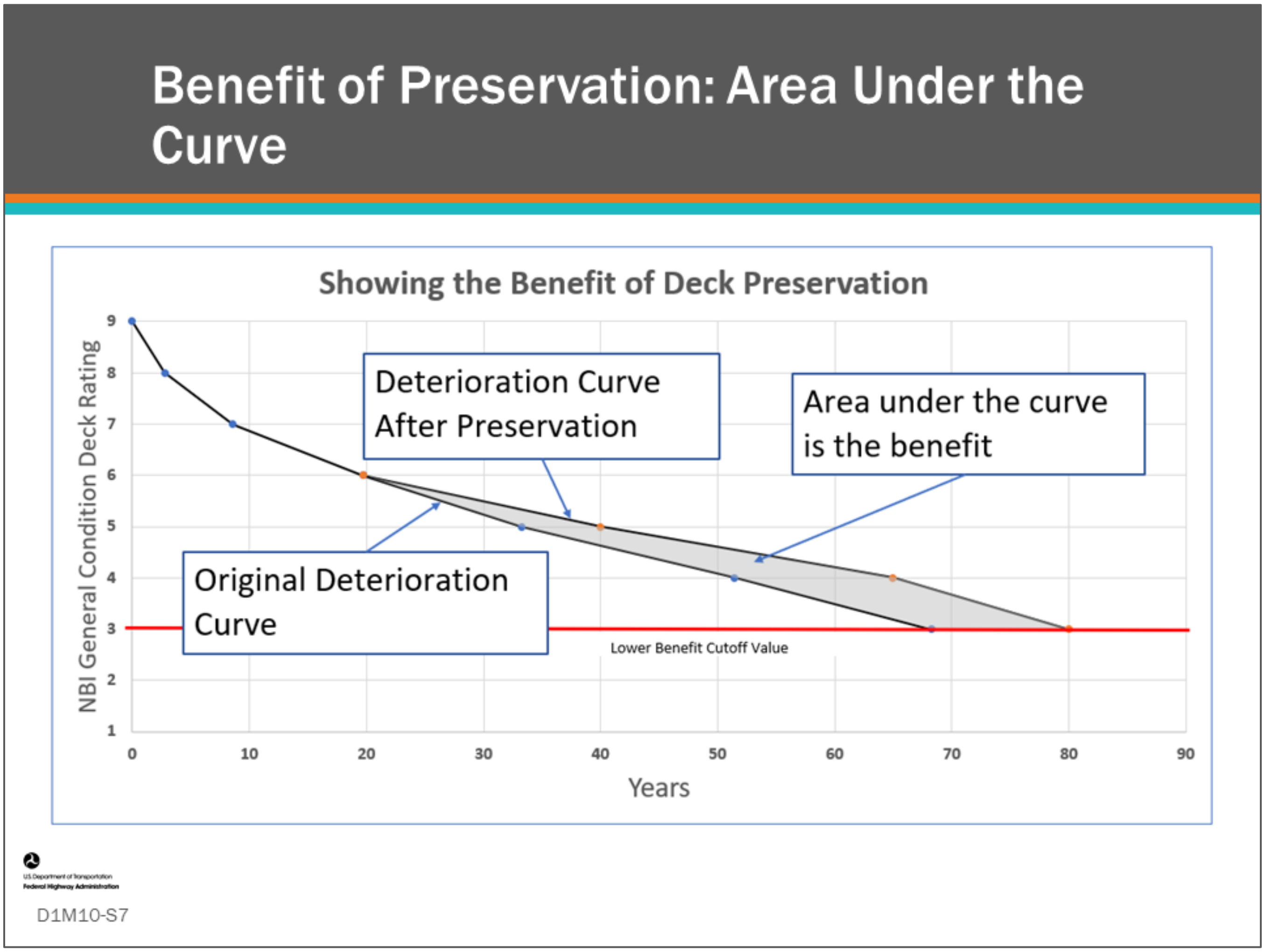


Key Message

Benefit can also be defined as the area between an original deterioration curve and a subsequent deterioration curve taking into account actions that improve the performance measure.

- On the slide, this is shown as a grey area. This is a common method of showing improvement for pavement analysis and it is used by the AgileAssets® Structures Analyst™ software and Deighton dTIMS© software for bridge analysis also. We will call this the area under the curve method.

D1M10-Slide 7



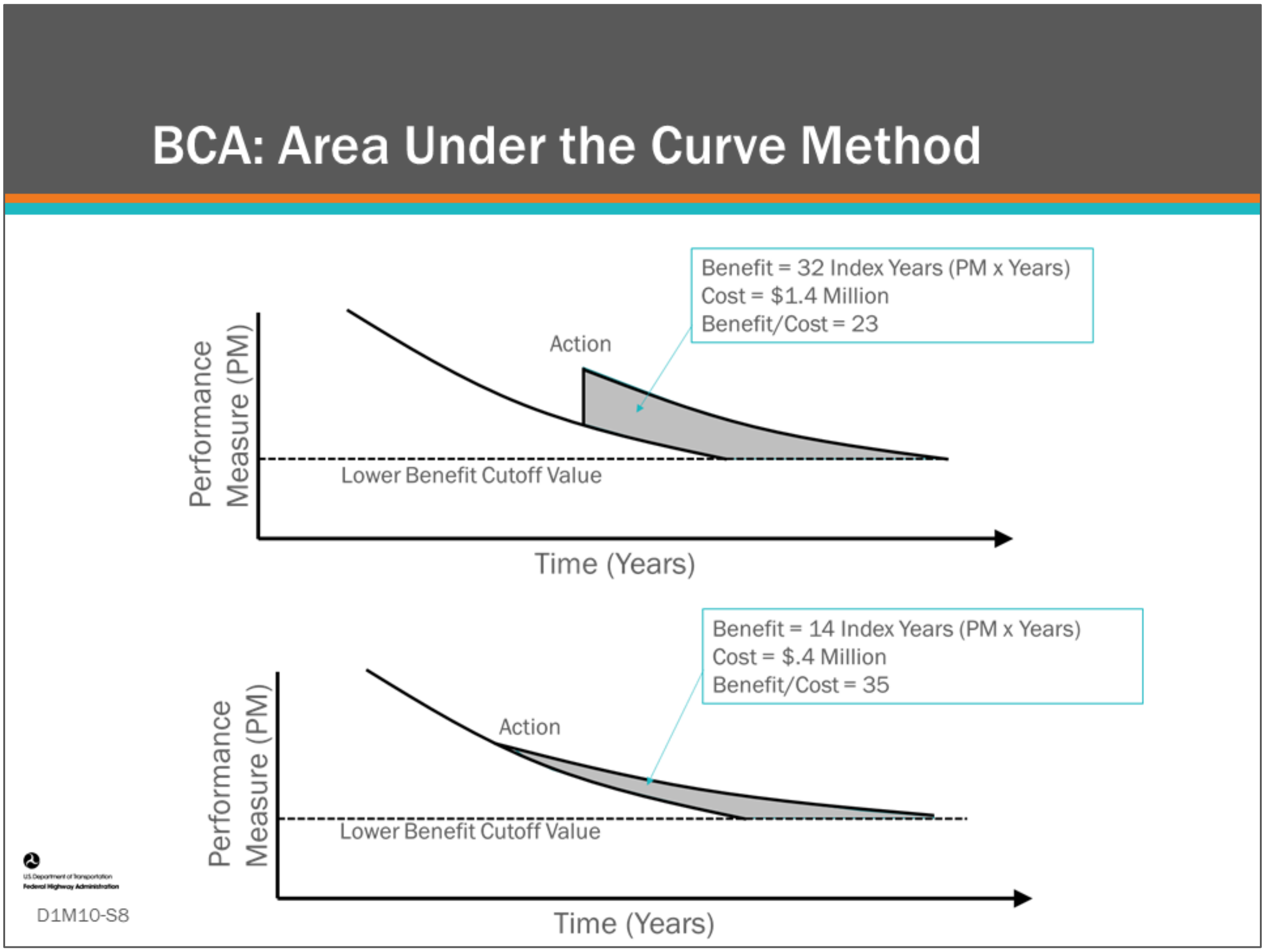
Key Message

Using the area under the curve method, preservation benefit can be shown.

- This slide shows two deterioration curves using NBI GCR rating for a bridge deck. When a preservation action is taken, the deterioration rate slows producing a new deterioration curve.
- As shown on the slide, the area between the new curve and the original curve is the benefit of the preservation action.

The AgileAssets® Structures Analyst™ and Deighton dTIMS© BMS software use this method to determine the benefit when completing BCA.

D1M10-Slide 8



Key Message

If you know the cost of the action (treatment) and you know the area under the curve for the action, you can calculate benefit/cost using the area under the curve method, which can be used to compare different actions for specific bridges, and compare candidate projects for a potential bridge program.

- This slide shows an example of benefit/cost calculations for a rehabilitation action in the top chart and a preservation action in the bottom chart, showing the preservation action having the higher benefit.

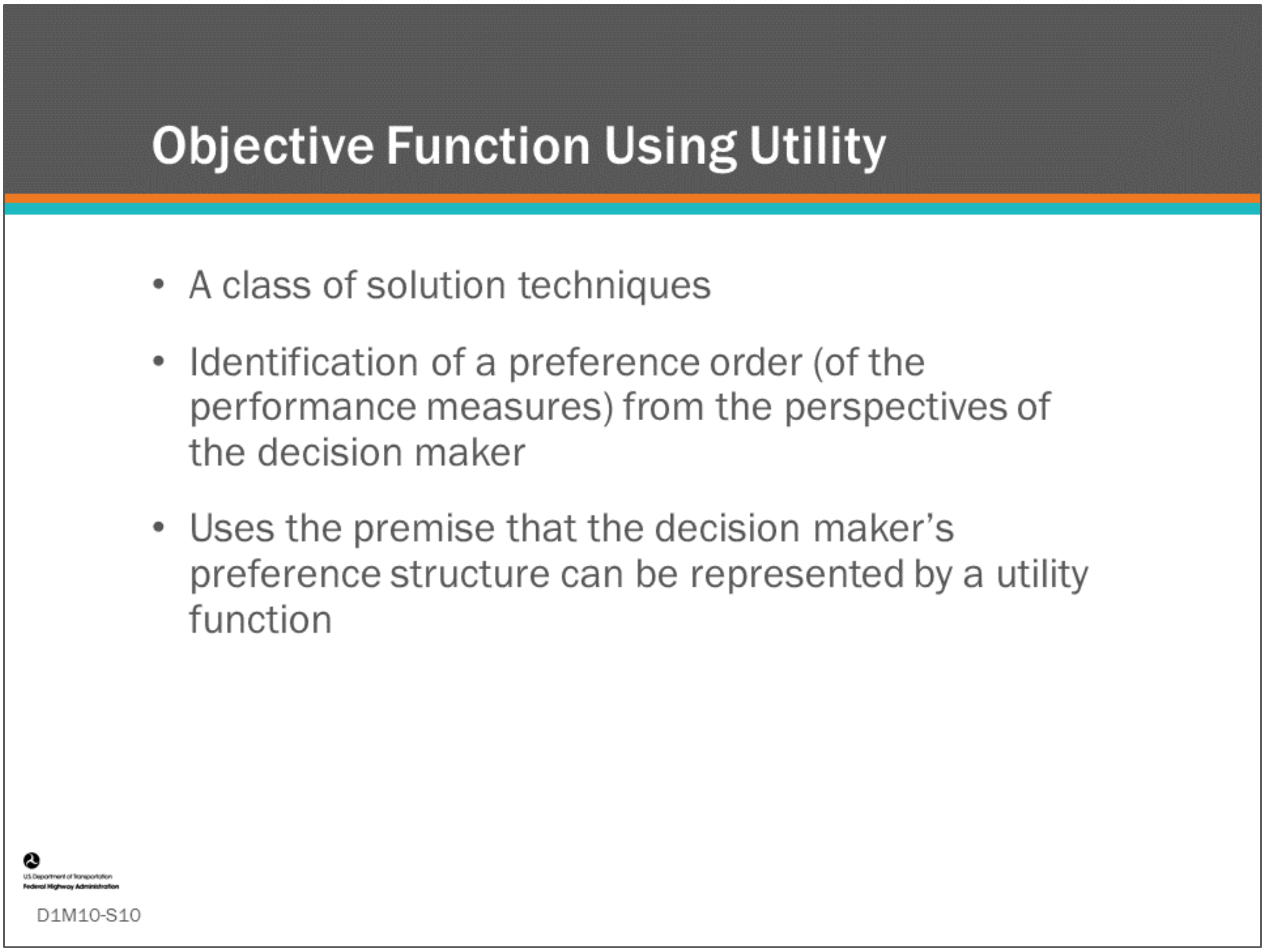
D1M10-Slide 9

Key Message

Agencies often have multiple objectives competing for resources. We will discuss how BMS software manage these trade-offs effectively.

- This slide shows examples of competing objectives.

D1M10-Slide 10

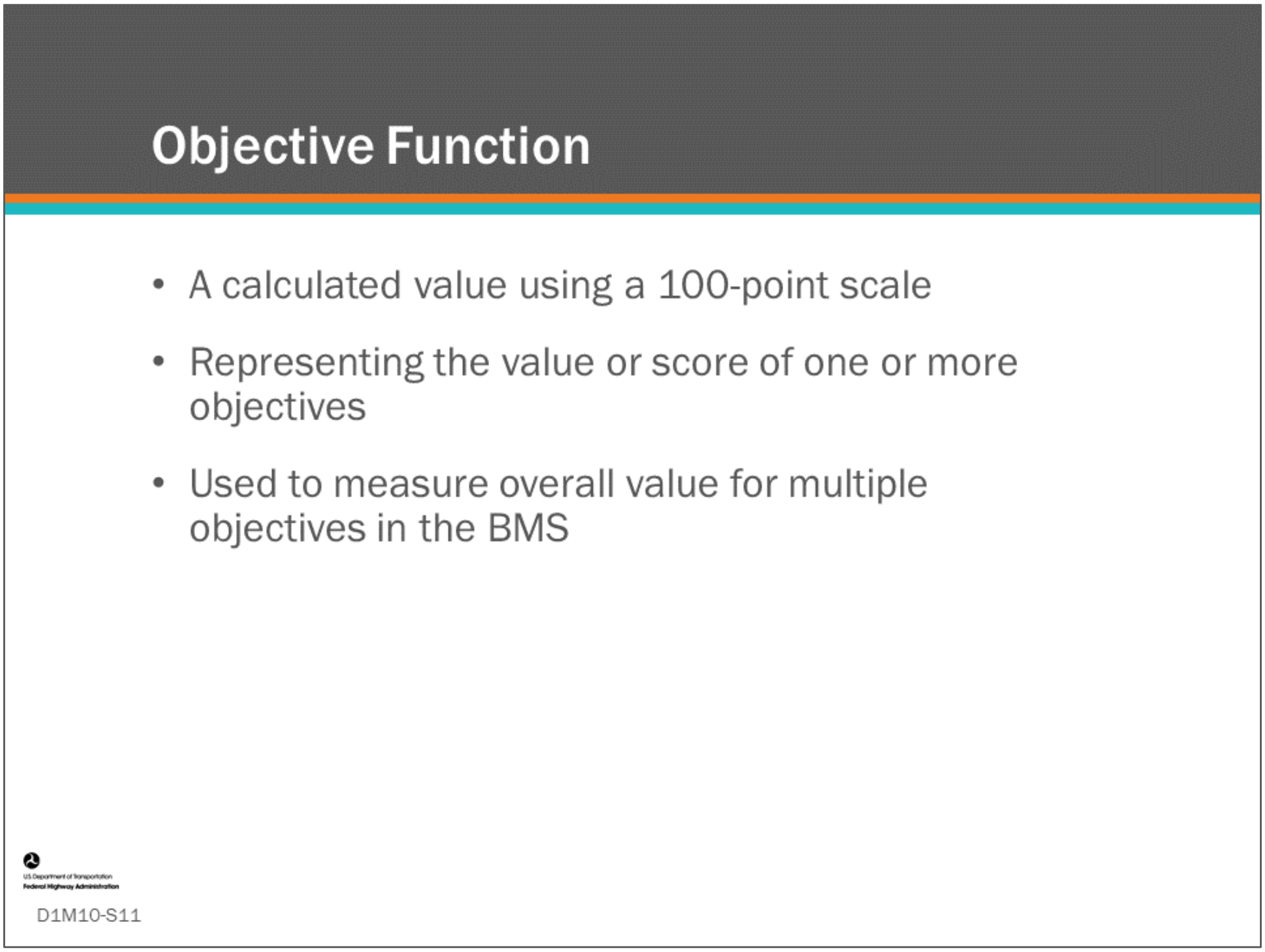


Key Message

NCHRP *Report 590, Multi-Objective Optimization for Bridge Management Systems,* discusses how utility theory is used to manage "trade-offs" between multiple Agency objectives.

- This is done by identifying the decision maker's preference toward different objectives in some direct fashion and attempting to construct some sort of preference order.
- A utility function represents the Agency's preference ordering over a choice set.

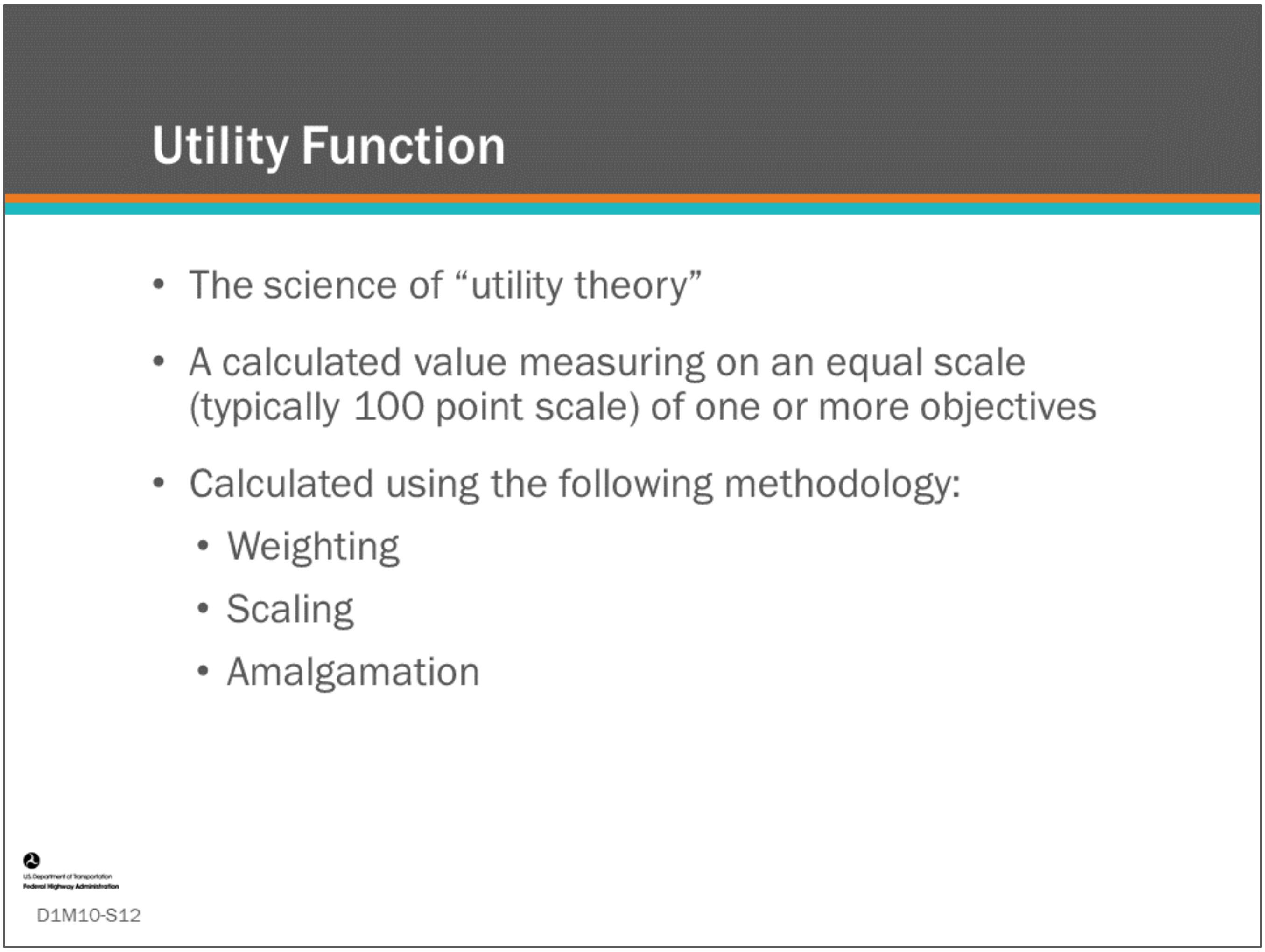
D1M10-Slide 11



Key Message

NCHRP *Report 590*, defines "Objective function" as a single utility function that represents all the utility functions or values of the multiple performance criteria.

D1M10-Slide 12

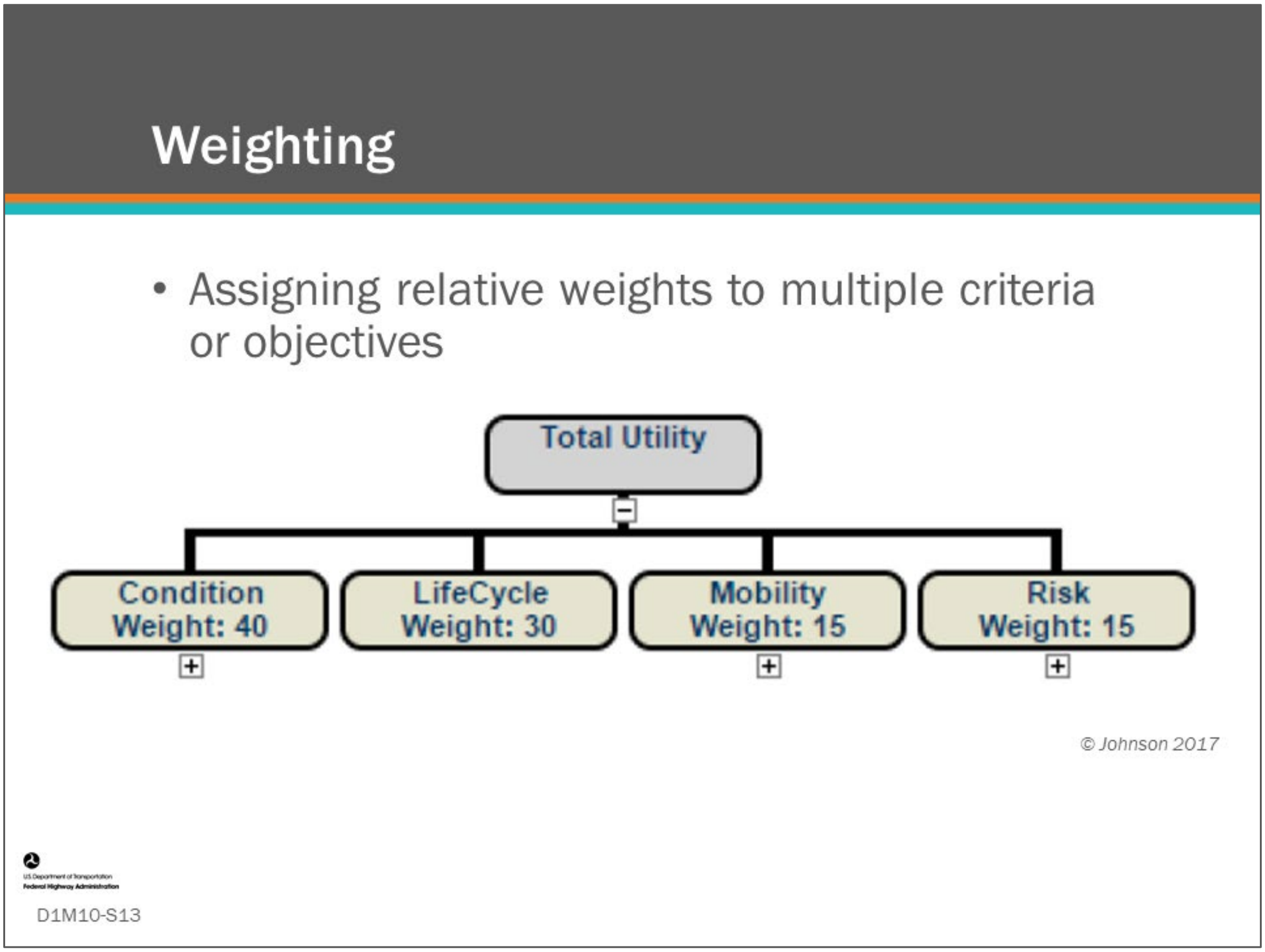


Key Message

This slide defines utility function. BMS software use utility functions to compare and weigh decisions between multiple objectives.

Weighting, scaling and amalgamation will be discussed further.

D1M10-Slide 13



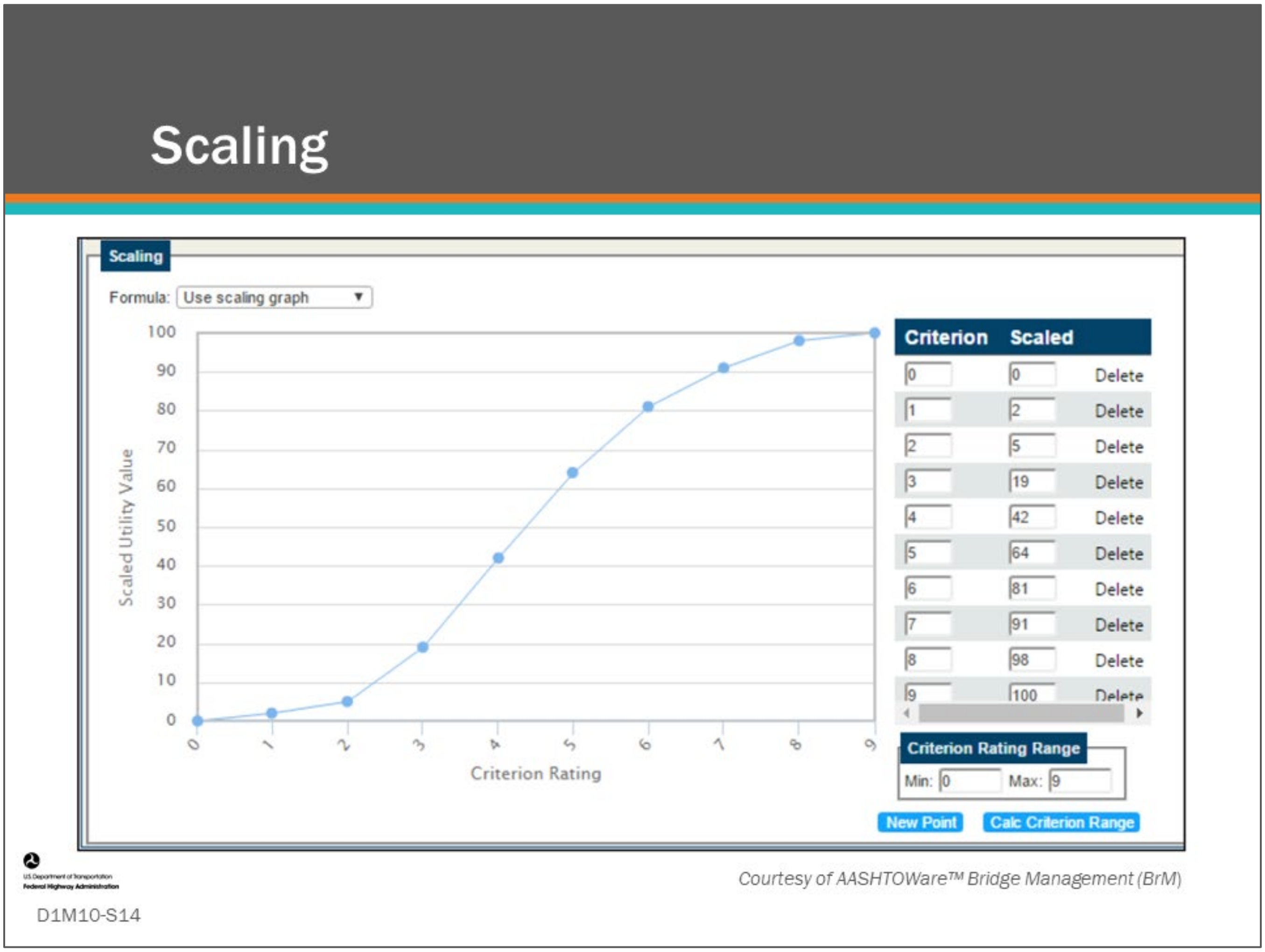
Key Message

Weighting involves assigning relative weights to multiple criteria (objectives). This is the importance that the Agency has given each of the objectives as they relate to each other.

Here we can see a utility tree with the following assigned weights:

- Condition = 40
- Life-Cycle = 30
- Mobility = 15
- Risk = 15

D1M10-Slide 14



Key Message

This slide provides a definition for scaling.

Scaling translates the decision maker’s preferences for each performance criteria to a 0–100 scale.

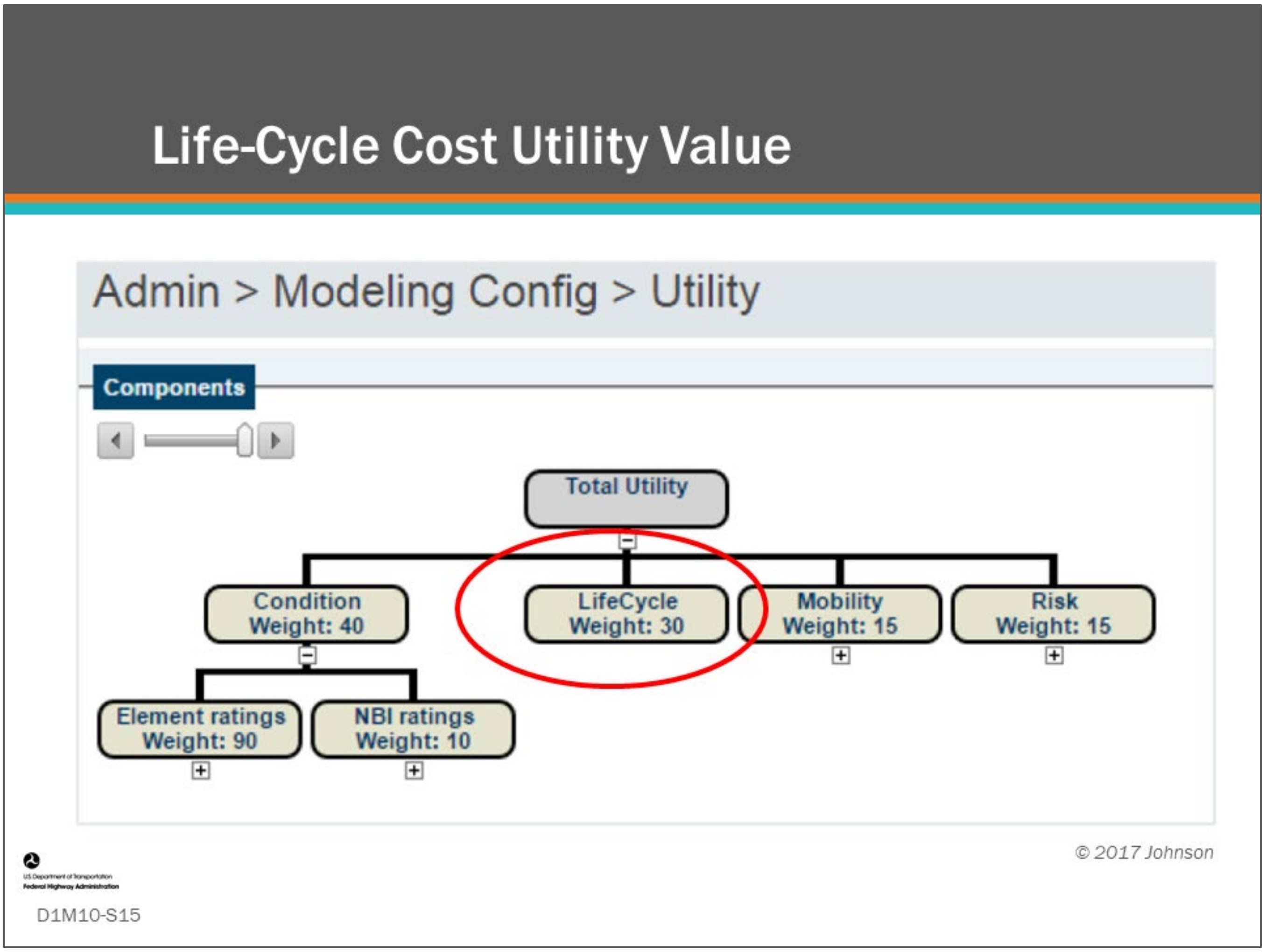
- This involves developing single-criterion utility functions.

Shown on the slide are scaled values for the 0 to 9 NBI GCRs as follows:

- 0 = 0
- 1 = 2
- 3 = 10
- 4 = 42
- 5 = 64
- 6 = 81
- 7 = 91
- 8 = 98
- 9 = 100

In AASHTOWare™ Bridge Management (BrM), the values are plotted for visualization purposes and are adjustable.

D1M10-Slide 15



Key Message

Another objective that can be included in the utility function is life-cycle cost.

- Life-cycle cost analysis (LCCA), as we learned in D1M7, is a way of comparing multiple strategies for a bridge to find the most cost-effective life-cycle plan.
- This can be converted into a utility value using scaling for comparing the value of projects during prioritization and optimization.

Life-cycle is included in the utility function to provide weight to cost effective preservation actions, which may not provide the immediate condition benefit that is included and weighted using the condition utility objective.

D1M10-Slide 16

Life-Cycle Cost Utility Value: Example Calculation

$$LCC_{Utility} = \left(1 - \frac{LCC}{2 \times replacement\ cost}\right) \times 100$$

$$LCC = \mathrm{ST} + \mathrm{LT} - Residual$$

$$Residual = \left(\frac{Remaining\ Service\ Life}{Service\ Life}\right) \times Replacement\ Cost$$

D1M10-S16

Key Message

As we learned in D1M7, present value is a measure of the long-term economic effectiveness of any present day action or sequences of actions throughout a bridge's life-cycle.

The lower the present value, the more efficient the plan. The Life-Cycle Cost (LCC) represented by net present value can be made into a utility value that can be compared to other objectives through formula. Shown in this slide is the AASHTOWare™ Bridge Management (BrM) formula for converting LCC into a utility value.

- ST equals Short-Term costs
- LT equals Long -Term costs
- LCC equals Life Cycle costs
- Residual is the remaining value of the structure at the end of the analysis period. Service life is the expected time the bridge will remain in service. Remaining service life is the expected time from the end of analysis period to the expected end of life for the structure.

D1M10-Slide 17

Life-Cycle Cost Utility Value: Example Calculation (con.)

Index	Date	Year	Action Name	Orig. Cost	NPV Cost
1	2016	0	Bridge-Rehab	$260,570	$260,570
2	2021	5	Paint-General, Thin Bonded Overlay	$45,844	$37,681
3	2036	20	Beams Rehab, Concrete Deck Overlay	$176,863	$80,718
4	2048	32	Beams Rehab, Deck-Replace	$292,525	$83,386
5	2059	43	Beams Rehab	$18,861	$3,493
6	2064	48	Substructure-Rehab	$21,984	$3,346
7	2069	53	Beams Rehab	$17,747	$2,220
8	2079	63	Beams Rehab	$17,768	$1,502
9	2080	64	Bridge-Replacement	$1,625,000	$132,044
10	2093	77	Paint-General	$13,176	$643
Remaining Life:	52 years				
Residual:				$1,242,647	$53,911
Total Life-Cycle Cost:					$551,691

Courtesy of AASHTOWare™ Bridge Management (BrM)

$$LCC = ST + LT - R = \$260{,}570 + \$345{,}032 - \$53{,}911 = \$551{,}691$$

$$LCC_{Utility} = \left(1 - \frac{\$551{,}691}{2 \times \$1{,}625{,}000}\right) \times 100 = \mathbf{83.02}$$

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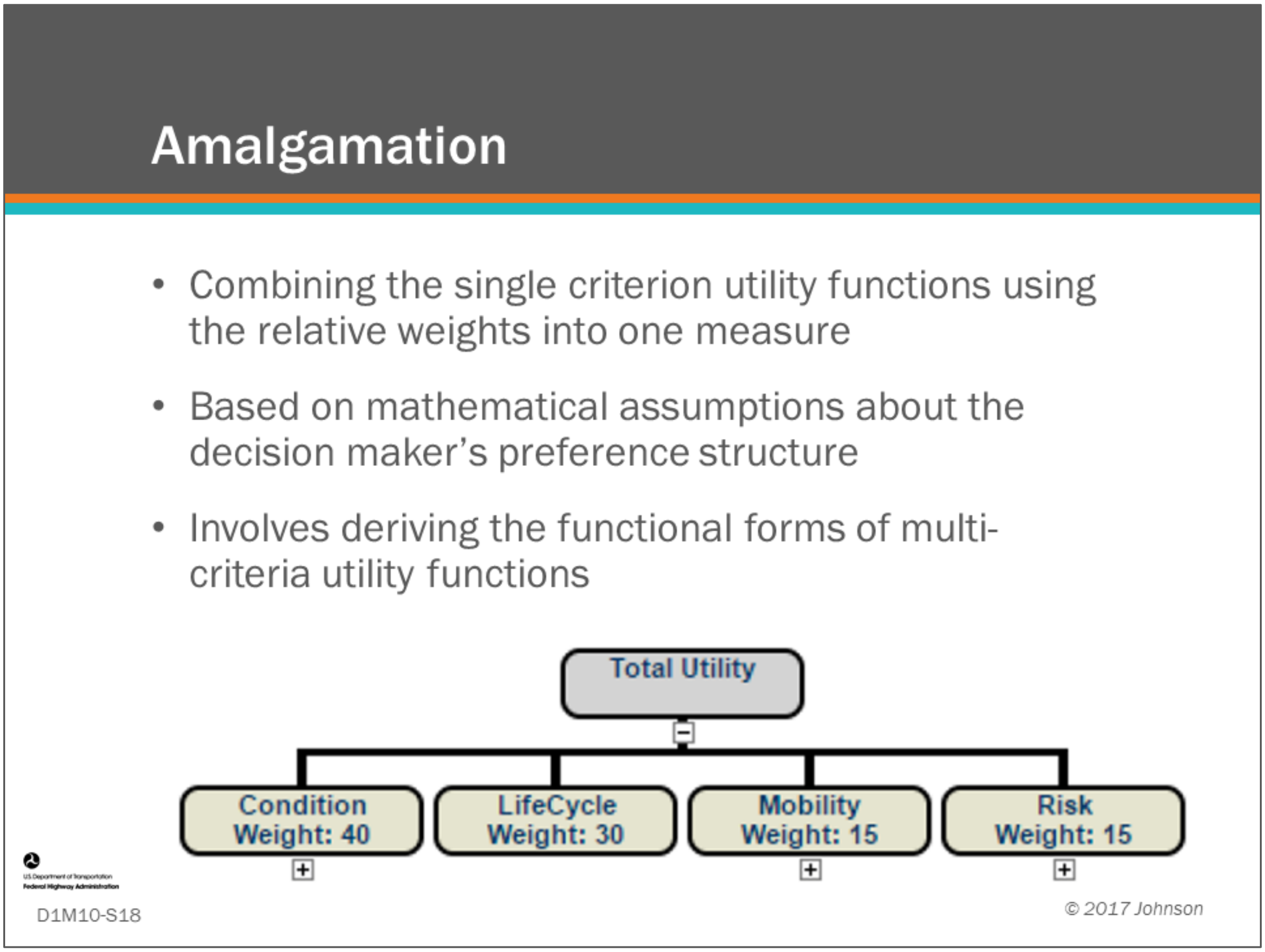
D1M10-S17

Key Message

This slide shows an example calculation of the AASHTOWare™ Bridge Management (BrM) life-cycle utility value.

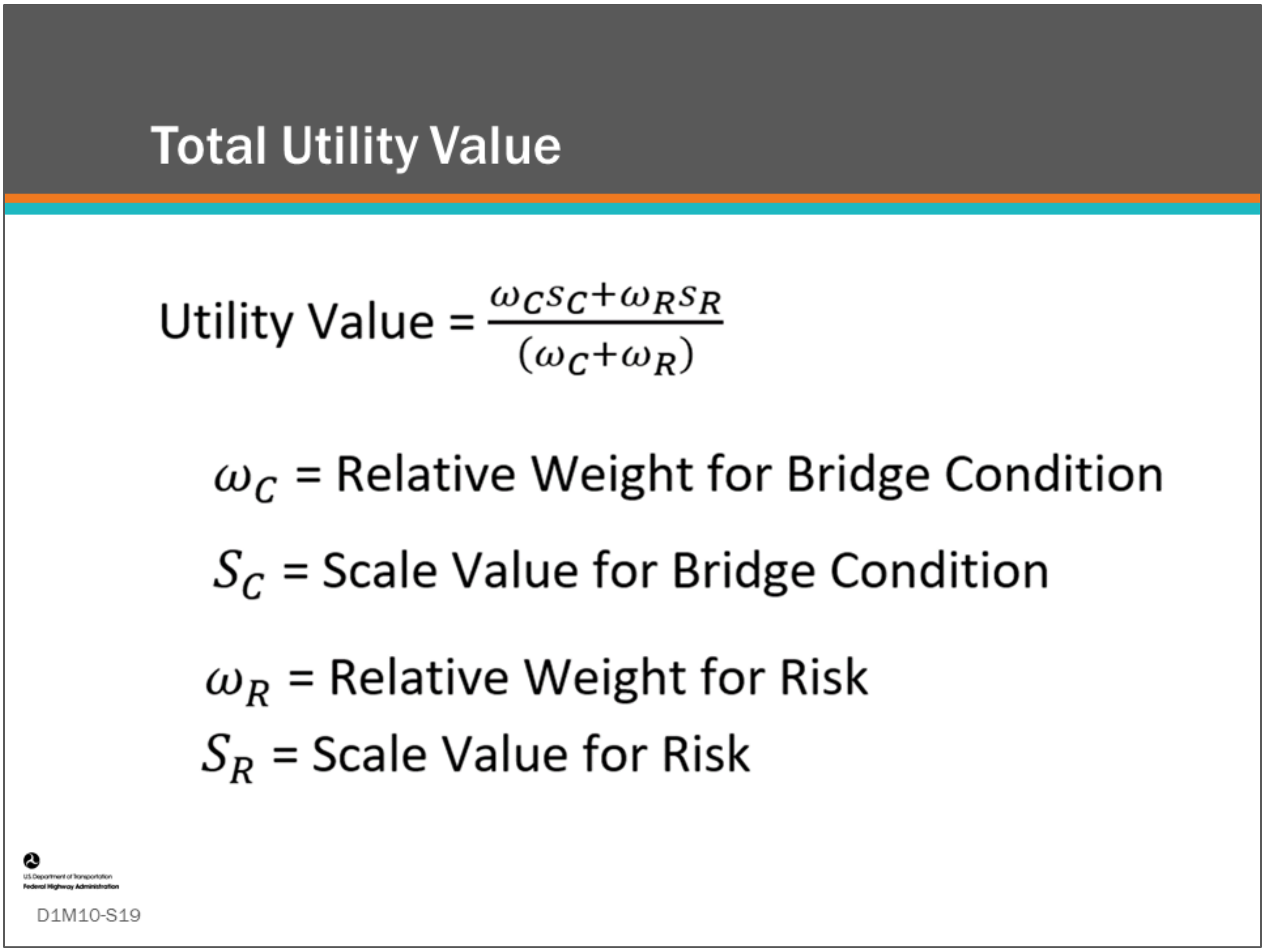
D1M10-Slide 18



Key Message
Definition of amalgamation.

The calculated single utility value is used for prioritization and optimization that we will learn about in D1M11.

D1M10-Slide 19

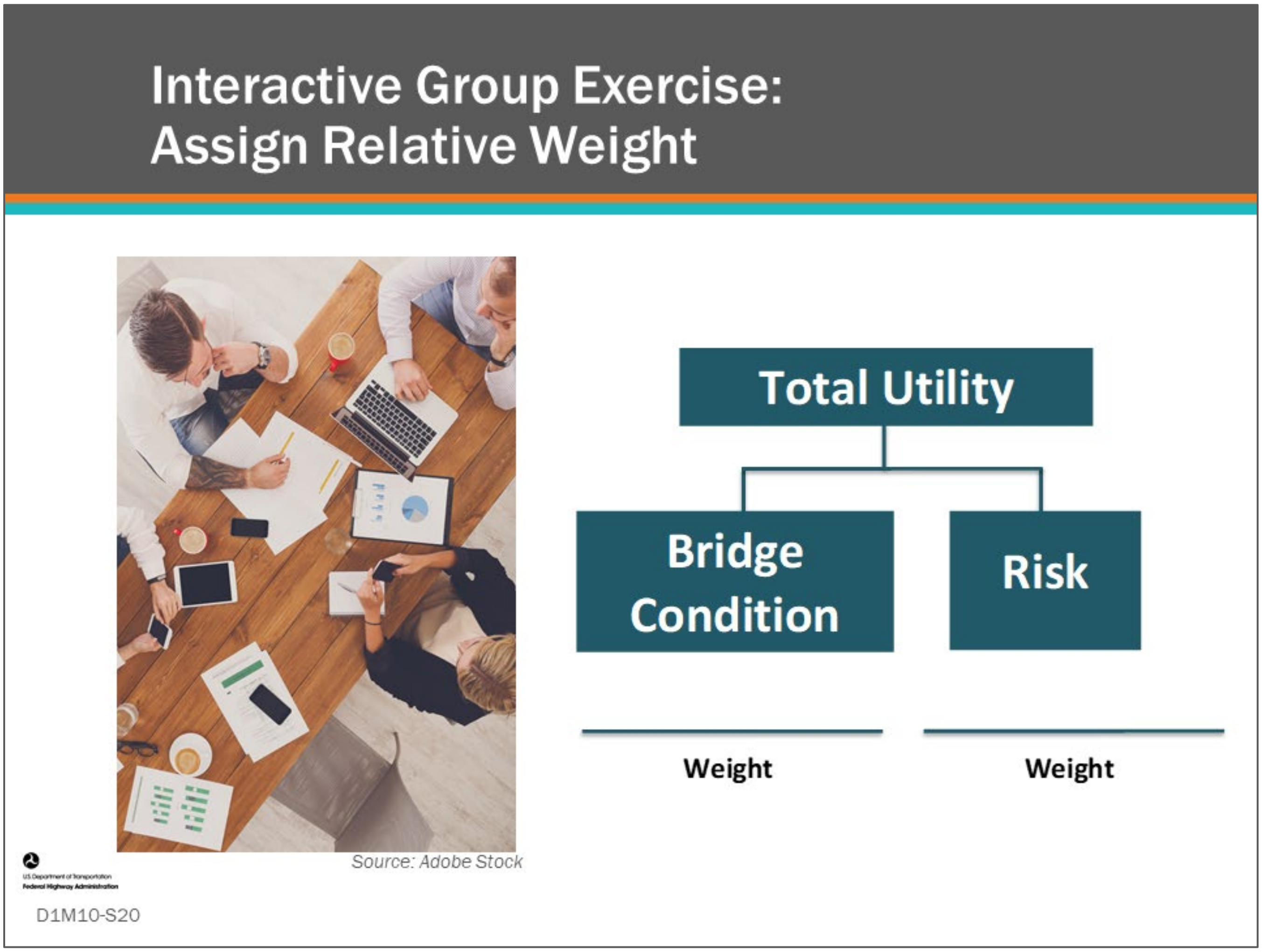


Key Message

Total utility value is a weighted average of all scaled utility values for each objective.

- Shown on this slide is a simple example showing the utility value equation for two objectives; bridge condition and risk, which will be used in the following exercise.

D1M10-Slide 20



Key Message

This interactive class exercise will give the class an opportunity to develop relative weights for two simple objectives: bridge condition and risk (i.e., scour susceptibility).

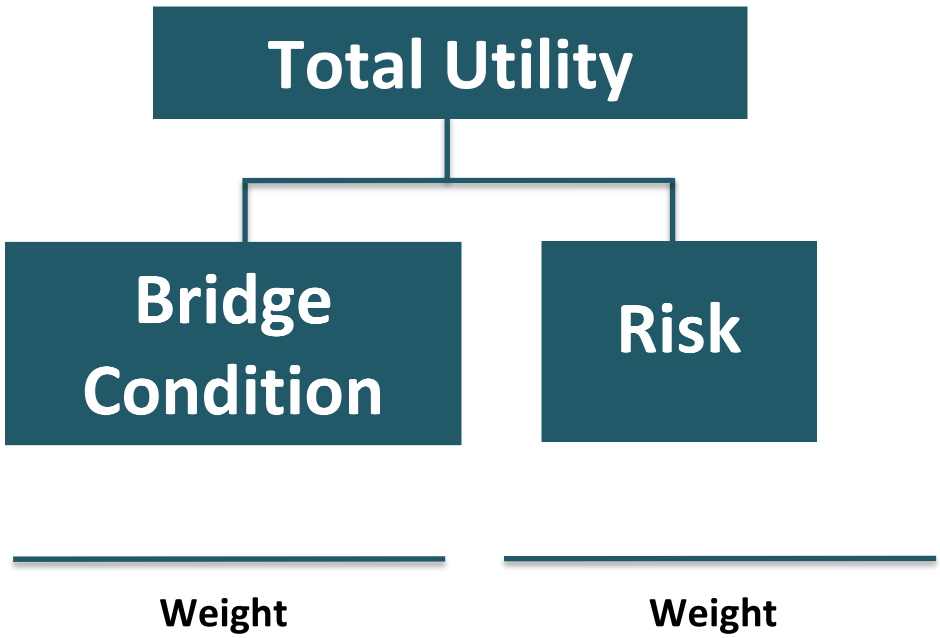
- Record your answer in your Participant Workbook.

D1M10 – Slide 20: Interactive Group Exercise Worksheet

Assign Relative Weight

Complete each of the questions below.

1. What do you think the relative weight is for the two objectives as compared to each other? Assign a number value for each condition based upon a 100-point scale. Record your answer below:



2. Explain why Bridge Condition and Risk should be weighted this way.

D1M10-Slide 21

Interactive Group Exercise: Assign Scaling – Scour Risk

Source: Adobe Stock

Risk	
Scour Vulnerability Rating	Scaling Value
Not Scour Critical (NBI Item 113 = 8)	
Mitigated For Scour (NBI Item 113 = 4, 5, Or 7)	
Scour Critical (NBI Item 113 = 3)	

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D1M10-S21

Key Message

Provide scaling numbers for simple bridge risk using the National Bridge Inventory (NBI) Item 113 – Scour Vulnerability rating.

- Record your answer in your Participant Workbook.

D1M10 – Slide 21: Interactive Group Exercise Worksheet

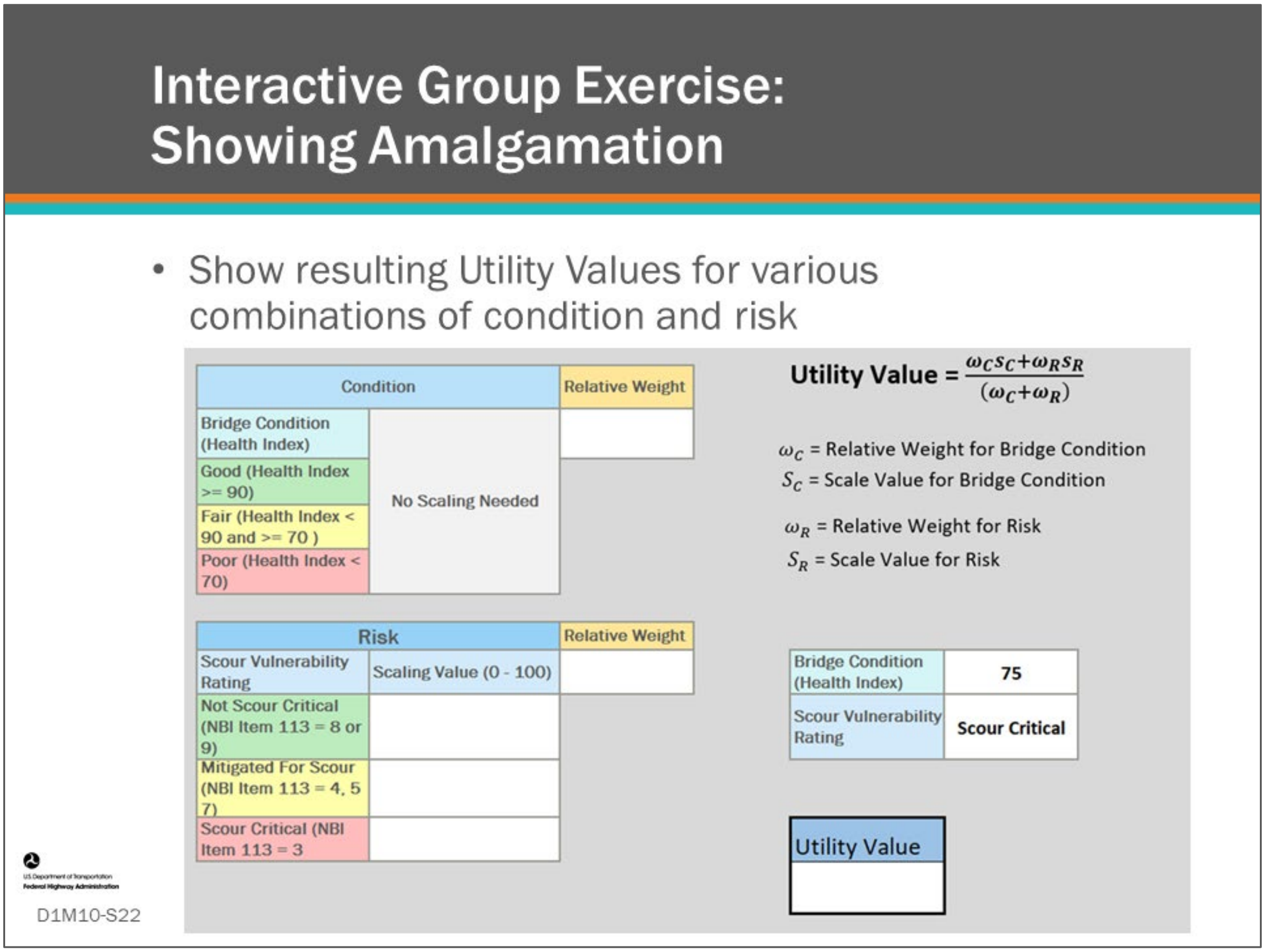
Assign Scaling – Scour Risk

1. Assign a number value for each scour vulnerability rating based upon a 100-point scale with 100 being best and 0 being worst. Record your values in the table below:

Risk	
Scour Vulnerability Rating	**Scaling Value**
Not Scour Critical (NBI Item 113 = 8)	
Mitigated for Scour (NBI Item 113 = 4, 5, or 7)	
Scour Critical (NBI Item 113 = 3)	

2. Explain your reasoning for scaling the scour vulnerability ratings.

D1M10-Slide 22



Key Message

Complete the group exercise showing resulting utility value when Bridge Condition (Health Index) equals 75, and Risk Scour Vulnerability Rating is “Scour Critical” when using the relative unit weights and scaling value for risk selected in the last two slide exercises.

- Record results in your Participant Workbook and discuss results.

D1M10 – Slide 22: Interactive Group Exercise Worksheet

Showing Amalgamation

1. Write the relative weight you selected for condition and risk for the Slide 20 exercise in the appropriate Relative Weight boxes below.
2. Write the Risk Scaling Values for Not Scour Critical, Mitigated for Scour, and Scour Critical for the Slide 21 exercise in the appropriate Scaling Value boxes below.
3. Using the Utility Value equation shown below, calculate the Utility Value when Bridge Condition (Health Index) equals 75, and Risk Scour Vulnerability Rating is "Scour Critical." Enter the value in the Utility Value box.

$$\text{Utility Value} = \frac{\omega_C s_C + \omega_R s_R}{(\omega_C + \omega_R)}$$

ω_C = Relative Weight for Bridge Condition
S_C = Scale Value for Bridge Condition
ω_R = Relative Weight for Risk
S_R = Scale Value for Risk

Condition		**Relative Weight**
Bridge Condition (Health Index)	**No Scaling Needed**	
Good (Health Index ≥ 90)		
Fair (Health Index < 90 and ≥ 70)		
Poor (Health Index < 70)		

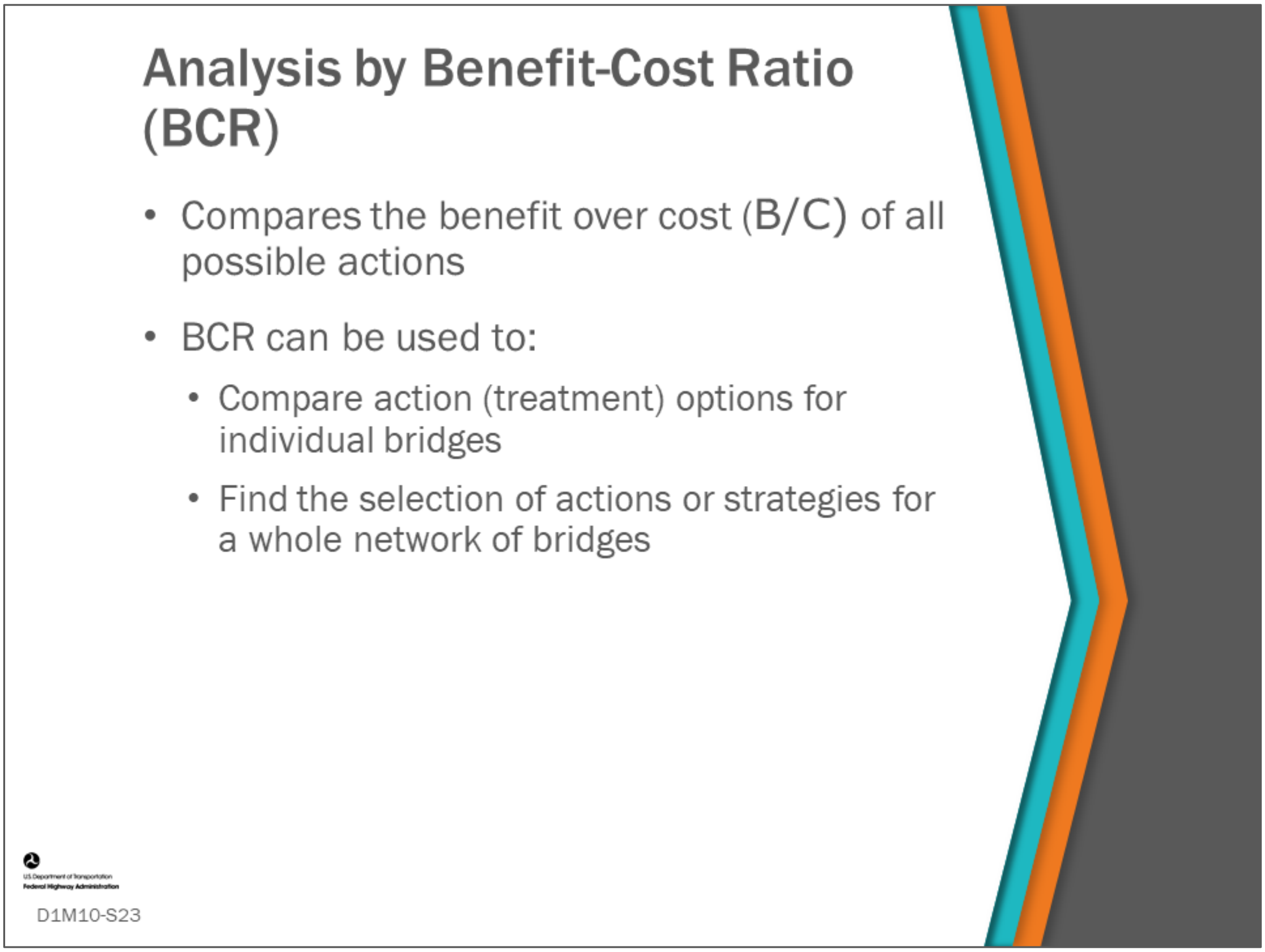
Risk		**Relative Weight**
Scour Vulnerability Rating	**Scaling Value (0 - 100)**	
Not Scour Critical (NBI Item 113 = 8 or 9)		
Mitigated for Scour (NBI Item 113 = 4, 5 7)		
Scour Critical (NBI Item 113 = 2 or 3)		

Bridge Condition (Health Index)	75
Scour Vulnerability Rating	Scour Critical

Utility Value

4. Does the Utility value seem reasonable? Explain why.

D1M10-Slide 23



Key Message

Analysis by BCR compares the benefit over cost (B/C) of all possible actions or strategies, e.g., when the performance index is Life-Cycle Cost (LCC).

Analysis by BCR can be used to compare the options for a single bridge and for a whole network of bridges and strategy options.

D1M10-Slide 24

BCR Calculation for Condition and Risk Utility Values

Example A - Increase Condition But Do Not Improve Risk	
Condition Before Project (Health Index)	55
Condition After Project	90
Risk Before Project	30
Risk After Project	30
Condition Relative Weight	50
Risk Relative Weight	50
Utiltiy Value Before Project	42.50
Utility Value After Project	60.00
Δ Utility	17.50
Project Cost	$1,200,000
Benefit/Cost	**14.58**

$$\text{Utility Value} = \frac{\omega_C s_C + \omega_R s_R}{100(\omega_C + \omega_R)}$$

Example B - Do Not Improve Condition But Improve Risk	
Condition Before Project (Health Index)	55
Condition After Project	55
Risk Before Project	30
Risk After Project	70
Condition Relative Weight	50
Risk Relative Weight	50
Utiltiy Value Before Project	42.50
Utility Value After Project	62.50
Δ Utility	20
Project Cost	$900,000
Benefit/Cost	**22.22**

$$\text{Utility Value} = \frac{\omega_C s_C + \omega_R s_R}{100(\omega_C + \omega_R)}$$

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D1M10-S24

Key Message

This slide shows two example calculations for benefit-cost ratio (BCR).

- The box on the left shows a project costing $1,200,000 which increases the bridge condition but does not improve the risk to the structure. The increase in utility is 18 points, resulting in a Benefit/Cost score of 14.58.
- The box on the right shows a project costing $900,000 which improves the risk for the bridge but does not improve the condition. The increase in utility is 20 points, resulting in a Benefit/Cost score of 22.22.

Note: There are various ways to calculate benefit (over the Do Nothing option); this is just one of them.

D1M10-Slide 25

BCR Calculation for Condition and Risk Utility Values – Third Option

- Compare Benefit/Cost Scores from Last Slide
  - A: Improve Condition But Do Not Improve Risk = 14.58
  - B: Do Not Improve Condition But Improve Risk = 22.22
  - C: Condition and Risk Improved Risk = 20.83

Example C - Improve Condition and Risk	
Condition Before Project (Health Index)	55
Condition After Project	90
Risk Before Project	30
Risk After Project	70
Condition Relative Weight	50
Risk Relative Weight	50

$$\text{Utility Value} = \frac{\omega_C s_C + \omega_R s_R}{100(\omega_C + \omega_R)}$$

Utiltiy Value Before Project	42.50
Utility Value After Project	80.00
Δ Utility	38
Project Cost	$1,800,000
Benefit/Cost	**20.83**

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D1M10-S25

Key Message

Shown on this slide is the Benefit/Cost Score equal to 20.83 if condition and risk is improved for a cost of $1,800,000. How does this compare to the Benefit/Cost Scores for the other two options presented on the previous slide? Recall:

- Improve Condition but Do Not Improve Risk equaled 14.58
- Do Not Improve Condition but Improve Risk equaled 22.22

This slide shows an example of looking at an individual bridge having several actions to choose from. In the following slides we will also look at how BCA can be used to compare multiple bridges with multiple actions on each.

D1M10-Slide 26

BCR Used to Prioritize Bridge Strategies

$$\frac{B}{C} = \frac{11}{\$0.1M} = 110$$

Bridge Number	Strategy Name	Action Cost (C)	Action Benefit (B)	Benefit/Cost
1001	Do Nothing	$0	0	
1001	Preservation	$100,000	11	110
1001	Rehabilitation	$350,000	20	57
1001	Replacement	$1,400,000	55	39
1002	Do Nothing	$0	0	
1002	Preservation	$150,000	15	100
1002	Rehabilitation	$180,000	20	111
1002	Replacement	$1,200,000	57	48
1003	Do Nothing	$0	0	
1003	Preservation	$60,000	4	67
1003	Rehabilitation	$190,000	10	53
1003	Replacement	$700,000	18	26

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D1M10-S26

Key Message

The purpose of doing BCA is to compare actions or life-cycle plan strategies for individual bridge actions and to compare strategies on multiple bridges.

Shown on this slide are the Net Present Value (NPV) action costs for four common options (do nothing, preservation, rehabilitation, and replacement) for three bridges.

- In the right-most column, benefit/cost scores are calculated.
- This is a simple example that demonstrates how to calculate BCR. When calculating benefits, some agencies have observed that bridges of different sizes need to have their benefits relative weighted. If not weighted, small bridges will be selected first because of their lower action cost.

D1M10-Slide 27

BCR Used to Prioritize Bridge Strategies: BCR Scores Sorted

Bridge Number	Strategy Name	Action Cost (C)	Action Benefit (B)	Benefit/Cost
1002	Rehabilitation	$180,000	20	111
1001	Preservation	$100,000	11	110
1002	Preservation	$150,000	15	100
1003	Preservation	$60,000	4	67
1001	Rehabilitation	$350,000	20	57
1003	Rehabilitation	$190,000	10	53
1002	Replacement	$1,200,000	57	48
1001	Replacement	$1,400,000	55	39
1003	Replacement	$700,000	18	26
1001	Do Nothing	$0	0	
1002	Do Nothing	$0	0	
1003	Do Nothing	$0	0	

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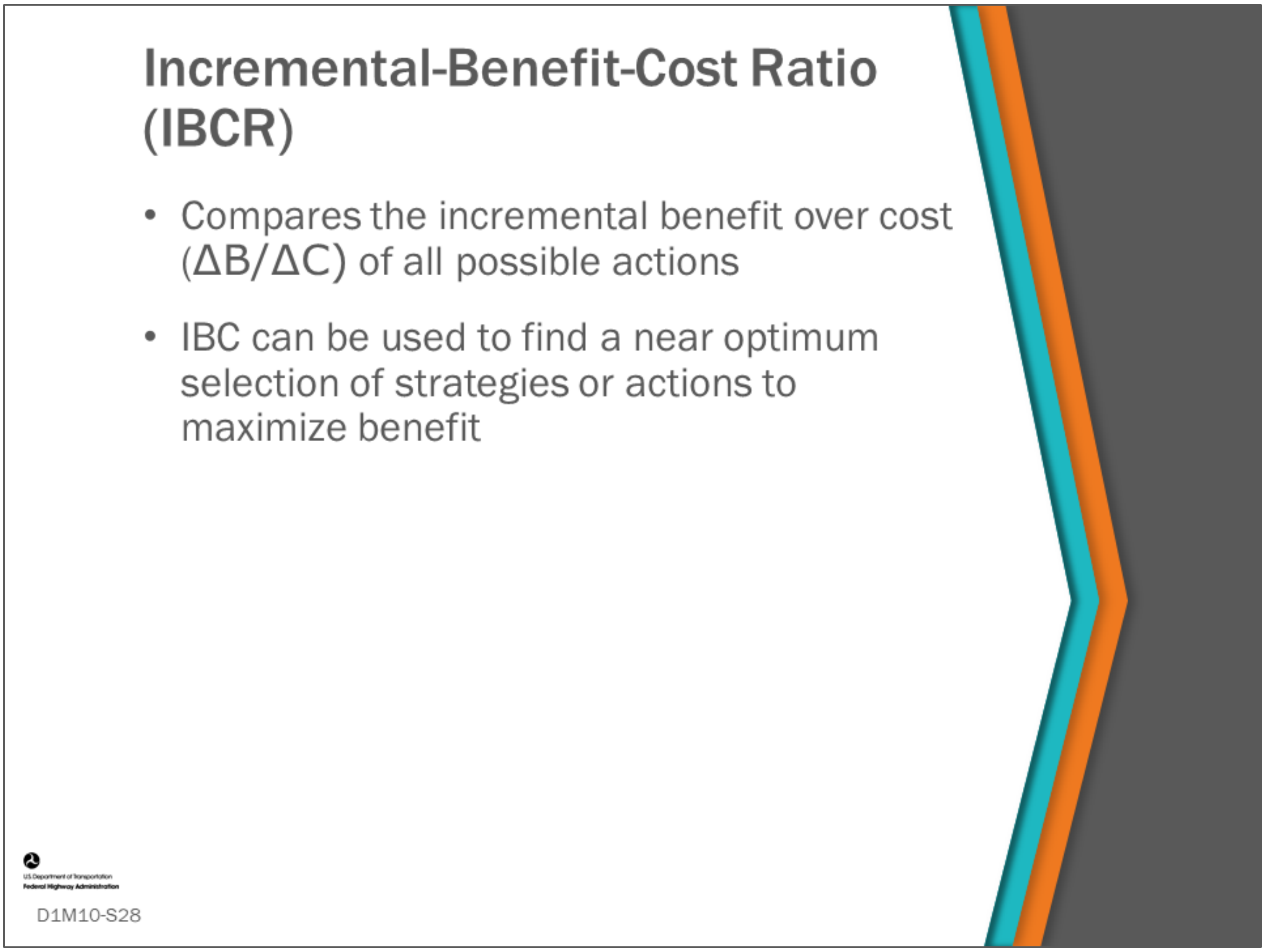
D1M10-S27

Key Message

Shown on this slide is the benefit/cost scores sorted from highest to Lowest. This can be used to prioritize bridge strategy selections by picking the strategy that will produce the maximum benefit given constraints such as budget. Methods for doing this are covered on the second day of the workshop.

D1M10-Slide 28

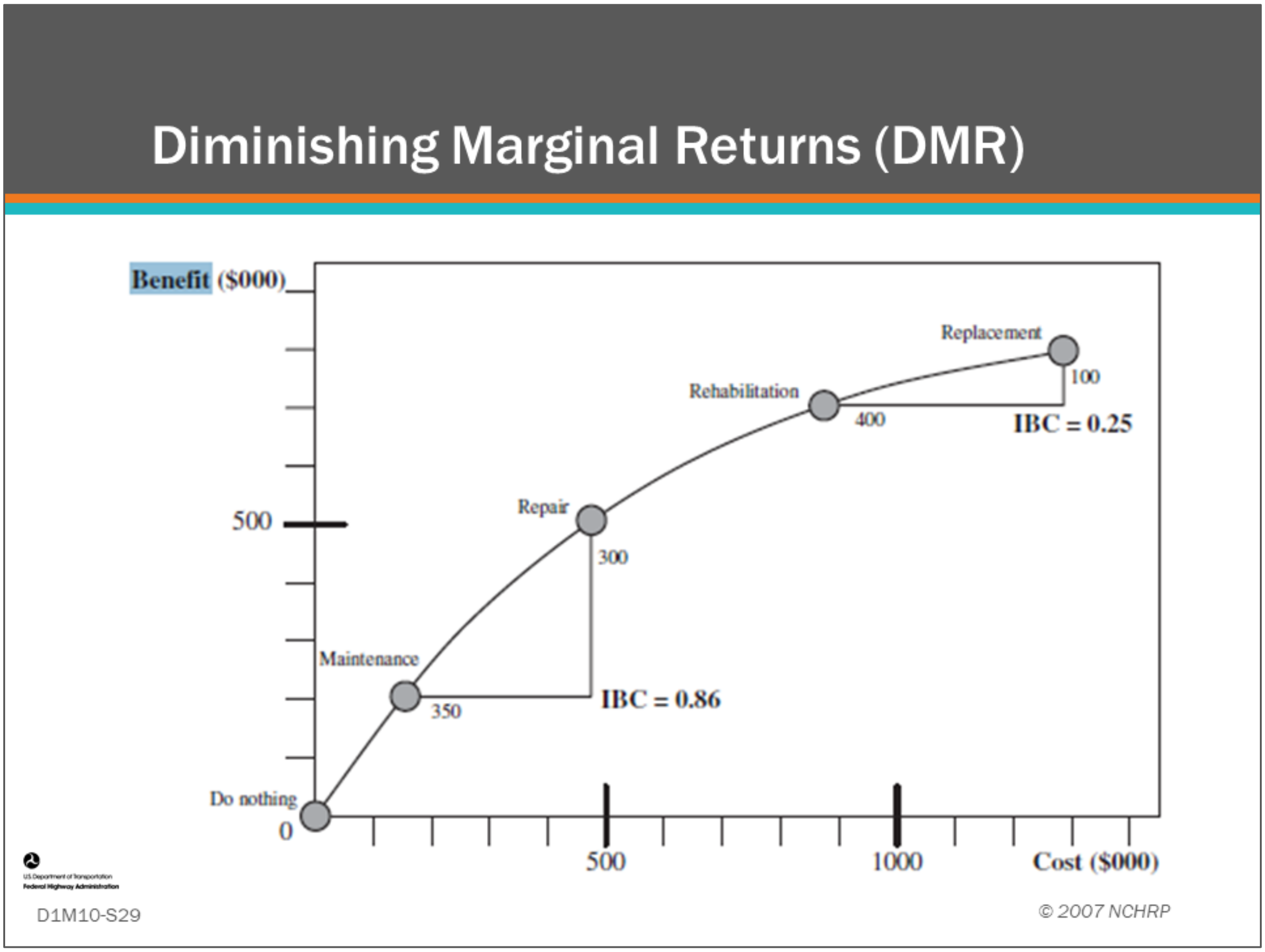


Key Message

Incremental Benefit-Cost Ratio (IBCR) is one of several more advanced methods used to optimize actions or strategy benefits having one or more constraints.

- IBCR is the “additional” utility or benefit gained from doing an action (treatment) over a less costly action (treatment).
- IBCR can be used to find the near optimum selection of actions to maximize benefit.

D1M10-Slide 29



Key Message

In this example from NCHRP *Report 590*, “benefit” is defined as the savings in cost of doing something, relative to the do nothing candidate, which can be quantified as the increase in utility of doing something rather than doing nothing.

- In this example, if the scope of work on the bridge is upgraded from maintenance to repair, then the additional cost is $350,000, and the additional benefit is $300,000, which means that the marginal return, or IBC, is 0.86.
- Similarly, if the scope of work is upgraded from rehabilitation to replacement, then the cost increases by $400,000 while the benefit increases by only $100,000, which means that the IBC is 0.25.
- Diminishing marginal returns is the observation that more expensive alternatives often (but not always) have progressively smaller incremental benefit/cost ratios.
- In other words, the first dollar gives the greatest benefit and the last dollar gives the smallest benefit. This is also a way to show the value of bridge preservation.

D1M10-Slide 30

Analysis by Incremental-Benefit-Cost Ratio (IBC) Example Calculations

$$\frac{\Delta B}{\Delta C} = \frac{(20 - 11)}{(\$0.35M - \$0.10M)} = 36$$

Bridge Number	Strategy Name	Action Cost	Action Benefit	Incremental Benefit/Cost
1001	Do Nothing	$0	0	
1001	Preservation	$100,000	11	110
1001	Rehabilitation	$350,000	20	36
1001	Replacement	$1,400,000	55	33
1002	Do Nothing	$0	0	
1002	Preservation	$150,000	15	100
1002	Rehabilitation	$180,000	20	167
1002	Replacement	$1,200,000	57	36
1003	Do Nothing	$0	0	
1003	Preservation	$60,000	4	67
1003	Rehabilitation	$190,000	10	46
1003	Replacement	$700,000	18	16

$$\frac{\Delta B}{\Delta C} = \frac{(4 - 0)}{(\$0.06M - \$0.0M)} = 67$$

D1M10-S30

Key Message

For Incremental Benefit-Cost Ratio (IBC), the ΔB/ΔC is calculated, as shown on the slide.

D1M10-Slide 31

Analysis by Incremental-Benefit-Cost (IBC) Example Calculations (con.)

Bridge Number	Strategy Name	Action Cost	Action Benefit	Incremental Benefit/Cost
1002	Rehabilitation	$180,000	20	167
1001	Preservation	$100,000	11	110
1002	Preservation	$150,000	15	100
1003	Preservation	$60,000	4	67
1003	Rehabilitation	$190,000	10	46
1002	Replacement	$1,200,000	57	36
1001	Rehabilitation	$350,000	20	36
1001	Replacement	$1,400,000	55	33
1003	Replacement	$700,000	18	16
1001	Do Nothing	$0	0	
1002	Do Nothing	$0	0	
1003	Do Nothing	$0	0	

D1M10-S31

Key Message

After ΔB/ΔC is calculated for each action, the list can be sorted from highest to lowest ΔB/ΔC, as shown on this slide.

- On the second day of the workshop we will look at methods to select a list of strategies to maximize benefit.
- Methods like this are used by BMS software to recommend project selection to maximize benefit given constraints.

D1M10-Slide 32

IBC Used to Maximize Benefit with Budget Constraint

Annual Budget
$1,500,000

Bridge Number	Strategy Name	Picked	Action Cost	Picked Option Cost	Action Benefit	Picked Option Benefit	Incremental Benefit/Cost
1002	Rehabilitation		$180,000	$0	20	0	167
1001	Preservation	1	$100,000	$100,000	11	11	110
1002	Preservation	-	$150,000	$0	15	0	100
1003	Preservation		$60,000	$0	4	0	67
1003	Rehabilitation	1	$190,000	$190,000	10	10	46
1002	Replacement	1	$1,200,000	$1,200,000	57	57	36
1001	Rehabilitation	-	$350,000	$0	20	0	36
1001	Replacement	-	$1,400,000	$0	55	0	33
1003	Replacement	-	$700,000	$0	18	0	16
1001	Do Nothing	-	$0	$0	0	0	
1002	Do Nothing	-	$0	$0	0	0	
1003	Do Nothing	-	$0	$0	0	0	

Total Scenario Cost:	**$1,490,000**
Total Scenario Benefit:	**78**
Remaining Budget	$10,000

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D1M10-S32

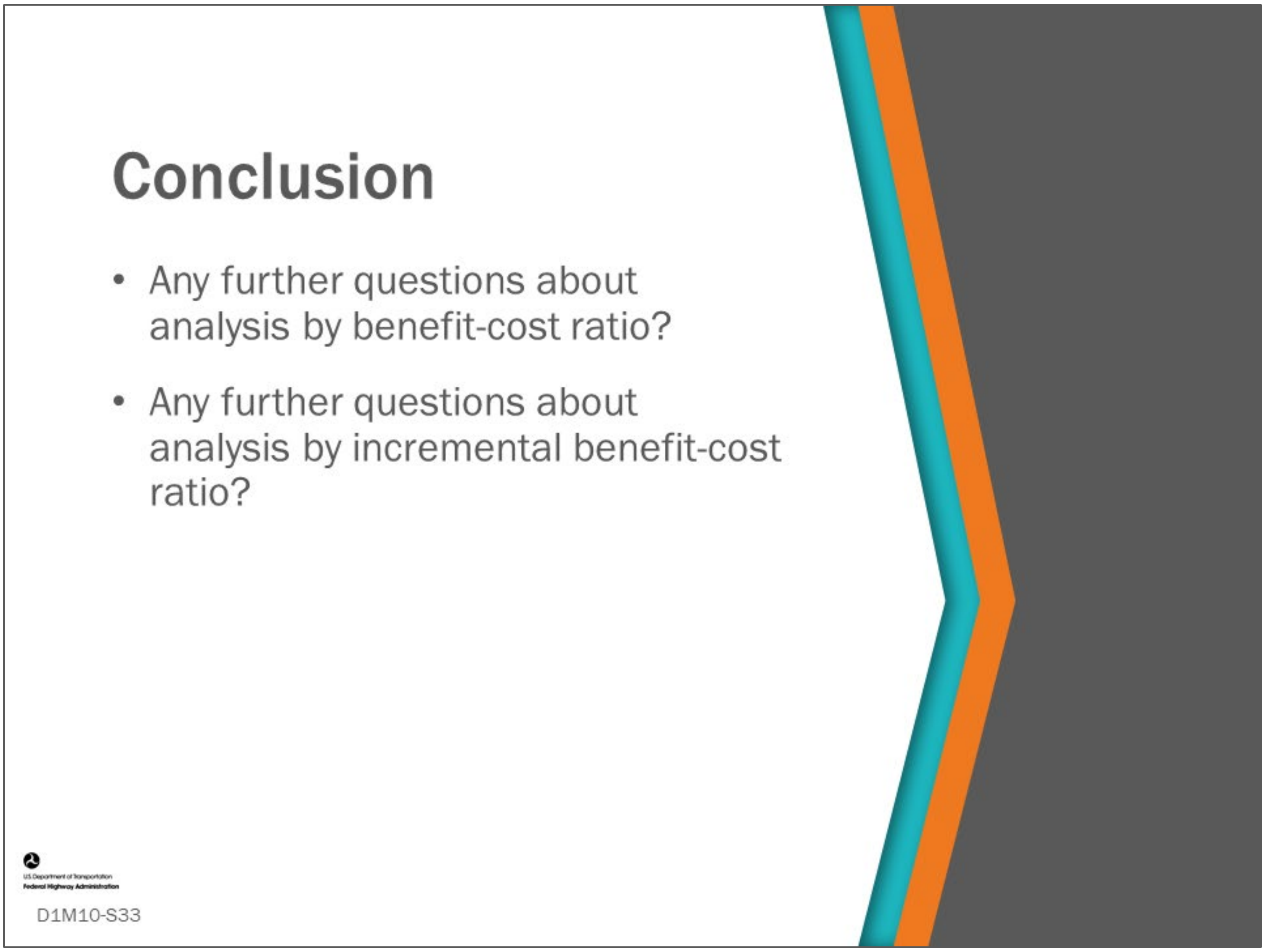
Key Message

On this slide, the spreadsheet shows the project selection that maximizes benefit using IBC.

BMS software will provide a similar list of project recommendations for a much larger list of candidate projects or strategies.

- On the second day of the workshop, we will learn how the strategy selections are made.

D1M10-Slide 33



Key Message

This concludes D1M10: Benefit-Cost Analysis.

- What questions do you have?

D1M10-Slide 34

Slide #	Image Description	Source Information
6	A line chart with Performance Measure on the y-axis and Time in Years on the x-axis. the chart shows an original deterioration curve.	This Workshop.
7	A line chart with NBI General Condition deck rating on the y-axis (1 to 9) and Time in Years on the x-axis.	This Workshop.
8	Two line charts are shown. The top chart shows Performance Measure on the y-axis, and Time(Years) on the x-axis. The bottom chart is a line chart with Performance Measure on the y-axis and Time (Years) on the x-axis.	This Workshop.
13	A family tree chart shows Total Utility at the top and Condition Weight (40), Lifecycle Weight (30), Mobility (15), and Risk (15) on the second level down.	Johnson, J. *AASHTOWare BrM 5.2.3. Deterioration and LCCA. Presentation.* April 2017.
14	A screen shot from AASHTOWare BrM shows a chart with Scaled Utility Value (0 - 100) on the y-axis, and Criterion Rating (0 - 9) on the x-axis.	AASHTOWare™ Bridge Management (BrM) software.
15	A family tree chart shows Total Utility at the top and Condition Weight (40), Lifecycle Weight (30), Mobility (15), and Risk (15) on the second level down.	Johnson, J. *AASHTOWare BrM 5.2.3. Deterioration and LCCA. Presentation.* April 2017.

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D1M10-S34

D1M10 Figure Source List

D1M10-Slide 35

Slide #	Image Description	Source Information
16	Screenshot of equations for $LCC_{Utility}$, LCC, and Residual.	Johnson, J. *AASHTOWare BrM 5.2.3. Deterioration and LCCA. Presentation.* April 2017.
17	Screenshot of AASHTOWare™ Bridge Management (BrM) software showing a table with columns; Index, Date, Year, Action Name, Org. Cost, and NPV Cost.	Johnson, J. *AASHTOWare BrM 5.2.3. Deterioration and LCCA. Presentation.* April 2017.
17	Equations for LCC and $LCC_{Utility}$.	Johnson, J. *AASHTOWare BrM 5.2.3. Deterioration and LCCA. Presentation.* April 2017.
18	A family tree chart shows Total Utility at the top and Condition Weight (40), Lifecycle Weight (30), Mobility (15), and Risk (15) on the second level down.	Johnson, J. *AASHTOWare BrM 5.2.3. Deterioration and LCCA. Presentation.* April 2017.
29	A line chart for DMR shows Benefit on the y-axis and Cost on the x-axis.	NCHRP. *Report 590 Multi-Objective Optimization for Bridge Management Systems.* Washington, DC, 2007. Page 3.

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D1M10-S35

D1M10 Figure Source List

Module Title: D1M11 – Optimization and Prioritization

Module Time: 45 minutes

Module Summary

Once it is established in the previous module how multiple strategies containing multiple actions over an analysis period can be analyzed for each bridge (or bridge component), and across multiple bridges in a network, the concept of finding the optimum strategy for each bridge and a network of bridges under an array of constraints will be introduced.

The purpose of optimization at the network-level is to select a set of bridge projects in such a way that the total benefit derived from the implementation of the selected projects is maximized, or costs to achieve a target are minimized. The ability to establish project priorities and optimally allocate limited funds over a predefined planning horizon, both short- and long-term, is a fundamental part of a BMS. The difference between optimization and prioritization will be discussed, as well as how they are related. At this point, the link between specific bridge management systems and more general asset management optimization will be introduced. A brief tour of the different optimization techniques used by the BMS software will be provided.

Expected Outcome(s)

The expected outcome of this topic will be a basic understanding of the terms and how optimization and prioritization are done within a BMS.

Resource List

Slide	Reference Information
21	NCHRP. *Report 590 Multi-Objective Optimization for Bridge Management Systems.* Washington, DC, 2007.
21	Martello, S. and P. Toth. *Knapsack Problems: Algorithms and Computer Implementations*. John Wiley and Sons. 1990.
26	Steuer, R. E. *Multiple Criteria Optimization: Theory, Computation and Application*. John Wiley and Sons. 1985.
32,33	AASHTO. *AASHTOWare™ Bridge Management (BrM) User's Manual*, version 5.2.3, Washington, DC, 2016.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D1M11-Slide 1

Key Message

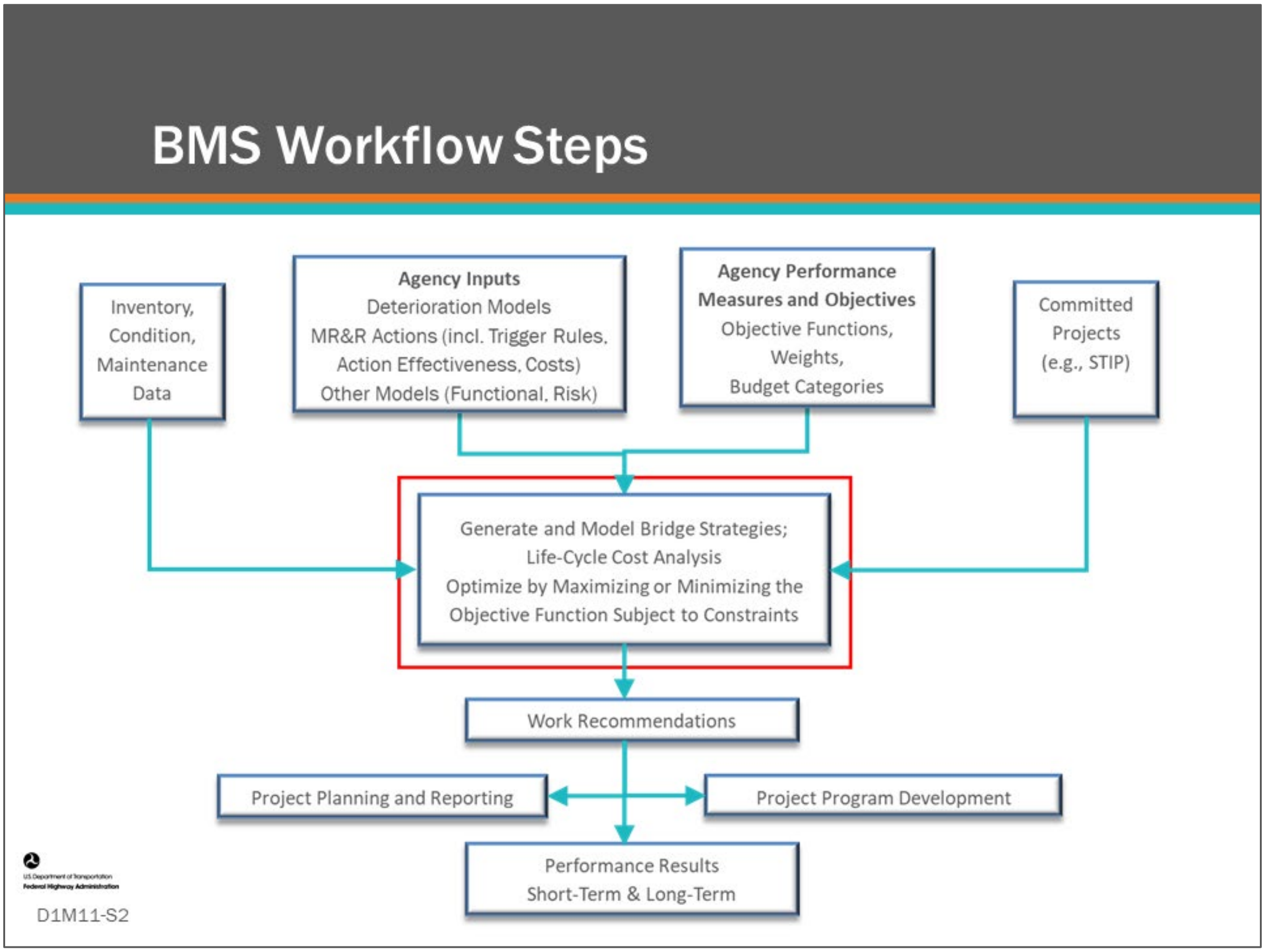
In the previous module, we presented the approach to comparing multiple strategies containing various actions over an analysis period for each bridge across multiple bridges in a network.

Next, we present concepts for optimization at the network level to find the optimum strategy for each bridge under an array of constraints.

Disclaimer

FHWA does not promote or endorse patented and proprietary products. Bridge management software is largely proprietary. Workshop content pertaining to proprietary software is included only to illustrate how bridge management system concepts and analyses are applied in practice. The included content shall not be construed as promotion or endorsement of specific software.

D1M11-Slide 2



Key Message

BMS workflow steps are shown on the slide. Optimization and prioritization procedures are used to generate and model bridge strategies as highlighted by the red box.

D1M11-Slide 3

Key Message

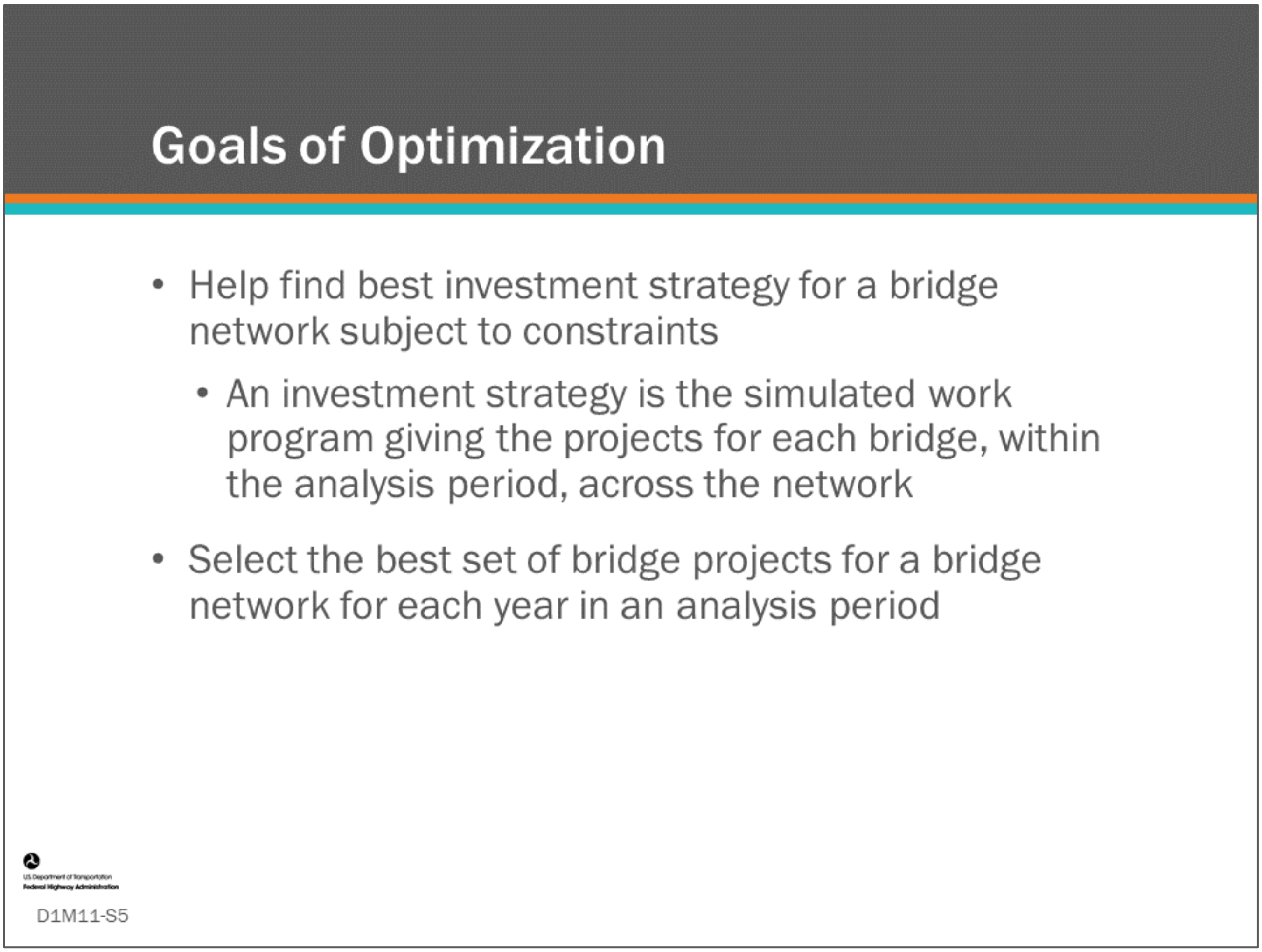
This module will cover the goals of performing optimization analysis, will discuss planning horizons, will discuss prioritization, and will give some background on what optimization is and how it works.

D1M11-Slide 4

Key Message

In this topic, we will talk about the general goals of optimization and how the optimization level affects the level of detail of the lifecycle modeling.

D1M11-Slide 5



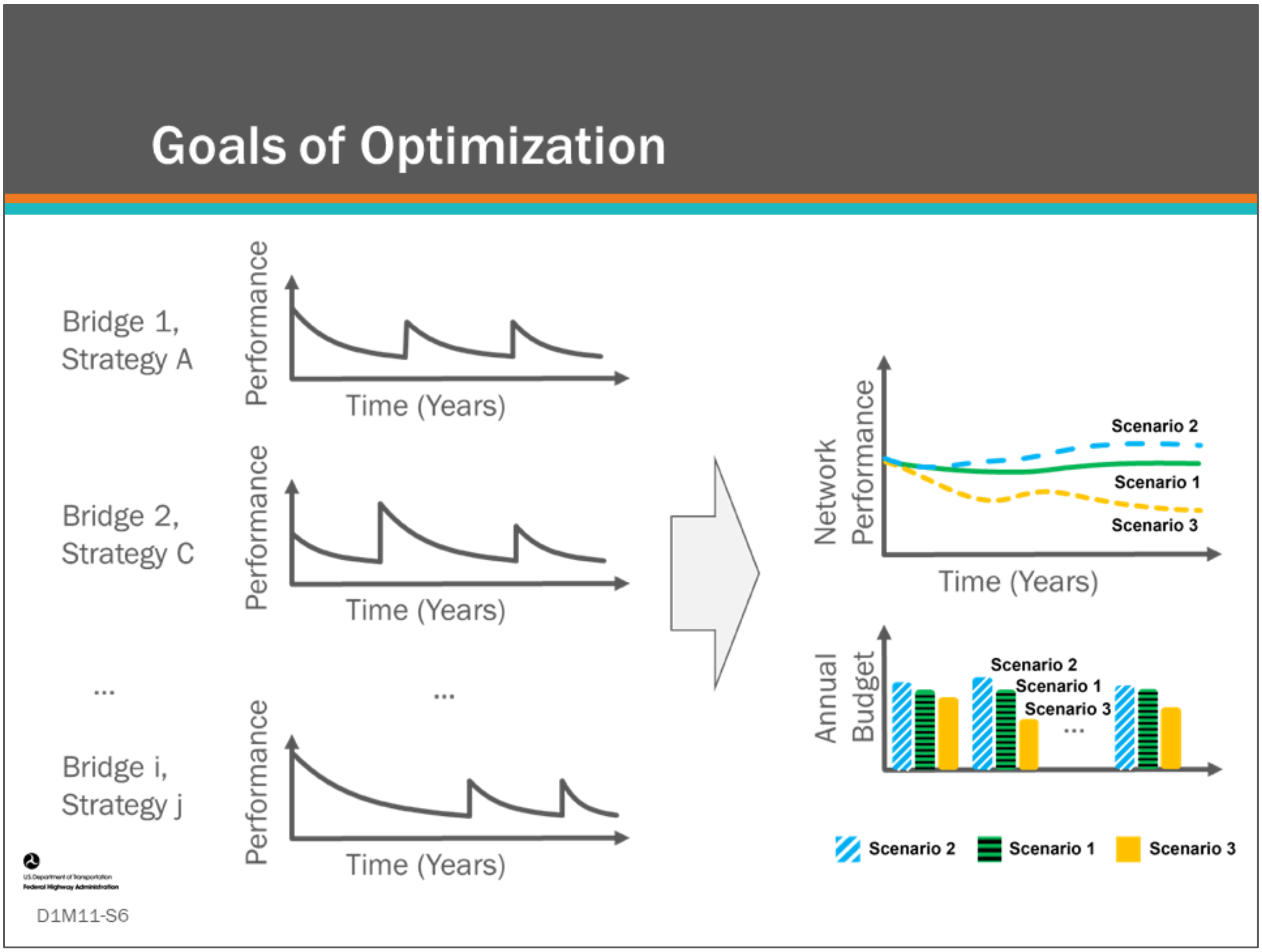
Key Message

The purpose of optimization at the network-level is to select a set of bridge projects in such a way that the total benefit derived from the implementation of the selected projects is maximized (or costs and risks are minimized). This can help to find the best investment strategy for your bridge network over time. It can also help identify cost beneficial candidates for preservation, maintenance, rehabilitation and replacement in the near term.

The ability to establish project priorities and optimally allocate limited funds over a predefined planning horizon, both short- and long-term, is a fundamental part of a BMS. The difference between optimization and prioritization will be discussed, as well as how they are related. At this point, the link between specific bridge management systems and more general asset management optimization will be introduced.

A brief tour of the different optimization techniques used by the BMS software will be provided.

D1M11-Slide 6



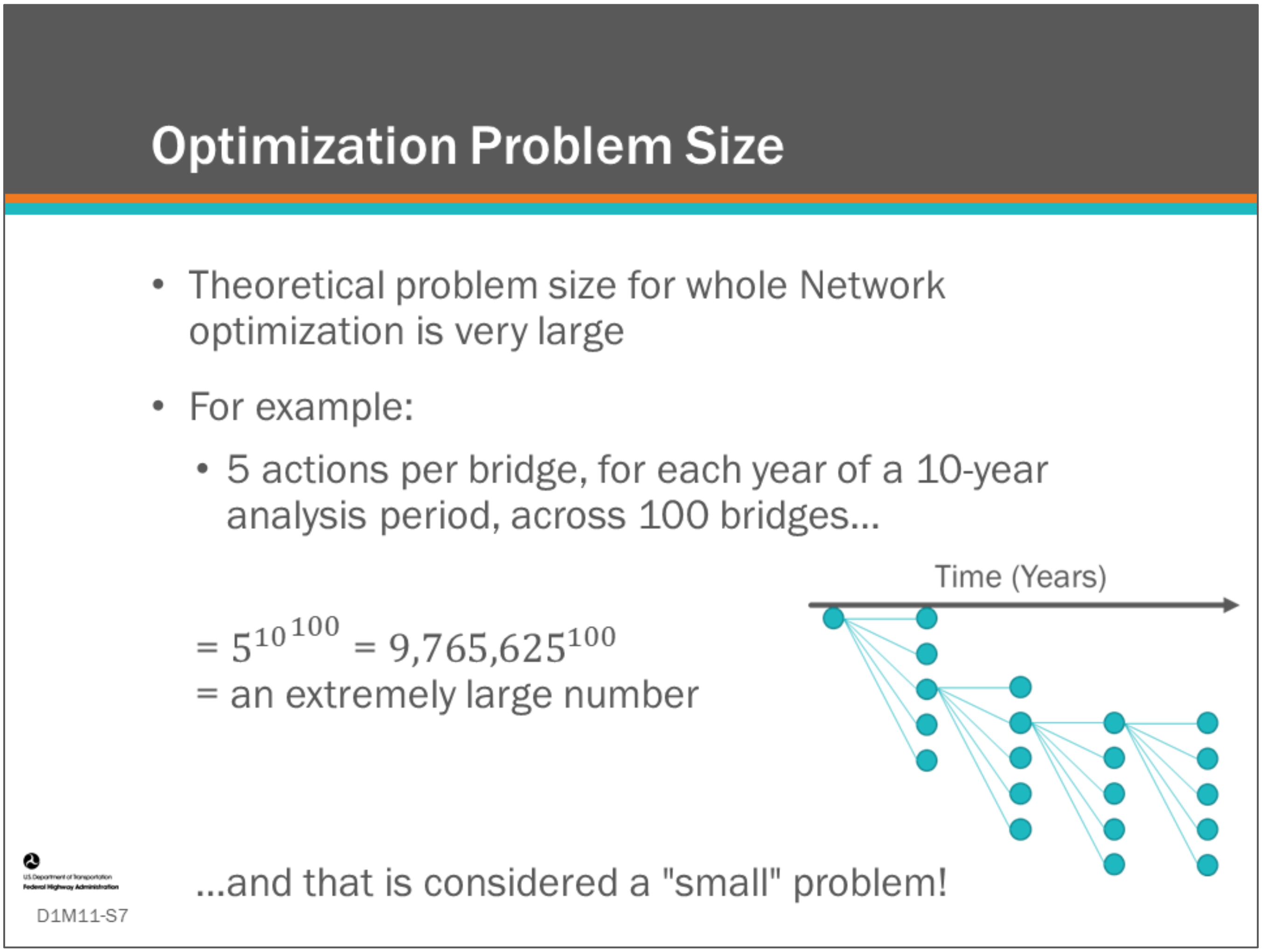
Key Message

Each investment scenario is made up of one bridge strategy for each individual bridge. The trick is to find the best set of bridge strategies (out of all the possible bridge strategies). Note that it is not possible to simply take the best individual strategy for each bridge since this would not be budget constrained. Similarly, it is not necessarily optimal to simply take the best strategy for each element or component and combine them to get the optimal solution for the bridge. As a result, it will be necessary to pick a combination of bridge strategies that:

- Not only matches the overall funding scenario
- But, also may need to match the budget across the network in every year of the analysis period

Note that the analysis is typically repeated each year because conditions change, and actual projects typically don't match up exactly with recommended projects from the previous year's analysis.

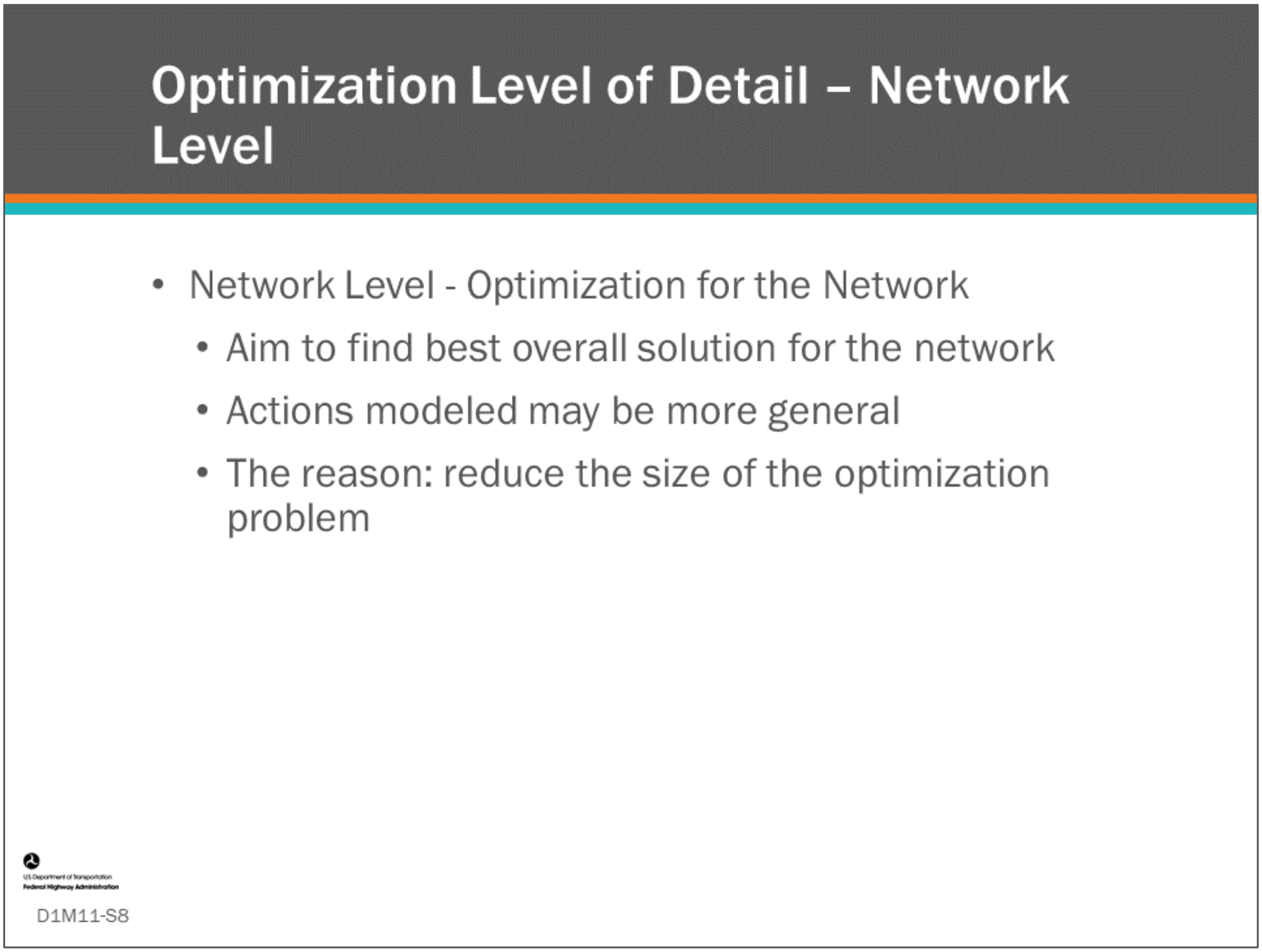
D1M11-Slide 7



Key Message

Although the previous slide showed just one strategy for each individual bridge, there are many possible strategies for each bridge. The theoretical size of the asset management network problem is huge. One of the key goals of a bridge management system is to find good ways to reduce the size of the problem being solved. Sometimes the term "recursive" is used when evaluating the large number of possible combinations and permutations.

D1M11-Slide 8



Key Message

Typically, when we talk about optimization, it is in terms of optimizing for the network.

For instance, we may want to maximize the utility for the whole network, subject to budget constraints. In this case, while we may still be modeling at the bridge level, the indexes and actions modeled for the lifecycle strategies being evaluated may be more general to reduce the size of the optimization problem. As we saw in the previous slide, even if we only have 5 different actions, we can take at the bridge level, the size of the network optimization problem over a 10-year analysis period is huge.

If we do not strategically reduce the size of the optimization problem the possible actions for each bridge over the analysis period quickly become unmanageable or even uncalculatable with common computers.

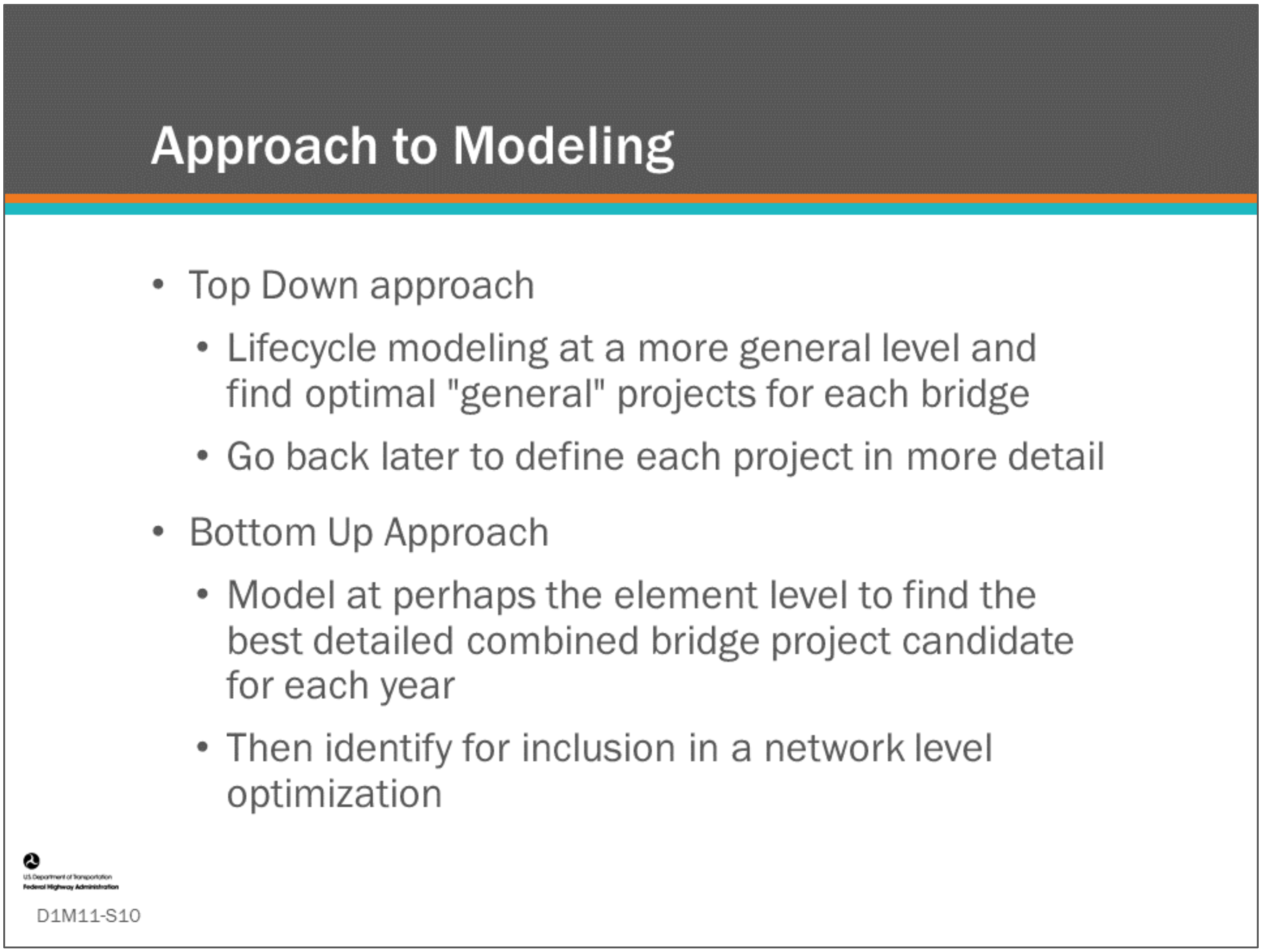
D1M11-Slide 9

Key Message

It is also possible to optimize for each bridge individually. You might think that if we could just decompose the network problem and find the best solution for each bridge individually, then we could just aggregate these bridge optimum solutions. However, as noted previously, you cannot simply aggregate individual long-term optimum bridge strategies if there are annual budget constraints.

This is because the individual projects for each bridge in each year will not sum up to match the annual budget. As a result, aggregating the optimal individual bridge strategies would be the optimal for the network, but will not comply with the problem constraints. This leads to following a suboptimal strategy for some bridges in some years, i.e., recommended work is deferred.

D1M11-Slide 10



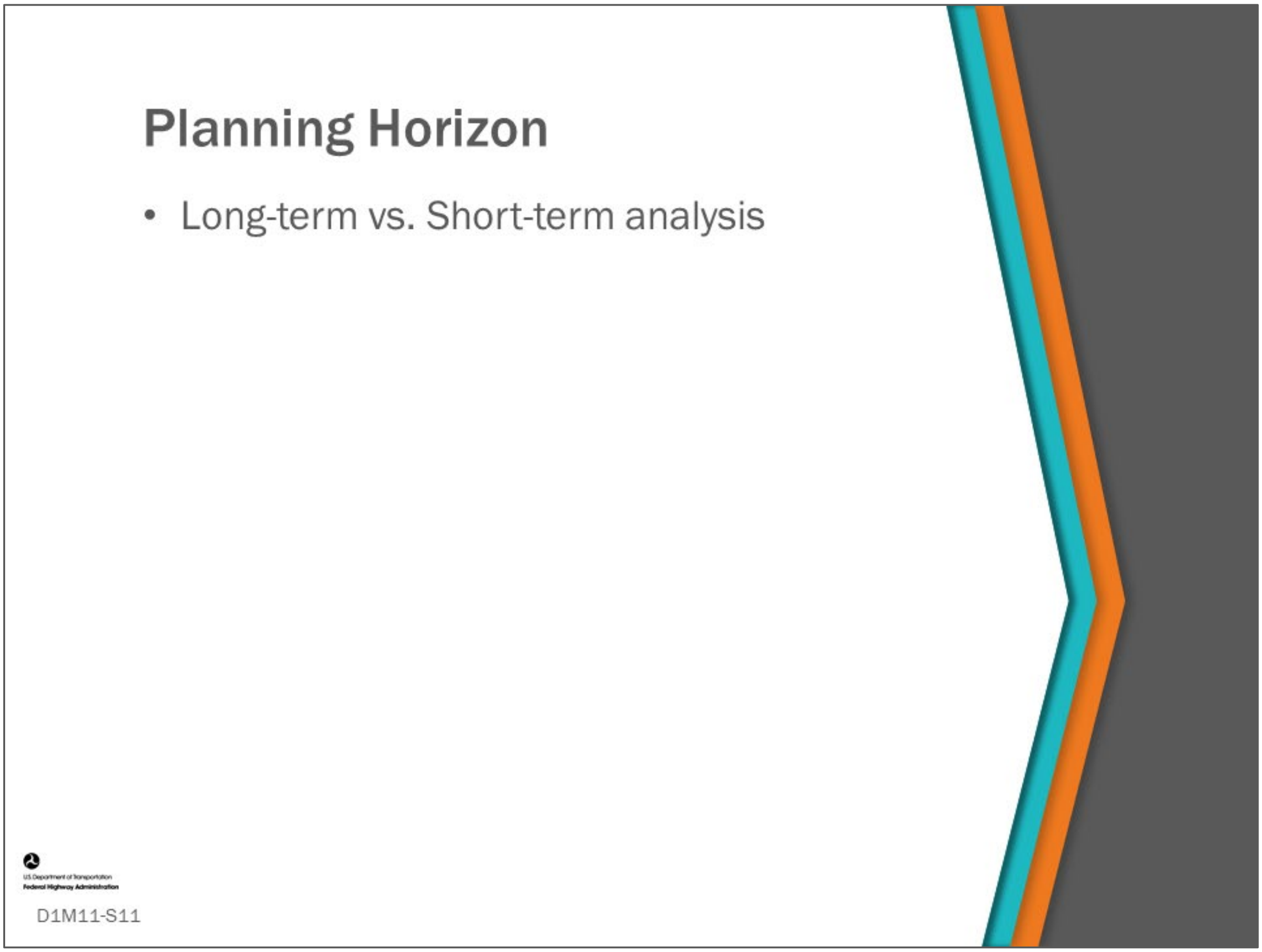
Key Message

You may come across the terms “top down” and “bottom up” approaches. In the top down approach, the bridge manager is trying to identify the best overall network strategy by finding a general set of bridge projects for each year of the analysis period, and then filling in the details as these projects come up.

In a bottom up approach, more detailed projects are defined first; then, these are used as candidate projects for inclusion in the network optimization problem. This bottom up approach is an example of “decomposition” of the optimization problem. However, this can only be made to work in the short-term where starting project candidates are evaluated (e.g., in the first year), and then depending on which projects are chosen in the first year, re-evaluating and repeating the process for the second year and so on. If only the best full long-term bridge strategies are chosen, this will likely not lead to a feasible solution for the network when annual budget constraints are imposed.

Given that the bottom up approach requires detailed analysis of each bridge, it is difficult to perform long range work program simulation and optimization using this approach.

D1M11-Slide 11

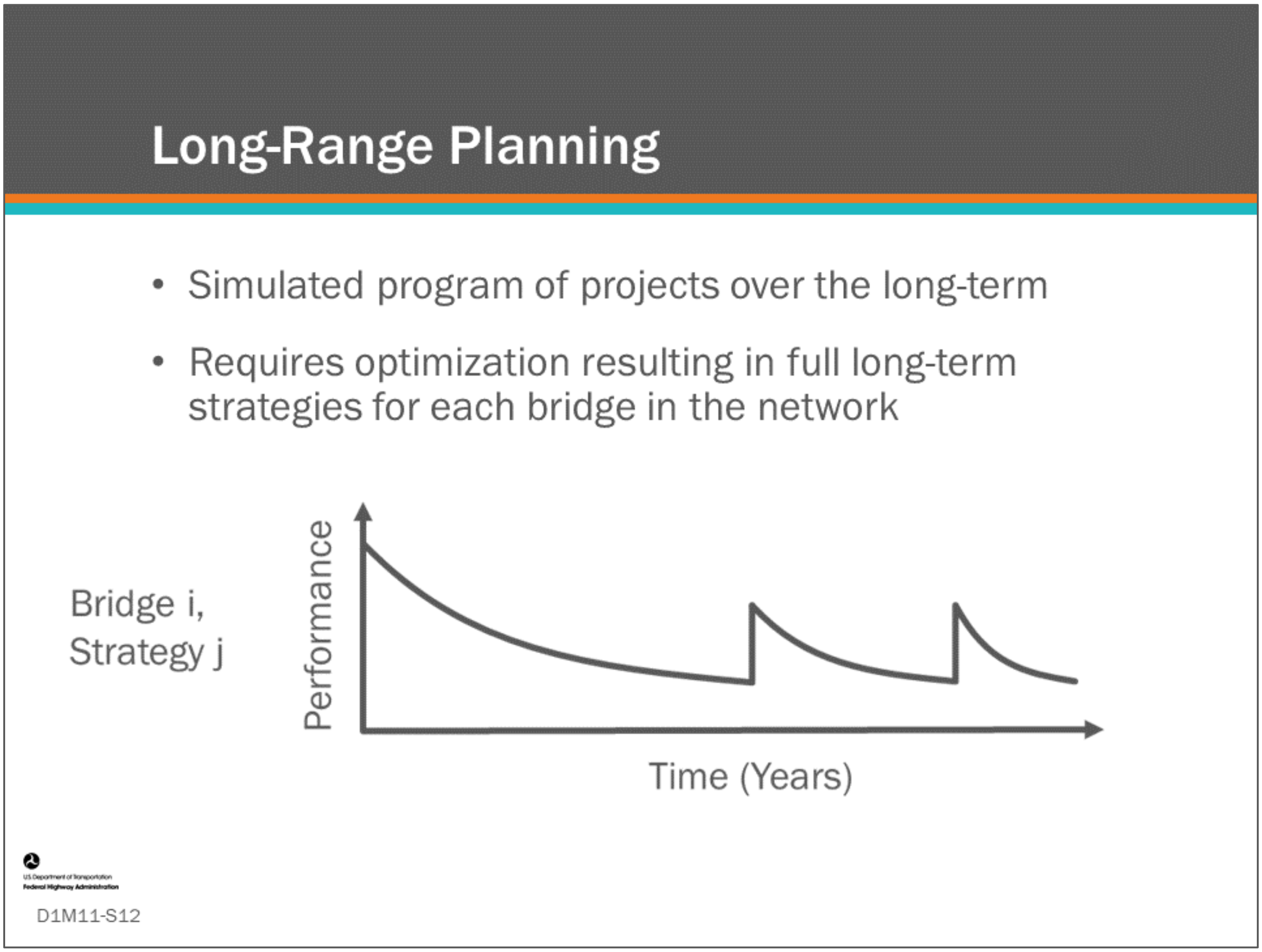


Key Message

In this topic, we discuss short versus long-term analysis. In optimization modeling, the planning horizon can be approached as a long-term or a short-term analysis.

We will learn when it is beneficial to use one method over the other.

D1M11-Slide 12



Key Message

In previous modules, we discussed the concept of life-cycle modeling or strategies, which are sequences of actions per bridge over the long-term.

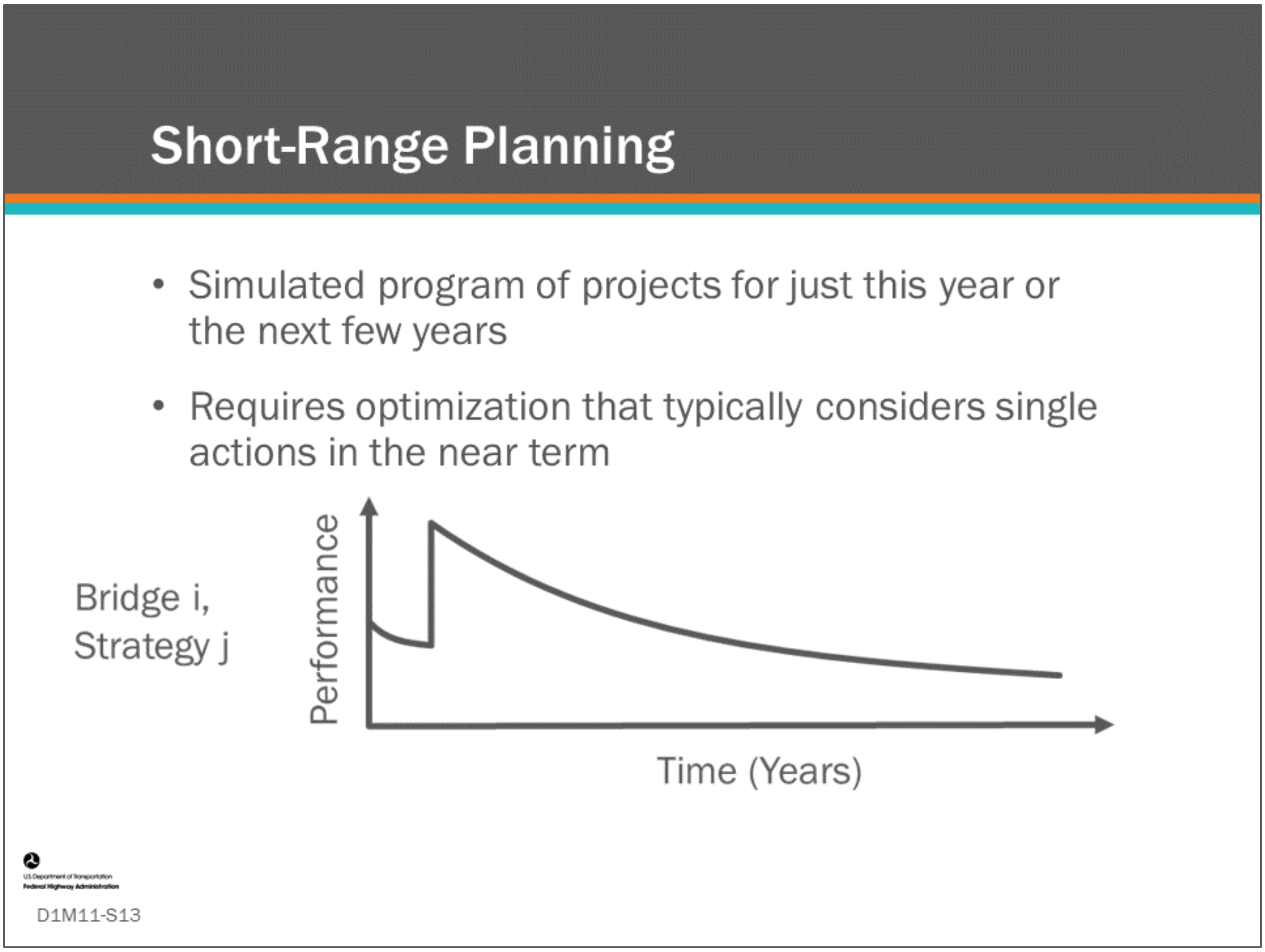
When performing optimization over the long-term, we need to be looking for good long-term strategies for each bridge.

Earlier in this module, we saw that all these long-term bridge strategies together combine to give a long-term investment scenario for the whole network.

- Some BMS select the optimal set of projects in each year rather than the optimal long-term strategy or set of projects. Those BMS must then incorporate LCC if the user wants assurance that the selected projects are least long-term cost.
- Regardless of approach, if the work program optimization and simulation is budget constrained, there is no guarantee that the life-cycle strategy or LCCA trailing projects will be funded beyond the year under analysis in the year-by-year work program simulation.
- When a future project from the life-cycle strategy or trailing projects is not funded in the work program simulation, a new life-cycle strategy or set of trailing projects is computed in the following year.

When performing optimization over the long-term, we need to be looking for good long-term strategies for each bridge.

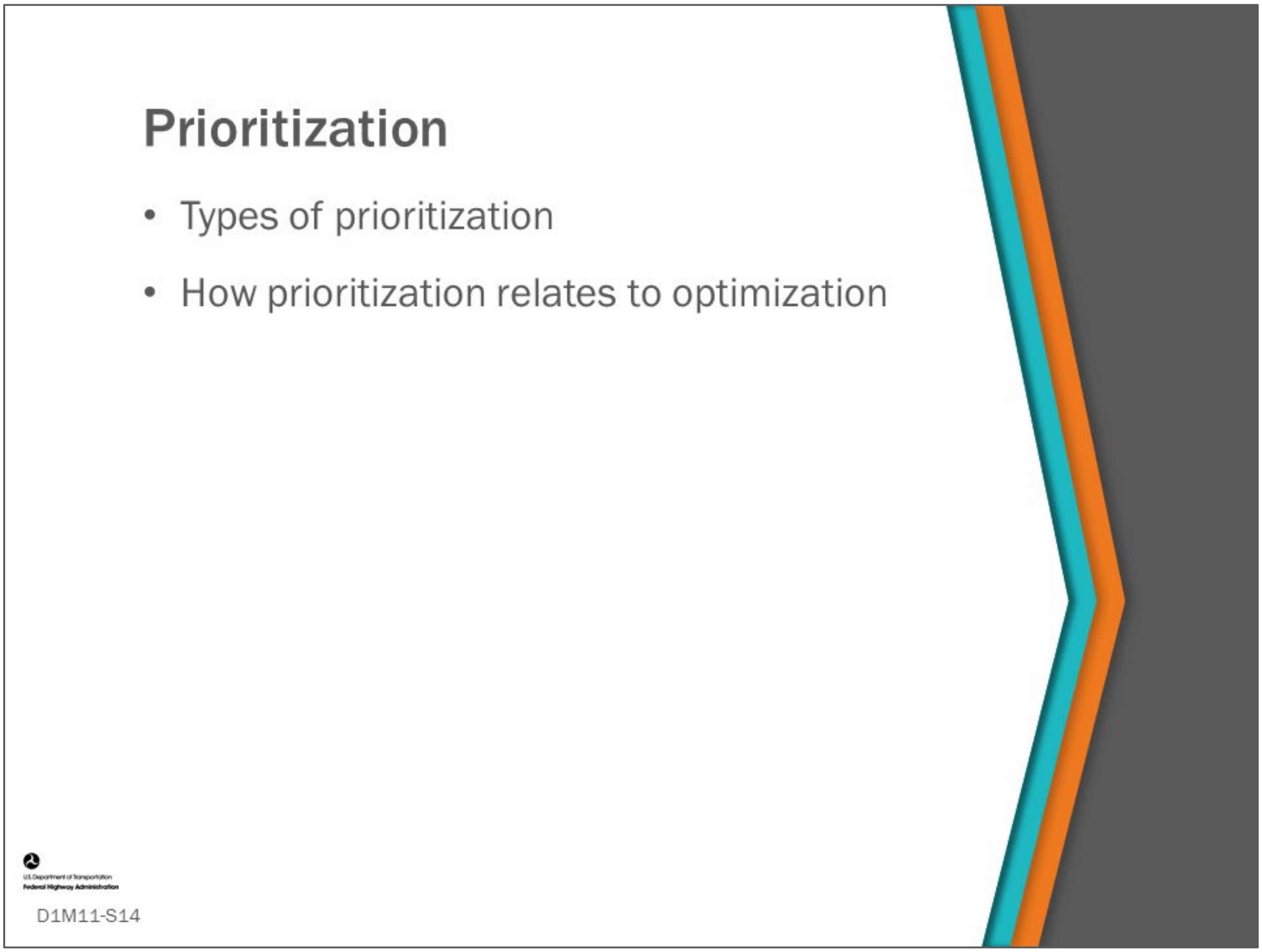
D1M11-Slide 13



Key Message

Short-term optimization analysis is typically a much smaller problem to solve because it typically (but not always) only involves picking one action (possibly from multiple options), and so the possible choices over time are vastly reduced. This can be thought of as optimizing across the whole network regarding what to do now. The limitation is that this analysis does not generate a long-term investment scenario analysis complying with long-term budget constraints.

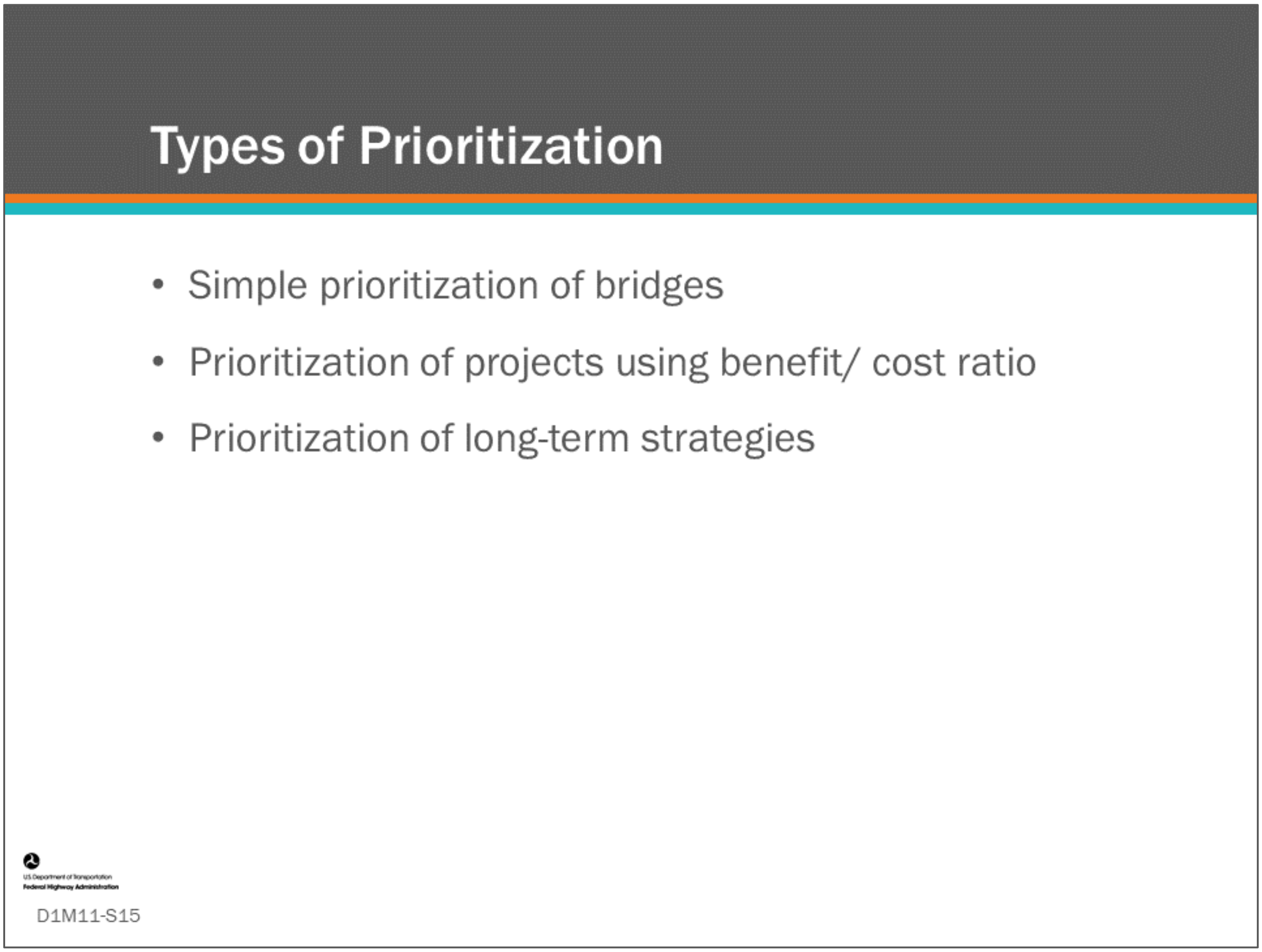
D1M11-Slide 14



Key Message

Next, we will discuss types of prioritization and how prioritization relates to optimization.

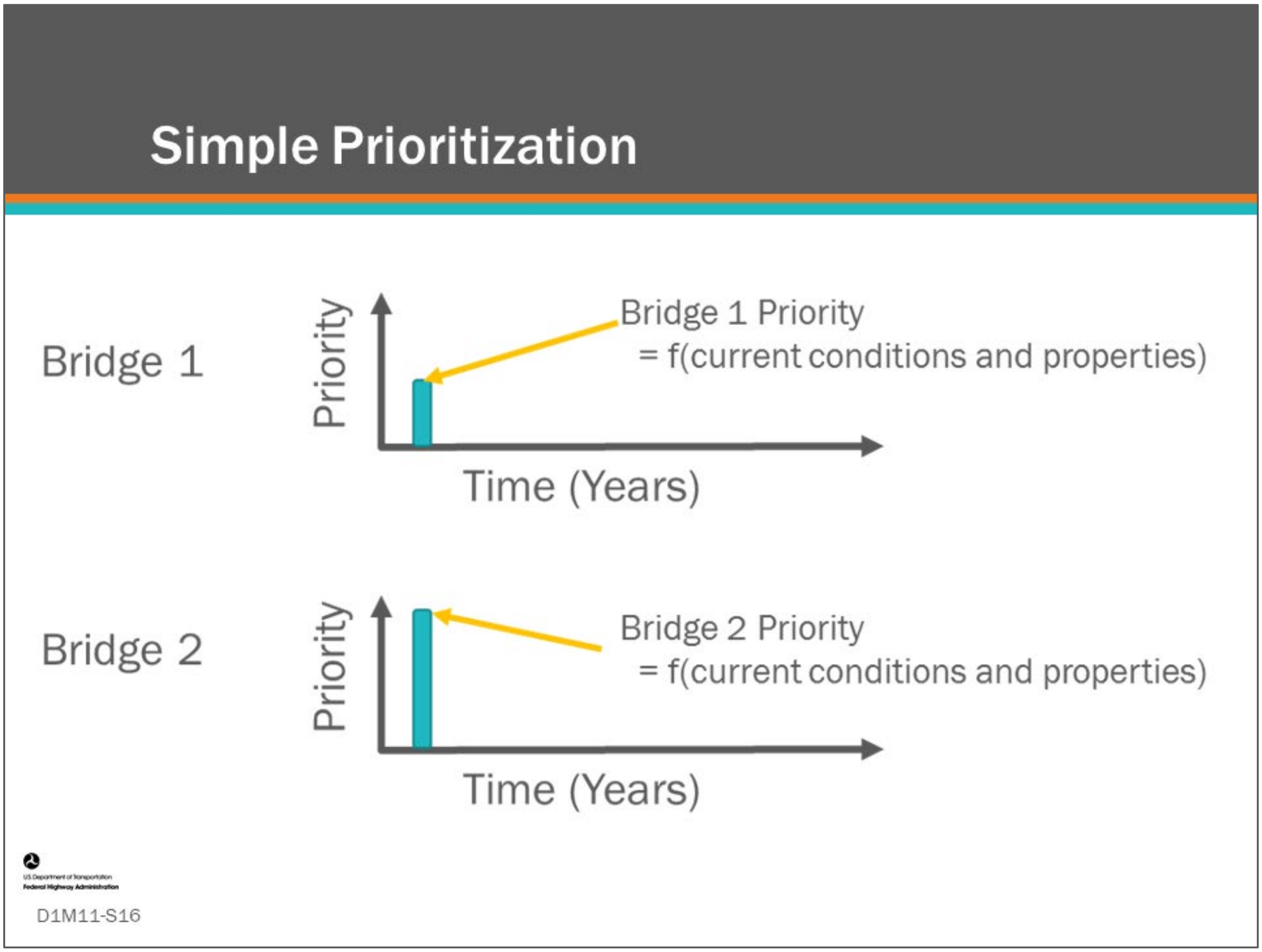
D1M11-Slide 15



Key Message

Traditionally, prioritization is a ranking method used to decide what bridge to work on first. Often it is used for specific work types such as bridge replacement. However, there are many more forms of prioritization with varying levels of sophistication, as introduced on the slide. Each of these types of prioritization will be further discussed.

D1M11-Slide 16



Key Message

Simple prioritization does not directly take into account performance over the long-term. The priority for the bridge is simply a function of current condition and properties of the bridge.

Simple prioritization involves ranking the projects based on some calculated priority. This can be a simple priority rating calculation that incorporates multiple properties of a bridge.

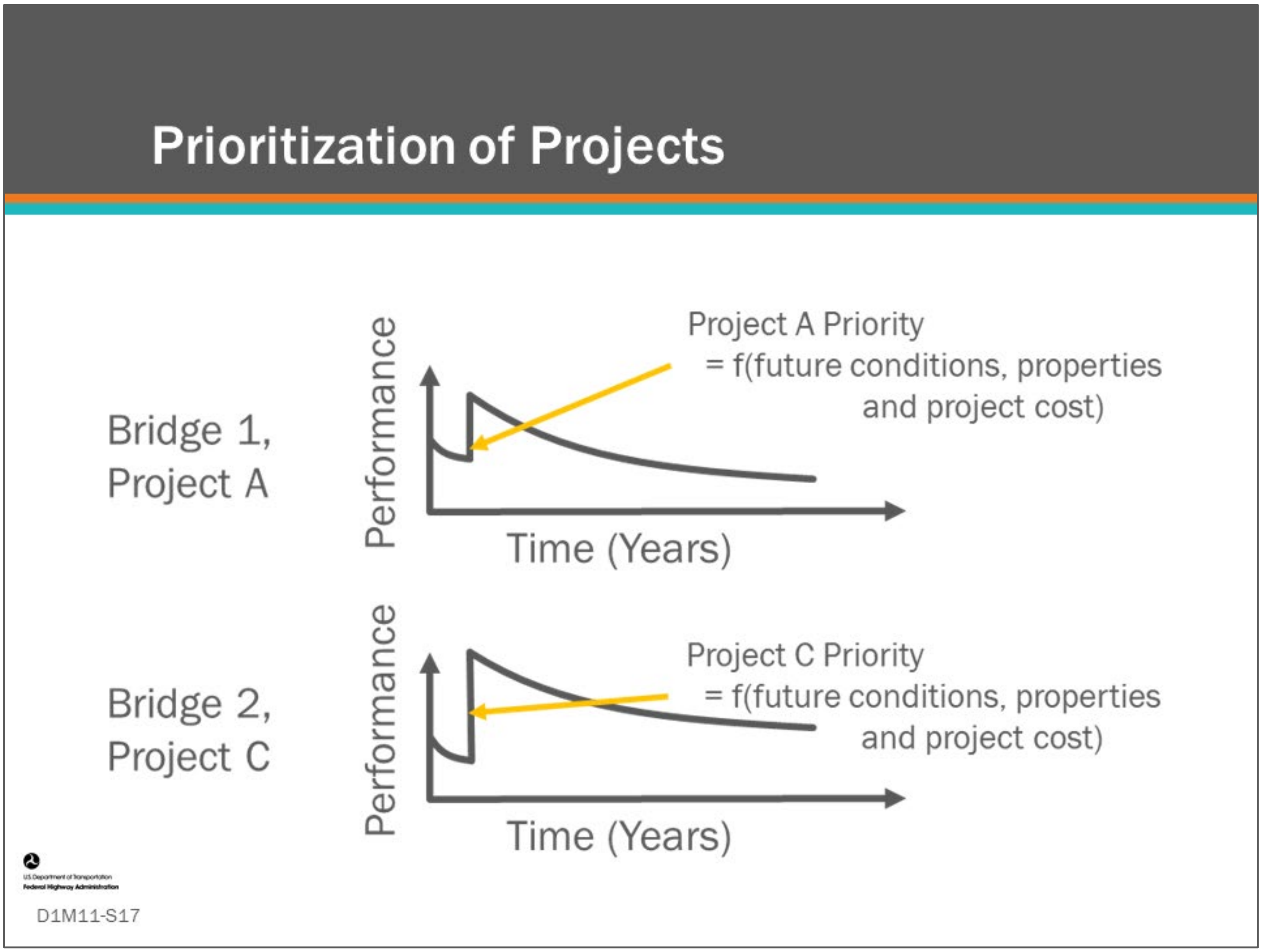
These properties may include:

- Condition criteria such as Deck, Superstructure and Substructure NBI general condition ratings
- Criteria such as traffic, deck area
- Whether the bridge is fracture critical or has a scour problem
- Length of the potential detour

There are many examples of state priority calculations. Simple prioritization is often used for prioritizing a specific type of work such as bridge replacement.

In this case, because the priority of Bridge 2 is higher, it would be picked first if bridges were sorted on priority in ascending order (assuming higher performance is better).

D1M11-Slide 17



Key Message

The ratio of the benefit/cost ratio can be used to prioritize projects.

In this case, instead of prioritizing bridges, projects (or actions) are prioritized. The benefit of doing the project can be traded off against the cost of the project or action.

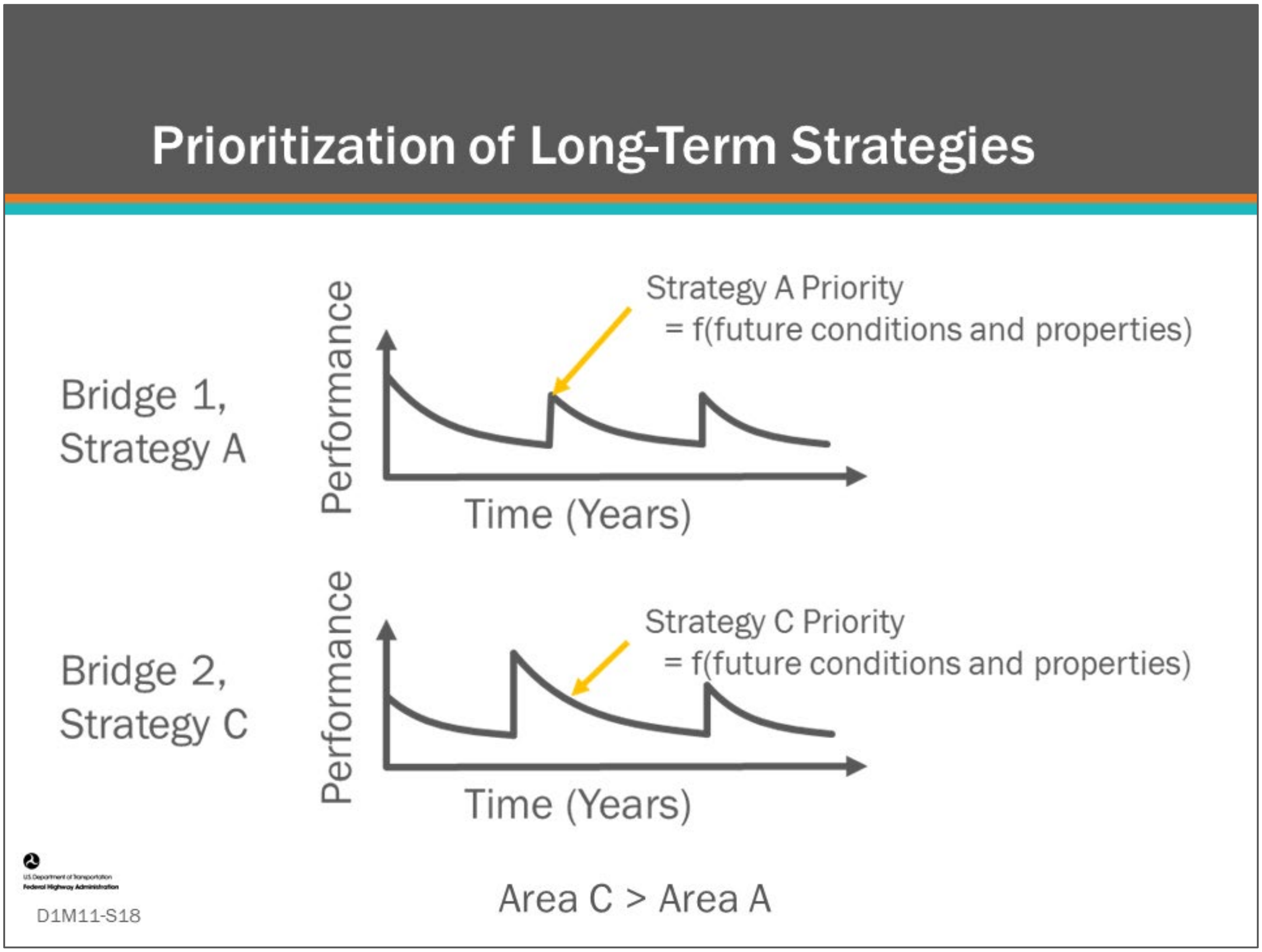
Prioritizing by benefit to cost ratio is a very well-known method of prioritization, and the use of benefit/cost (BCR) ratio was covered in the previous module.

- The fundamental challenge in this case is to define "benefit,“ – it was noted earlier that this could be defined as the area between two performance curves (AgileAssets® Structures Analyst™ and Deighton dTIMS©), or possibly computed by including net present value of life cycle cost into in a utility function (AASHTOWare™ Bridge Management (BrM)).
- For instance, AASHTOWare™ Bridge Management (BrM) applies Incremental Benefit Cost Ratios (IBCR) to bridge utility values representative of alternative combinations of actions where utility values can represent any combination of measures and measure weights including net present value of life cycle cost (LCC). We will see how this fits in the next slide.

It is very interesting to consider the benefit as being the difference between two plots of a simple prioritization formula considered above over time that are modeled for two different bridge strategies. In the example shown on the slide, the benefit/cost ratios of individual projects are evaluated to prioritize short-term projects. Both bridge projects initially step up in performance. In the long-term, Bridge 2, Project C may be assumed to have the higher benefit due to the overall larger area under its Performance curve. If the costs were the same, Bridge 2, Project C would have the higher benefit/cost ratio and would likely be picked first if bridge projects were sorted in order of priority.

Note, there may be a further level of prioritization that can be included to identify the best actions to take for each individual bridge component or element to make up the bridge project.

D1M11-Slide 18



Key Message

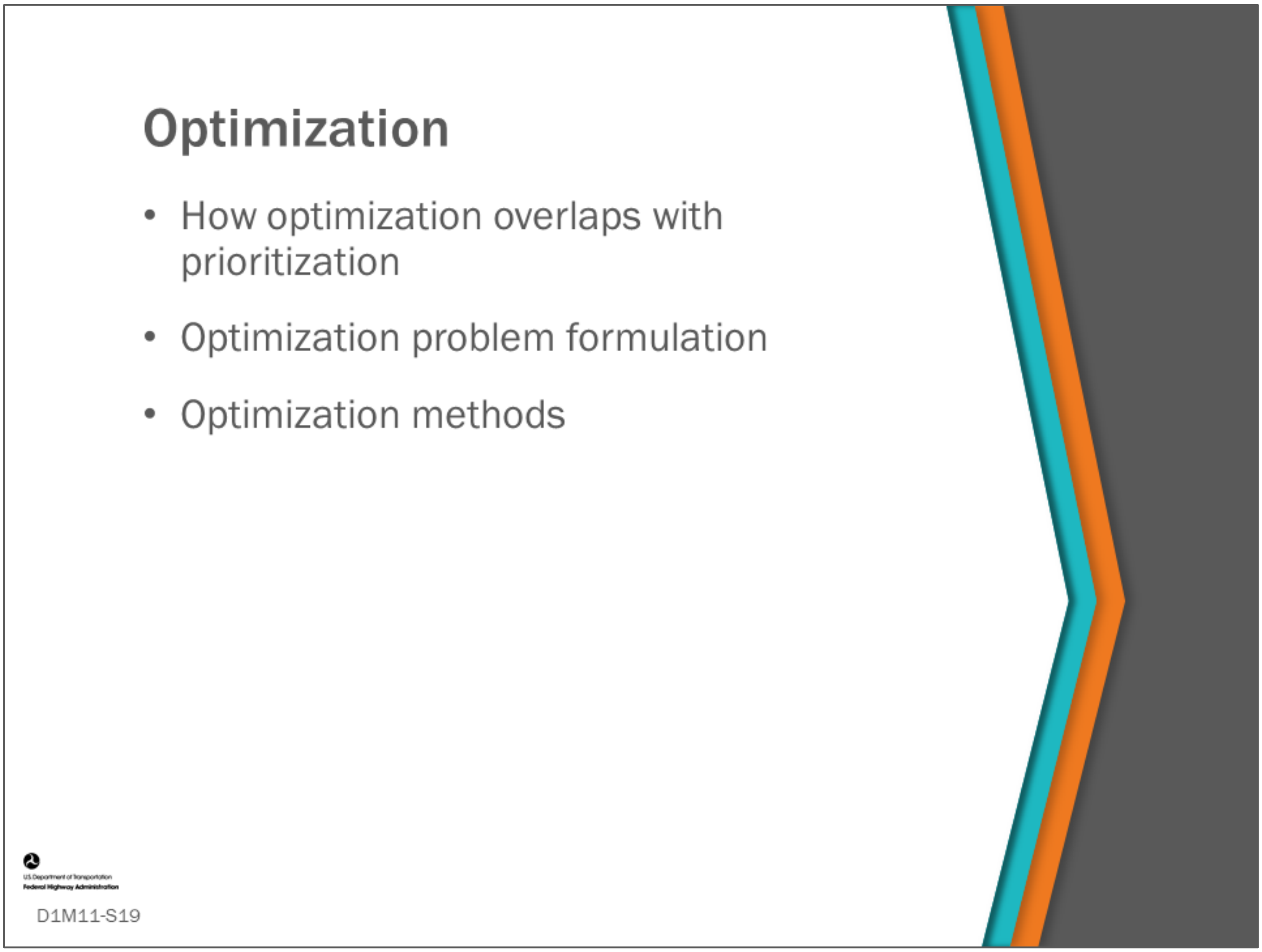
In the last couple of slides, we learned about simple "bridge" prioritization and then "project" prioritization using benefit/cost (BCR) ratio and incremental benefit/cost ratio (IBCR). Now we can take our analysis a leap forward by prioritizing long-term strategies. There are multiple methods to do this. One is to calculate the overall long-term benefit/cost ratio for a strategy over an analysis period, then rank individual bridge *strategies,* so that the strategy which yields the best benefit/cost ratio is ranked highest.

In this case, again assuming (for simplicity) that the two strategies had the same costs, if the bottom one (Bridge 2, Strategy C) had a greater area under the performance "curve", then this would be picked first if the strategies were sorted in order of priority since Bridge 2, Strategy C would have the higher benefit/cost ratio.

Note once again that another property of the strategy is the life cycle cost (LCC) for the multiple future projects in the strategy. The "benefit" in this case would be a result of savings in life cycle cost (LCC) of one strategy over another. This method is used by AASHTOWare™ Bridge Management (BrM). As noted above, another approach to measure the benefit of a strategy would be to use, for example, the area under the performance "curve" for the strategy. This method is used by AgileAssets® Structures Analyst™ and Deighton dTIMS©.

One way to use such a ranked list with an annual budget constraint would be to start at the top and add first year projects to the list until the first year's budget is exhausted. A new set of candidate strategies would then be generated for the next year and the process repeated.

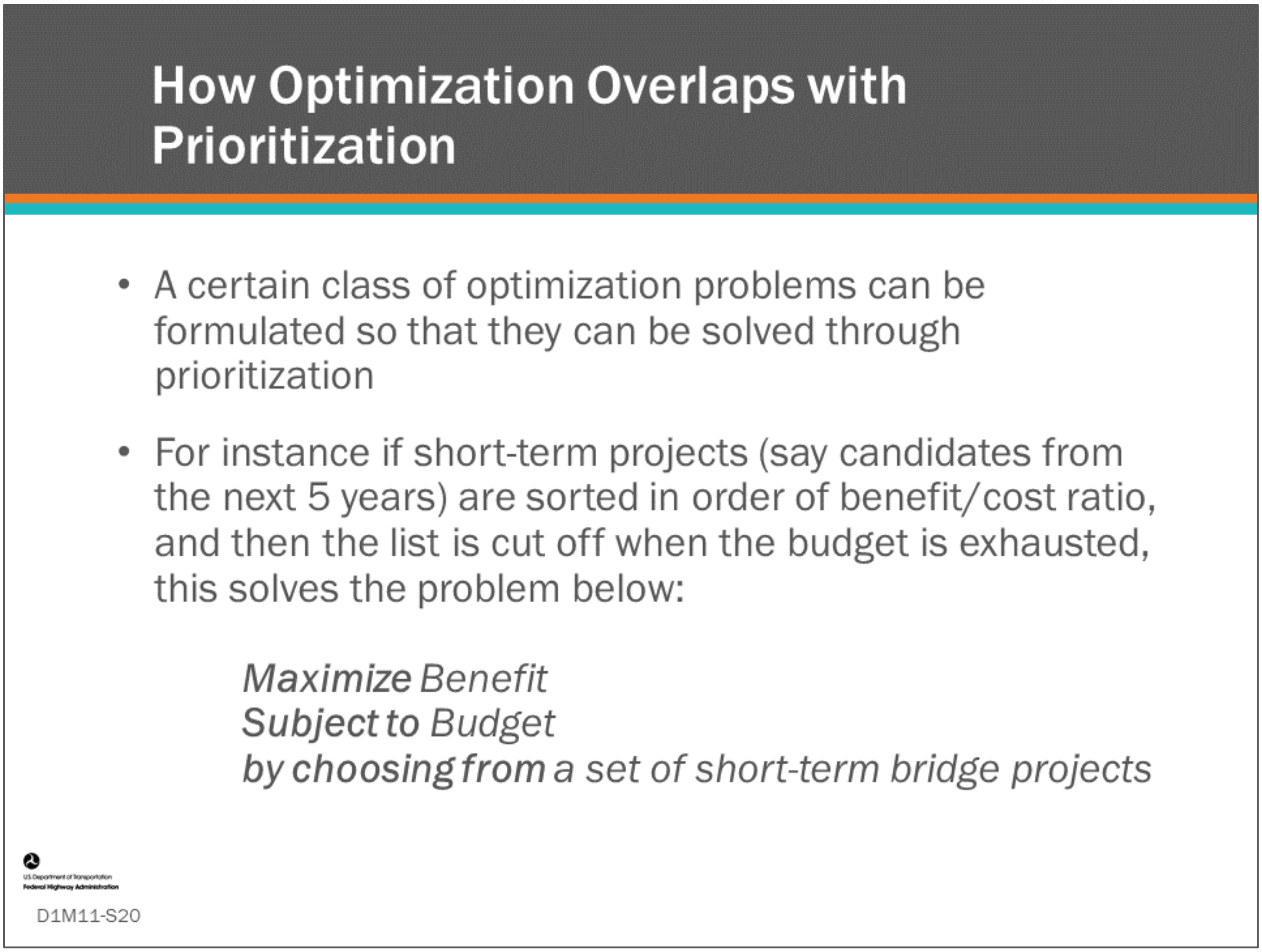
D1M11-Slide 19



Key Message

In this topic, we first consider how optimization relates back to the prioritization discussed previously. We then give a very short primer on optimization problem formulation. Finally, we discuss some basic optimization methods and approaches.

D1M11-Slide 20



Key Message

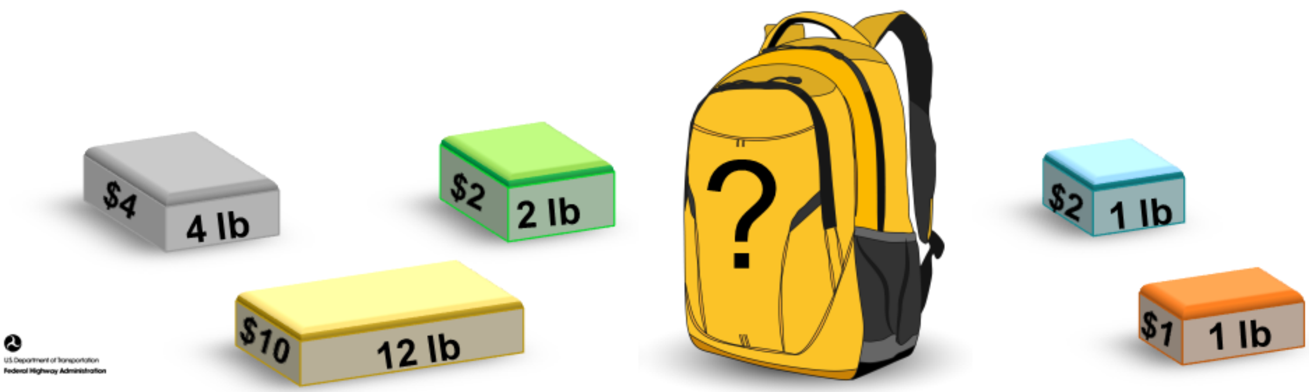
Prioritization is not always optimal. However, some optimization problems can be formulated as prioritization problems. The challenge is to define the "benefit" of a project. As we have seen in previous modules, and previous slides in this module, there are two common methods used to define benefit:

- Area under the plot of an index or utility value over time (or difference in area if comparing two strategies such as "Do Nothing" and “Project A"). This method of defining benefit is commonly used by Deighton dTIMS© and AgileAssets® Structures Analyst™.
- Difference in Utility between two strategies (where the difference in Utility may include the difference in Net Present Value between the two strategies). This method is used by AASHTOWare™ Bridge Management (BrM).

D1M11-Slide 21

How Optimization Overlaps with Prioritization: Knapsack Problem

- By prioritizing the list of projects by benefit/cost ratio, we are formulating the problem as a “Knapsack Problem”
  - This is equivalent to lining up items to take in a knapsack in order of benefit to cost ratio and loading them in that order until you run out of space



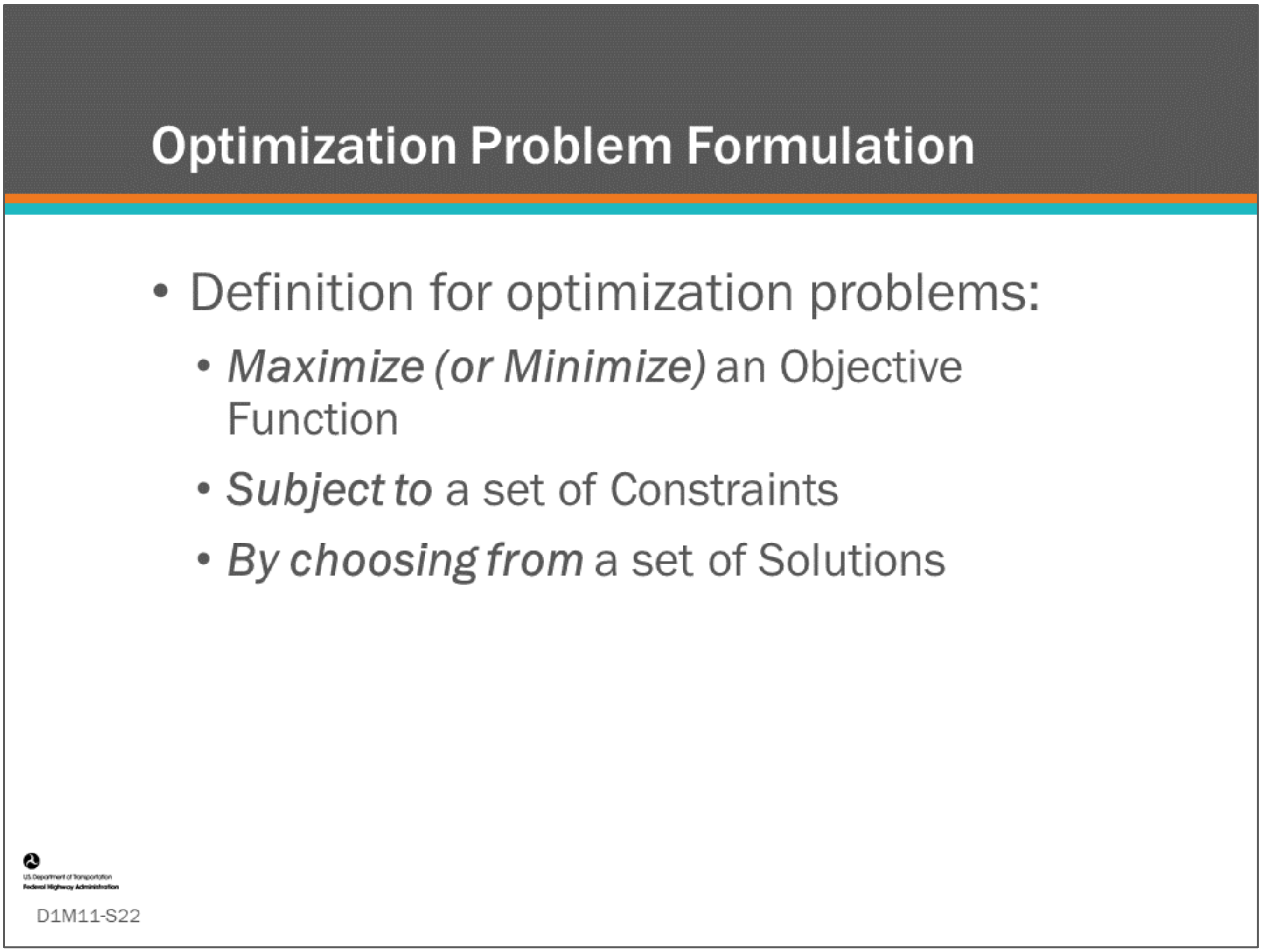
D1M11-S21

Key Message

In the example shown here, which boxes should be chosen to maximize the value of items in the knapsack while still keeping the overall weight under or equal to 15 lb?

Solution: Taking all but the green box would be the optimal (highest value) set of items to take if the constraint was 15 lb.

D1M11-Slide 22



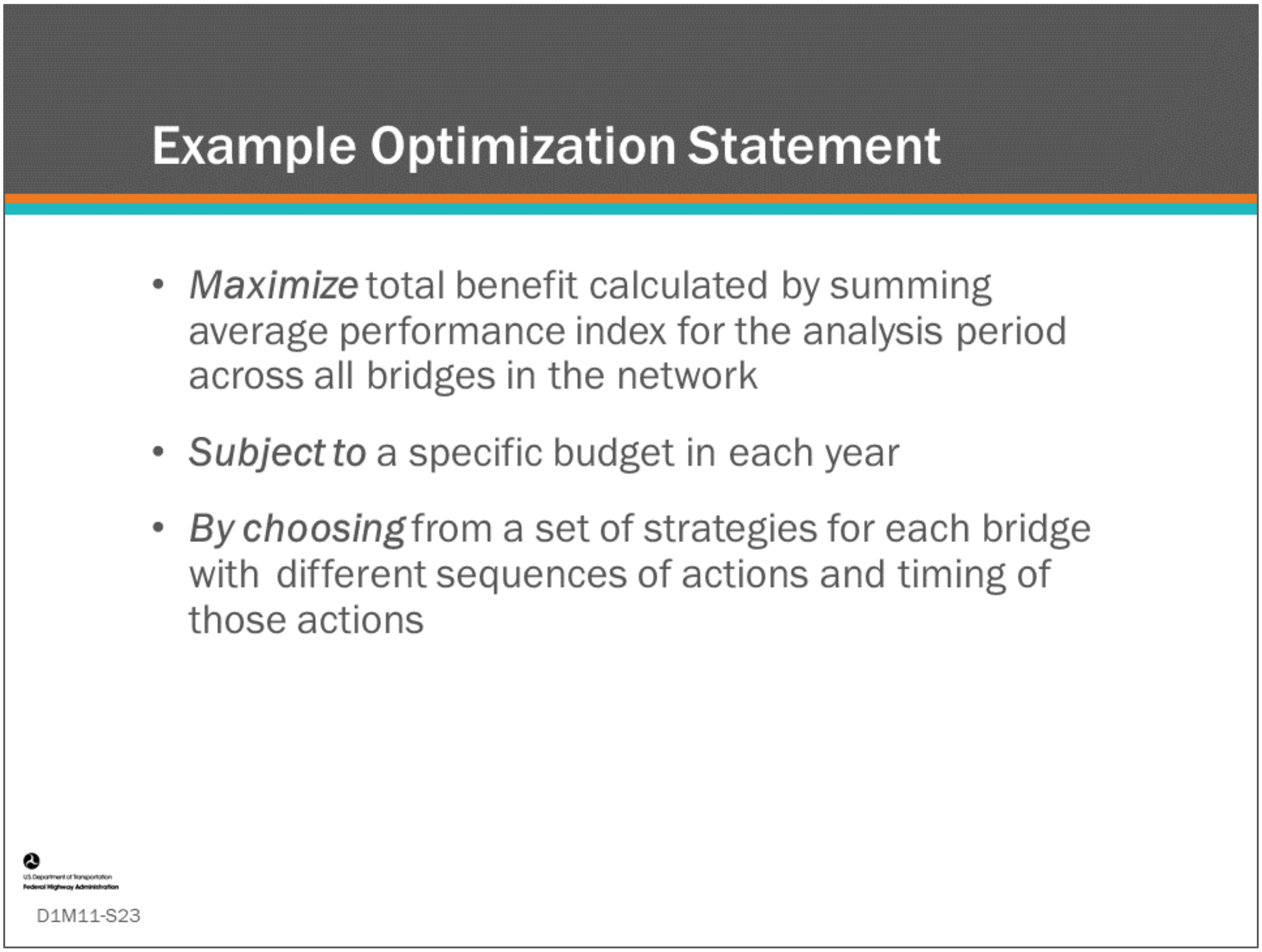
Key Message

The definition of a single objective optimization is a problem that can be defined by writing it out in the form:

- Maximize an Objective Function
- Subject to a set of Constraints
- By choosing from a set of solutions

By writing the problem out in this way, the bridge manager can focus in on what they want to maximize or minimize, what their constraints are, and what varying individual possible solutions within the optimum set look like. The example given in the next slide is a problem for long range planning written out in this way.

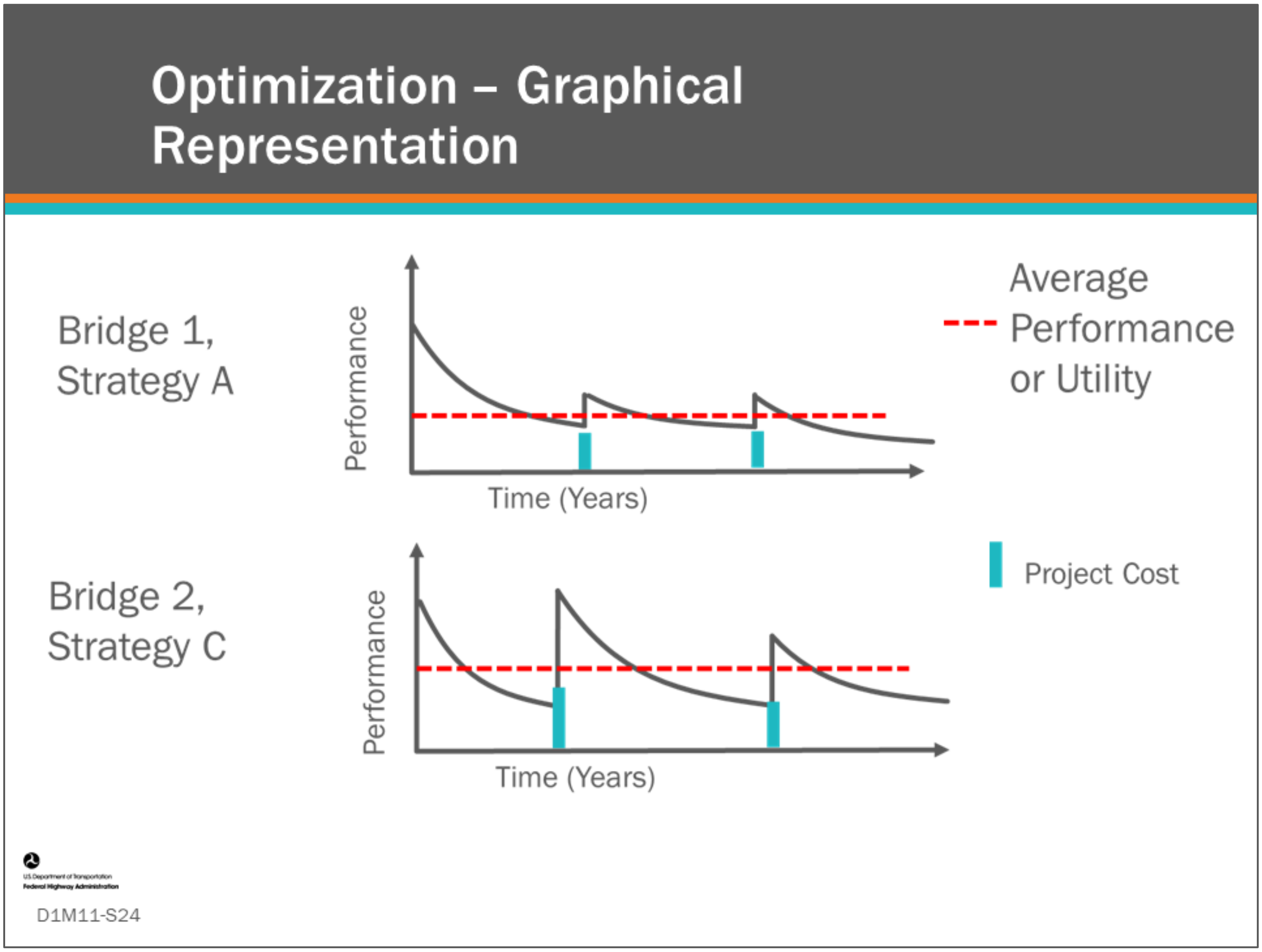
D1M11-Slide 23



Key Message

This slide shows an example optimization statement. This optimization problem is one formulation of the general network optimization problem. The objective function that we want to maximize is essentially the sum of the average performance indices (in each year of the analysis period) across all bridges. We will look at this graphically on the next slide.

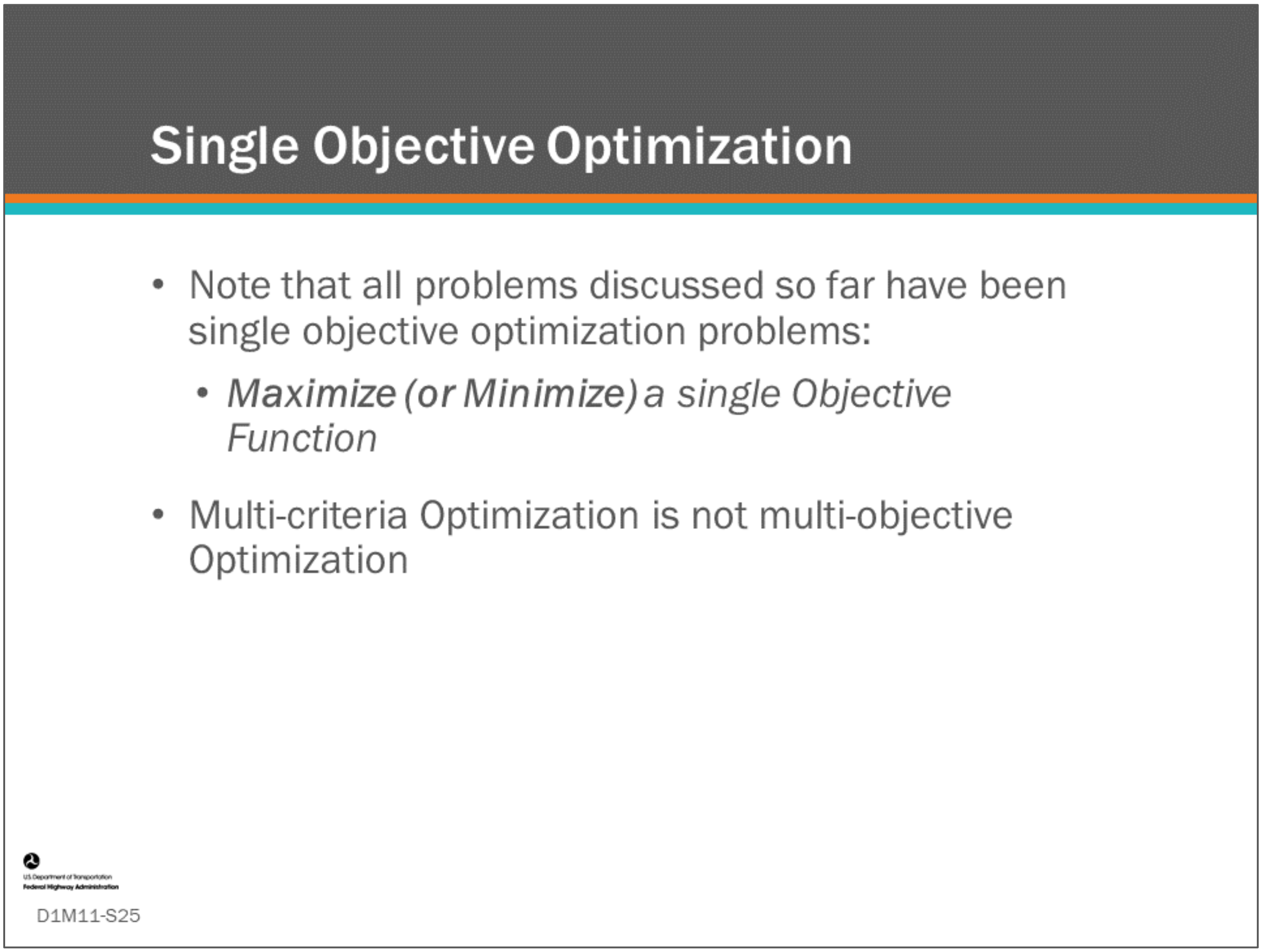
D1M11-Slide 24



Key Message

This is a graphical representation of the previous slide. The solutions that the optimization is choosing from are bridge strategies consisting of sequences of actions where costs and a performance index have been modeled over time. Bridge management systems create these sets of possible strategies in different ways for each bridge included in the dataset. In this slide, the preferred option is Bridge 2, Strategy C which has the higher average performance or utility. However, this strategy may cost more.

D1M11-Slide 25



Key Message

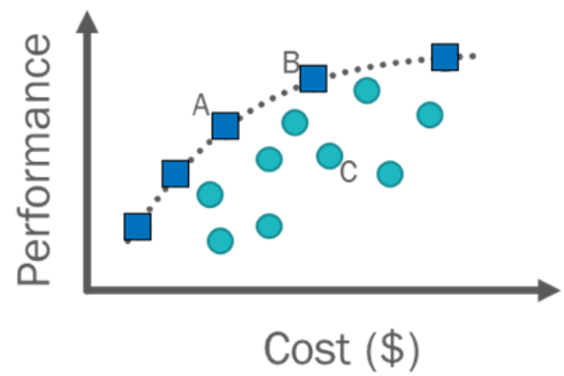
The example shown in the previous two slides shows single objective optimization. In this case the single objective is maximize the average performance index. A single objective optimization may have multiple criteria.

- For example, we saw in Module 10 how multiple criteria or objectives can be combined into a "Total Utility Function," or an overall "Objective Function."
- However, even though the overall objective function may be calculated by summing any number of differently weighted criteria or objectives, it is still a single objective function.
- This is sometimes confused in the bridge management literature for multi-objective optimization which is a higher level of optimization that none of the BMS software do.

D1M11-Slide 26

Multi-Objective Optimization

- Multi-objective optimization is the maximization (or minimization) of multiple objectives simultaneously
- For two objectives, multi-objective Optimization results in a Pareto Frontier
- For objectives of “Benefit” and “Cost,” solutions can be plotted on these two axes



D1M11-S26

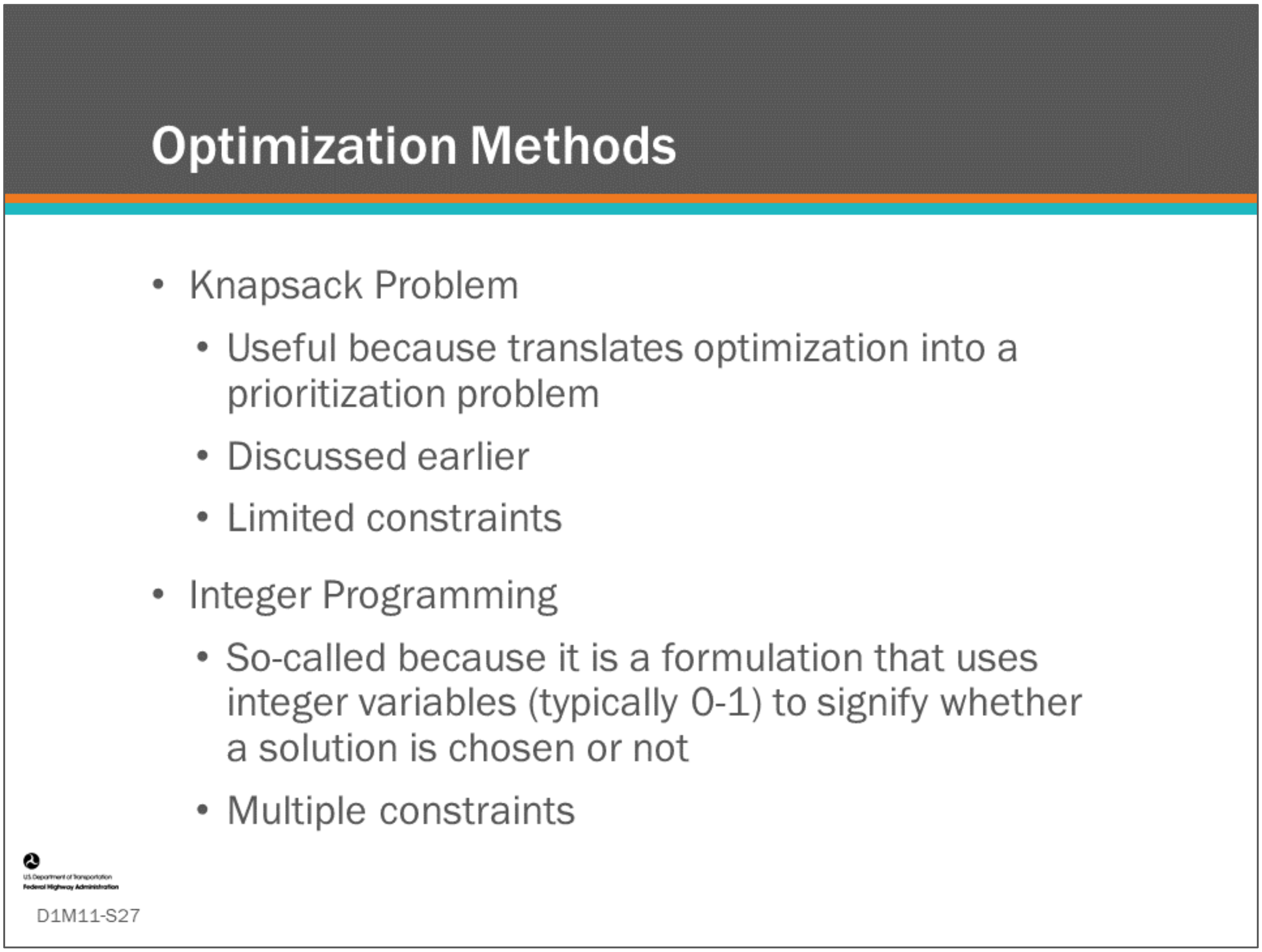
Key Message

Multi-objective optimization is the maximization (or minimization) of multiple objectives simultaneously such that multiple solutions are generated in the dimensions of the objectives.

Solutions that are not dominated are called "efficient" solutions and form what is known as a Pareto (or Efficient) Frontier.

If considering two objectives, e.g., Benefit and Cost, efficient solutions can be plotted with Benefit on the Y axis, and Cost on the X axis.

D1M11-Slide 27

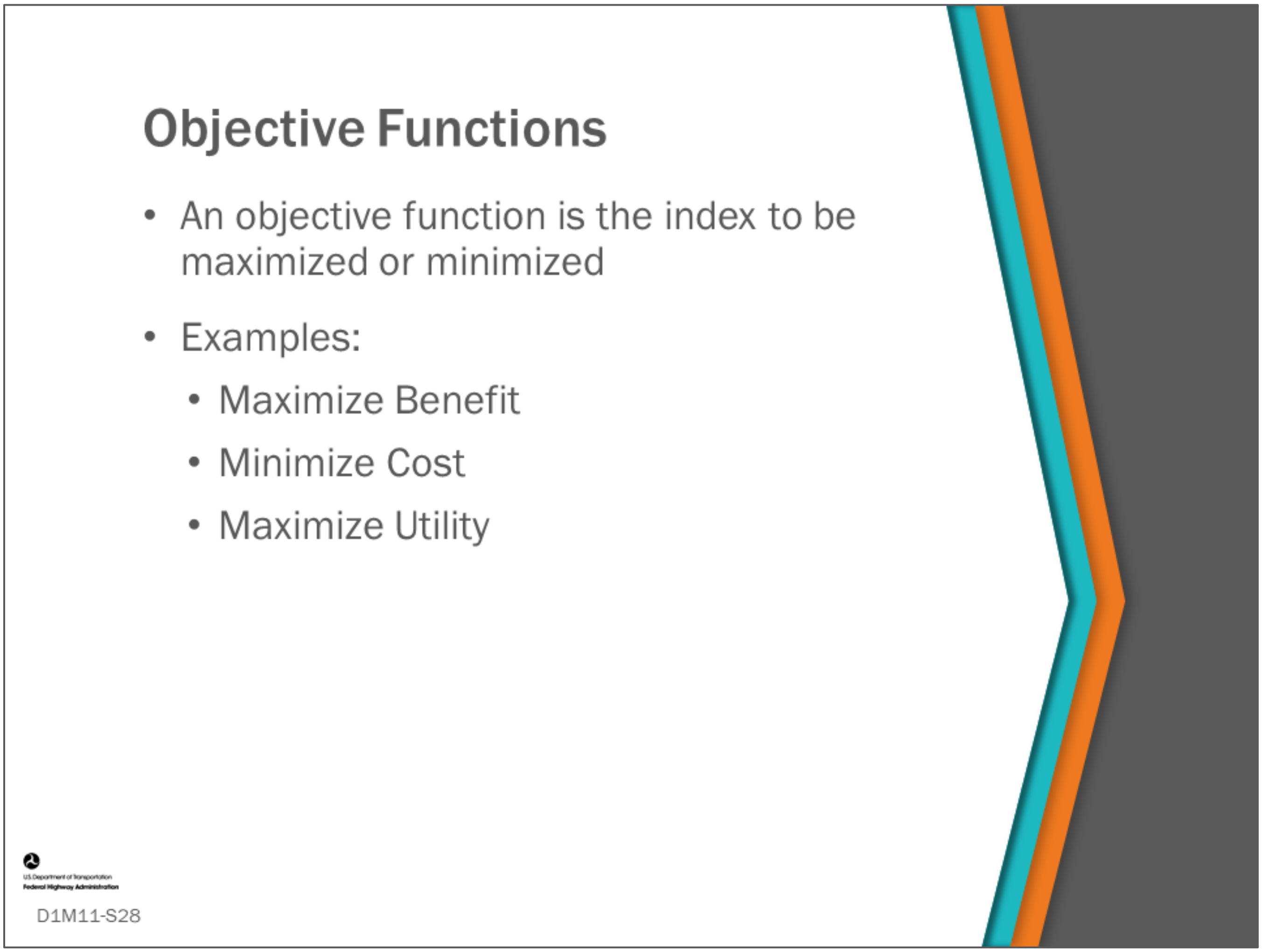


Key Message

We have already talked about simplifying (changing) the general optimization problem so as to be able to formulate it as a simple Knapsack Problem, which is useful because it essentially translates the optimization problem into a prioritization problem. It is harder to use prioritization to solve the knapsack problem when there are too many solutions to be evaluated exhaustively (which is necessary if using the knapsack formulation) because it will take too much time, and [simple Knapsack Problem] does not typically allow multiple constraints. However, it is very efficient for many problems.

Integer Programming is another method of formulating the optimization problem and is used by AgileAssets® Structures Analyst™. It uses variables in the objective function that are set to zero or one to signify if the solution is chosen or not. It requires an integer programming solver engine to be incorporated into the software that can handle multiple constraints.

D1M11-Slide 28



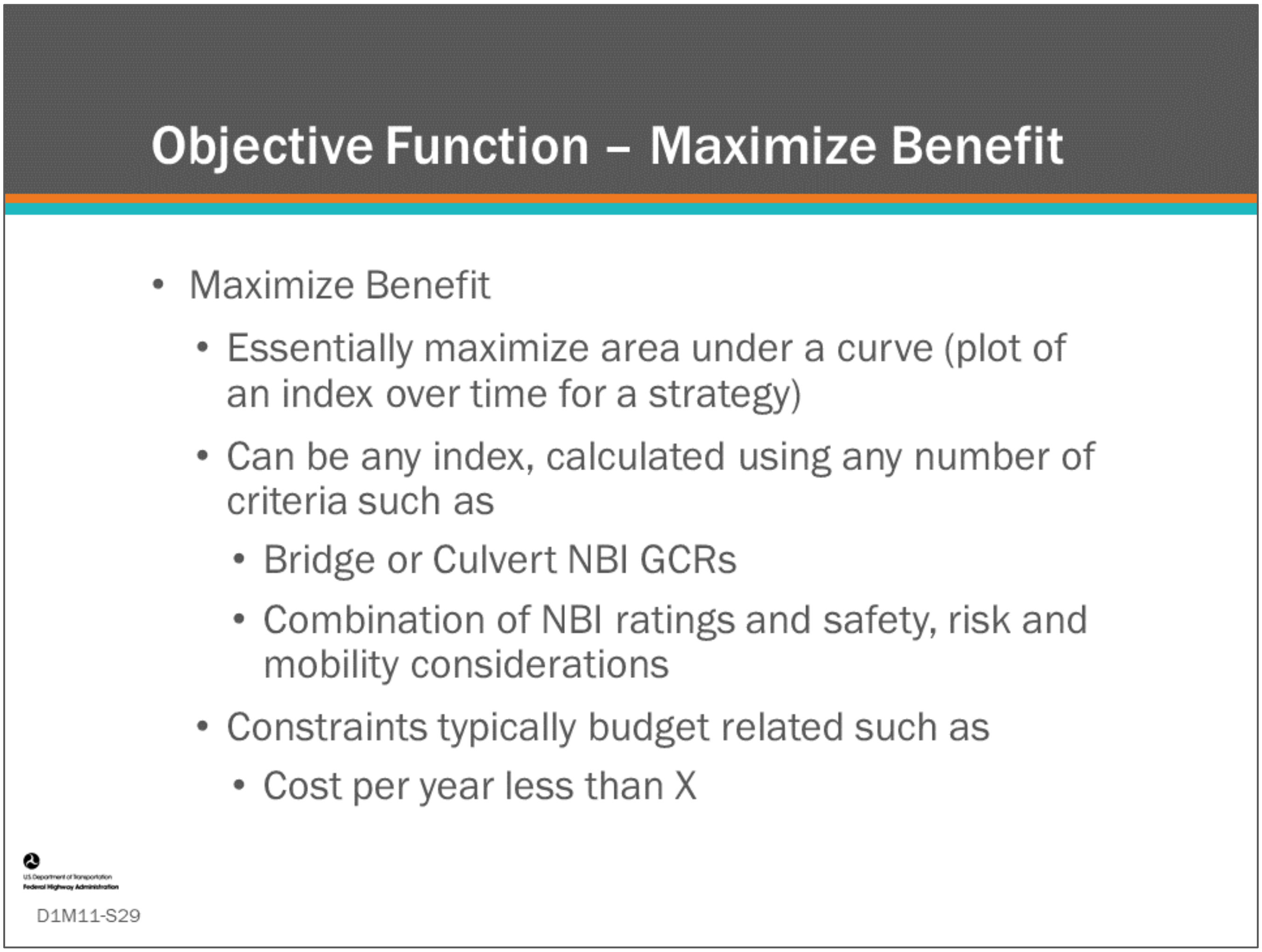
Key Message

In this topic we will discuss some common objective functions and their typical associated constraints.

Note, that the evaluation of an objective function results in a single value which is to be maximized or minimized.

However, this single value can be a composite function made up of various attributes of a solution.

D1M11-Slide 29

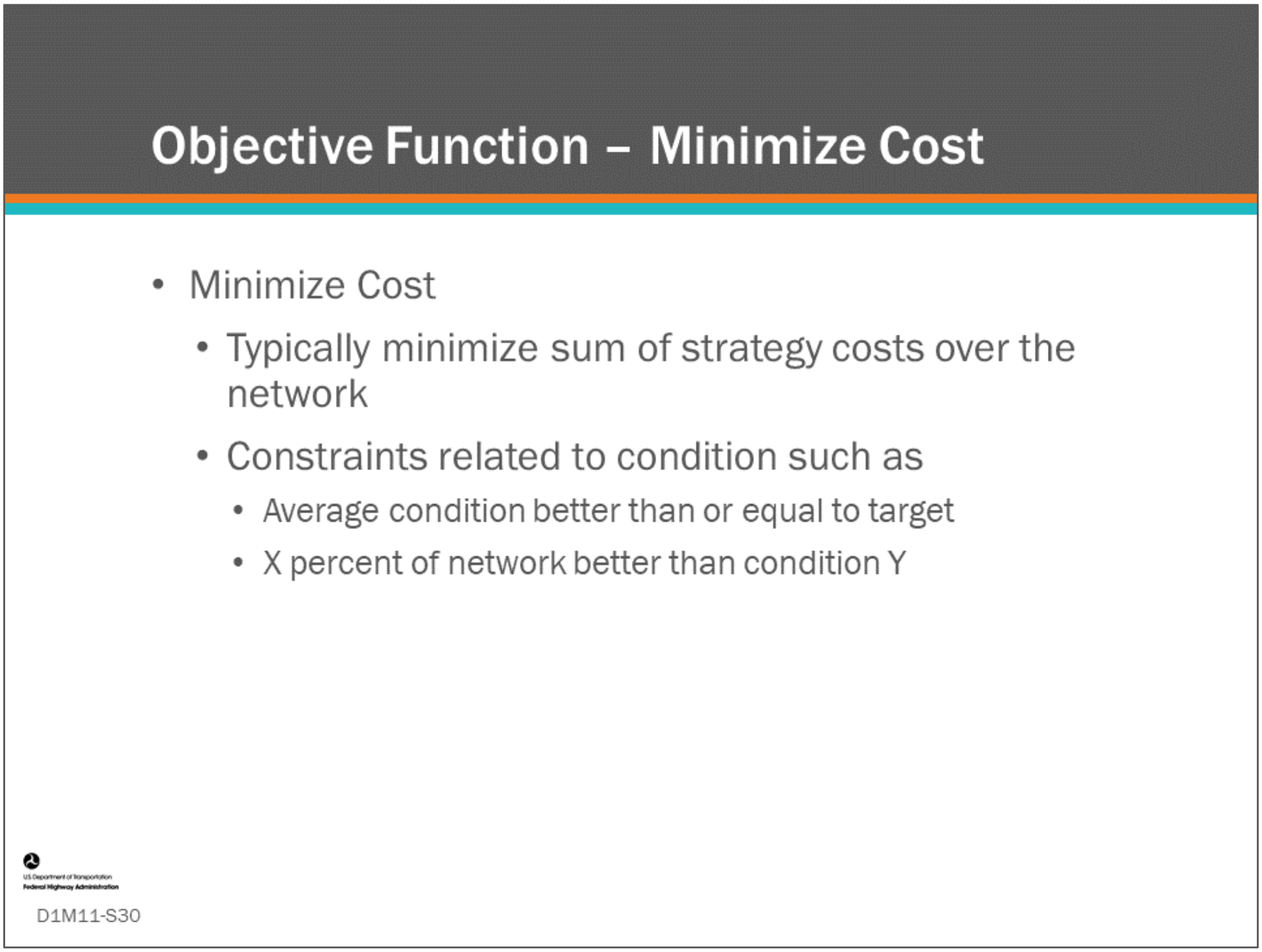


Key Message

One common objective function is to maximize benefit. In this case, the objective is to maximize the performance of the bridge network over time. We have generically called this "benefit," and it is measured by some BMS software as either the area directly under a plot of a performance index over time, or when evaluating individual projects, the difference in area between the plot of a performance index over time if the project was done and the same plot for the "Do Nothing" alternative.

When the objective is to maximize the overall benefit across the network over time, the limit is almost always the budget since, if there was no limit on budget, bridges would be replaced continuously (except as constrained by decision rules or LCCA). The use of this type of objective function is common in Deighton dTIMS© and AgileAssets® Structures Analyst™.

D1M11-Slide 30



Key Message

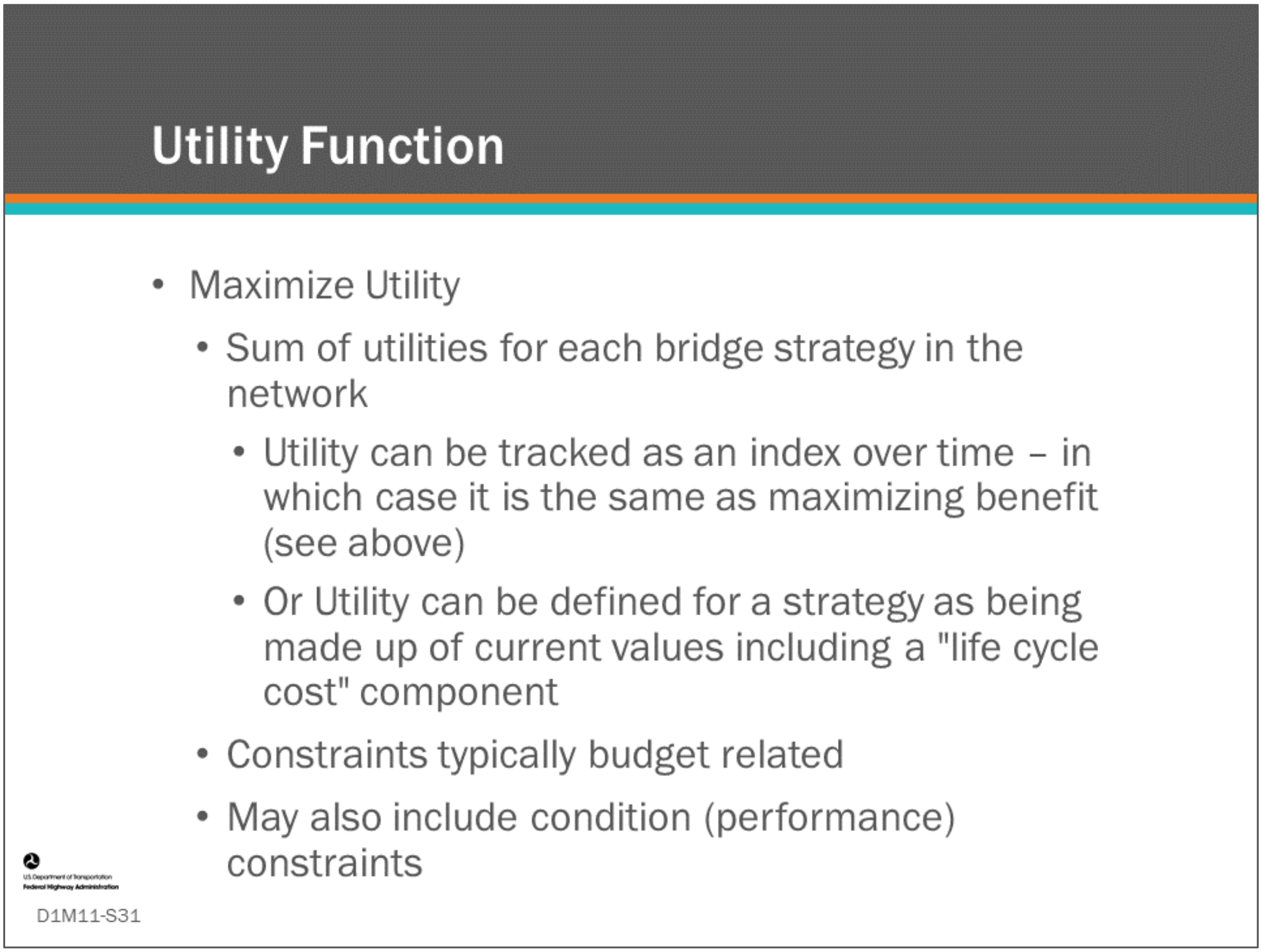
Another common objective is to minimize cost.

- In this case, the constraints are typically related to condition since the minimum cost solution would be to do nothing.
- Constraints on condition (or performance) typically involve setting targets on the condition distribution of bridges in the network.
- This can be as simple as setting a target for the average condition. Or it might involve setting targets such as "percent poor. "

Setting this kind of target constraint is typically in the form of specifying a target minimum percentage should be within a particular condition range.

- For example, less than 4 percent of Deck Area should have an NBI rating of 4 or less.
- This type of objective function is used by Deighton dTIMS©, AgileAssets® Structures Analyst™, and AASHTOWare™ Bridge Management (BrM).

D1M11-Slide 31



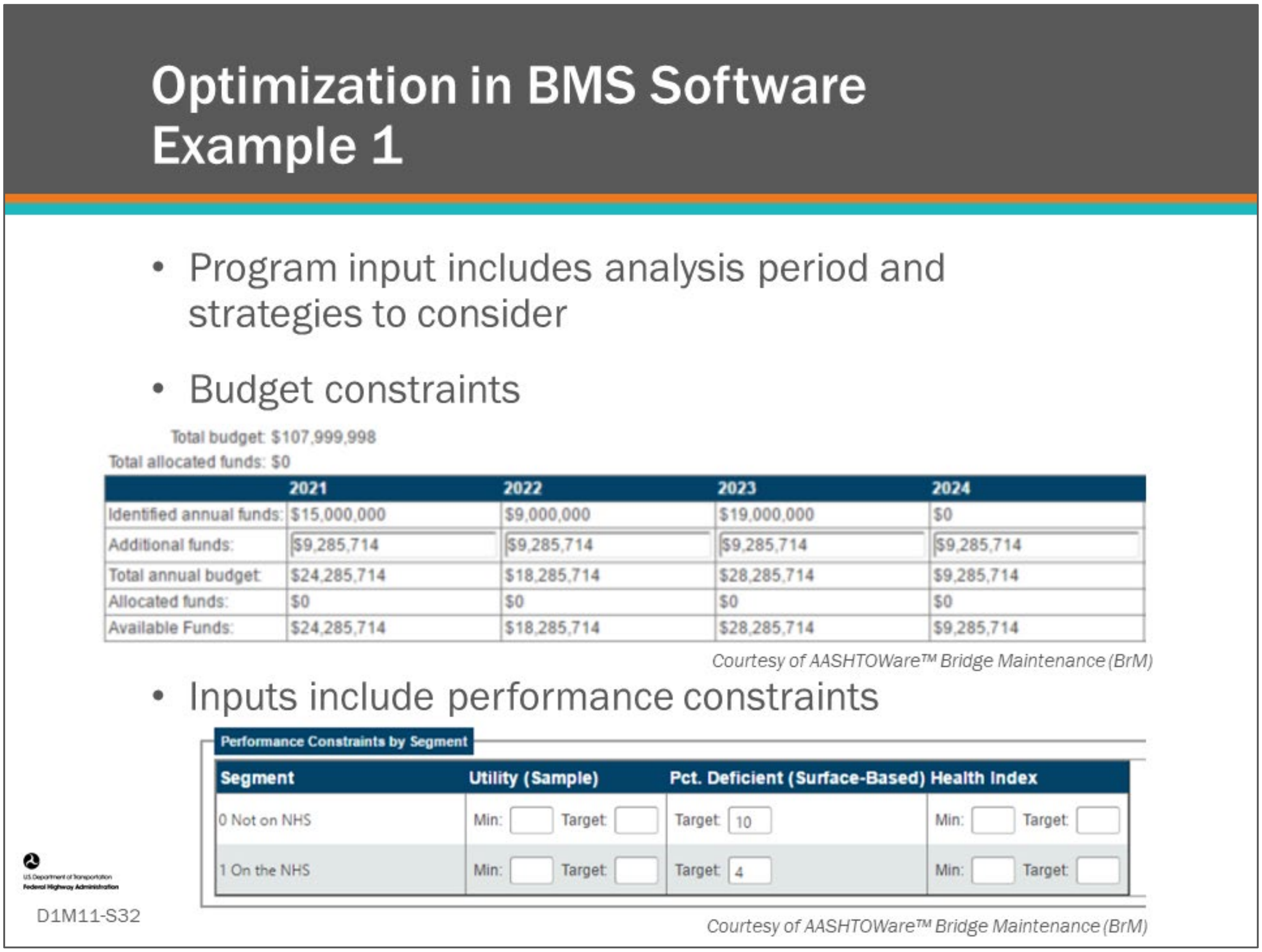
Key Message

If an index includes multiple components and is a measure of "value" of a solution, then this index can be termed a utility function.

If, for a solution, the benefit is a property of the index over time (such as the average of the index or the area under the index curve), then this is the same as maximizing benefit as discussed earlier.

However, we differentiate from maximizing benefit here because specifically in the case of AASHTOWare™ Bridge Management (BrM), the Utility of a strategy does not take into account the long-term area under the projected utility plot of a bridge strategy, but rather takes into account the long-term by using life cycle cost.

D1M11-Slide 32



	2021	2022	2023	2024
Identified annual funds:	$15,000,000	$9,000,000	$19,000,000	$0
Additional funds:	$9,285,714	$9,285,714	$9,285,714	$9,285,714
Total annual budget:	$24,285,714	$18,285,714	$28,285,714	$9,285,714
Allocated funds:	$0	$0	$0	$0
Available Funds:	$24,285,714	$18,285,714	$28,285,714	$9,285,714

Performance Constraints by Segment

Segment	Utility (Sample)	Pct. Deficient (Surface-Based)	Health Index
0 Not on NHS	Min: Target:	Target: 10	Min: Target:
1 On the NHS	Min: Target:	Target: 4	Min: Target:

Key Message

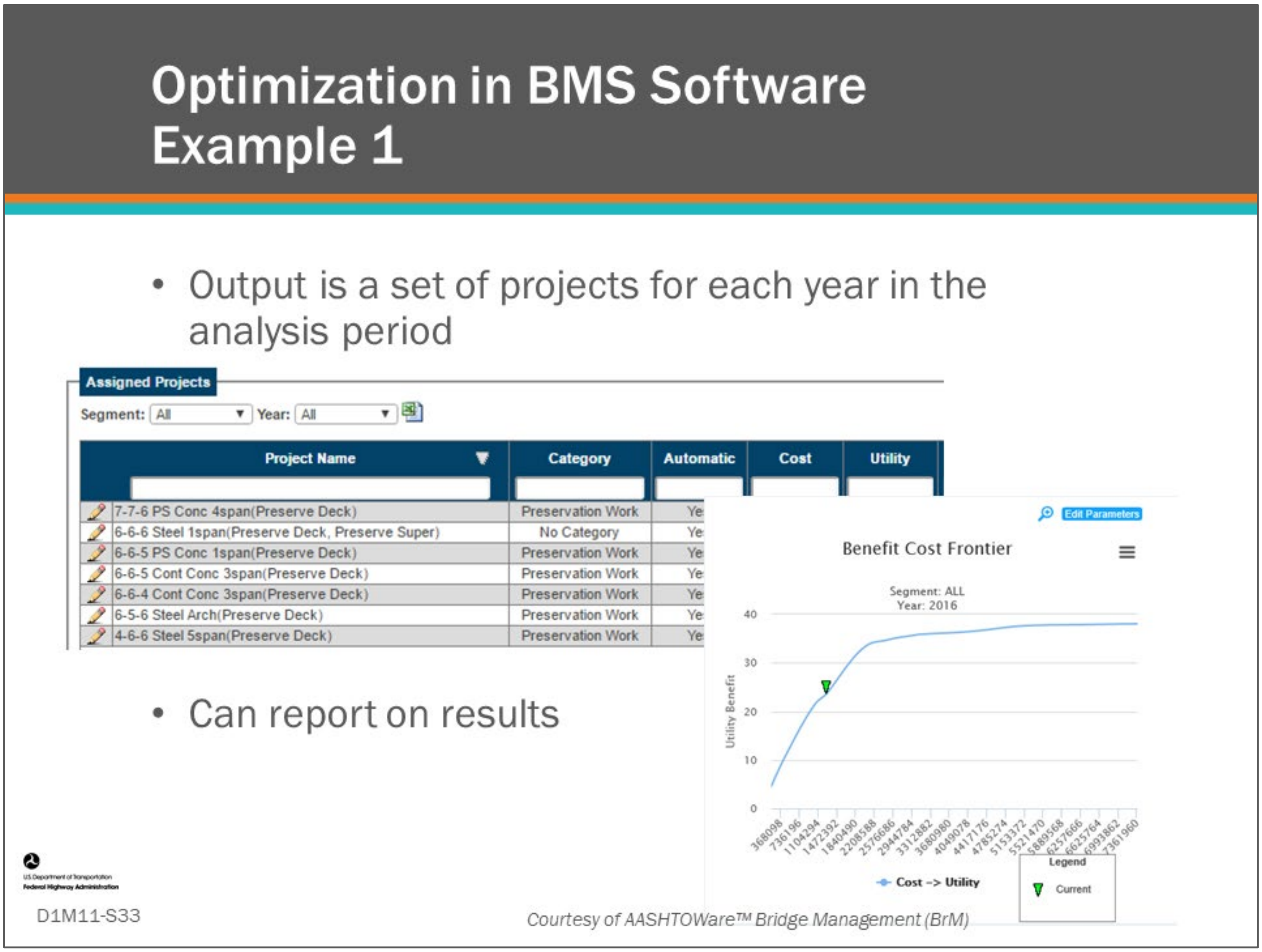
AASHTO™ Bridge Management (BrM) allows the use of two of the three example objective functions shown in the previous slides:

- Maximize Utility - The optimization tries to maximize the overall utility of the program within the specified budget and/or performance constraints (if desired).
- Minimize Cost - The optimization generates a program with the minimum possible cost that meets the specified performance constraints. Utility is not factored into minimizing the cost. This method will consider increasingly expensive project alternatives until the performance constraints are met.

For the optimization analysis, AASHTOWare™ Bridge Management (BrM) generates and evaluates a set of strategies (combinations of actions using the user-selected Network Policies) for each bridge. This is done one year at a time such that future strategies from each successive year are evaluated and based on the chosen strategies for one year (including the specific projects that were chosen for that year), the next set of strategies are evaluated using the updated conditions from the previous year. When maximizing utility, for each successive year, the algorithm orders the strategies based on incremental utility cost ratio. For each year, the system can then go down the list selecting strategies until the performance and budget constraints are met.

When minimizing cost, the same strategies as for maximizing Utility are ordered by cost rather than incremental utility cost ratio (and utility is not considered). The system can then again go down the list selecting increasingly more expensive projects until the performance constraints are met. The system repeats this process for each year in the short-term analysis period.

D1M11-Slide 33



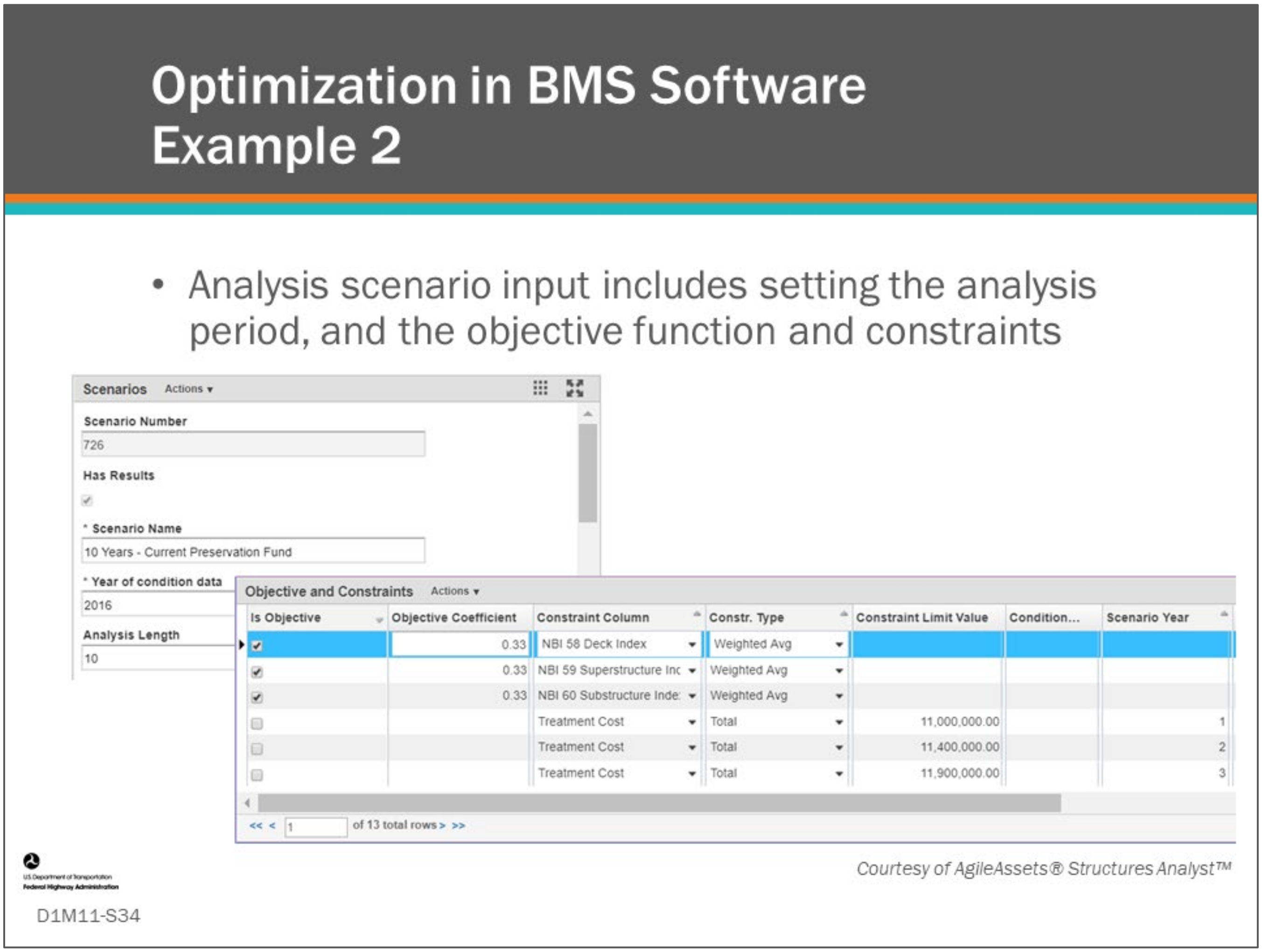
Key Message

The output from the optimization in AASHTOWare™ Bridge Management (BrM) is a set of bridge projects for each year in the analysis period that meet the performance criteria during the analysis period.

The resulting utility and various other statistics can be reported based on this set of proposed bridge projects.

For either of the optimization types, the accumulating cost and utility can be plotted for the ordered list of projects. This plot is shown as a benefit cost frontier.

D1M11-Slide 34



Key Message

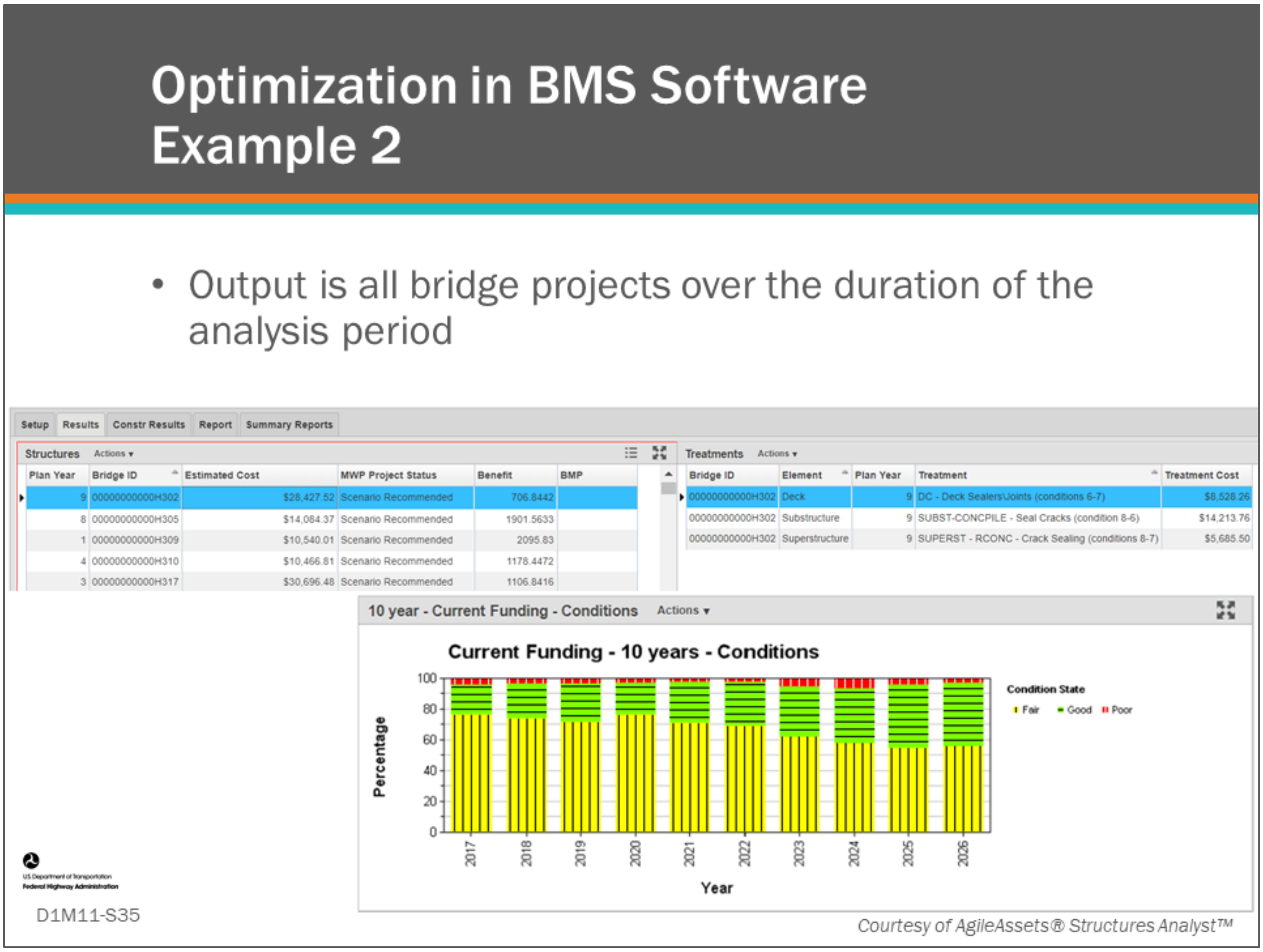
For AgileAssets® Structures Analysis, properties such as the analysis period, and the objective function and constraints are defined for an analysis scenario.

In the example shown, the objective function is set as the weighted average (by deck area) of the sum of 1/3 of the Deck NBI, 1/3 of the Superstructure NBI, 1/3 of the Substructure NBI, for each bridge.

The constraints in this example are per year of the analysis period. Any objective function can be set up and chosen for the analysis, and any number of budget or performance constraints can be set.

The optimization is performed using integer programming.

D1M11-Slide 35



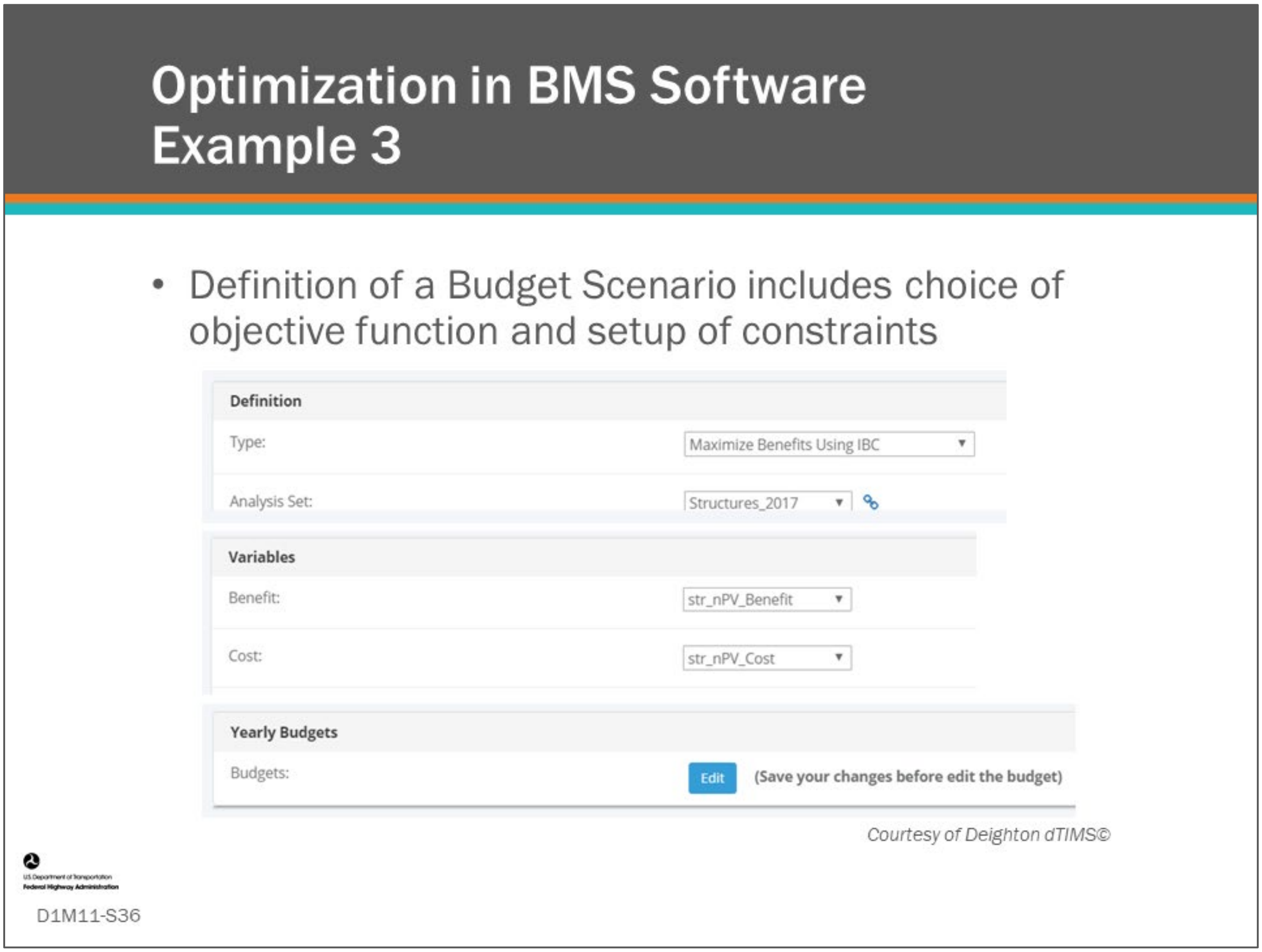
Key Message

The output of the AgileAssets® Structures Analyst™ is a list of bridge projects for each year in the analysis period.

Each bridge project consists of specific actions for each element defined.

The levels of any specified performance indices resulting from the optimized set of bridge strategies (sequences of bridge projects) for a scenario can be plotted over time.

D1M11-Slide 36



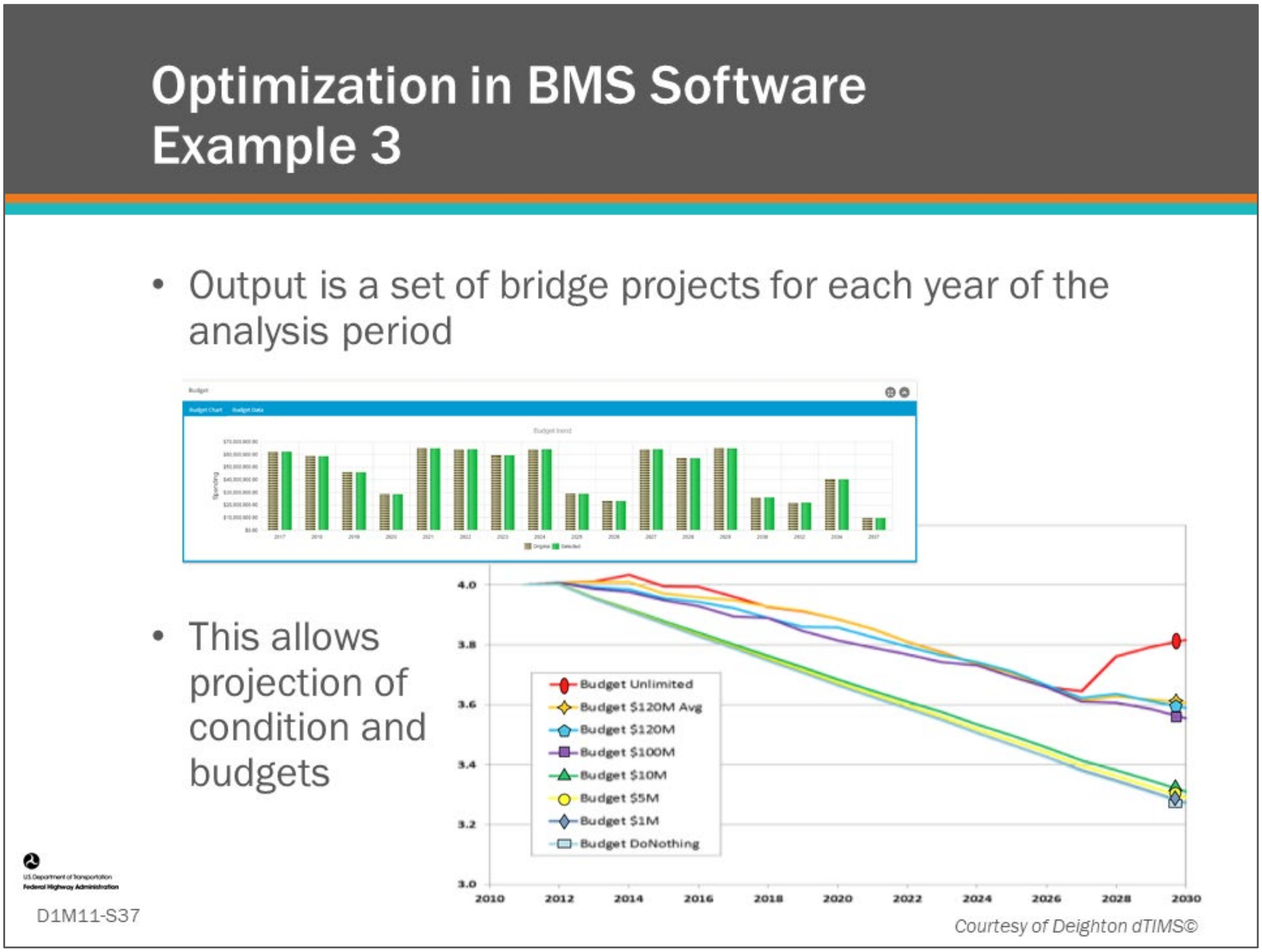
Key Message

In Deighton dTIMS©, the objective function is set by selecting the type of analysis (in this example Maximize Benefits using incremental benefit/cost ratio).

The specific analysis variables (which define the formulas) for benefit and cost are chosen by the user. In this example, yearly budget constraints are defined.

This is another example of the Maximize Benefit objective function discussed earlier.

D1M11-Slide 37



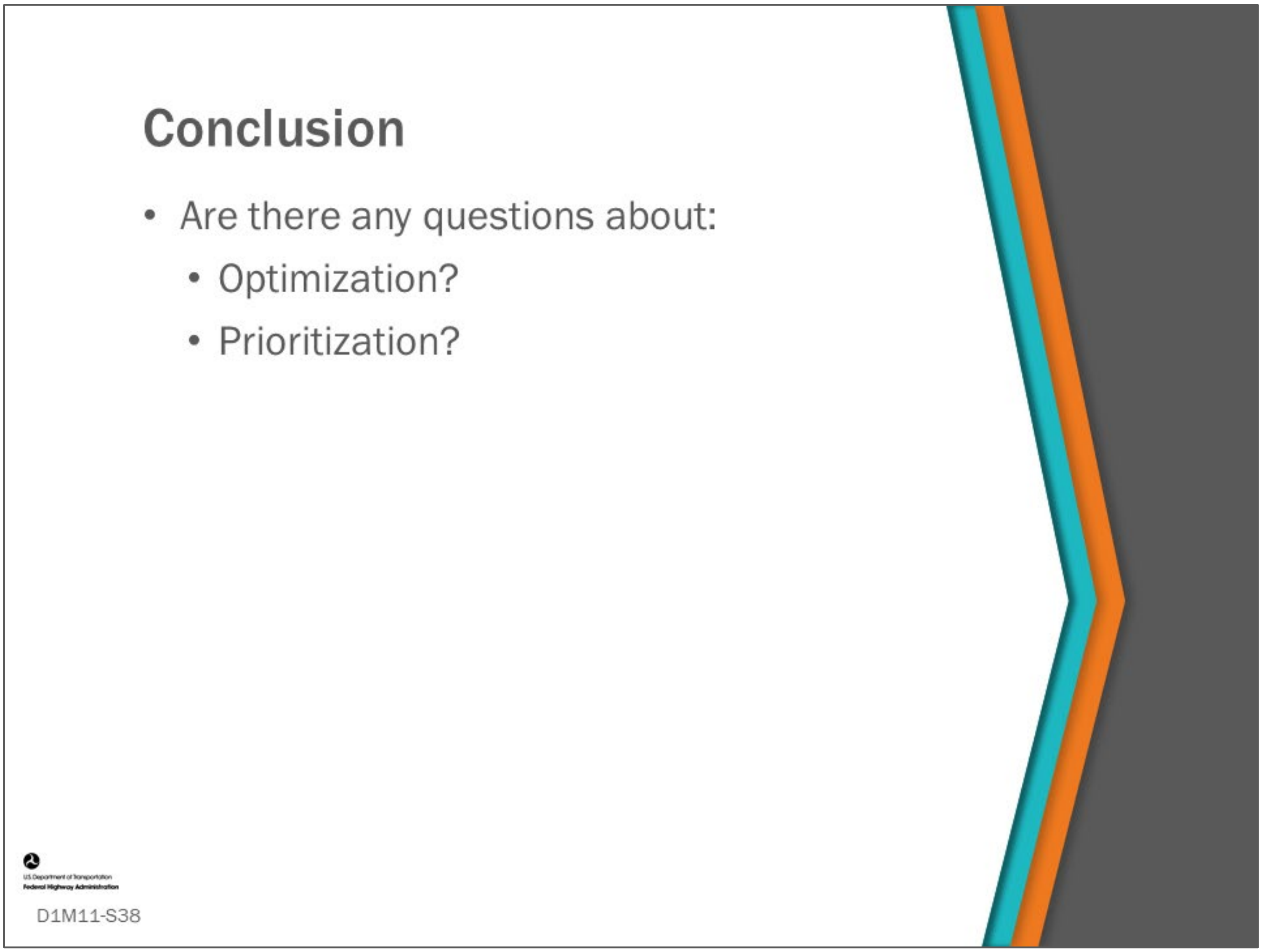
Key Message

This slide shows optimization results for the Deighton dTIMS© software given the budget constraints.

The detailed output is a list of bridge projects for each year in the analysis period.

Based on this detailed output work plan, spending and performance can be projected over time.

D1M11-Slide 38



Key Message

This concludes D1M11: Optimization and Prioritization.

D1M11-Slide 39

Slide #	Image Description	Source Information
6	This is a figure showing the performance over time of three bridge strategies on the left. An arrow indicates how these are summarized into a plot of overall network performance, and overall network cost, in two figures on the right.	This Workshop.
7	Figure showing a branching set of actions with an arrow at the top showing Time in years increasing to the right.	This Workshop.
12	A chart shows Bridge i, strategy j with Performance on the y-axis and time (years) on the x-axis. A performance curve shows two actions increasing performance over time.	This Workshop.
13	A chart shows Bridge i, strategy j with Performance on the y-axis and time (years) on the x-axis. A performance curve shows one action increasing performance.	This Workshop.
16	The top chart shows Bridge 1 with one action with a function of current conditions and properties. The bottom chart shows Bridge 2 with one action with a function of current conditions and properties.	This Workshop.
17	The top chart shows Bridge 1, Project A. A line chart shows Performance on the y-axis and Time (years) on the x-axis The bottom chart shows Bridge 2, Project C. A line chart shows Performance on the y-axis and Time (years) on the x-axis.	This Workshop.
18	The top chart shows Bridge 1, Project A. A line chart shows Performance on the y-axis and Time (years) on the x-axis. The bottom chart shows Bridge 2, Strategy C. A line chart shows Performance on the y-axis and Time (years) on the x-axis.	This Workshop.

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D1M11-S39

D1M11 Figure Source List

D1M11-Slide 40

Slide #	Image Description	Source Information
21	Knapsack illustration.	This Workshop.
24	A line chart shows Performance on the y-axis and Time (years) on the x-axis. A performance curve is shown on the chart for Bridge 1, Strategy A showing two actions that increase performance or utility.	This Workshop.
24	A line chart shows Performance on the y-axis and Time (years) on the x-axis. A performance curve is shown on the chart for Bridge 2, Strategy C showing two actions that increase performance or utility.	This Workshop.
26	A scatter chart shows function f1 on the y-axis and function f2 on the x-axis. Markers are plotted on the chart and a dashed line represents the Pareto or efficient frontier.	This Workshop.
32	AASHTOWare™ BrM screenshot showing performance constraints.	AASHTOWare™ Bridge Maintenance (BrM).
32	AASHTOWare™ BrM screenshot showing budget constraints.	AASHTOWare™ Bridge Maintenance (BrM).
33	AASHTOWare™ BrM screenshot showing assigned projects.	AASHTOWare™ Bridge Maintenance (BrM).
33	AASHTOWare™ BrM screenshot showing benefit cost frontier.	AASHTOWare™ Bridge Maintenance (BrM).
34	AgileAssets® screenshot showing scenario screen.	AgileAssets® Structures Analyst™.
34	AgileAssets® screenshot showing objectives and constraints.	AgileAssets® Structures Analyst™.

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D1M11-S40

D1M11 Figure Source List

D1M11-Slide 41

Slide #	Image Description	Source Information
35	AgileAssets® screenshot showing results of analysis.	AgileAssets® Structures Analyst™.
35	AgileAssets® screenshot showing results from analysis the percentage of bridges rated good, fair, and poor for each year in the analysis.	AgileAssets® Structures Analyst™.
36	Screenshot 1 from Deighton dTIMS© of Definition of a Budget Scenario.	Deighton dTIMS©.
36	Screenshot 2 from Deighton dTIMS© of Definition of a Budget Scenario showing Variable inputs.	Deighton dTIMS©.
36	Screenshot 3 from Deighton dTIMS© of Definition of a Budget Scenario showing Yearly Budgets.	Deighton dTIMS©.
37	A screenshot of Deighton dTIMS(c) software showing budget screen.	Deighton dTIMS©.
37	Screenshot of Deighton dTIMS showing line chart showing NBI condition projections over time for multiple different budgets.	Deighton dTIMS©.

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D1M11-S41

D1M11 Figure Source List

Module Title: D1M12 – Investment Strategy Simulation and Investigation

Module Time: 20 minutes

Module Summary

Investment strategy simulation and investigation in a BMS starts with scenario modeling, which is a major functionality of advanced BMS software. This is typically done by running multiple "what-if" scenarios to evaluate network management policy such as program funding, performance measure targets, and work categories (mix-of-fixes). This module will go over how scenario modeling is done in a BMS by adjusting the many input parameters including the objective function (utility functions and their weights when the agency has multiple objectives), constraints, and targets. It will show how the results of scenario modeling are used to forecast bridge performance measures into the future and develop investment strategies.

Expected Outcome(s)

Participants will understand how simulations are used to analyze different investment strategies.

Resource List

Slide	Reference Information
15,16	FHWA. *Using a Life Cycle Planning Process to Support Asset Management*. Washington, DC, 2017.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D1M12-Slide 1

Key Message

Investment strategy simulation and investigation in a BMS starts with scenario modeling, which is a major functionality of advanced BMS software. This is typically done by running multiple “what-if” scenarios to evaluate network management policy such as program funding, performance measure targets, and work categories (mix-of-fixes). This module will go over how scenario modeling is done in a BMS by adjusting the many input parameters including the objective function (utility functions and their weights when the agency has multiple objectives), constraints, and targets. It will show how the results of scenario modeling are used to forecast bridge performance measures into the future and develop investment strategies.

Disclaimer

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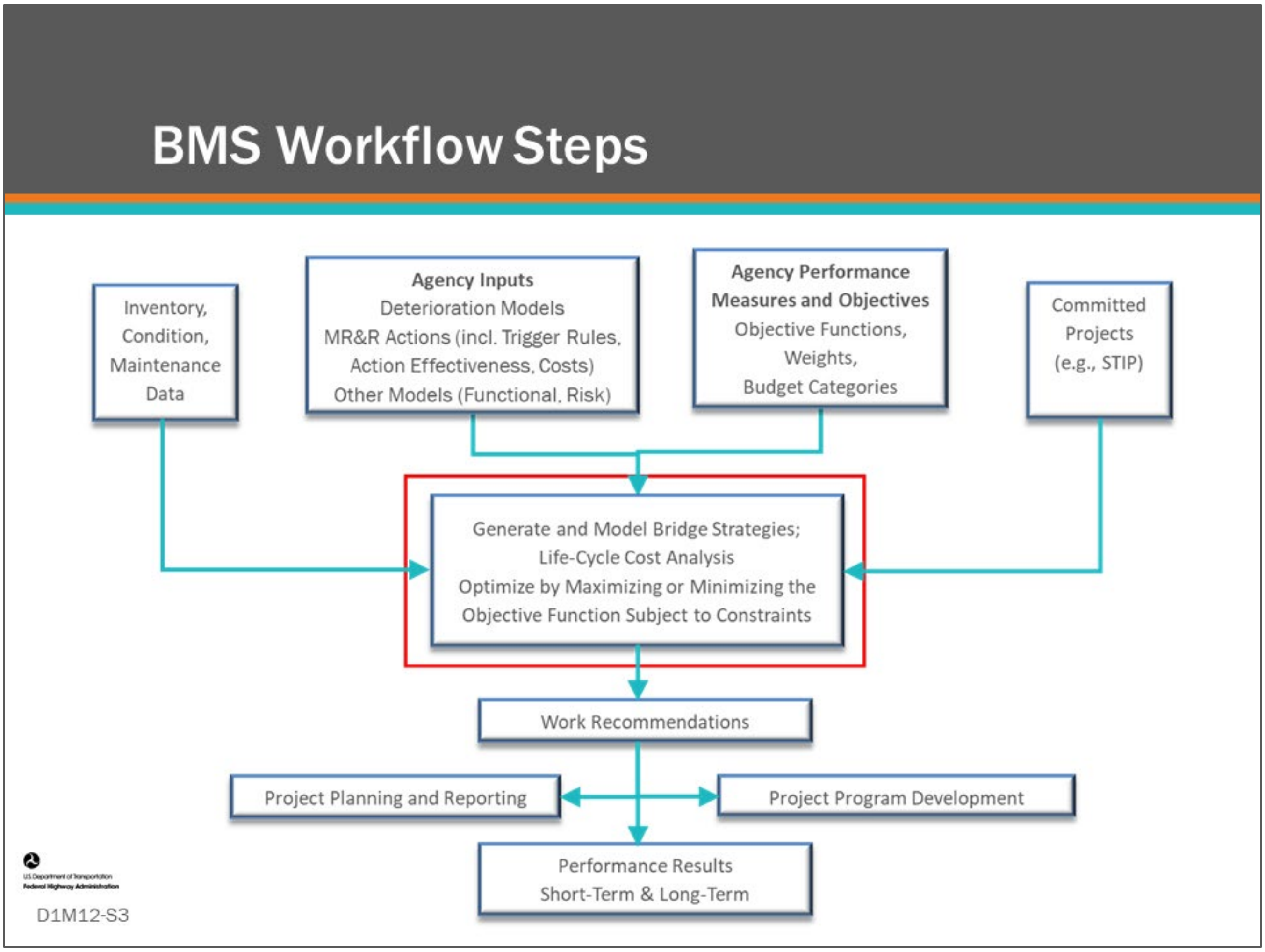
D1M12-Slide 2

Key Message

In this module, we will look at how to model scenarios in a BMS. Scenario modelling is used for investment strategy analysis and investigation.

D1M12-Slide 3



Key Message

A major function of BMS software is doing scenario modeling. Advanced BMS software provides functionality to do this work program simulation and optimization, and it is important that bridge managers learn how to utilize this capability to evaluate the results of alternative work programs in order to decide on an investment strategy.

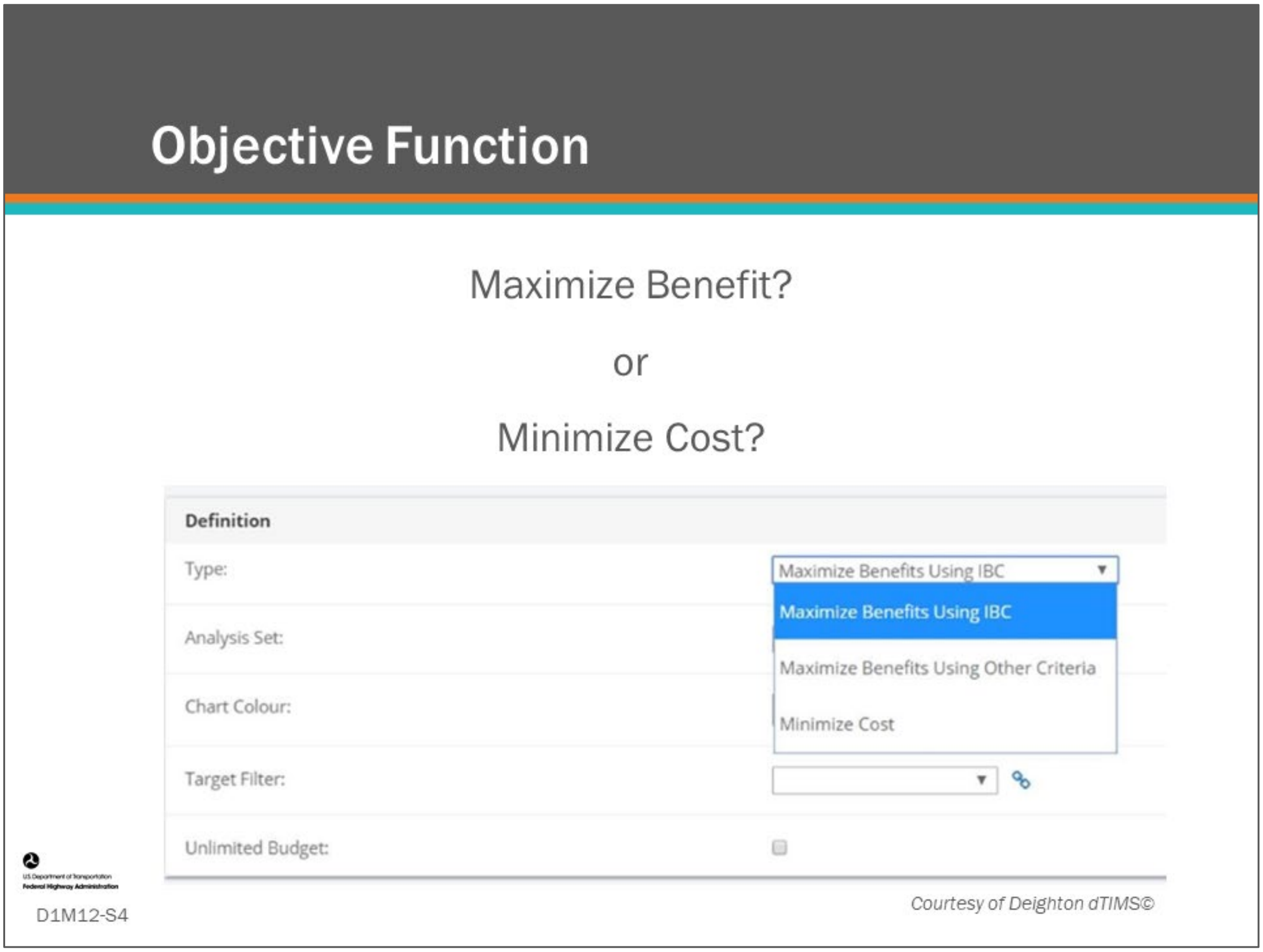
The BMS workflow process diagram is presented on this slide and is highlighted with a red box around Generate and Model Bridge Strategies. This involves using all the data inputs that we have discussed in previous modules, shown as boxes with arrows flowing into the Generate and Model Bridge Strategies box.

Scenario modeling for a specific scenario involves:

- Picking the objective function (also called performance measure or optimization index) to maximize or minimize.
    - In AASHTOWare™ Bridge Management (BrM), the objective function is typically total utility, however, the included objectives and objective weights are flexible and can be adjusted to consider desired objectives. The other option is to use cost as the objective function.
    - In AgileAssets® Structures Analyst™ and Deighton dTIMS©, flexibility is given to set the objective function.
- Setting constraints based on agency budgets or using an agency's performance measures and objectives.

By varying the objective and constraints, the bridge manager can generate projections for multiple scenarios with different budget constraints and different targets. Slightly more difficult, but possible in concept, is to model different scenarios by varying the Agency Inputs such as using different actions, different unit costs, or different trigger rules.

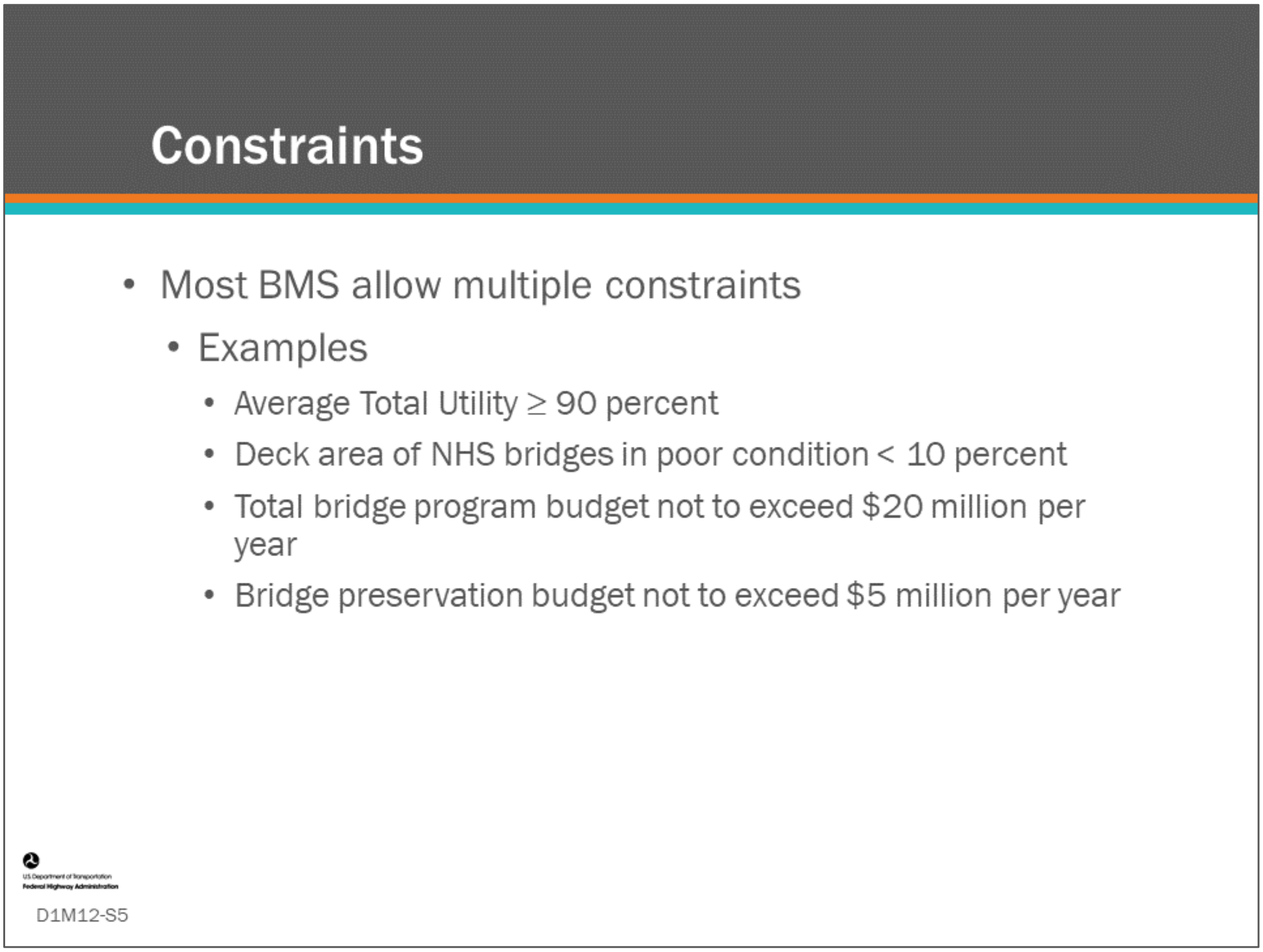
D1M12-Slide 4



Key Message

An important decision to make when running a scenario is to decide what objective function (i.e., optimization index) you are going to use and whether you are going to maximize or minimize it. Often you will maximize benefit or minimize cost. The project selections the BMS will recommend will likely be different depending on what the software is being asked to do. An agency may even want to run scenario models doing both for comparison.

D1M12-Slide 5

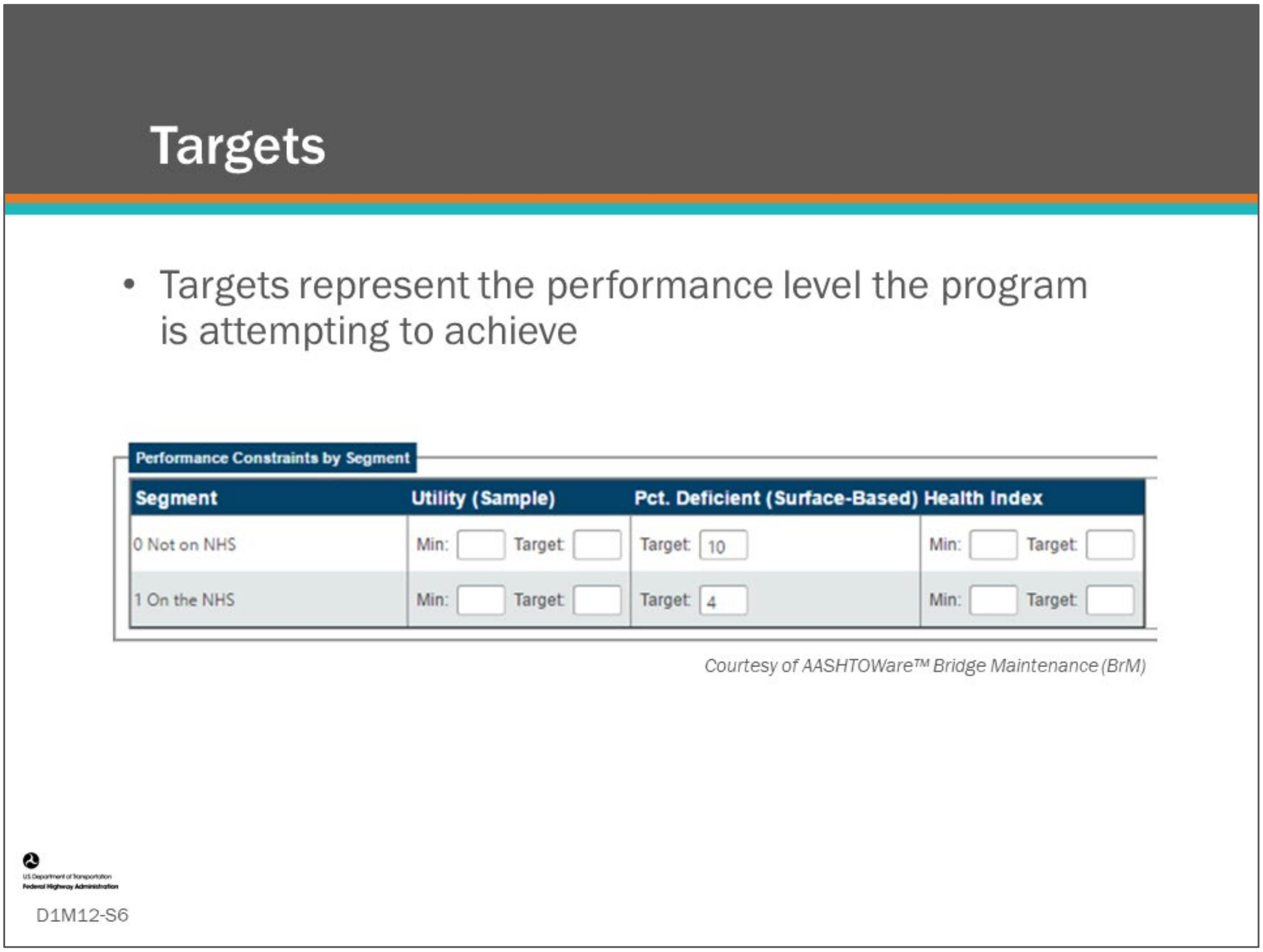


Key Message

Constraints are the second part of the optimization problem formulation.

- BMS software allows you to set multiple constraints (the number being dependent upon the software).
- Constraints tell the software what minimum or maximum values the model must achieve.
- The optimization routine will work to select projects that maximize or minimize the objective function and at the same time it will check to see if all constraints are met.
- If not, it will make adjustments to the program of projects until the best value for the objective function is found while satisfying the constraints.
- Keep in mind, imposing constraints will move the problem solution away from optimal.
- Therefore, one should be judicious when imposing constraints. One may even analyze a range of values for the constraints by running different scenarios in order to determine their effect on the problem solution.

D1M12-Slide 6



Key Message

Targets represent the performance level the program is attempting to achieve. Targets are just another kind of constraint but can be useful for analyzing a scenario where you want to understand what funding levels would be needed to meet or sustain a performance target.

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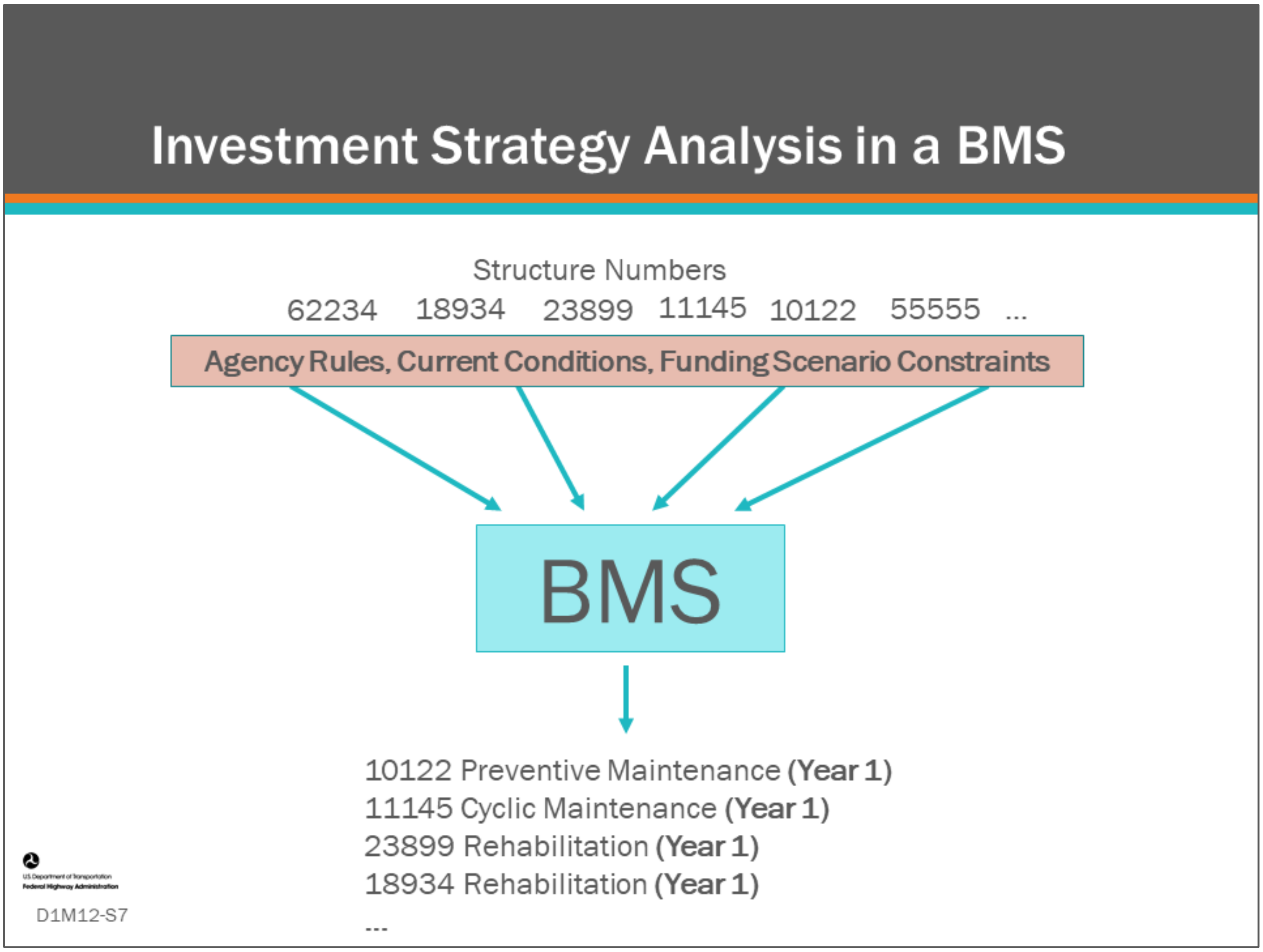
D1M12-Slide 7



Key Message

Scenario modeling takes all the input information feeding into the optimization routine with the objective function and constraints. When the program is run, the result is a list of bridge projects in each year of the analysis period. For example, the slide shows four projects from the above list as recommended projects for Year 1 of the analysis.

The projects that are recommended are improved as per the agency benefit rules. Two structures numbers did not make the list (62234 and 55555) because of funding or other constraints.

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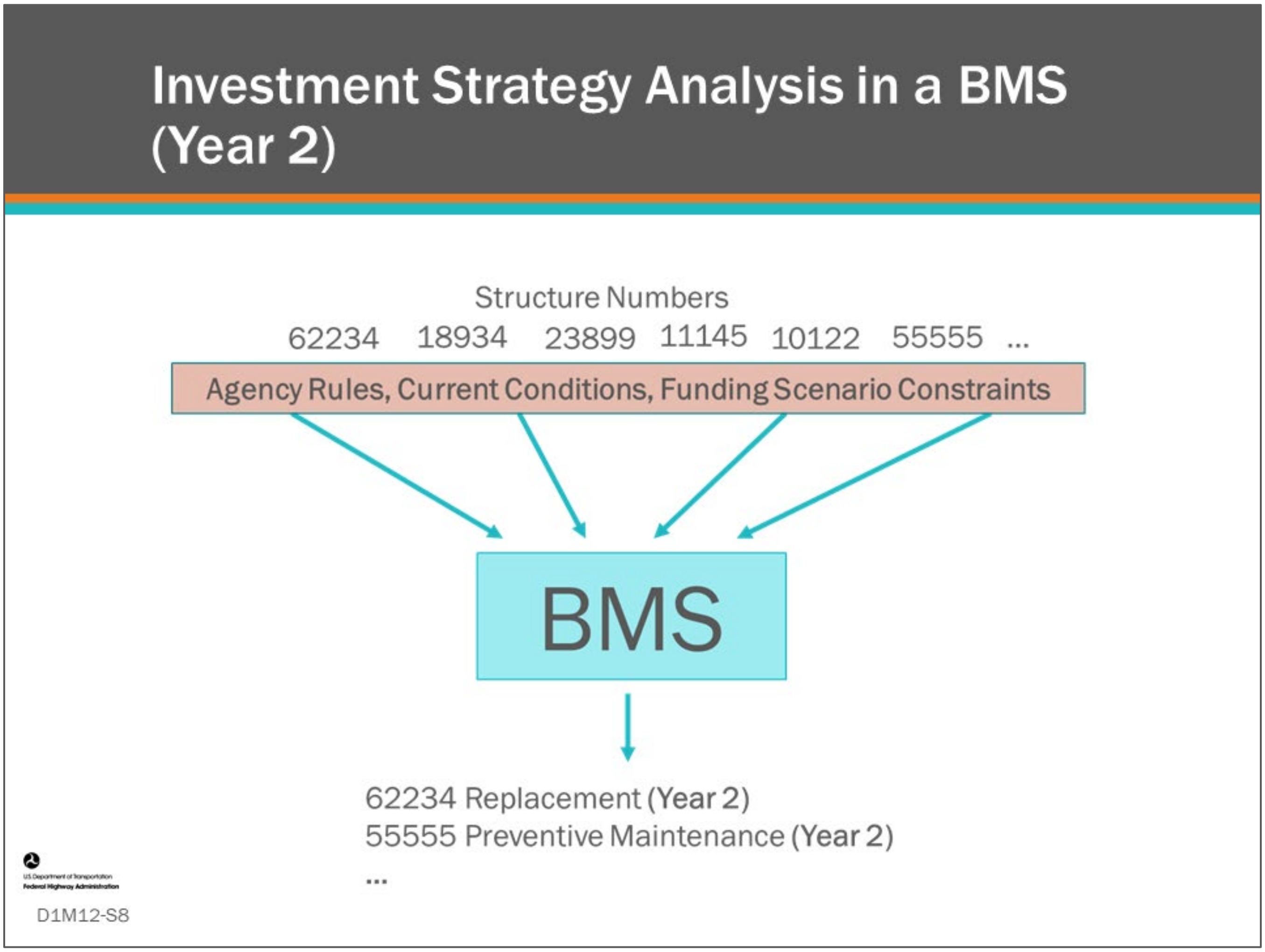
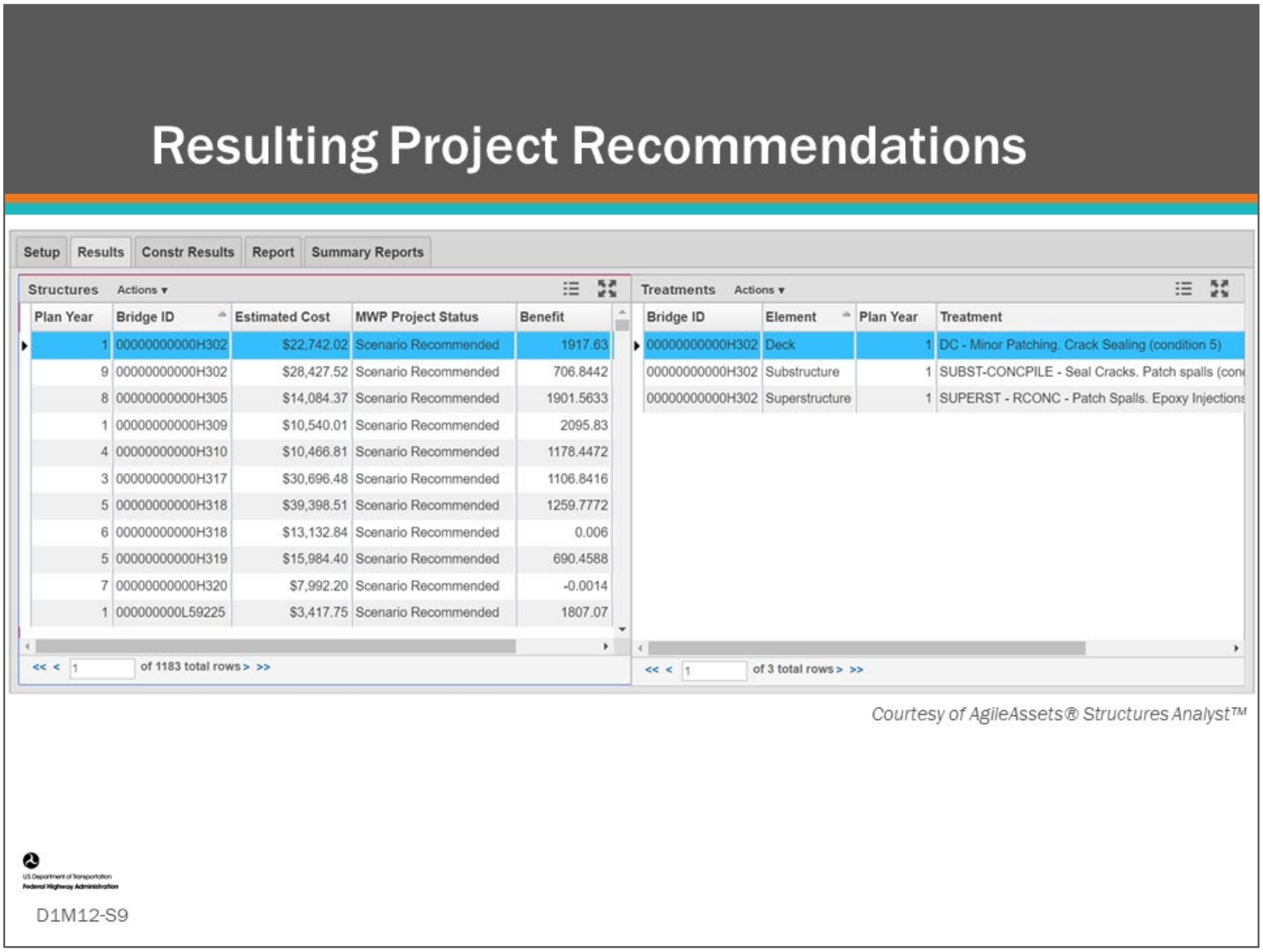
D1M12-Slide 8



Key Message

In the Year 2 of the analysis, the population of bridges is deteriorated one year, and the optimization routine is repeated. Notice, in Year 2, the two structure numbers (62234 and 55555) that did not make the list in Year 1 are recommended. The deterioration then optimization routines are repeated for each year in the analysis, producing a recommend list of projects for each year.

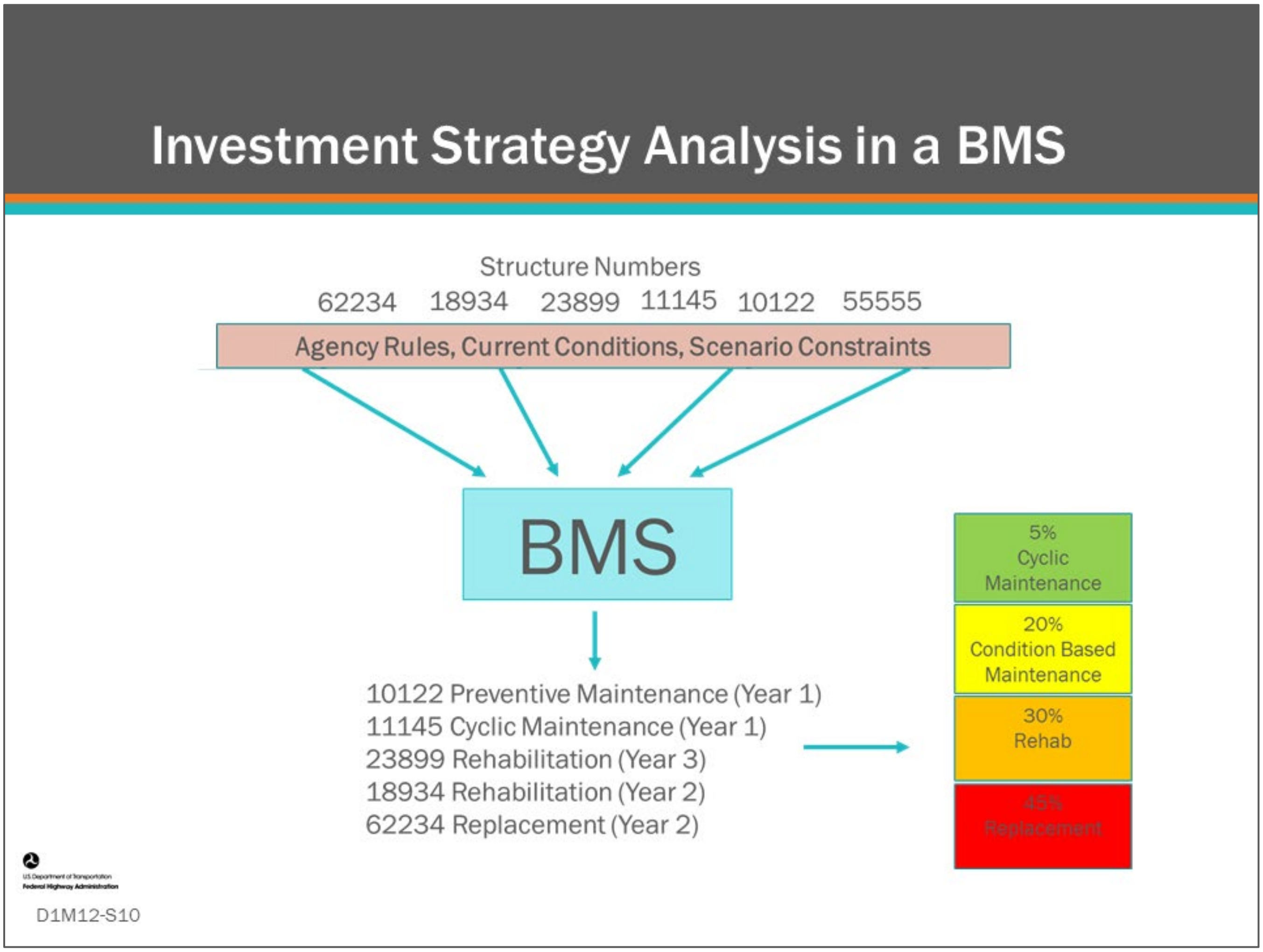
D1M12-Slide 9



Key Message

Shown on this slide is an example project list showing the project on the left, with the details of the highlighted bridge on the right.

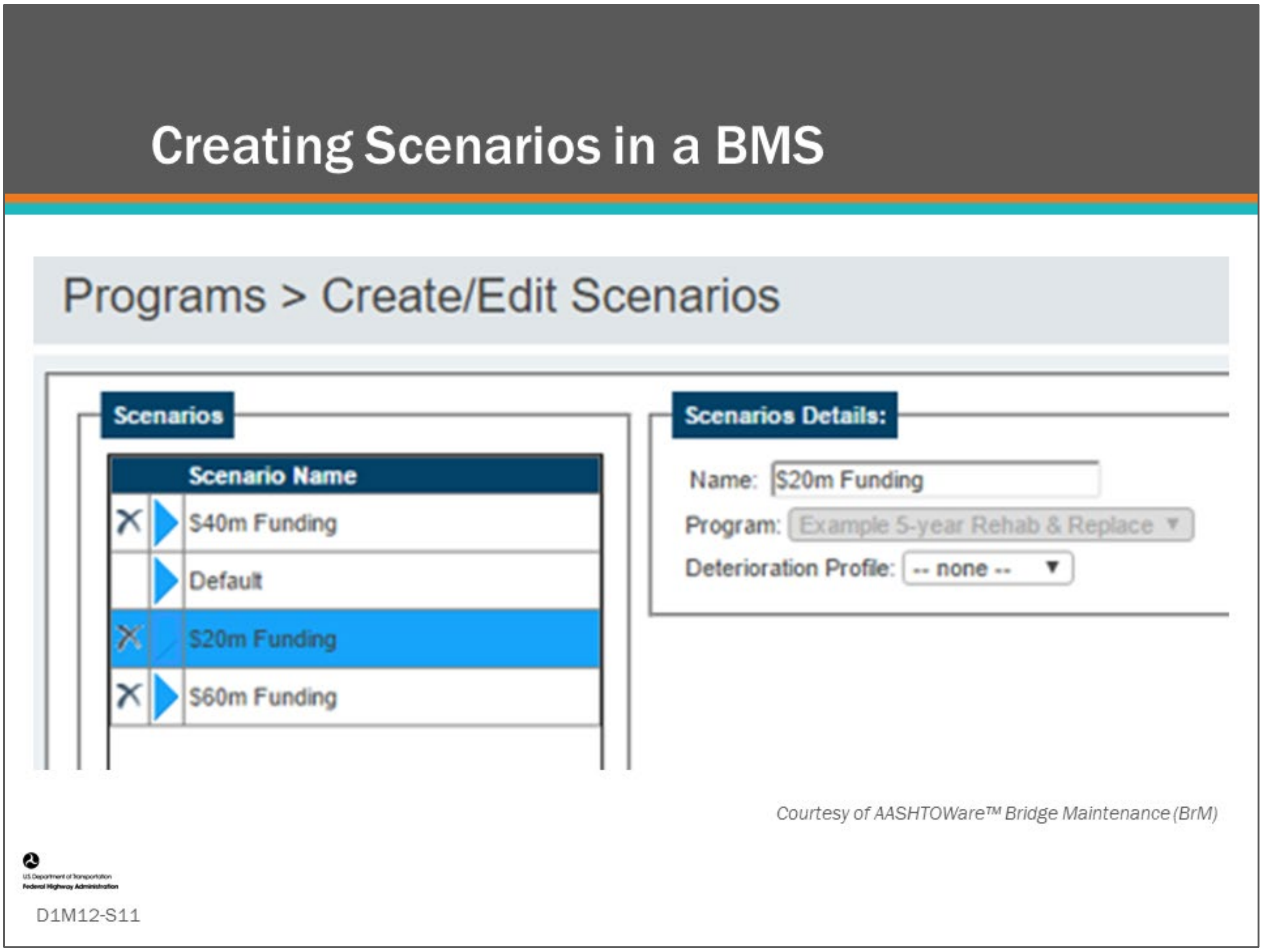
D1M12-Slide 10



Key Message

Post processing may be used to review the categories of work that the program recommends for developing a mix of fix percentages for each year in the program, as shown on the slide at bottom right.

D1M12-Slide 11



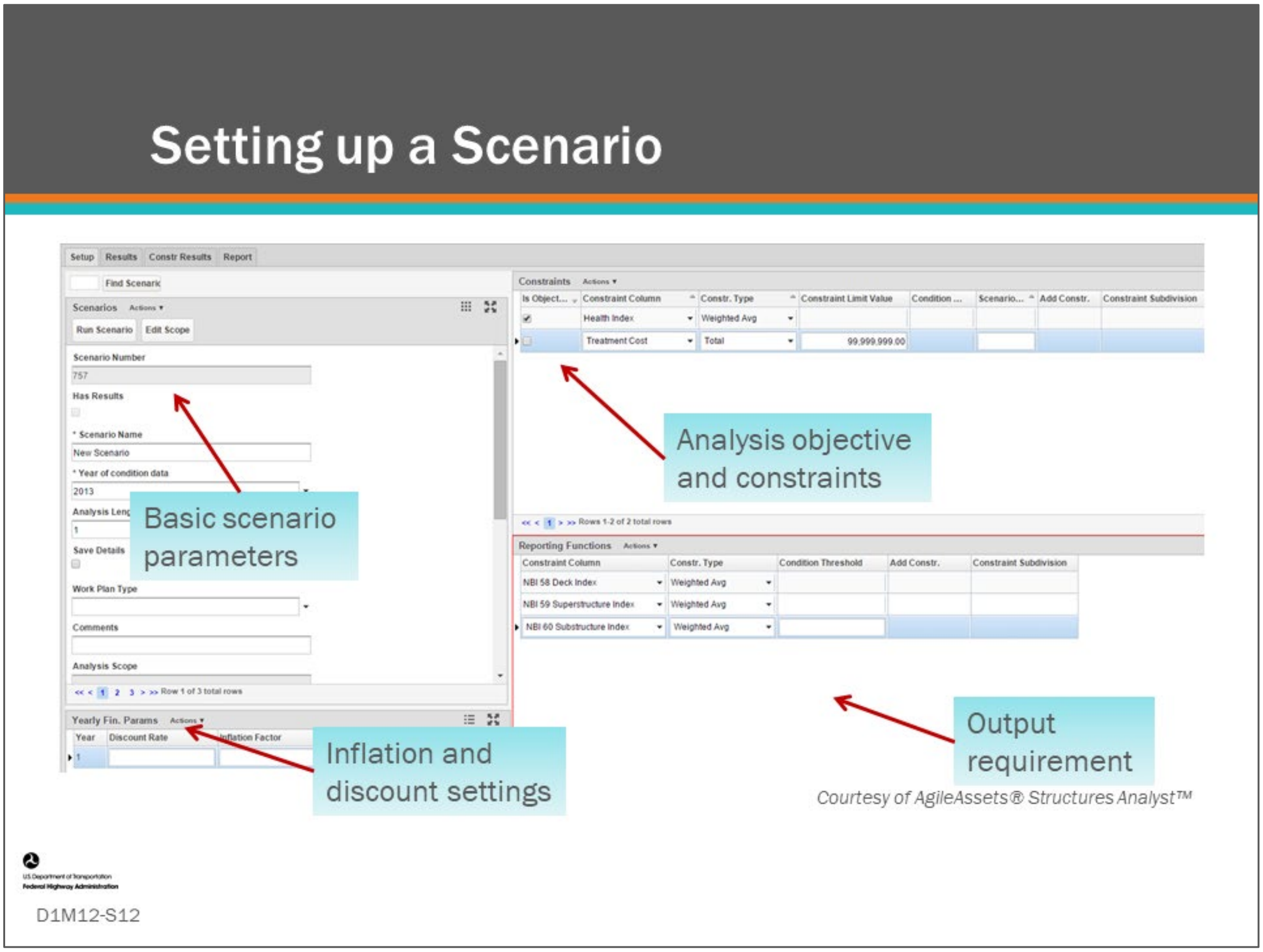
Key Message

Multiple scenarios can be created and run in a BMS so that results can be compared.

- In AgileAssets® Structures Analyst™, a scenario includes setting the objective function and constraints, and multiple scenarios can be set up and saved.
- In AASHTOWare™ Bridge Management (BrM) and Deighton dTIMS©, scenarios are set up separately from the objective function and constraints.

Shown on the slide is the Create/Edit Scenario screen in the AASHTOWare™ Bridge Management (BrM) software.

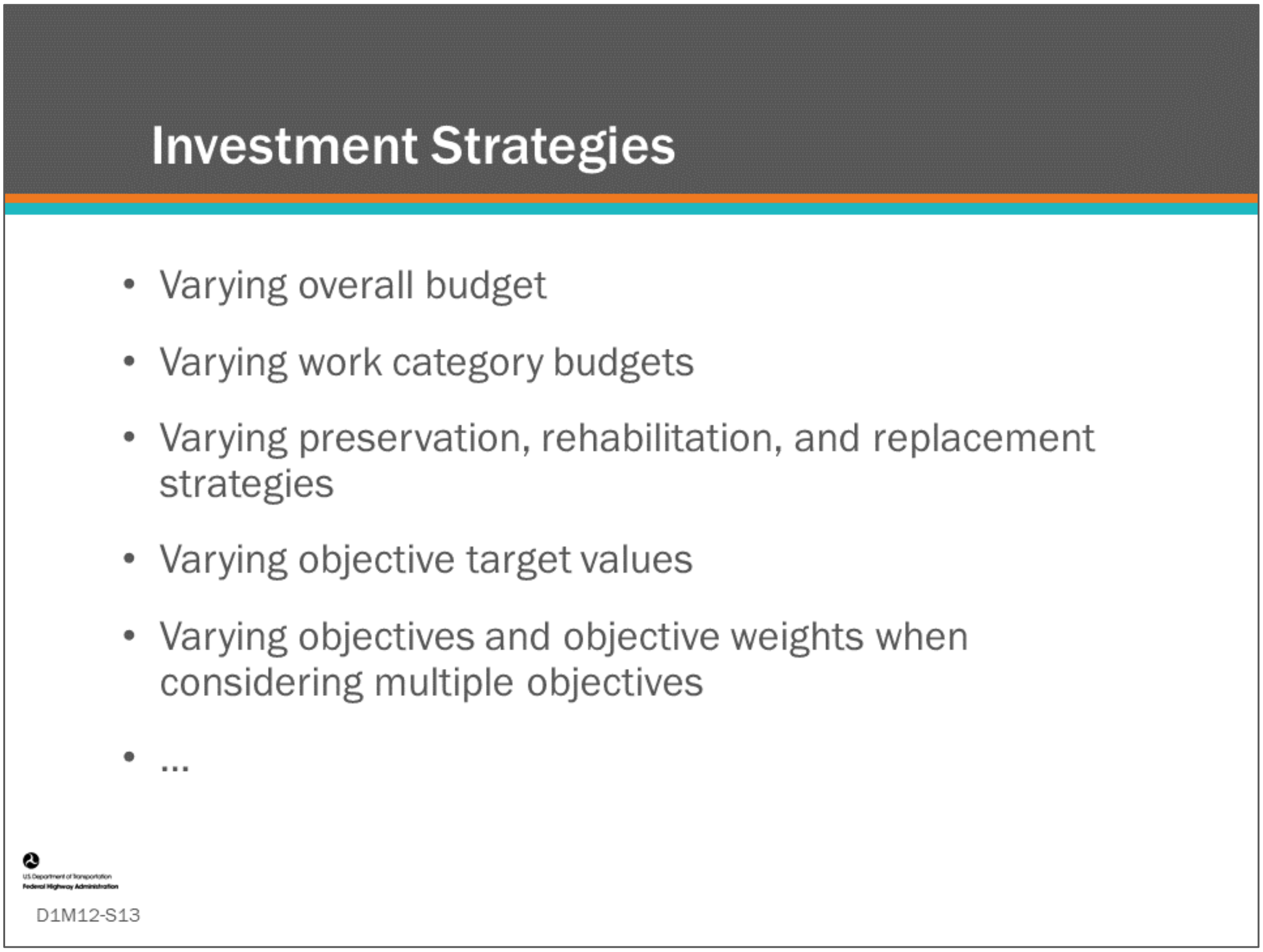
D1M12-Slide 12



Key Message

Shown on this slide is the Optimization Analysis screen from AgileAssets® Structure Analyst™ showing the scenario setup and run screen and the objective function and constraints screen.

D1M12-Slide 13



Key Message

Scenarios can be defined and varied by such things as total budget, sub-program budgets, work categories, and segments of the bridge network.

The number and combination of scenarios the user can create is limited only by their imagination and program need.

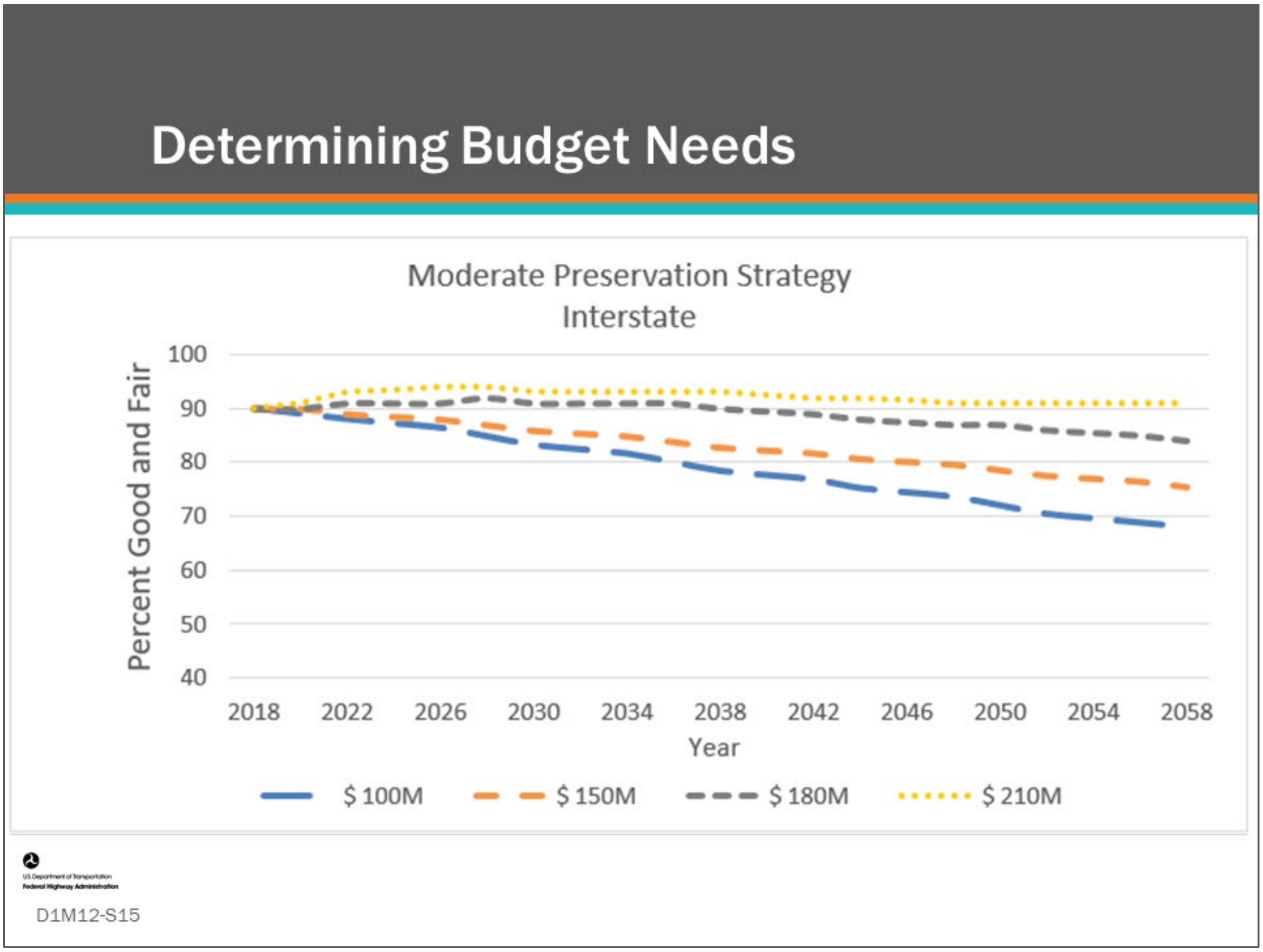
D1M12-Slide 14

Key Message
Once you know how to model scenarios in your BMS software, then you are ready to run an investment strategy analysis.

This often involves:

- Running multiple scenarios
- Analyzing results
- Modifying agency inputs
- Resetting the objective function and constraints
- Rerunning the optimizer routine

D1M12-Slide 15



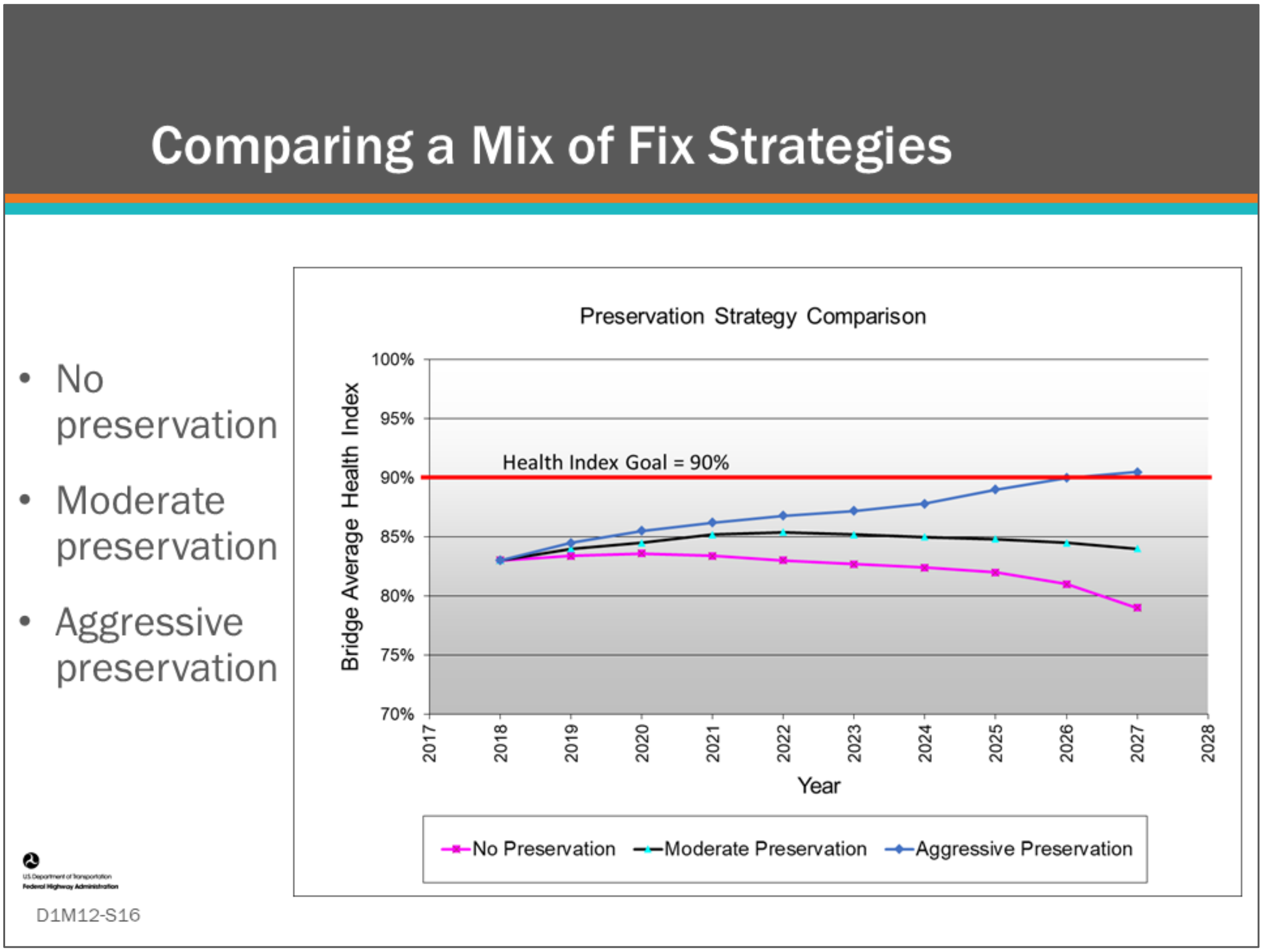
Key Message

Analysis of a BMS scenario models can be used to estimate the budget required to meet agency goals and objectives and to estimate the projected conditions for various funding levels. The bridge manager can run multiple scenarios with various budgets and review results that forecast the agency performance measures over a planning horizon.

This slide shows an example of four different budgets and their effect on future bridge condition.

- The BMS uses multiple reports and charts that utilize scenario analysis results to forecast bridge condition or other agency performance measures into the future.
- In this slide, an example preservation program is shown with four different budgets: $100 Million, $150 Million, $180 Million, and $210 Million. Future network condition, in this case measured as percent good and fair, is shown in a long-range forecast to 2058. Long range forecasts typically use more general condition data and agency policies.

D1M12-Slide 16

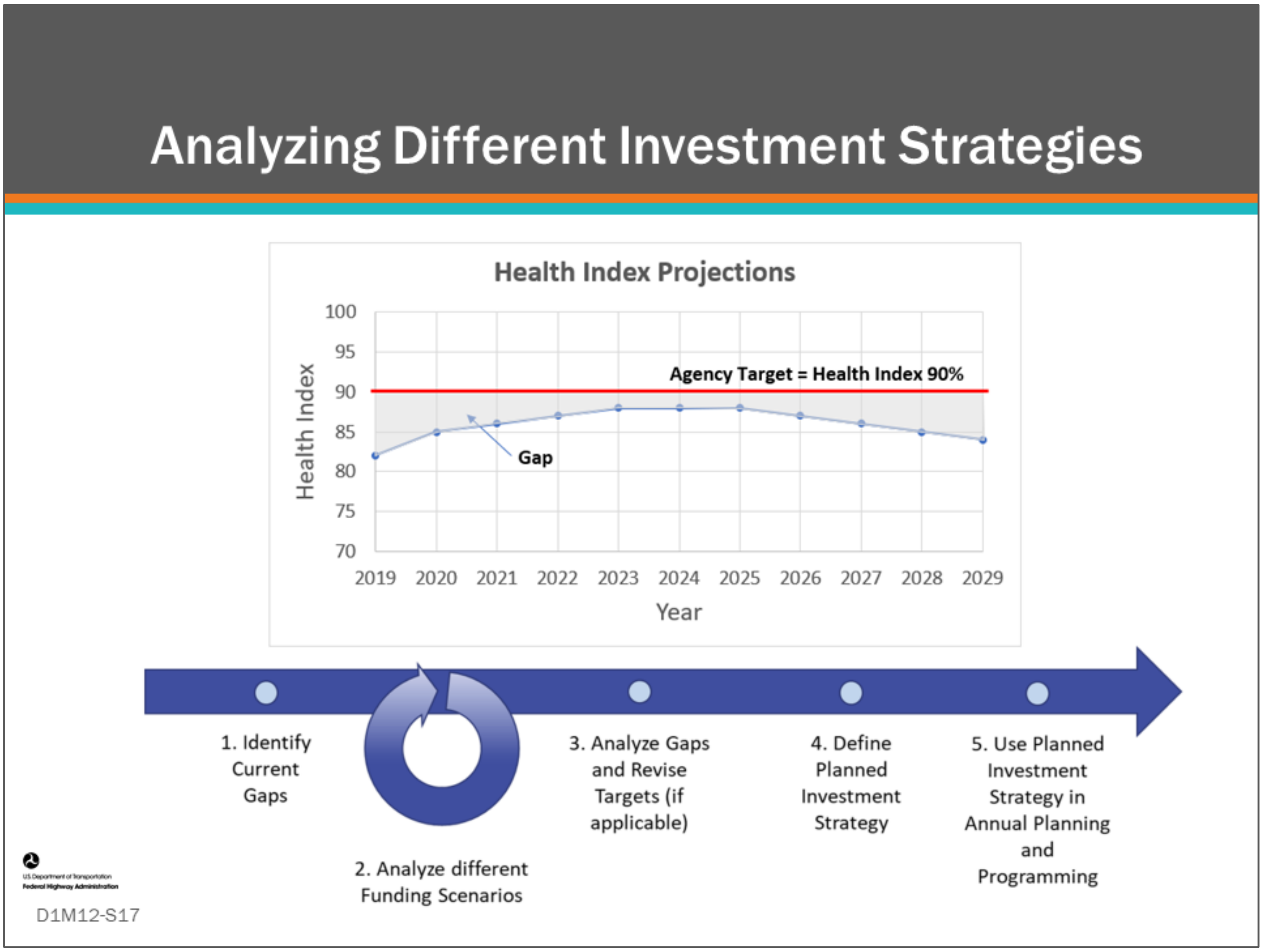


Key Message

Post processing of BMS scenario models can also be used to compare different strategies, such as levels of preservation as shown on this slide.

- When forecasting a performance measure, it is often shown with the objective's target (goal), as shown on the slide, where the aggressive preservation strategy meets the Agency's Health Index goal in 2026.

D1M12-Slide 17



Key Message

BMS scenario models can be used to evaluate agency strategy and to create a ten-year forecast and a gap analysis with respect to the Agency's objectives and performance targets. Once gaps are identified, the BMS can be used to analyze different funding scenarios and strategies to redefine an investment plan to meet agency targets. For instance, in this case increased funding may be required. It might also require a revision of targets if the targets are not practical under realistic funding scenarios.

D1M12-Slide 18

Key Message

Discuss the following:

- Describe your experience with scenario modeling with a BMS
- Describe what investment strategies you have evaluated, or that you would like to evaluate

D1M12-Slide 19

Key Message

This concludes D1M12: Investment Strategy Simulation and Investigation.

D1M12-Slide 20

Slide #	Image Description	Source Information
3	BMS scenario modeling diagram.	This Workshop.
4	Screenshot of Deighton dTIMs© objective function drop down list.	Deighton dTIMS© software.
6	Screenshot AASHTOWare™ Bridge Maintenance (BrM) performance constraints by segment illustrating target.	AASHTOWare™ Bridge Maintenance (BrM) software.
7	Strategic investment plan analysis graphic.	This Workshop.
8	Strategic investment plan analysis graphic.	This Workshop.
9	Screenshot of AgileAssets® Structures Analyst example project list.	AgileAssets® Structures Analyst™ software.
10	Strategic investment plan analysis graphic.	This Workshop.
11	Screenshot of AASHTOWare™ BrM Scenarios screen.	AASHTOWare™ Bridge Maintenance (BrM) software.
12	Screenshot of AgileAssets® Optimization Analysis screen with arrows point to; basic scenario parameters, analysis objective and constraints, and output requirement.	AgileAssets® Structures Analyst™ software.
15	A line chart titled Moderate Preservation Strategy Interstate.	This Workshop.
16	Line chart titled Preservation Strategy Comparison.	This Workshop.
17	Line chart titled Health Index Projections.	This Workshop.

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D1M12-S20

D1M12 Figure Source List

Module Title: D1M13 – Project and Program Planning and Management

Module Time: 20 minutes

Module Summary

The greatest value of a BMS is when it is made functional to the extent it can be used to do practical project and program planning. In this way, the BMS is integrated with an Agency's business practice. This module will show how BMS functionality can assist in the planning and project programming processes. It will discuss how using budget constrained scenarios can result in project-level work plans, and it will demonstrate some of the tools some BMS software have to assist network and project-level management.

Expected Outcome(s)

The expected outcome of this topic will be an understanding how a calibrated BMS can be used by agencies to set programs and select projects.

Resource List

Slide	Reference Information
8,10, 13-17	AASHTO. *AASHTOWare™ Bridge Management (BrM) User's Manual*, version 5.2.3. Washington, DC, 2016.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D1M13-Slide 1

Key Message

The implementation of an investment strategy requires allocating funds to programs, projects, and work actions that reflect the strategy. The BMS identified projects will need to be refined in timing and scope and may be combined with other projects of similar work type or location, or other highway projects, which may also influence scope, timing, and program assignment. This module will show how BMS functionality can assist in the planning and project programming processes. It will discuss how using budget constrained scenarios can result in project level work plans, and it will demonstrate some of the tools some BMS software have to assist network and project level management.

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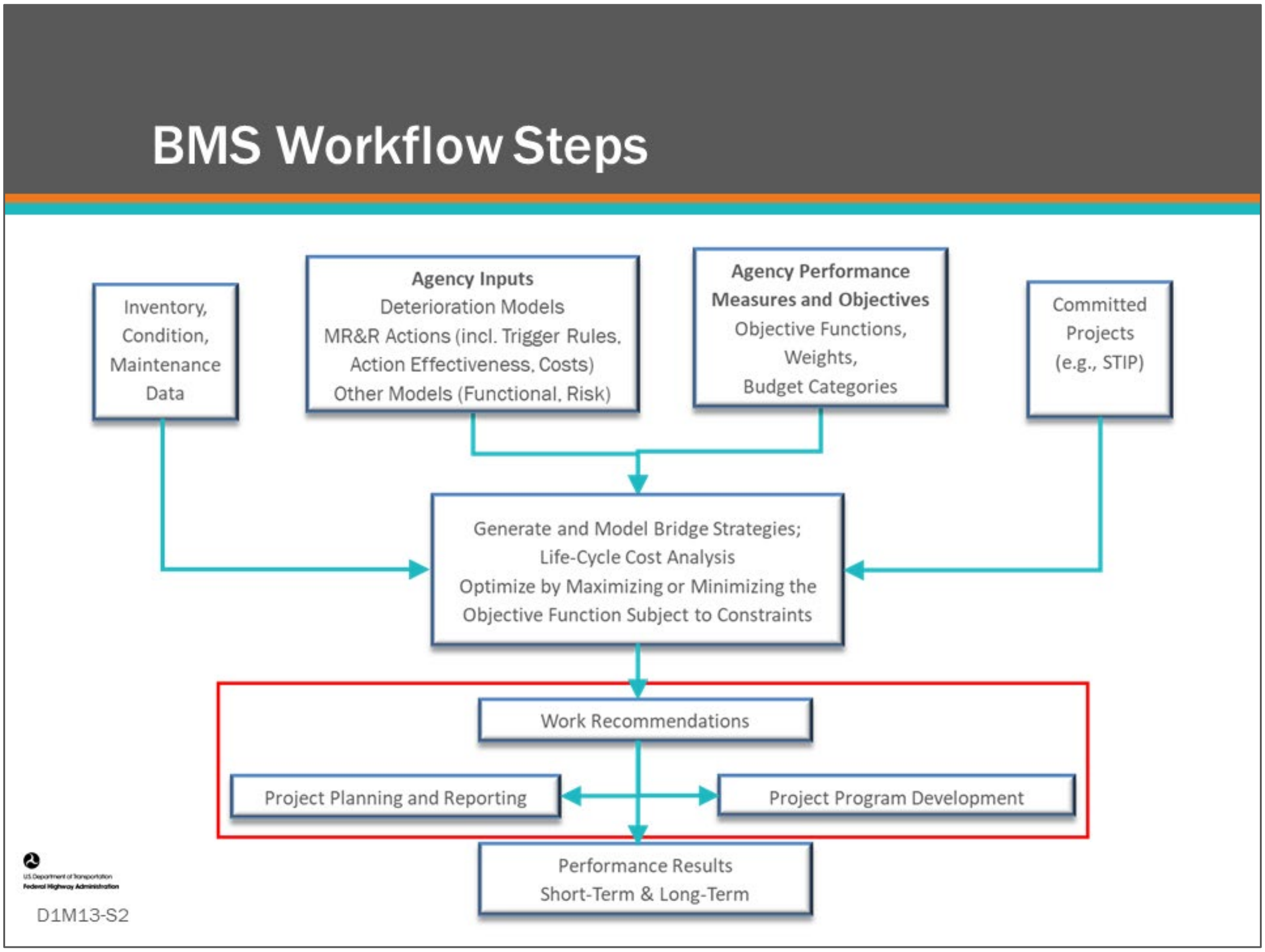
D1M13-Slide 2



Key Message

BMS workflow steps are shown on the slide. Program and project planning occur after the BMS does optimization and prioritization as highlighted by the red box.

D1M13-Slide 3

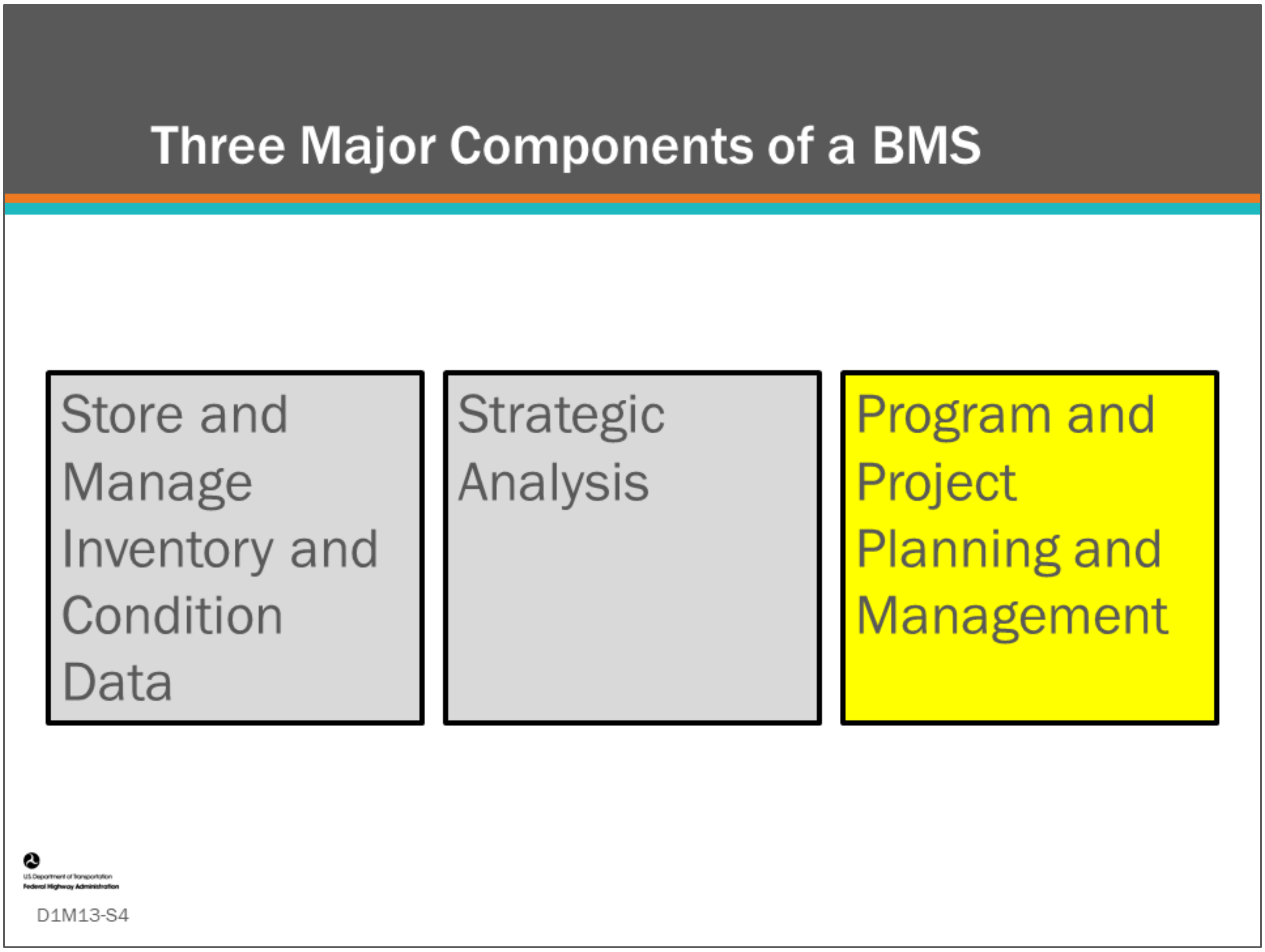
Key Message

The topics covered in this module are program and project planning and using BMS software to help manage a bridge program.

- Program planning is putting together a program of projects for one or more years in an Agency’s call for project process. It comes after Agency goal, objectives, performance measures, trend monitoring, and strategic planning are done. It includes developing an investment strategy and allocating money to program categories and regions or districts.
- Project planning includes the development of project scopes, costs, and schedules. It is performed using optimization and investment strategy simulation. Project planning in a top down approach is about refining project recommendations and may include bridge-level analysis. In a bottom up approach, it includes bridge-level analysis.

Bridge program management involves the day-to-day activities necessary for implementing the program. We will look at how a BMS is used for these activities.

D1M13-Slide 4



Key Message

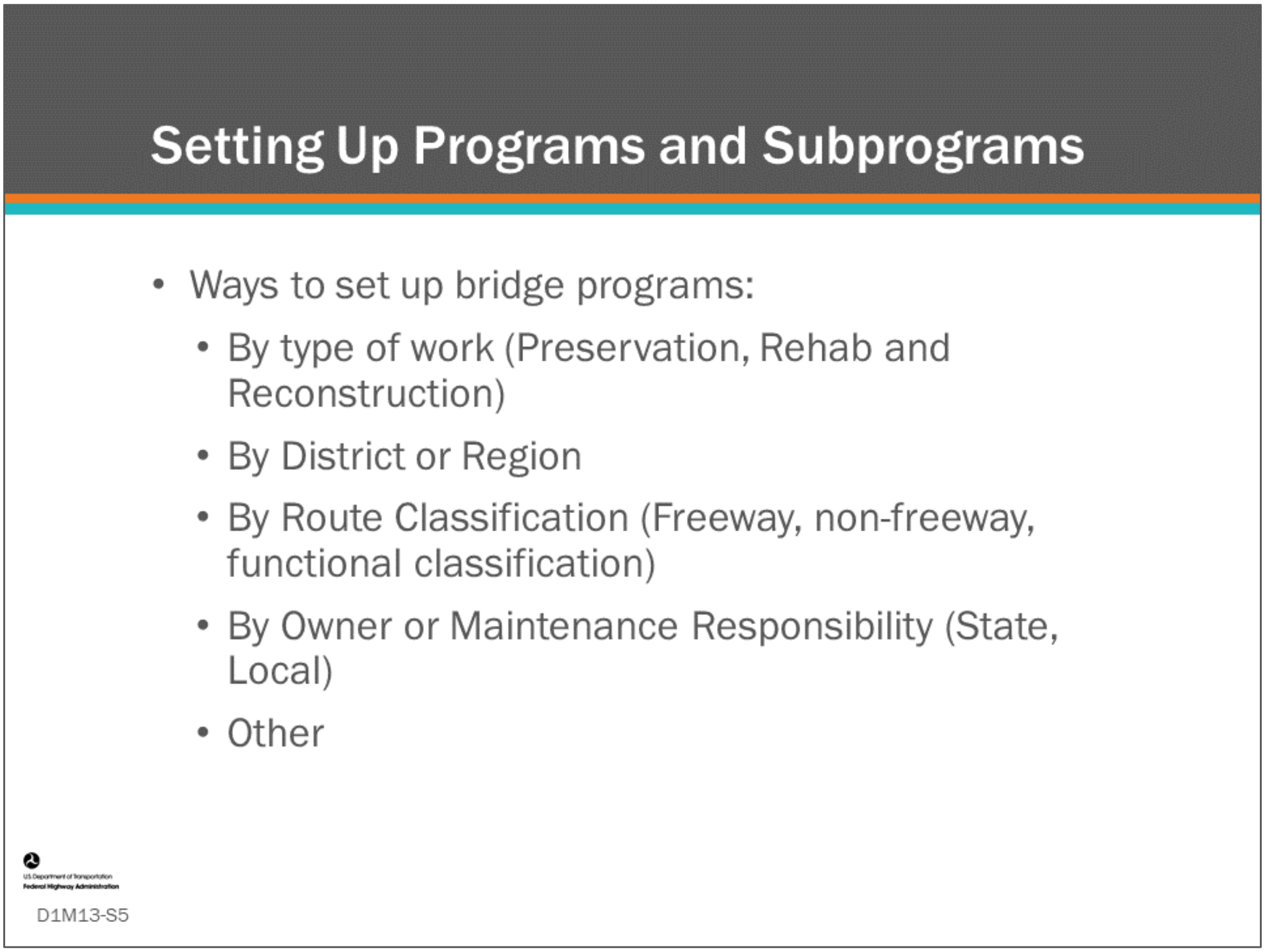
At the beginning of this workshop, we talked about the importance of a BMS and the steps. Ultimately the purpose is to manage an Agency's bridge program well.

On this slide, the leftmost two boxes, shown in grey, are two of the three major components of a BMS; store and manage inventory and condition data and doing strategic investment analysis.

The third major component of a BMS is program and project planning and management. This is where the BMS is integrated into the agency's business practice for delivering programs and projects, and it should be used daily.

All the work that has been done to populate the BMS with data, set Agency rules and run multiple scenarios is used to set program and project plans.

D1M13-Slide 5



Key Message

Strategic investment planning discussed in the previous module was used to justify a bridge program budget and determine funding in programs such as preservation, rehabilitation, and reconstruction. Agencies have their own ways of providing organization to their infrastructure and bridge program. A bridge program budget may be divided according to type of work, by district or region, route classification, or by owner or maintenance responsibility.

D1M13-Slide 6

Allocating Money to Subprograms

Bridge Subprogram - By Work Category	
Preservation	$30 Million
Rehabilitation	$55 Million
Reconstruction	$25 Million

Bridge Subprogram - By District	
District 1	$40 Million
District 2	$50 Million
District 3	$20 Million

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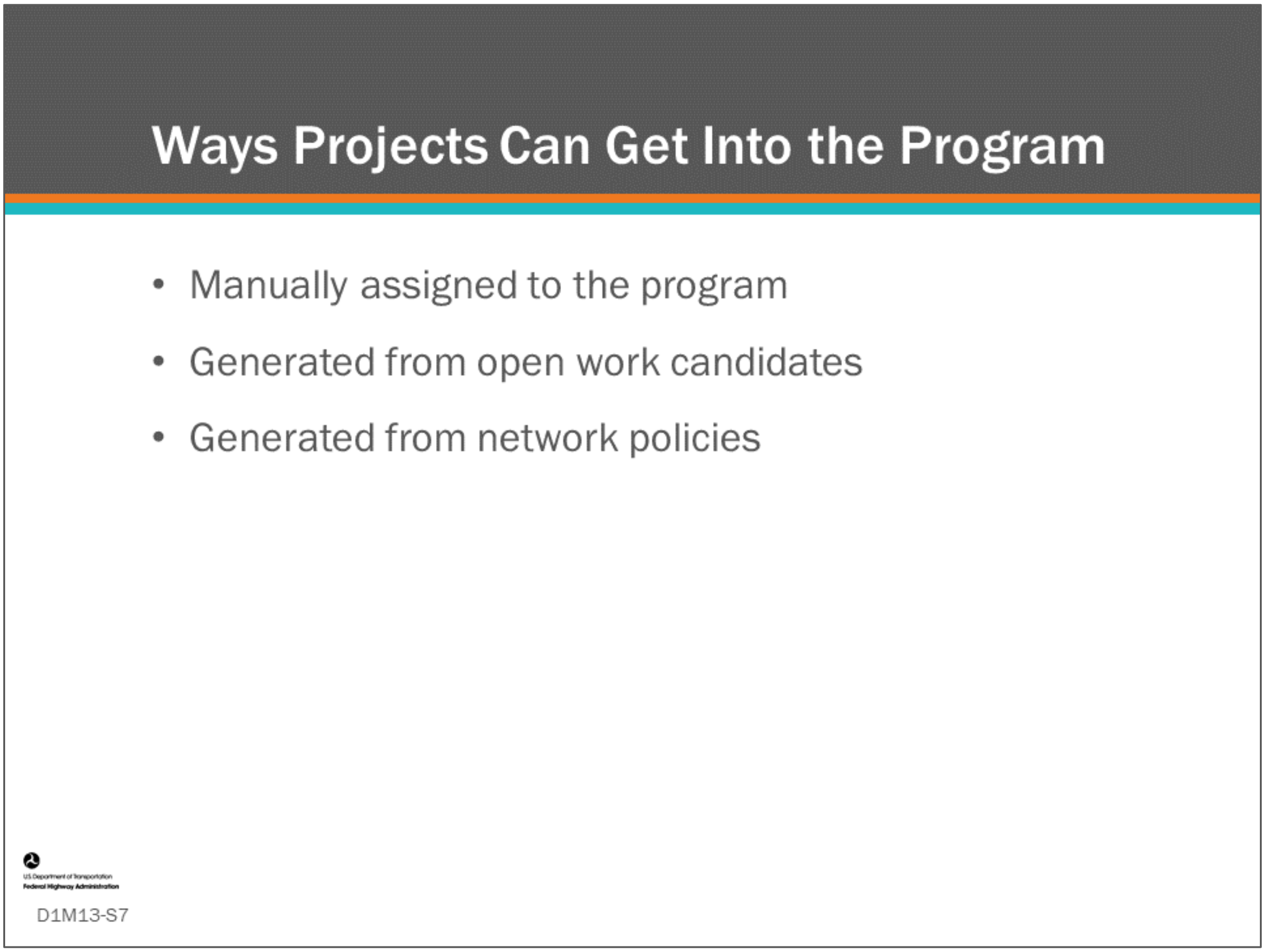
D1M13-S6

Key Message

A BMS can be used to determine allocation of funds to subprograms. This is done similarly to the strategic investment strategy methods and trade-off analysis that was discussed in the previous module.

- Regions/districts often have different condition and needs as measured by the Agency's performance measures.
- Agencies should have a systematic method for allocation of funds that is repeatable and accepted. This can be done by formula, such as deck area of need for each of the performance measures, but ideally could be decided based on projects from the optimal strategies generated by the bridge management system.

D1M13-Slide 7



Key Message

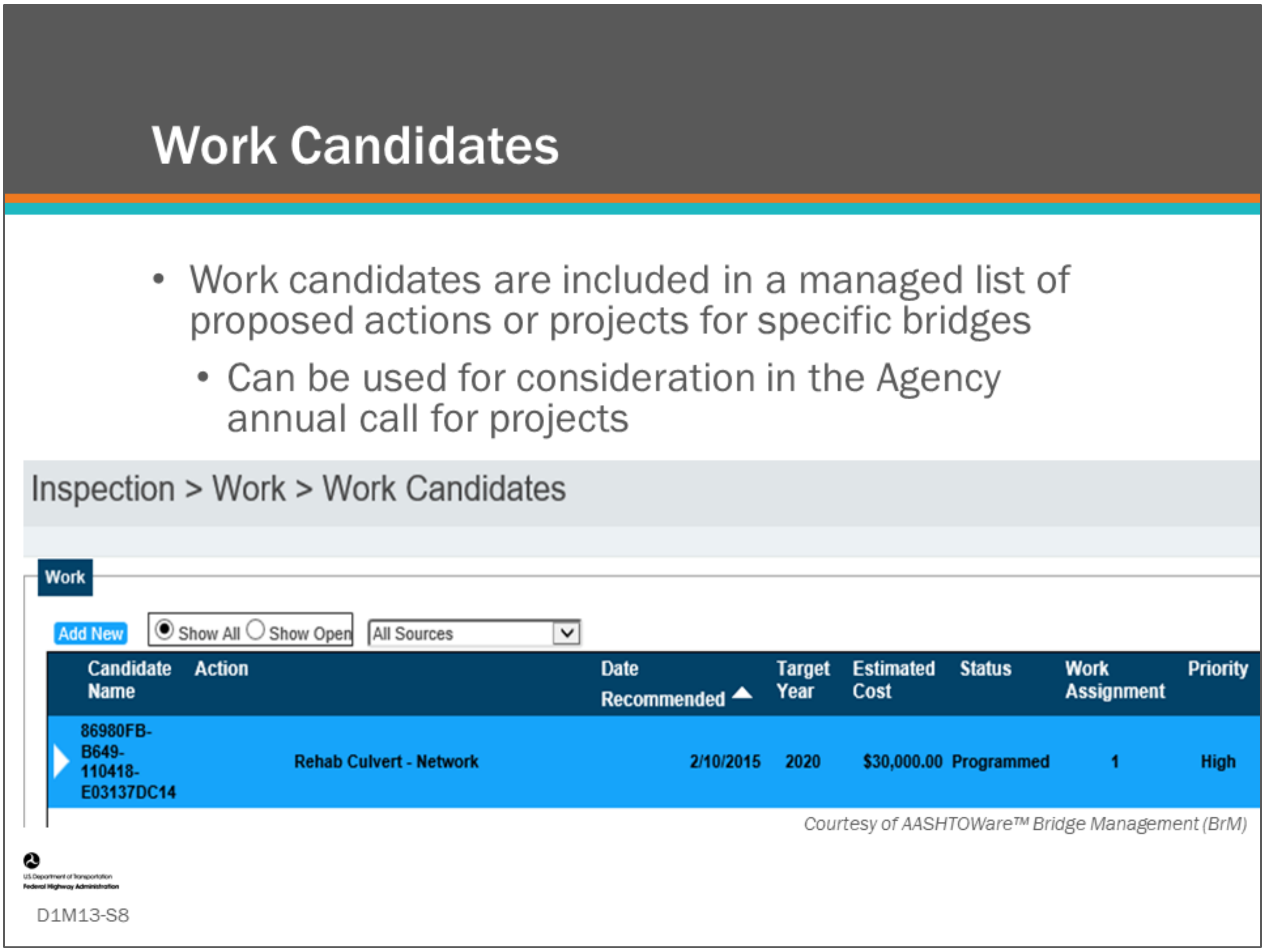
Your BMS should be used to manage your annual bridge program. When a bridge is put into your STIP (Statewide Transportation Improvement Program), it should also be input as a committed project in your BMS including the year of the work, type of work, what elements it will improve, and cost of the project. When in the system, this information will be included in future scenario runs.

In the AASHTOWare™ BrM software, an annual program of projects is generated using three types of information:

- Projects manually assigned to the program (these could be projects initiated by inspector recommendations or a project that must be done to coordinate with a road or safety program),
- Projects generated from open work candidates (we will discuss work candidates more in the next slide),
- Projects generated from network policies that are identified during the prioritization and optimization.

A user can similarly define a work plan of projects in Deighton dTIMS© and AgileAssets® Structures Analyst.

D1M13-Slide 8



Key Message

Work candidates are included in a managed list of proposed actions or projects for specific bridges which can be used for consideration in the Agency's annual call for projects.

- Shown on the slide is a screenshot of the AASHTOWare™ Bridge Management (BrM) work candidate list for a bridge showing a recommendation to rehab a culvert in 2020.
    - In BMS software, the user may choose whether to have the software consider a project 'fixed' or not.
    - If a project is designated as being fixed or committed, then during an optimization analysis the project will be assumed to happen in the given year and the resulting improvement and cost in that year will be modeled as part of the strategy.

D1M13-Slide 9

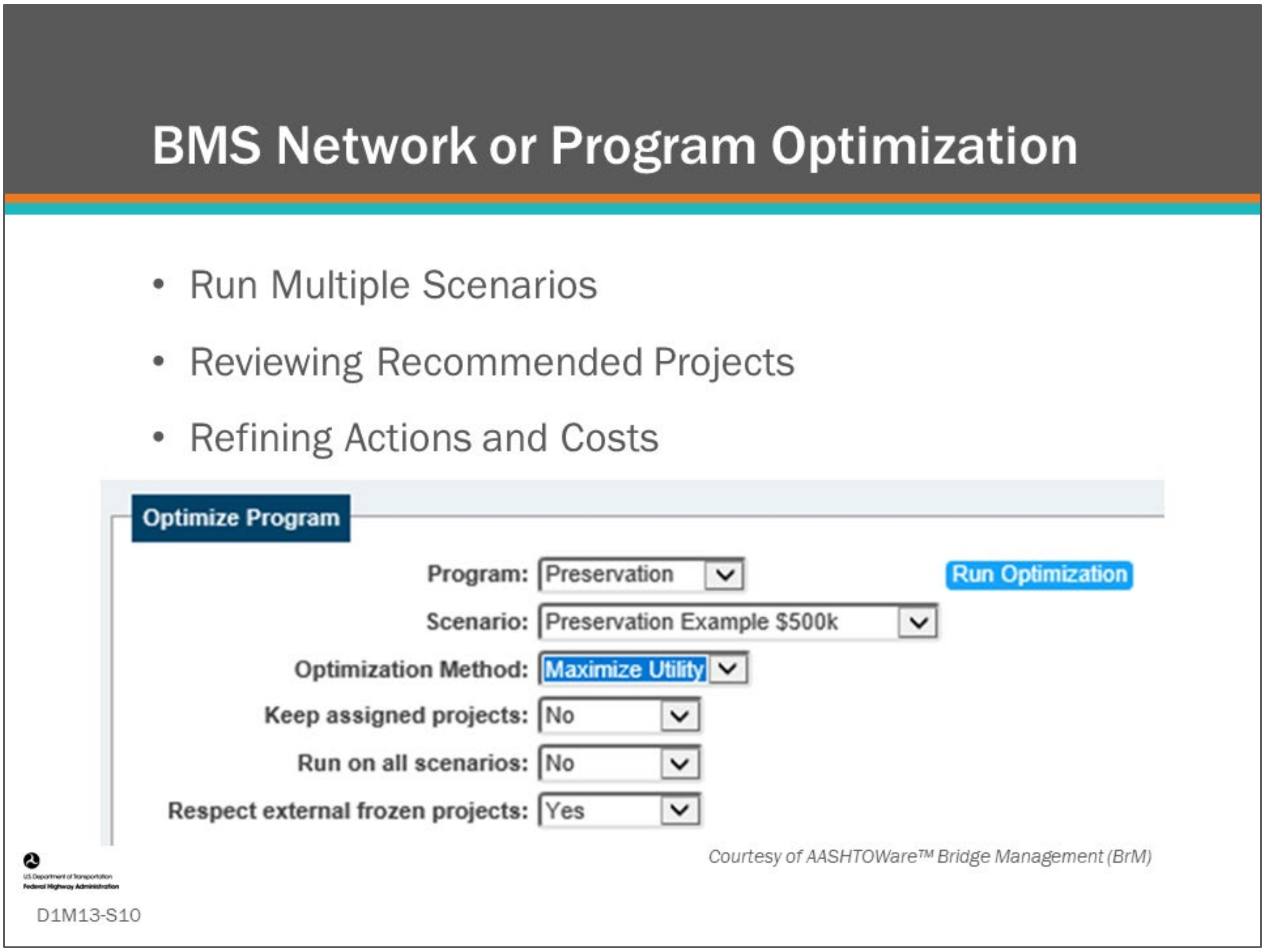
Key Message

BMS software help program and project planning in different ways.

- Some BMS software are specifically built to do optimization analysis (e.g., AgileAssets® Structure Analyst and Deighton dTIMS©).
- Other BMS software (e.g., AASHTOWare™ Bridge Management (BrM)) have additional functionality built in to assist program management and bridge project-level LCCA.

In this section, we are going to look at a few of these tools.

D1M13-Slide 10

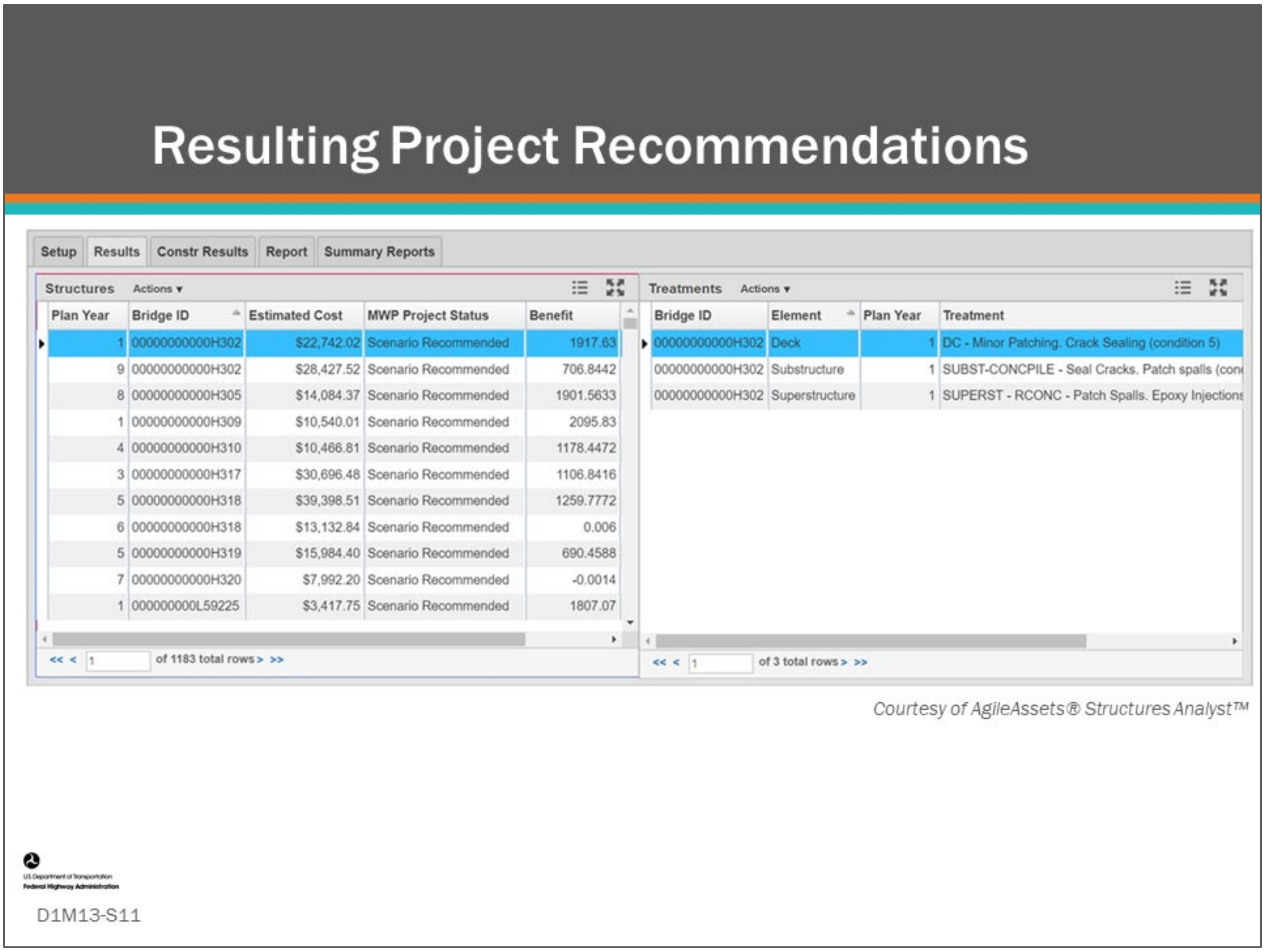


Key Message

In D1M12, we learned how to analyze alternative investment strategies using scenarios composed of different simulated and optimized work programs.

- This is the core function of any advanced BMS. Most BMS software provide functionality to run multiple scenarios for comparison.
- This is used for many tasks at the program level including developing an investment strategy, setting programs and subprograms, and allocating funds.
- It is also used at the project level when it provides a list of projects that can be reviewed and used for project selection for an annual call for projects.

D1M13-Slide 11



Key Message

Running a scenario produces an optimized list of projects.

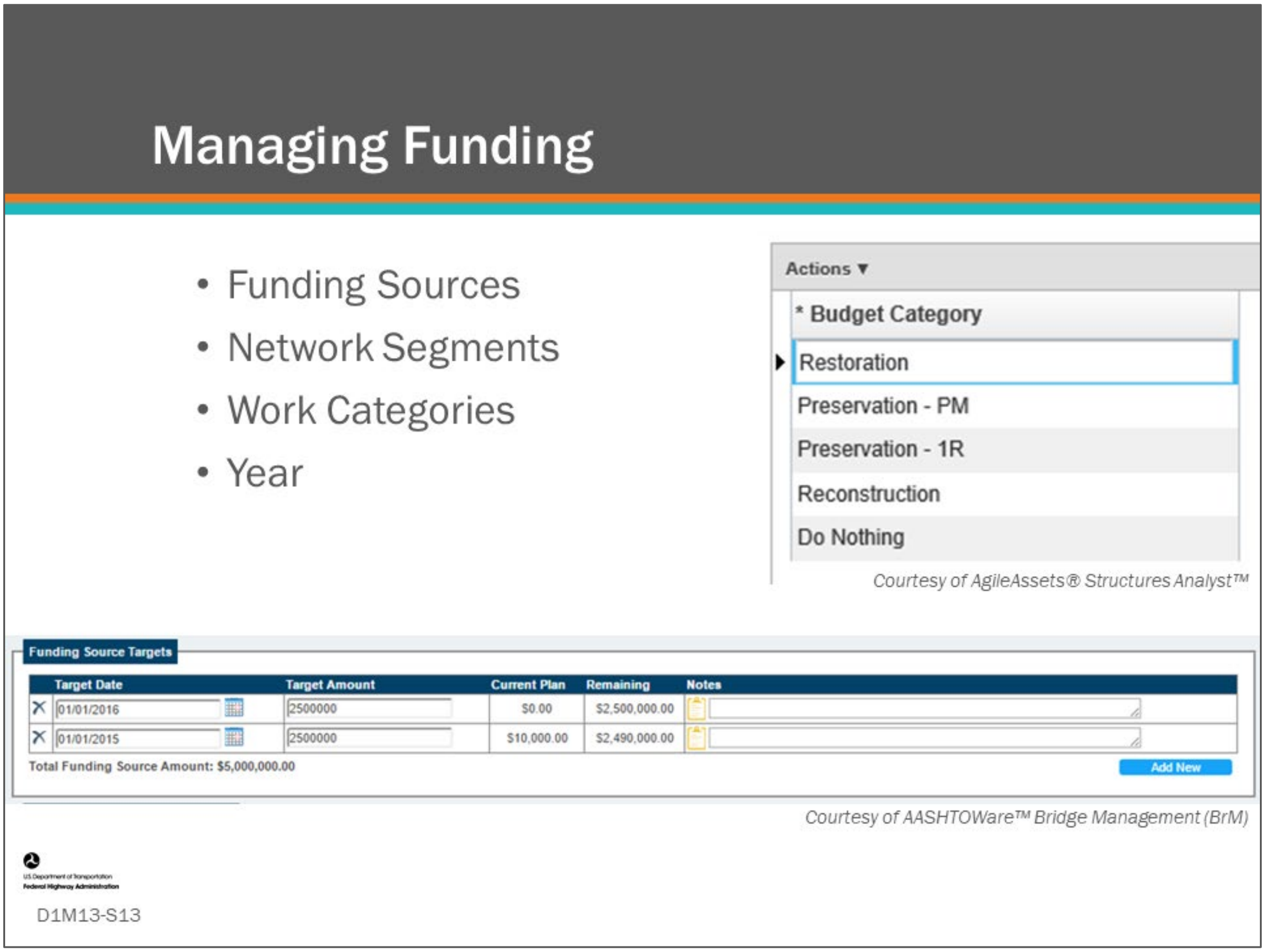
Shown on this slide is an example project list showing the bridge project on the left, with the details of the highlighted project on the right. The bridge project manager will select projects from this list to place in the program.

D1M13-Slide 12

Key Message

Your BMS will also provide functionality to manage bridge projects, such as managing project funding sources, setting project categories or work codes, combining and splitting projects, moving projects to different years, and moving projects to different programs or work plans. We will show several examples of these tools.

D1M13-Slide 13

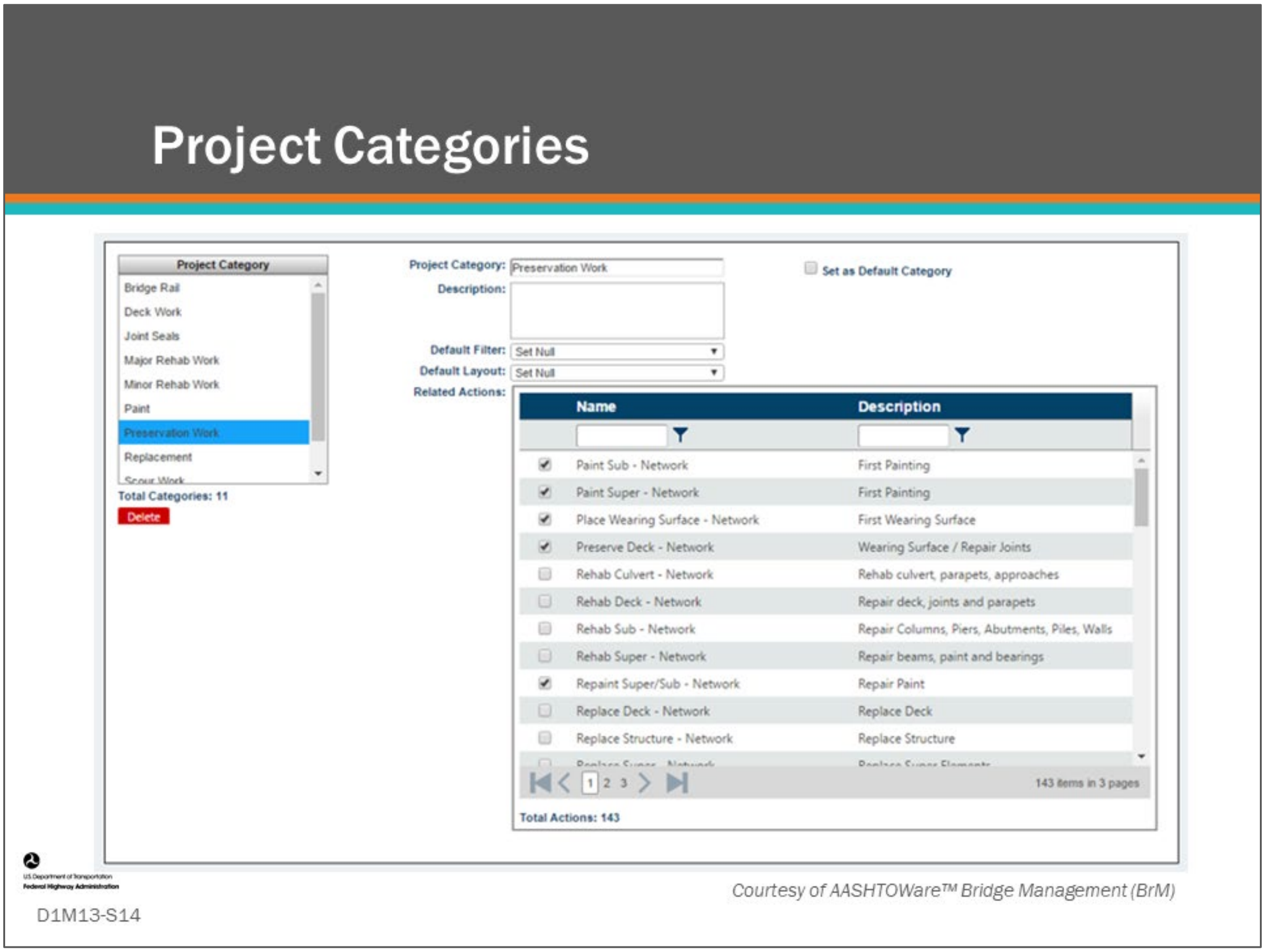


Key Message

Some BMS software offer various tools to manage funding by funding source, network segment, work category, and year.

Funding constraints may be applied to each. Funding also needs to be managed at the project level, where a bridge project may use several different funding sources. Since funding is often a constraint during the work program simulation and optimization, it is important to understand how your BMS funding management tools work.

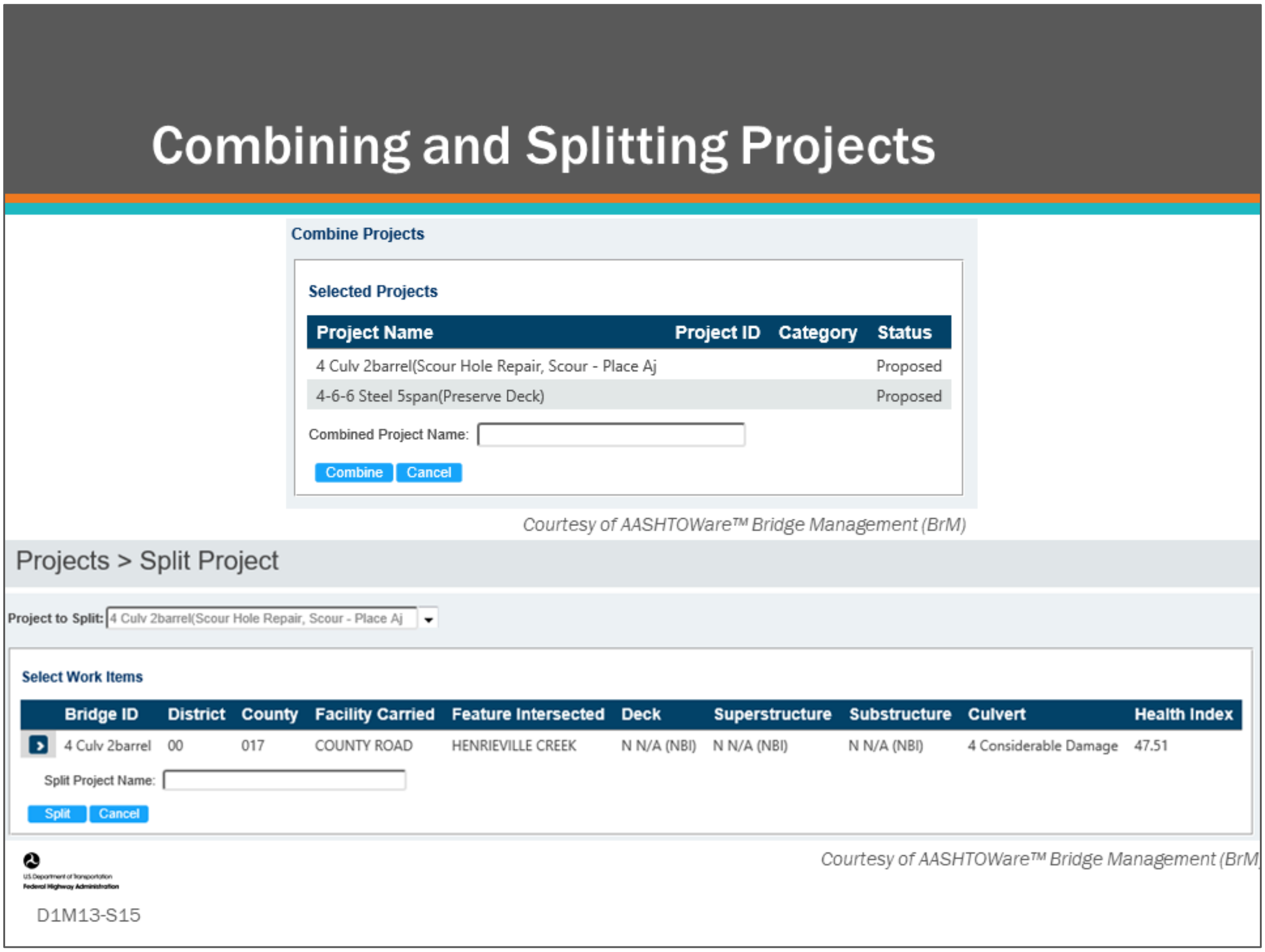
D1M13-Slide 14



Key Message

BMS software allow you to set up project categories. These can be used to help an Agency manage the bridge program using subprograms such as preservation, rehabilitation, and replacement. Project categories can be further delineated by activity type within major work category. For example, preservation - deck, preservation, superstructure, preservation - paint.

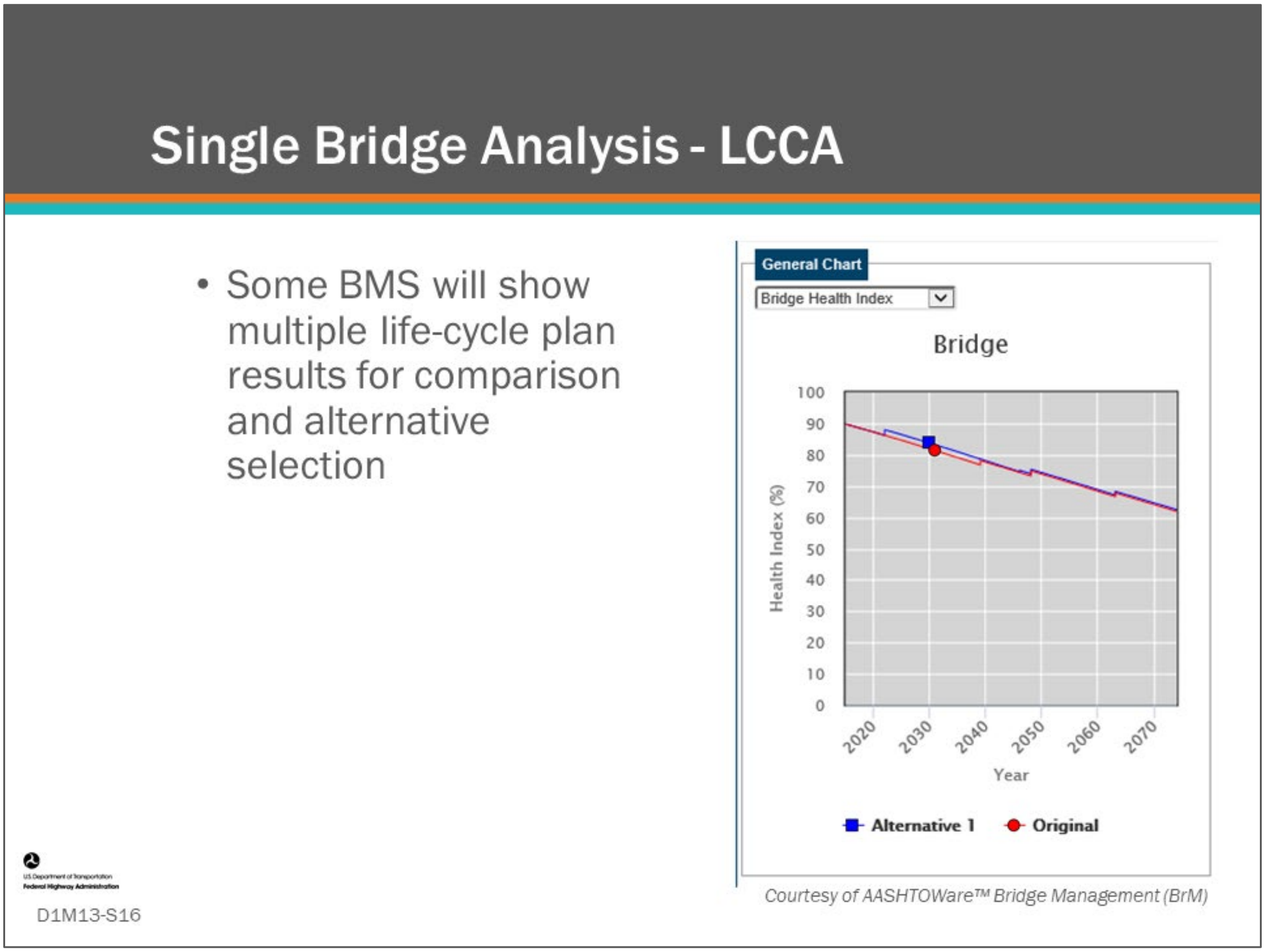
D1M13-Slide 15



Key Message

Your BMS may allow for combining projects into one project. Agencies often do this for efficiency in letting projects, so it is helpful to show the projects this way also in the BMS software when it is being used as a management tool. If combined projects need to be split into individual projects, this can also be done. In AgileAssets® Structures Analyst™, projects can be edited, split or combined manually by editing the work plan directly. In Deighton dTIMS©, the editing, splitting or combining of projects is called “Review and Adjust”, and it is a standard part of the workflow.

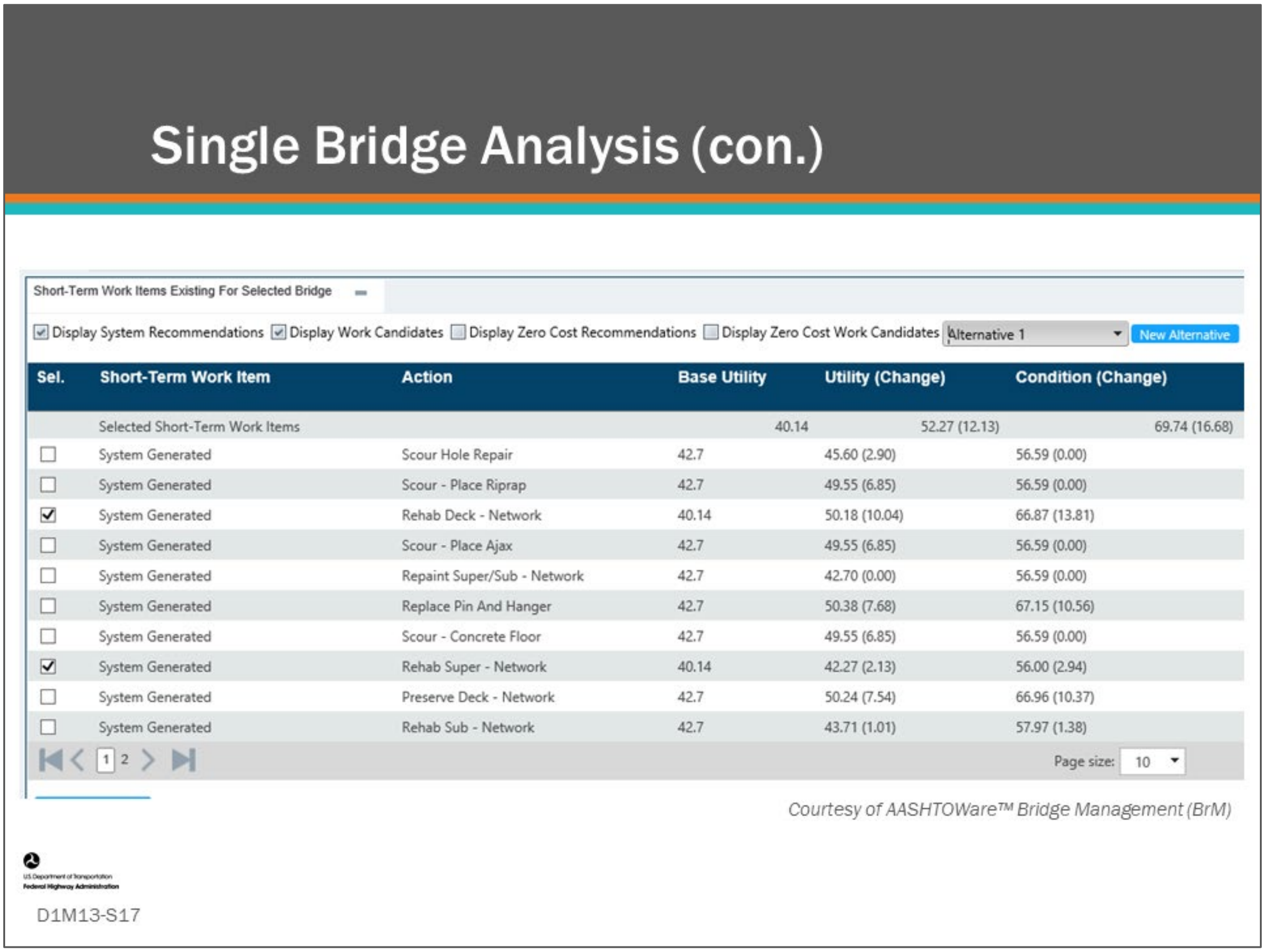
D1M13-Slide 16



Key Message

Your BMS may also provide tools for doing detailed life-cycle cost comparisons of life-cycle plans for individual bridges without consideration of network level constraints such as annual budgets. Shown on the slide is a deterioration curve over time with actions taken to a bridge.

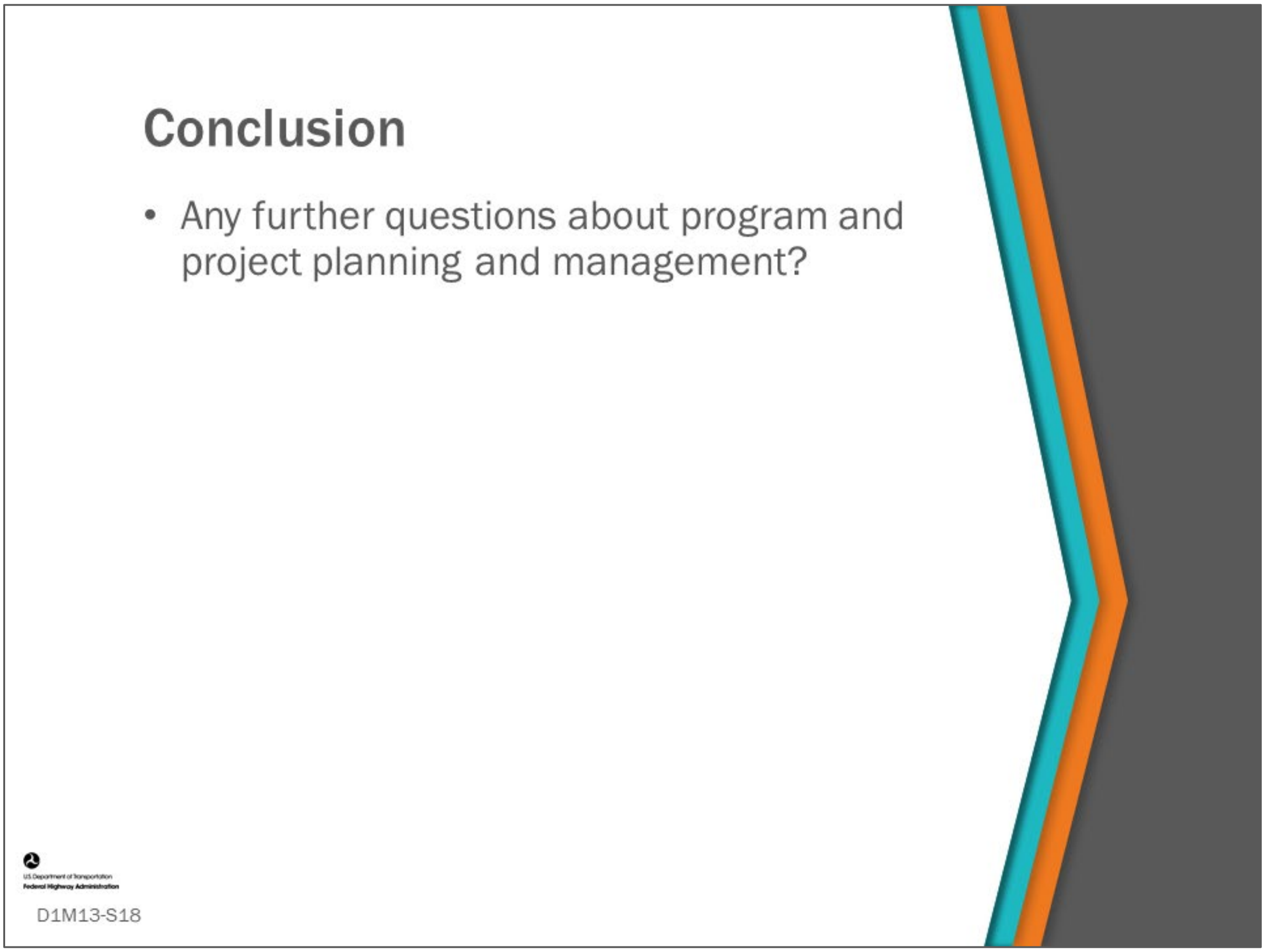
D1M13-Slide 17



Key Message

Shown on this slide are possible short-term work items for a bridge. The user can select a work item and do a bridge specific LCCA analysis. If a project is identified that the bridge manager wants to include in the program, they can select it as a fixed project. Using system generated work items, inspector recommendations, and fixed projects, a program can be assembled for each year in a call for projects. After all project selections, the work program would be simulated again to see the long-range results with respect to targets and goals.

D1M13-Slide 18



Key Message

This concludes D1M13: Program and Project Planning and Management.

D1M13-Slide 19

Slide #	Image Description	Source Information
4	Gray box stating Store and Manage Inventory and Condition.	This Workshop.
4	Gray Box stating Strategic Analysis.	This Workshop.
4	Yellow box stating Program and Project Planning.	This Workshop.
6	Table titled, "Bridge Subprogram - By Work Category."	This Workshop.
6	Table titled, "Bridge Subprogram - By District."	This Workshop.
8	AASHTOWare™ Bridge Management (BrM) screenshot showing Inspection Work Candidates Option with Example Work item below.	AASHTOWare™ Bridge Management (BrM) software.
10	Screenshot of AASHTOWare™ Bridge Management (BrM) scenario optimization screen.	AASHTOWare™ Bridge Management (BrM) software.
11	Screen shot of AgileAssets® Structure Analyst Optimization Analyst screen.	AgileAssets® Structures Analyst™ software.
13	Screenshot of AgileAssets® Structure Analyst Actions drop down box.	AgileAssets® Structures Analyst™ software.
13	Screenshot of AASHTOWare™ Bridge Management (BrM) funding source screen.	AASHTOWare™ Bridge Management (BrM) software.
14	Screenshot of AASHTOWare™ Bridge Management (BrM) project category screen.	AASHTOWare™ Bridge Management (BrM) software.
15	Screenshot of AASHTOWare™ Bridge Management (BrM) combining projects screen.	AASHTOWare™ Bridge Management (BrM) software.
15	Screenshot of AASHTOWare™ Bridge Management (BrM) combining projects / split project screen.	AASHTOWare™ Bridge Management (BrM) software.
16	Screenshot of AASHTOWare™ Bridge Management (BrM) Bridge Health index chart.	AASHTOWare™ Bridge Management (BrM) software.
17	Screenshot of AASHTOWare™ Bridge Management (BrM) showing possible short-term work items.	AASHTOWare™ Bridge Management (BrM) software.

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D1M13-S19

D1M13 Figure Source List

Module Title: D1M14 – Communication and Reporting

Module Time: 15 minutes

Module Summary

Once the BMS is up and running and you have the ability to run scenarios, develop strategic investment plans, and use the BMS to plan and program projects, you will need to provide communication and reporting to executives, stakeholders, and the public. This module will share methods how best to convey these BMS analysis results and recommendations to gain support for implementing recommendations.

Expected Outcome(s)

The expected outcome of this topic will be an understanding how a BMS helps bridge practitioners and managers share bridge needs and performance with agency executives, stakeholders, and the public.

Resource List

Slide	Reference Information
4	AASHTO. *AASHTOWare™ Bridge Management (BrM) User's Manual*, version 5.2.3. Washington, DC, 2016.
10	FHWA. *Transportation Asset Management Case Studies, Bridge Management Practices in Idaho, Michigan and Virginia.* Washington, DC, 2012.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D1M14-Slide 1

Key Message

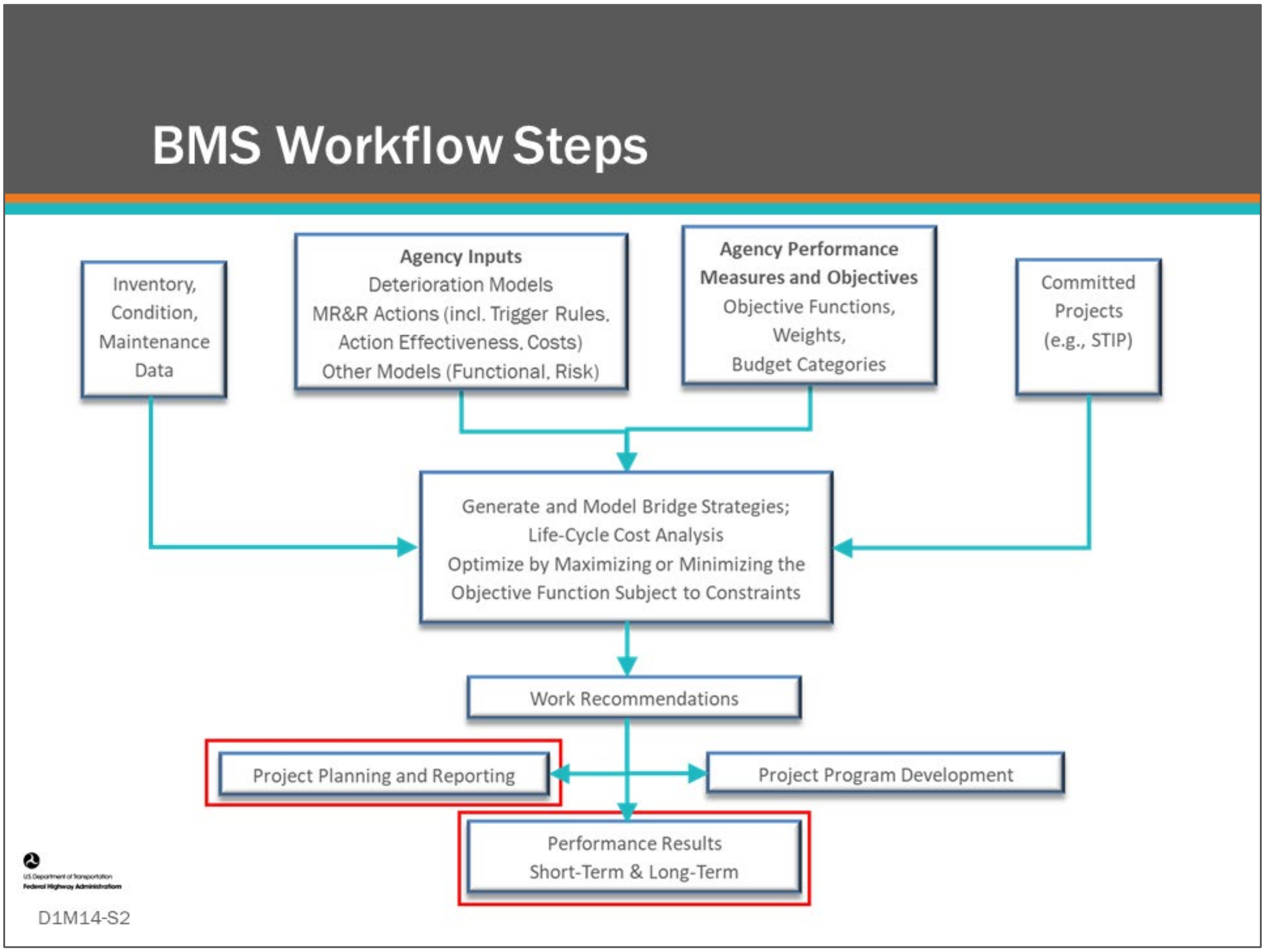
When the BMS is up and running, and you have the ability to run scenarios, develop investment strategies, and use the BMS to plan and program projects, you will then need to provide communication and reporting to executives, stakeholders, and the public.

This module will share methods how best to convey these BMS analysis results and recommendations to gain support for implementing recommendations.

Disclaimer

FHWA does not promote or endorse patented and proprietary products. Bridge management software is largely proprietary. Workshop content pertaining to proprietary software is included only to illustrate how bridge management system concepts and analyses are applied in practice. The included content shall not be construed as promotion or endorsement of specific software.

D1M14-Slide 2



Key Message

BMS workflow steps are shown on the slide. Communication and reporting occur after optimization, prioritization, and program and project planning are performed, as indicated by the red boxes.

D1M14-Slide 3

Key Message
This module with cover some common reports and charts, discuss reports for practitioners and bridge managers, as well as reporting for executives and stakeholders. Finally, communication and reporting to the public will be discussed.

D1M14-Slide 4

Software Example of Executive Summary

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D1M14-S4

Courtesy of AASHTOWare™ Bridge Management (BrM)

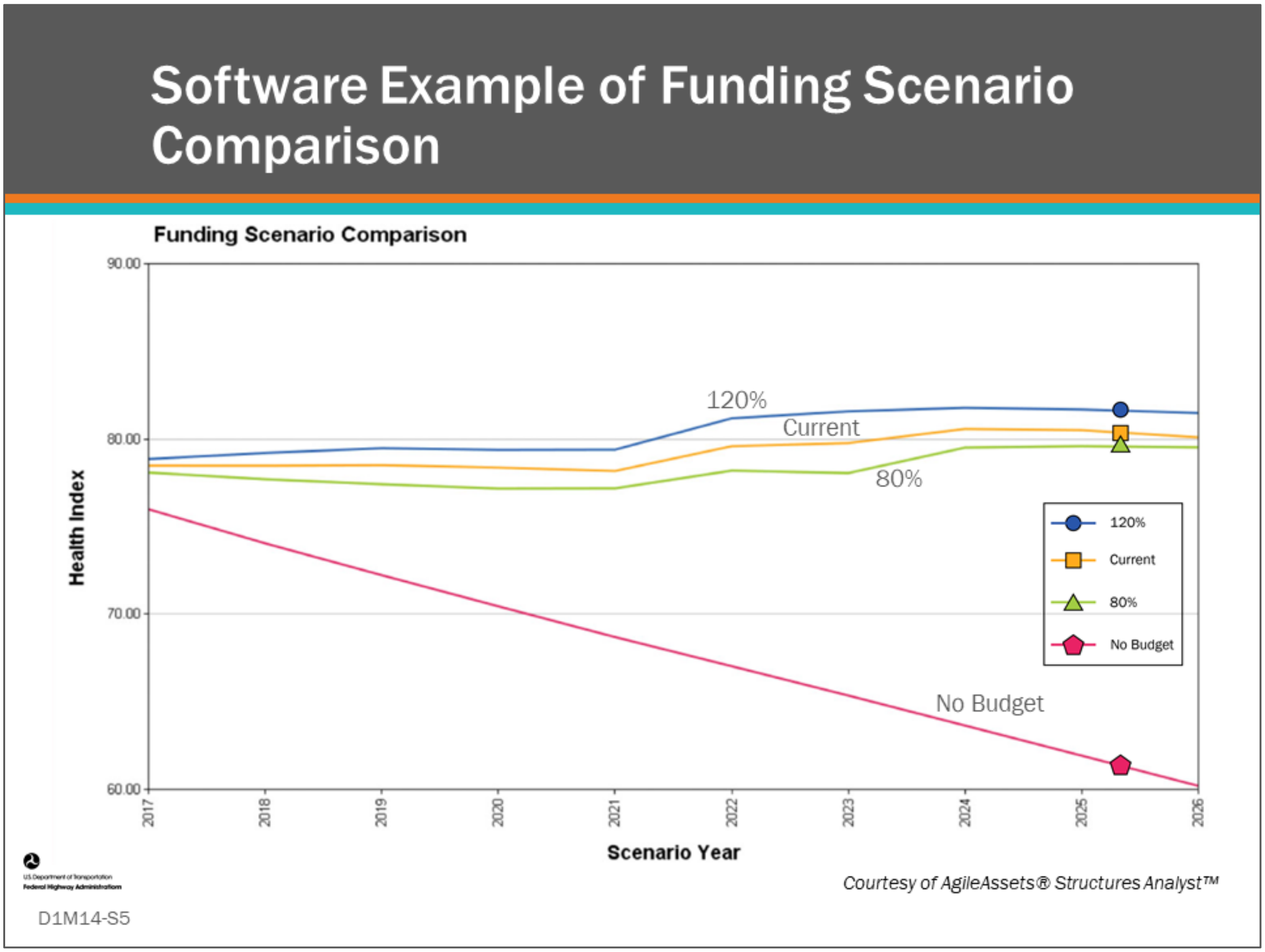
Key Message

All BMS software comes with standard reports that are commonly used.

On the following slides, we show some common reports and charts from BMS software. These include pie charts for condition often shown as good (green), yellow (fair), and red (poor). Line charts are also frequently used to report condition or performance measure trends over time. Column charts also are also a good way to show condition or performance trends over time.

As an example, this slide shows charts available in the AASHTOWare™ Bridge Management (BrM) Programs on the Executive Summary tab.

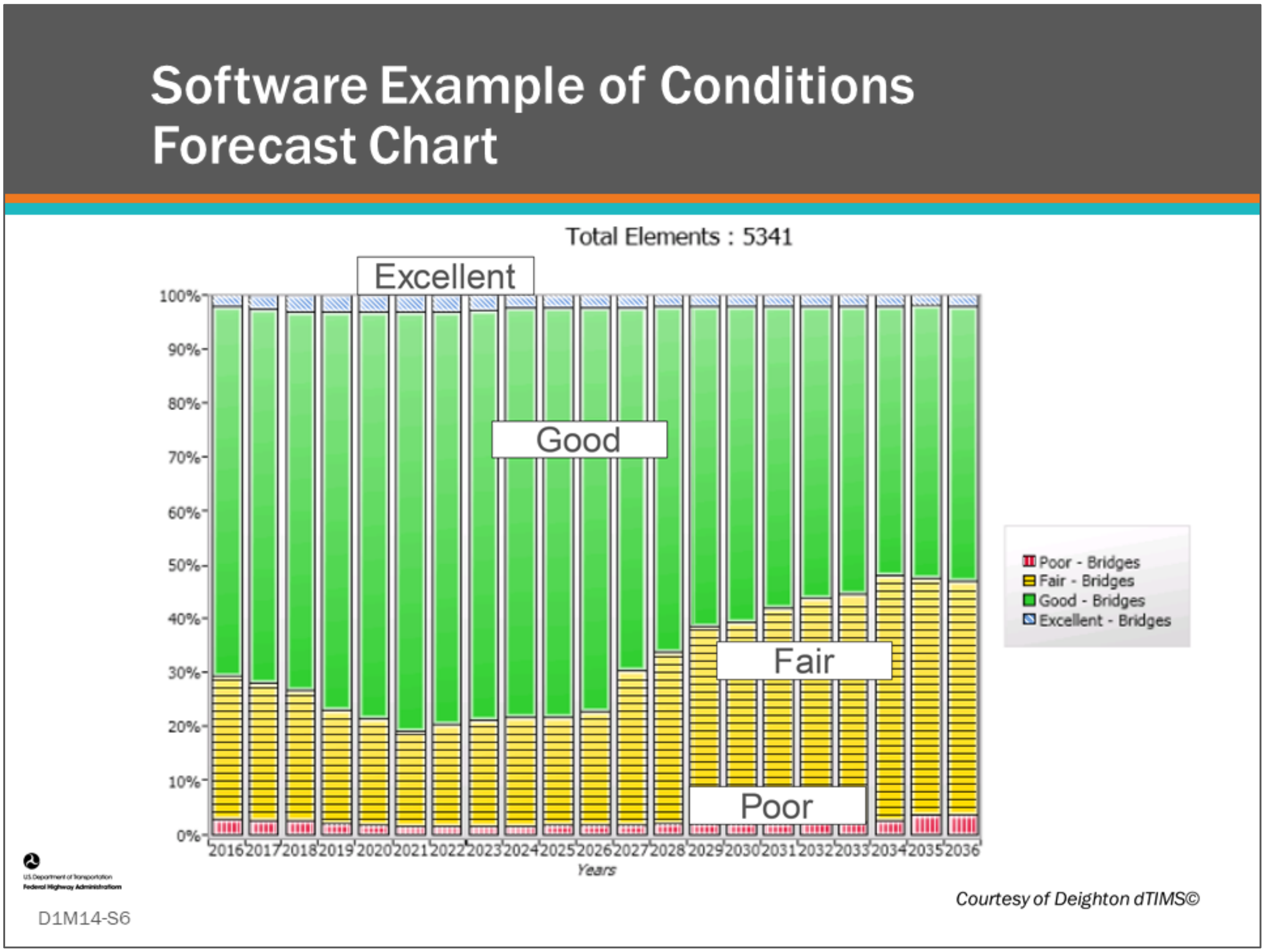
D1M14-Slide 5



Key Message

AgileAssets® Structures Analyst™ has the common charts shown in the previous slide. Another example of a chart that is available in AgileAssets® Structures Analyst™ is a Health Index trend chart over time showing four different scenarios.

D1M14-Slide 6

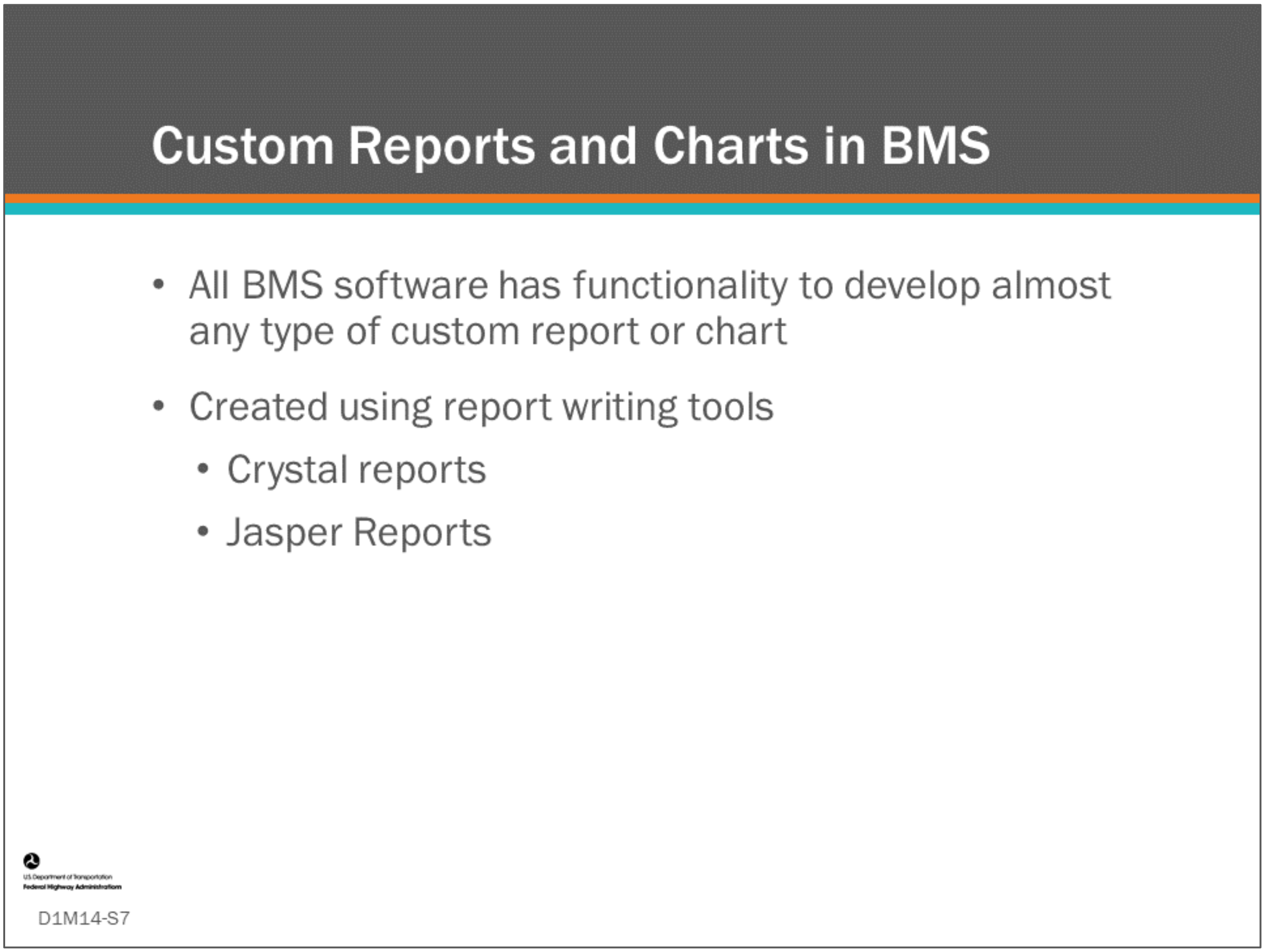


Key Message

Deighton dTIMS© also has the common charts shown in the previous slides.

Shown on this slide is an example of a column chart showing excellent, good, fair and poor bridge condition forecast over time.

D1M14-Slide 7



Key Message

Reporting from BMS software is not limited to only the pre-packaged reports.

Custom reports can be configured, and it is the responsibility of the Agency to identify and define any additional reports required to effectively communicate information to stakeholders.

You will need someone who knows how to use tools such as Crystal Reports or Jasper reports to create the custom reports.

D1M14-Slide 8

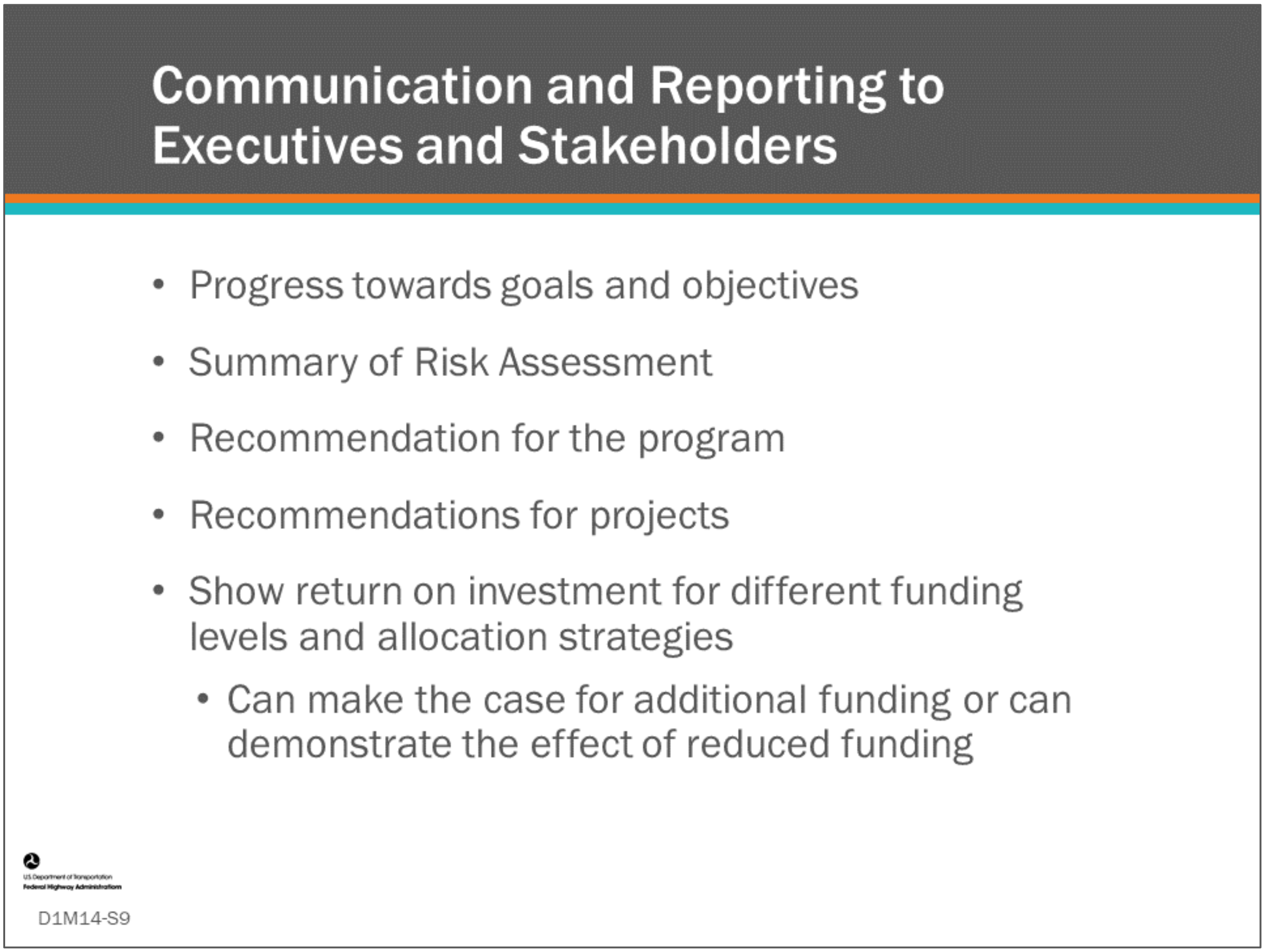
Key Message

Communication and reporting to practitioners includes much (if not all) of the information shown in the previous modules of this workshop.

The purpose of communication and reporting to practitioners is to provide needed information for them to do their part in the bridge management process.

Shown on this slide are a few of the information types and reports that are available and needed to run a bridge management program using BMS.

D1M14-Slide **9**



Key Message

Communication to executives and stakeholders should be at a higher level relating to the Agency goals and objectives.

It can summarize risk assessments.

Executives often sign-off on the Agency's program before projects are added to the State Transportation Improvement Plan (STIP), which is presented as a report.

D1M14-Slide 10

Communication and Reporting to the Public

- Progress towards goals and objectives
- Dashboards
- GIS maps

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D1M14-S10

Key Message

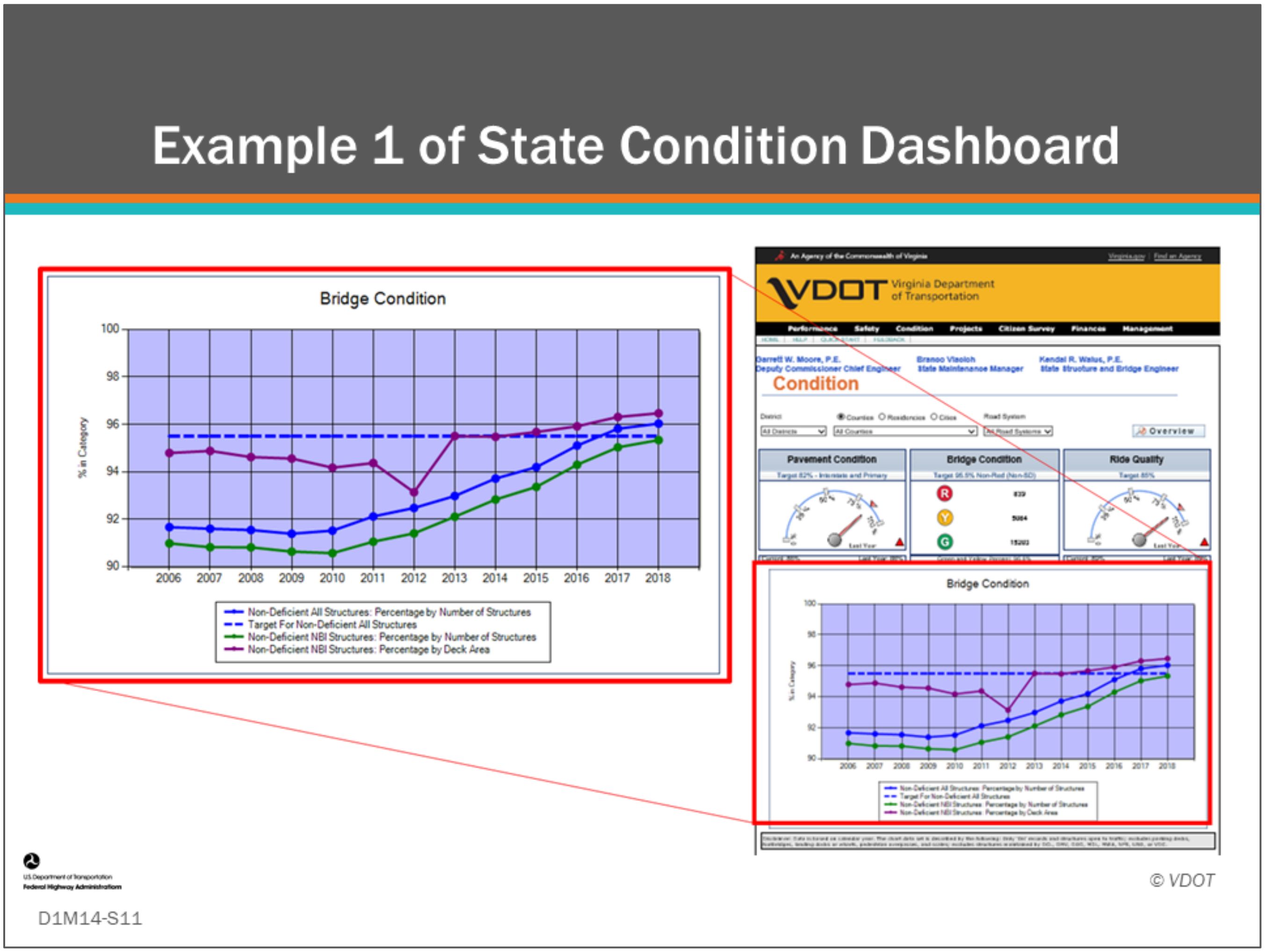
Communicating and reporting to the public will also relate to Agency goals and objectives.

Reporting often occurs on websites and may take the form of a dashboard and GIS maps.

Many Agencies use dashboards to give a snapshot of Agency performance measures where a BMS is used to provide periodic updates to the Agency performance measure dashboard, or automated data updates can even be programmed.

Shown on this slide is the Virginia DOT Performance Reporting System Dashboard. The public can click on any of the performance dial gauges to drill down deeper into the performance measure. Here, when you click on "Condition", a new webpage shows the condition of Virginia's infrastructure, including bridges as shown in the next slide.

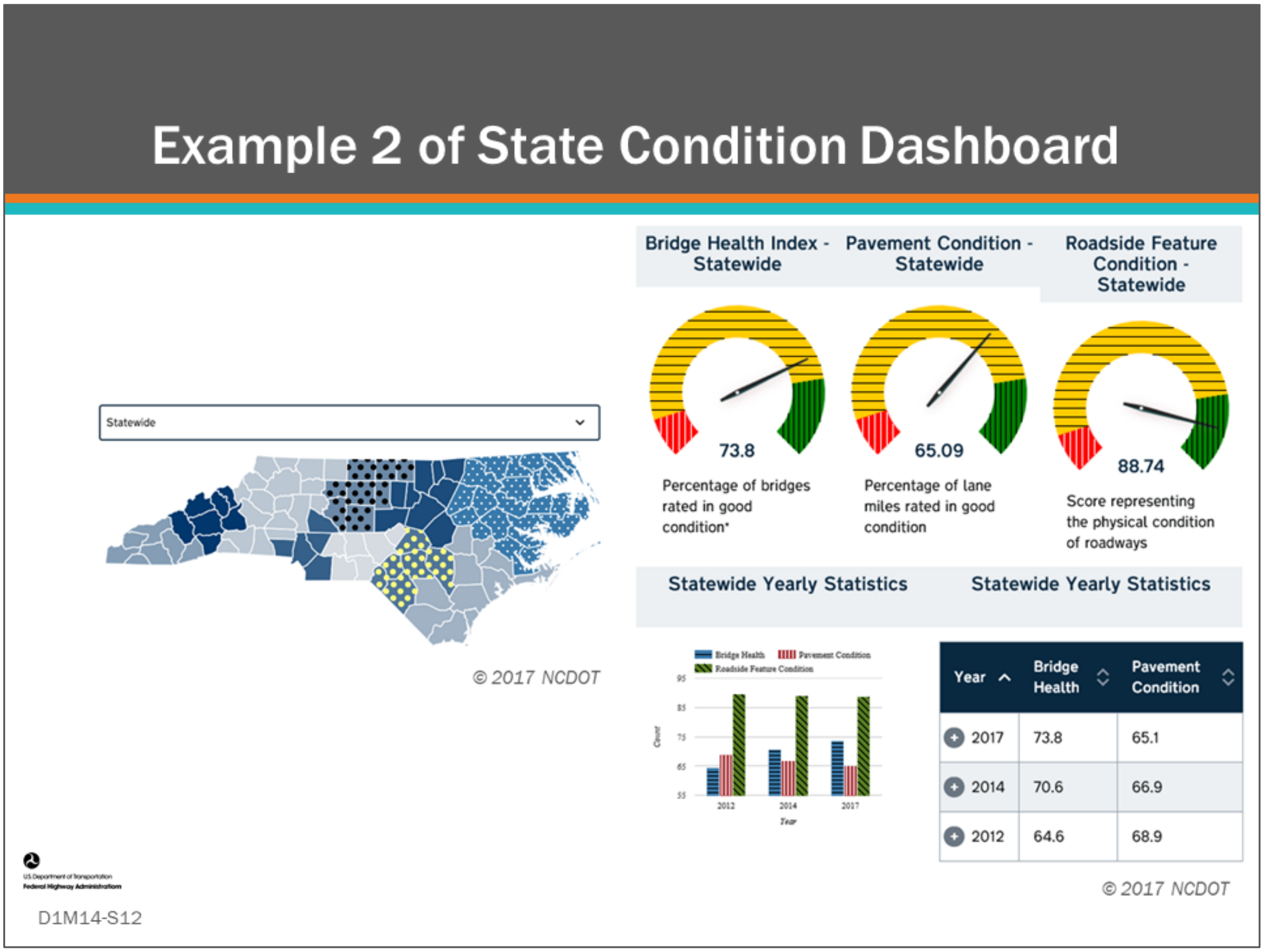
D1M14-Slide 11



Key Message

Shown on this slide is an example of an Agency infrastructure condition dashboard. These dashboards are often interactive so that the public can select options to view information in which they have interest.

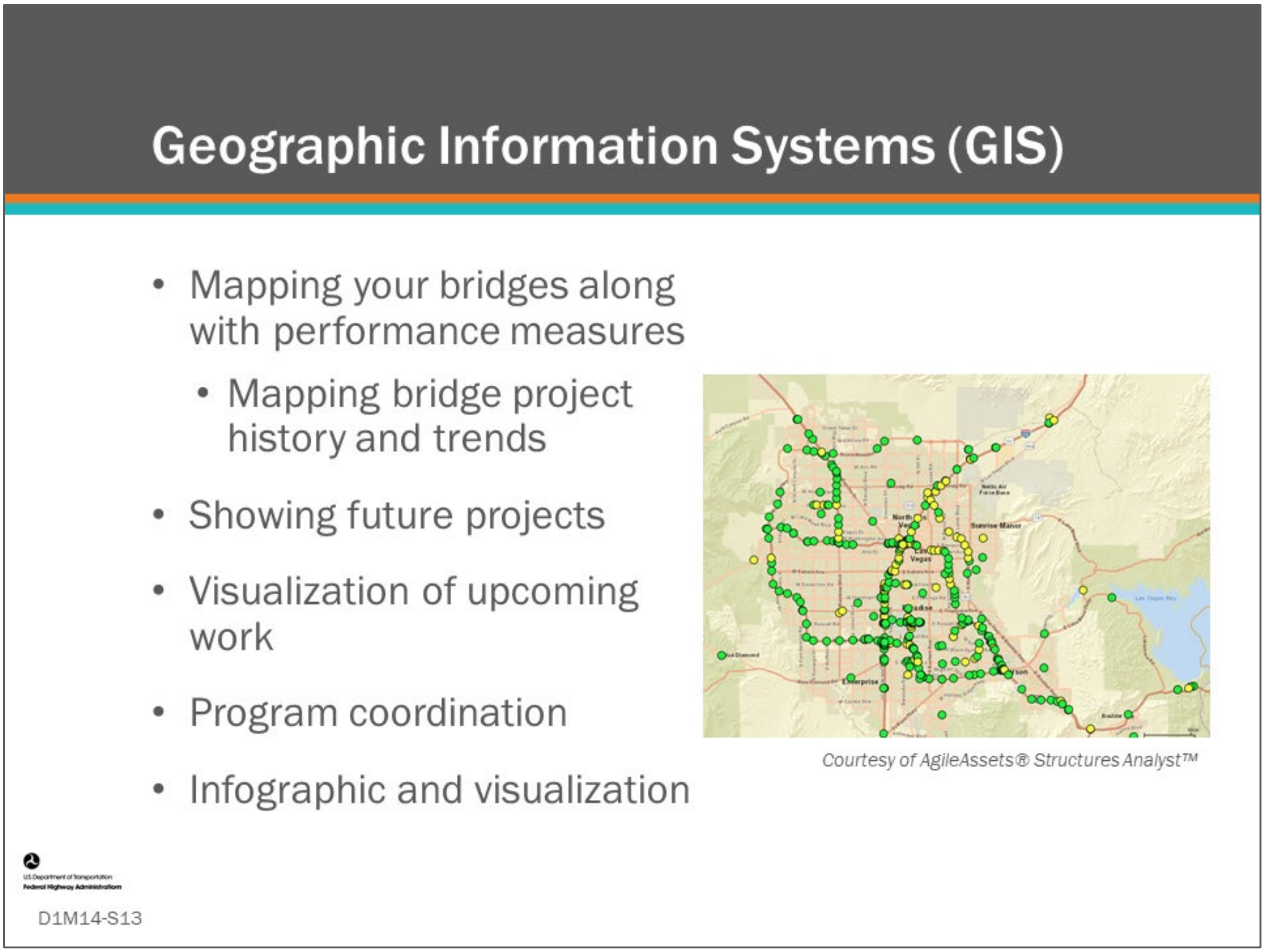
D1M14-Slide 12



Key Message

This slide shows the North Carolina Infrastructure Health Dashboard. In this case, counties can be selected from the map on the left to show more detailed information for that locality.

D1M14-Slide 13

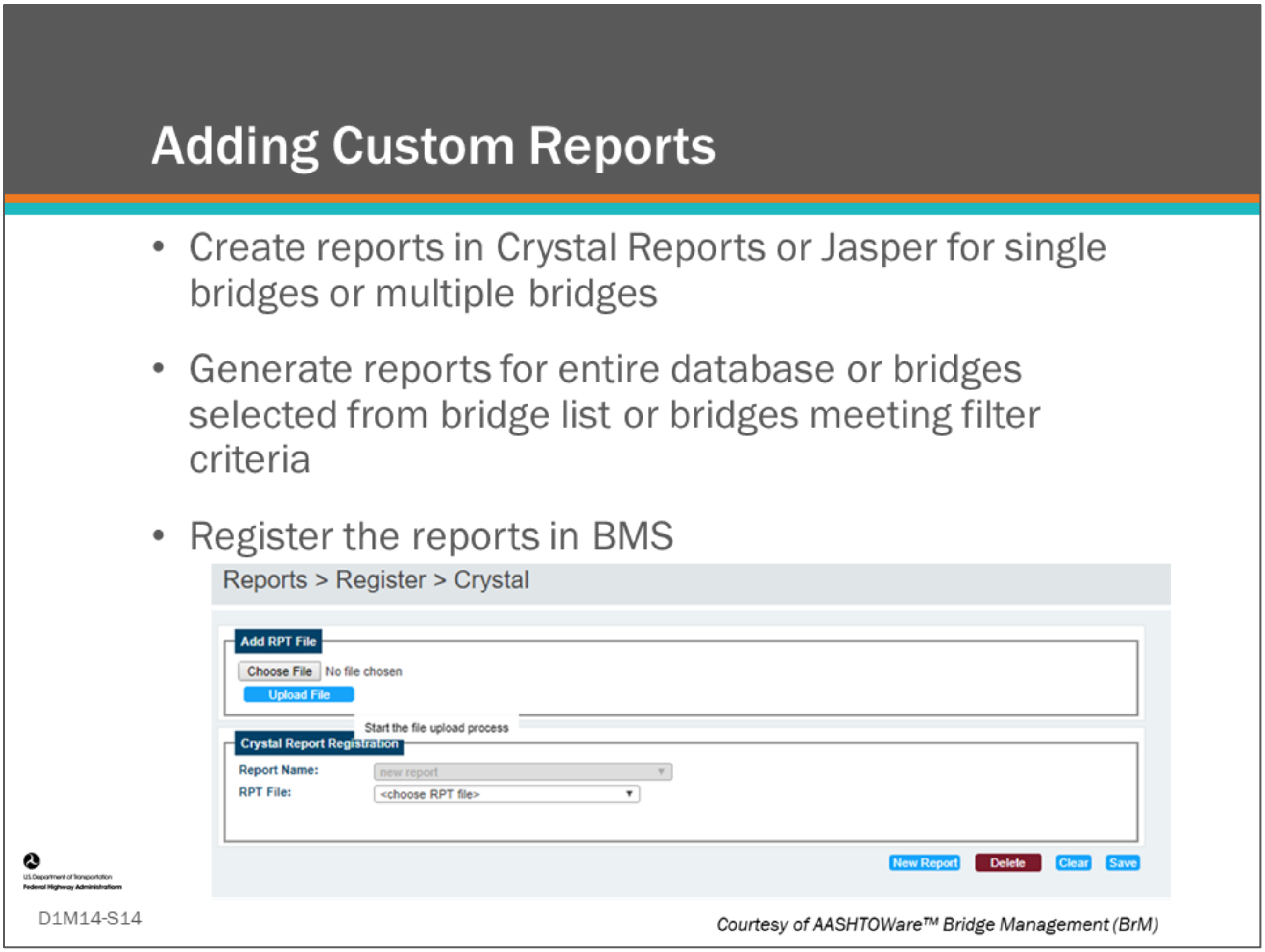


Key Message

Geographic Information Systems (GIS) mapping is a common tool today in BMS software for communication and reporting.

The bullets on this slide shows several ways GIS maps can be used.

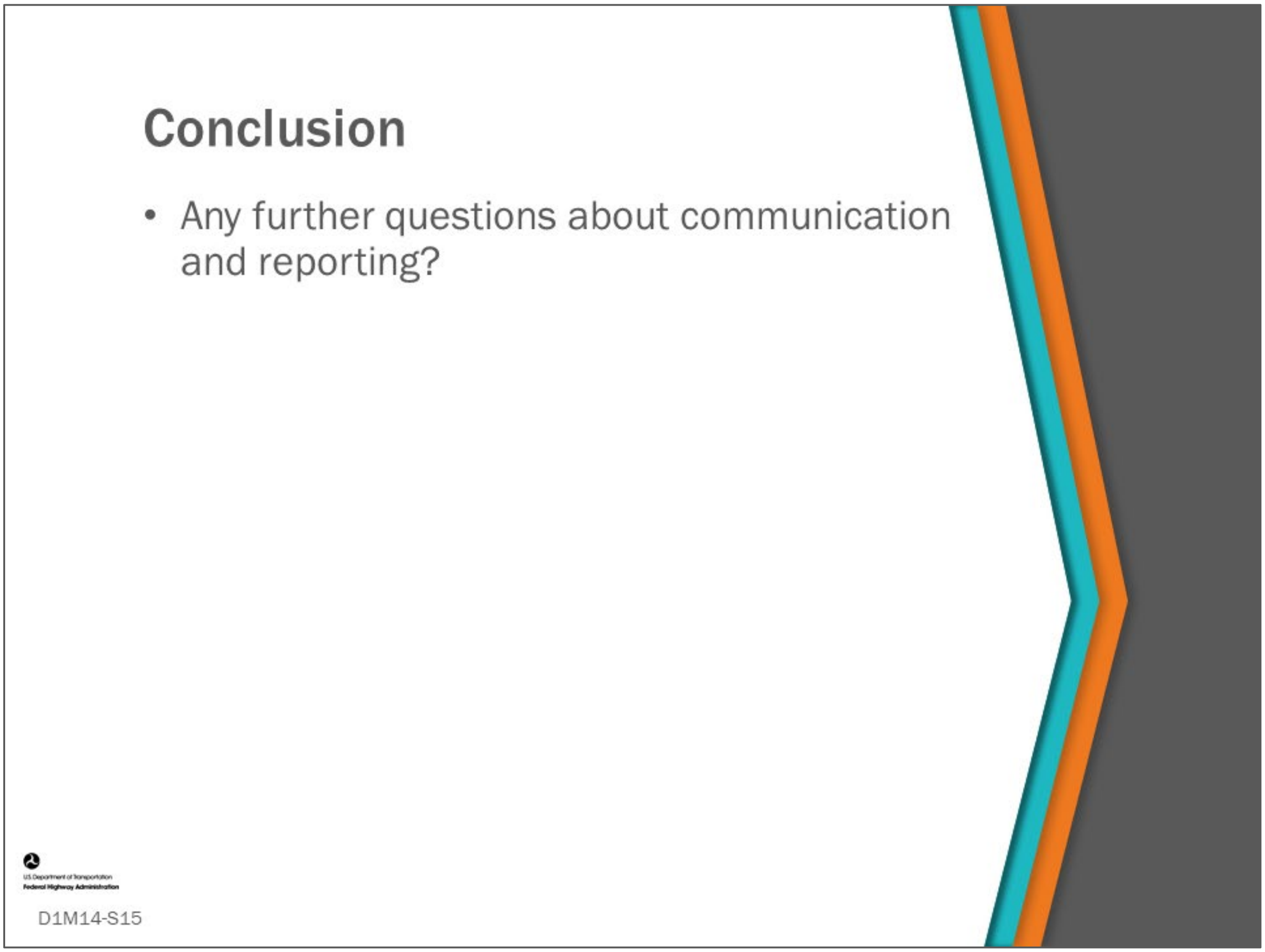
D1M14-Slide 14



Key Message

Most BMS software support adding custom reports, however, you will need to have a person who knows how to use third party report creating software, such as Crystal Reports or Jasper.

D1M14-Slide 15



Key Message

This concludes D1M14: Communication and Reporting.

D1M14-Slide 16

Slide #	Image Description	Source Information
4	Screenshot of the AASHTOWare™ BrM software Executive Summary screen.	AASHTOWare™ Bridge Management (BrM) software.
5	A chart shows Health Index (60 - 90) on the y-axis and scenario Year (2017 - 2026) on the x-axis.	AgileAssets® Structures Analyst™ software.
6	Screenshot of a Deighton dTIMS column chart showing Percentage on the y-axis and Year on the x-axis.	Deighton dTIMS© software.
10	Screenshot of the Virginia DOT Performance Reporting Dashboard showing gauges for performance, safety, condition, finance, VDOT Management, citizen Survey Results, and projects.	FHWA. *Transportation Asset Management Case Studies, Bridge Management Practices in Idaho, Michigan and Virginia.* Washington, DC, 2012. Page 32.
11	Screenshot of the Virginia DOT Condition Dashboard with a callout box showing Bridge Condition over time trend chart.	VDOT website.
12	Screenshot of North Carolina showing counties that can be selected to see information about that locality.	NCDOT website.
12	Screenshot of the North Carolina Infrastructure Health Dashboard showing dial gauges for bridge condition, pavement condition, roadside feature condition.	NCDOT website.
13	Screenshot of AgileAssets® Structures Analyst™ software showing a map of the greater Las Vegas area with markers showing good (green), fair (yellow), and poor (red) bridges.	AgileAssets® Structures Analyst™ software.
14	Screenshot from AASHTOWare™ Bridge Management (BrM) software showing how to create an example Reports Register Crystal custom report.	AASHTOWare™ Bridge Management (BrM) software.

D1M14-S16

D1M14 Figure Source List

Module Title: D2/3M1 – BMS Software Implementation Steps

Module Time: 120 Minutes

Module Summary

This module will go over the implementation steps to setup and run a BMS software. Through classroom group discussions, it gives the participants an opportunity to identify implementation steps they are doing and steps they can do in the future. This module builds upon the steps that were shown in day one of the workshop and takes a closer look at several BMS implementation steps including modeling actions using decision trees, creating action effects (benefits), and developing agency direct and indirect costs.

Expected Outcome(s)

The expected outcome of this module is to get practical hands-on experience in setting up and calibrating a BMS.

Module Outline

The expected outcome of this module is to get practical hands-on experience identifying agency BMS implementation steps.

Resource List

Slide	Reference Information
4	Definition of Data Reconciliation. Experian. 2019.
13	Boyle, Z. *AASHTOWare BrM 5.2.3 Training User Group Walkthrough Example.* September 2016.
18-22	AASHTO. *Manual for Bridge Element Inspection*. Washington, DC, 2013.
18-22	FHWA. *Specification for the National Bridge Inventory Bridge Elements.* Washington, DC, 2014.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D2/3M1-Slide 1

Key Message

This module will go over the implementation steps to setup and run a BMS software. This module builds upon the steps that were shown in day one of the workshop and delves deeper into how to get the information needed for input into your BMS. This module will show how inventory and condition information is used along with agency rules to determine actions. It will show how to set realistic costs to those actions and will estimate the benefits resulting from those actions. The module includes several participant exercises.

Disclaimer

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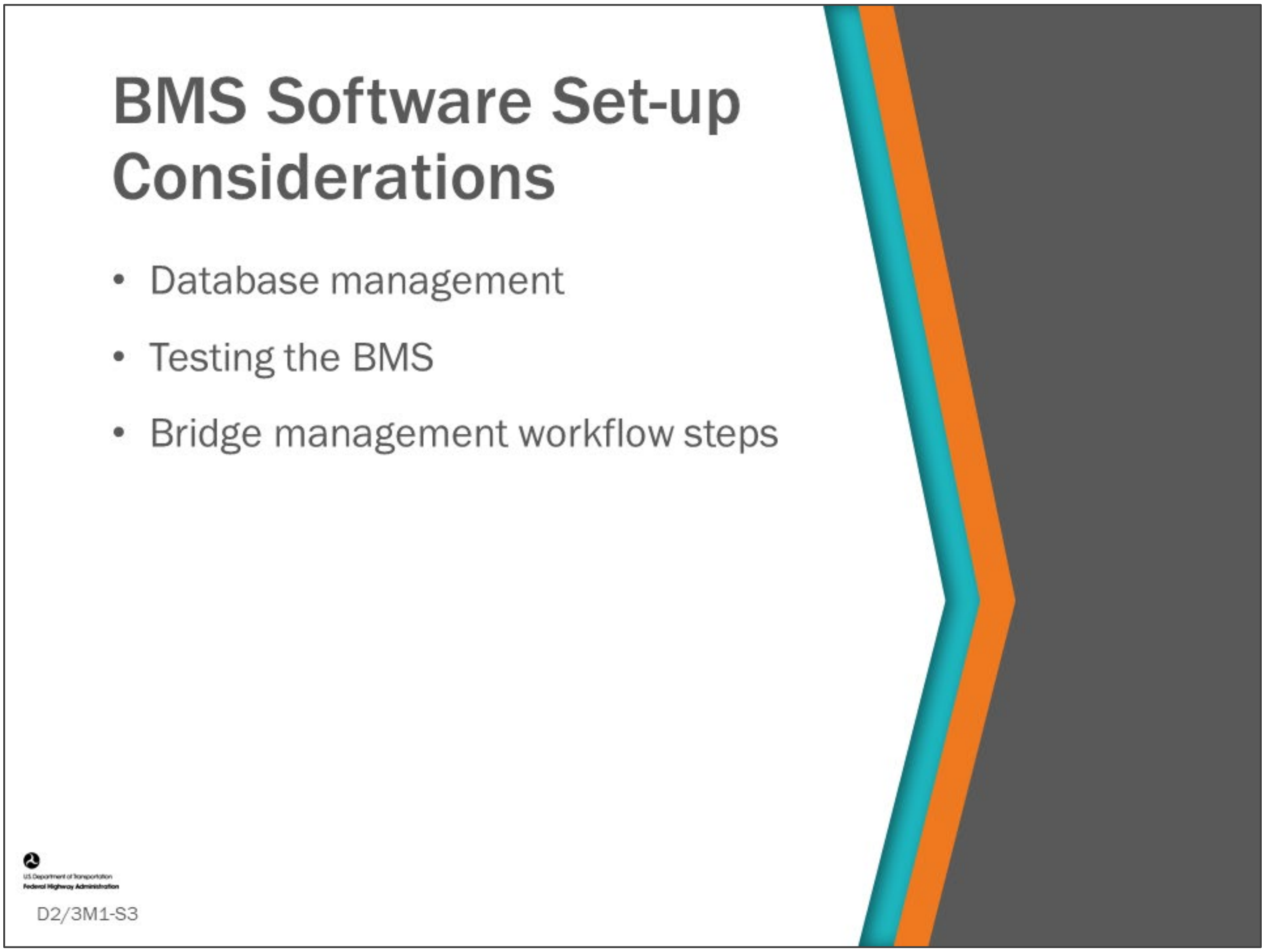
D2/3M1-Slide 2

Key Message

BMS software applications require many decisions and activities to set up and run the system. This includes many preliminary activities and implementation steps to make it work and give good results. Given the BMS workflow, process, and agency input learned about in Day One, the class participants will walk through the implementation steps of a BMS, getting an opportunity to develop the agency input information including creating a decision tree or matrix, estimating benefits of actions, and calculating cost.

D2/3M1-Slide 3

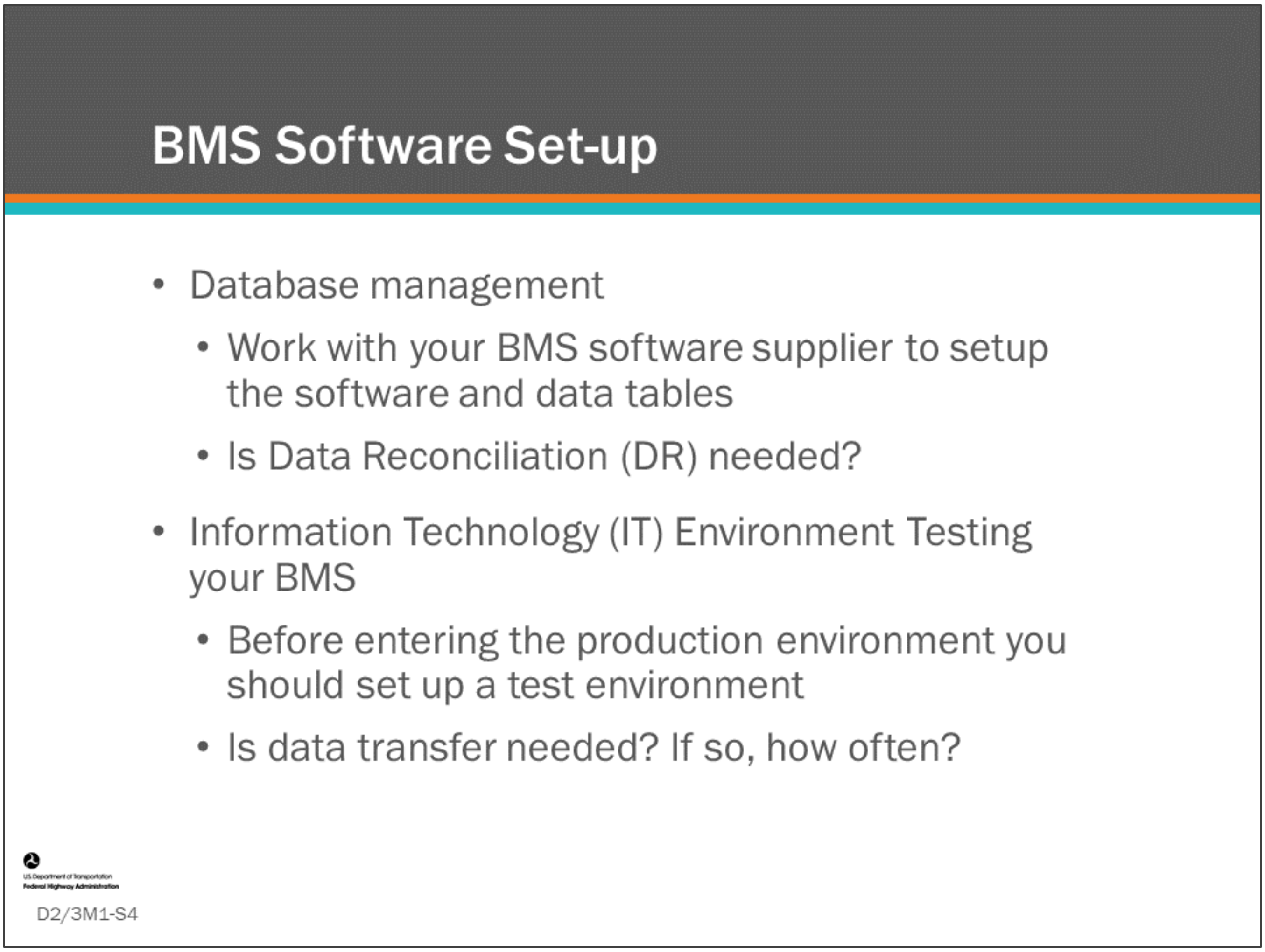


Key Message

In this section of the module, we will discuss the following considerations in regard to setting up your BMS software:

- Database management
- Testing the BMS
- Bridge management workflow steps

D2/3M1-Slide 4

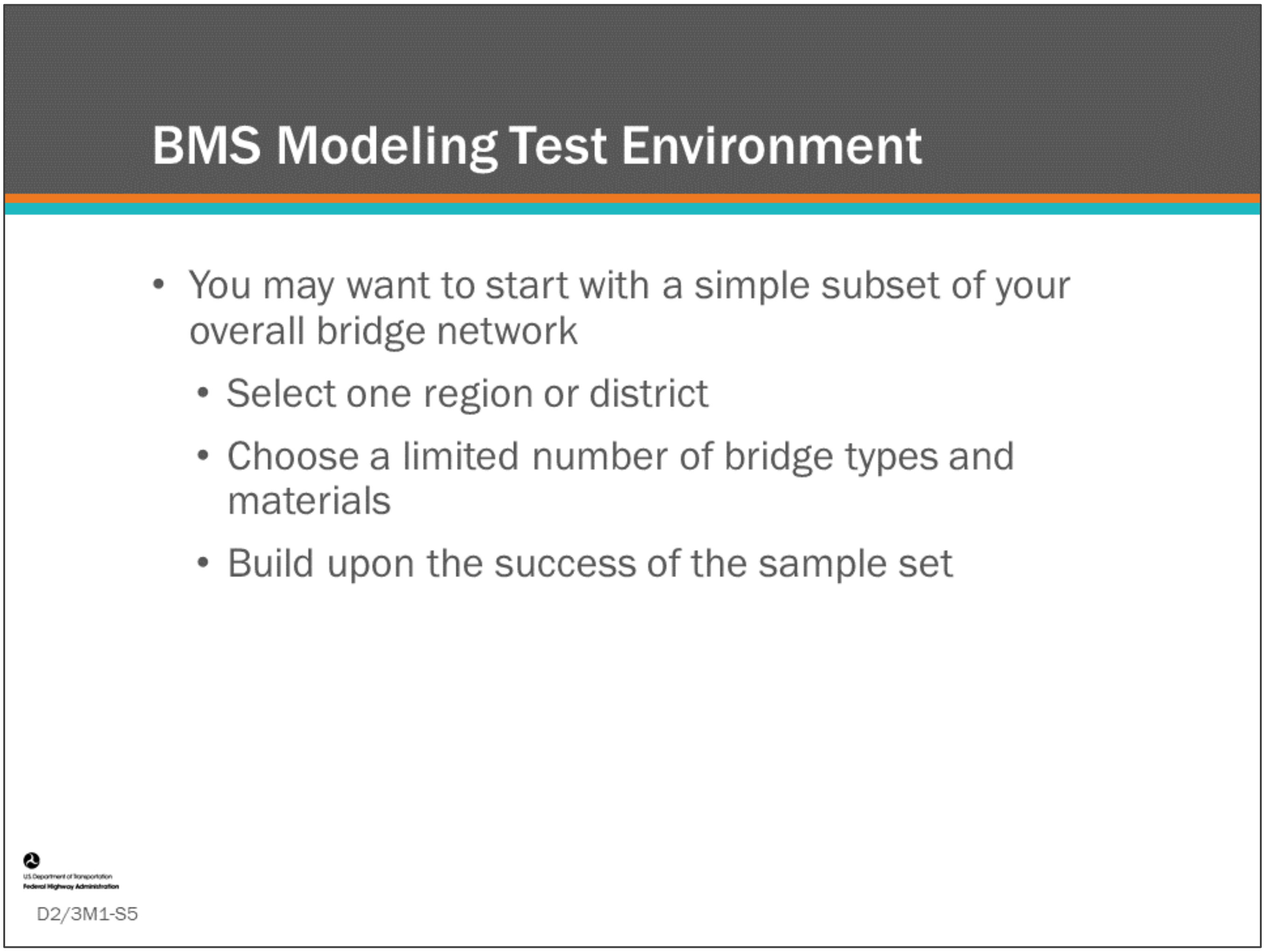


Key Message

There is a lot of work needed to setup a BMS software. It is important to have a team of database managers and bridge managers working with your software supplier to set up the system.

- Data reconciliation (DR) is a term typically used to describe a verification phase during a data migration where the target data is compared against original source data to ensure that the migration architecture has transferred the data correctly.
- An agency may set up the BMS software on a workstation before incorporation of the enterprise version.
- Most agencies set-up and implement the enterprise version of their BMS long before set-up and testing of the modeling and analysis, in order to get pre-existing data into the system, and they may use the system to manage inventory items and collect condition data.

D2/3M1-Slide 5

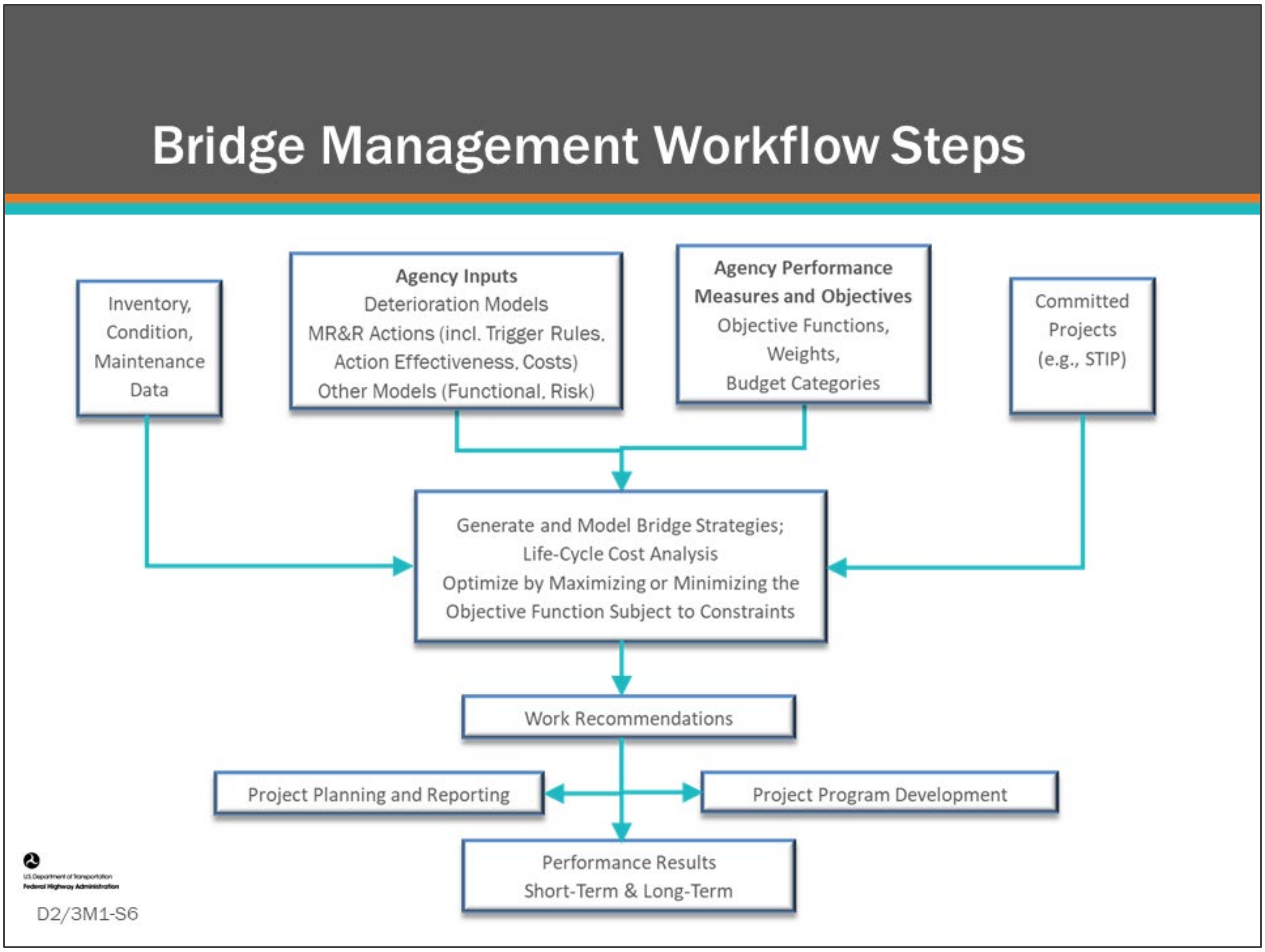


Key Message

The test environment is a place your BMS's staff can ensure data is imported and configured correctly, and that each component of the software is functioning.

- Working with a smaller dataset will make the feedback loop shorter and calculations will run quicker. It will take less time for reasonableness checks, and iterations will be quicker.
- As you build the test environment, you will need a representative sample set that will have the full range of bridge management needs.

D2/3M1-Slide 6



Key Message

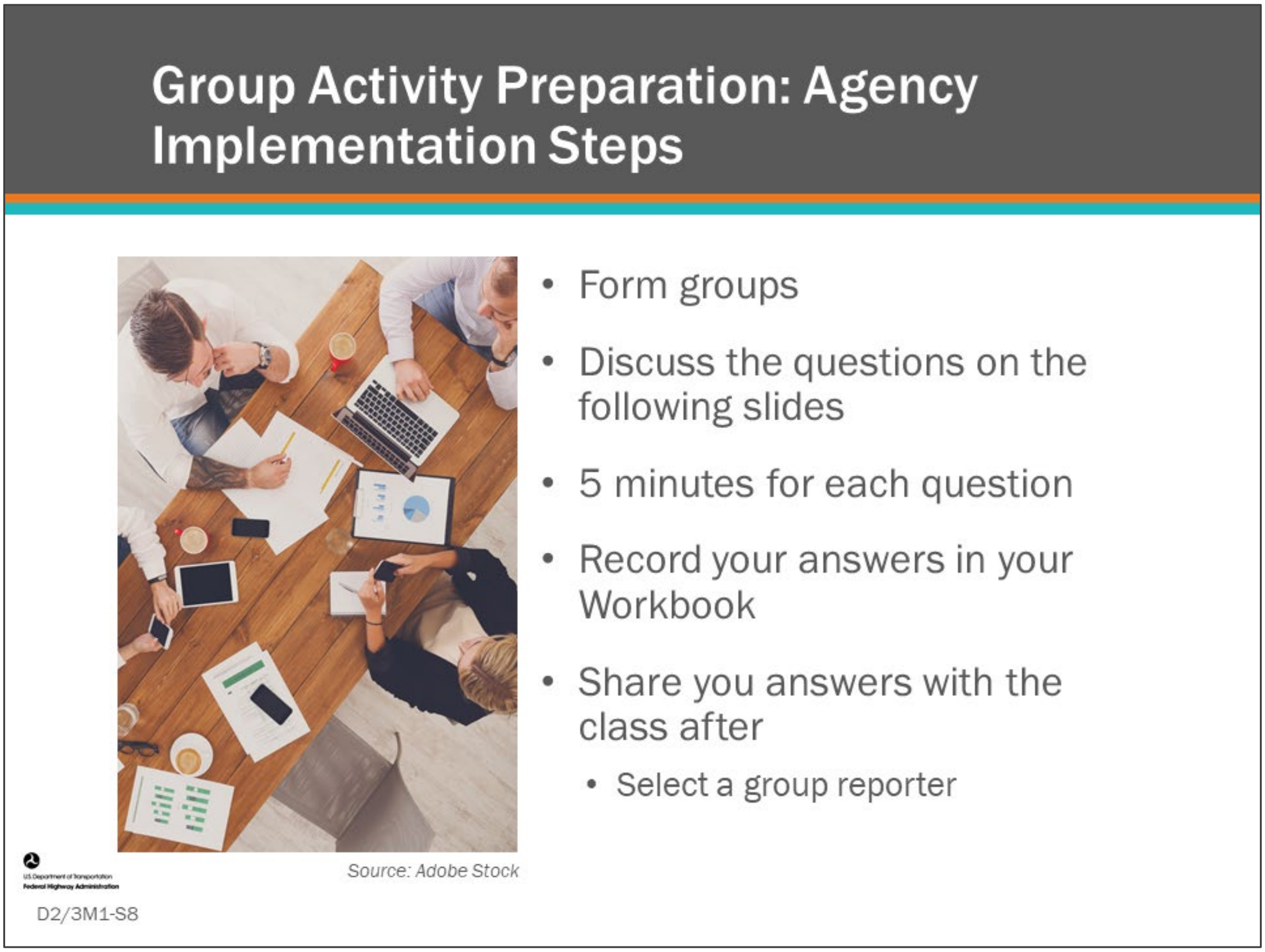
On the first day of the workshop we introduced the Bridge Management Workflow steps of a BMS. This diagram shows common data inputs necessary to run a BMS. In this section, we are going take a closer look at your agency workflow and implementation steps to help you provide good data and agency inputs into your BMS, so that it can give you meaningful results.

D2/3M1-Slide 7

Key Message

In this section, we will give you an opportunity to review and discuss your BMS Implementation Steps. Then we will compare to our ongoing list of BMS implementation steps and discuss any differences.

D2/3M1-Slide 8



Key Message

In this group activity, we will list agency implementation steps necessary to implement a BMS.

D2/3M1-Slide 9

Key Message

Each group is asked to list the following:

- Describe the steps that need to be taken to implement a BMS.
- Indicate which steps your agency has done.
- Indicate any challenges you are having with ongoing steps or steps you have not done yet.

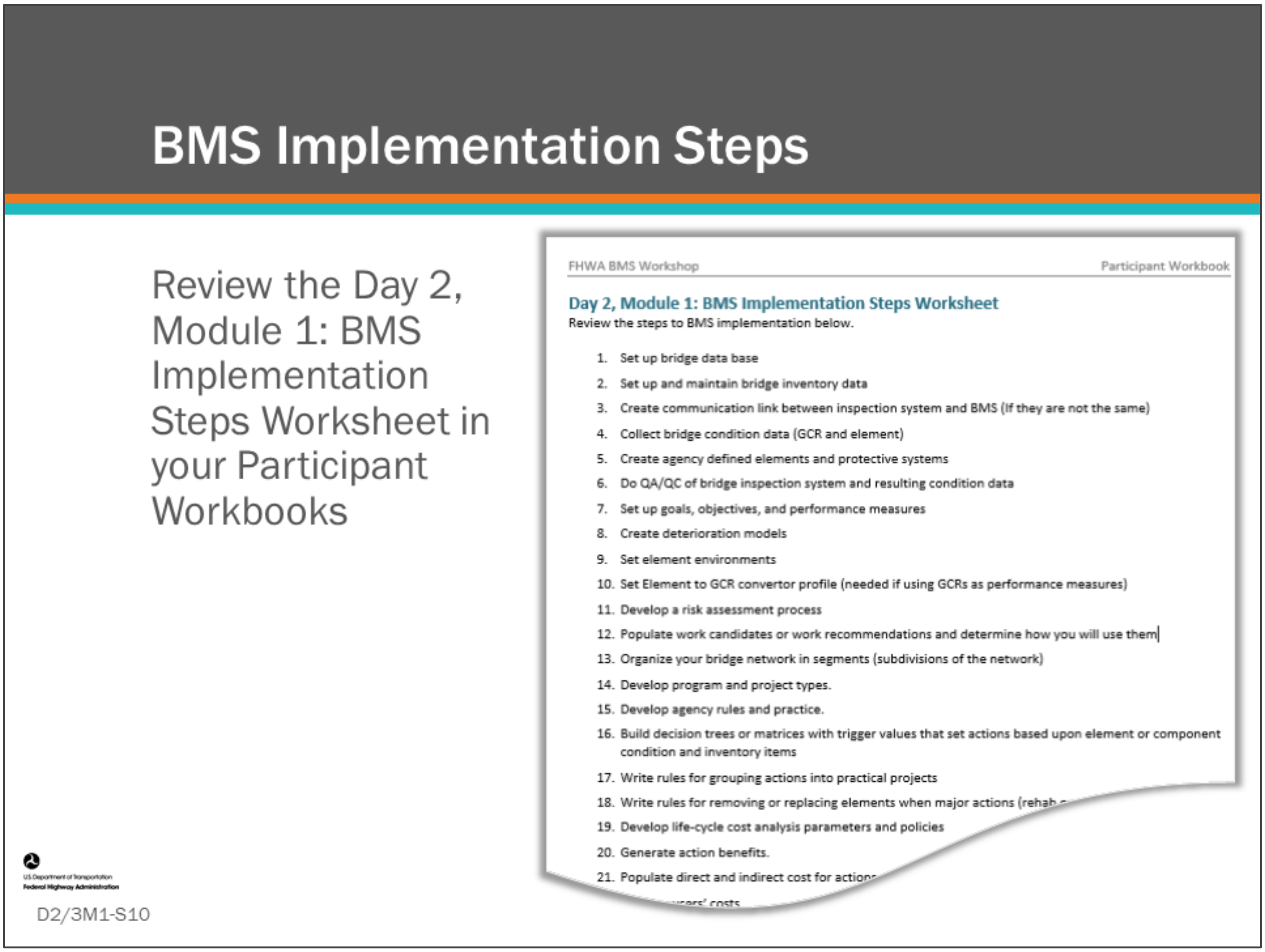
D2/3M1 - Slide 9: Agency Implementation Steps

1. Describe the steps that need to be taken to implement a BMS.

2. Indicate which steps your agency has done.

3. Indicate any challenges you are having with ongoing steps or steps you have not done yet.

D2/3M1-Slide 10



Key Message

Review the list of BMS implementation steps in your PW and compare to list developed by participants.

Potential answers include:

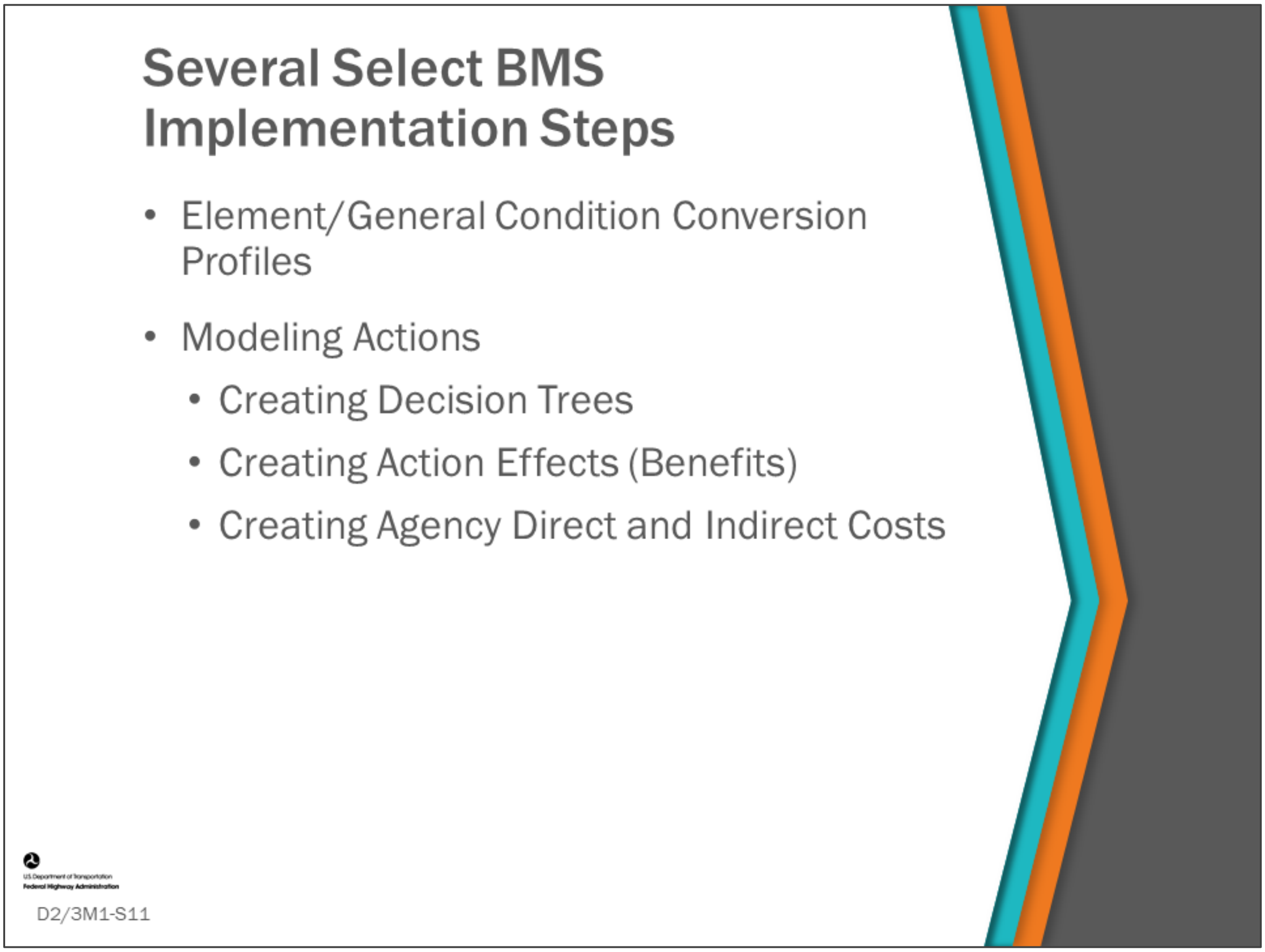
1. Set up bridge data base
2. Set up and maintain bridge inventory data
3. Create communication link between inspection system and BMS (If they are not the same)
4. Collect bridge condition data (GCR and element)
5. Create agency defined elements and protective systems
6. Do QA/QC of bridge inspection system and resulting condition data
7. Set up goals, objectives, and performance measures
8. Create deterioration models
9. Set element environments
10. Set element to GCR convertor profile (needed if using GCRs as performance measures)
11. Develop a risk assessment process
12. Populate work candidates or work recommendations and determine how you will use them
13. Organize your bridge network in segments (subdivisions of the network)
14. Develop program and project types
15. Develop agency rules and practice
16. Build decision trees or matrices with trigger values that set actions based upon element or component condition and inventory items

17. Write rules for grouping actions into practical projects
18. Write rules for removing or replacing elements when major actions (rehab or replacement) are taken
19. Develop life-cycle cost analysis parameters and policies
20. Generate action benefits
21. Populate direct and indirect cost for actions
22. Develop user costs
23. Set project and program funding sources
24. Create and track fixed projects
25. Create deferment rules (used with LCCA)
26. Create optimization objective function and multi-objective scaling, weighting, and amalgamation rules (utility tree)
27. Set constraints for the optimization problem

D2/3M1 - Slide 10: Agency Implementation Steps – Potential Answers

1. Set up bridge data base
2. Set up and maintain bridge inventory data
3. Create communication link between inspection system and BMS (If they are not the same)
4. Collect bridge condition data (GCR and element)
5. Create agency defined elements and protective systems
6. Do QA/QC of bridge inspection system and resulting condition data
7. Set up goals, objectives, and performance measures
8. Create deterioration models
9. Set element environments
10. Set element to GCR convertor profile (needed if using GCRs as performance measures)
11. Develop a risk assessment process
12. Populate work candidates or work recommendations and determine how you will use them
13. Organize your bridge network in segments (subdivisions of the network)
14. Develop program and project types.
15. Develop agency rules and practice.
16. Build decision trees or matrices with trigger values that set actions based upon element or component condition and inventory items
17. Write rules for grouping actions into practical projects
18. Write rules for removing or replacing elements when major actions (rehab or replacement) are taken
19. Develop life-cycle cost analysis parameters and policies
20. Generate action benefits.
21. Populate direct and indirect cost for actions
22. Develop user costs
23. Set project and program funding sources
24. Create and track fixed projects
25. Create deferment rules (used with LCCA)
26. Create optimization objective function and multi-objective scaling, weighting, and amalgamation rules (utility tree)
27. Set constraints for the optimization problem

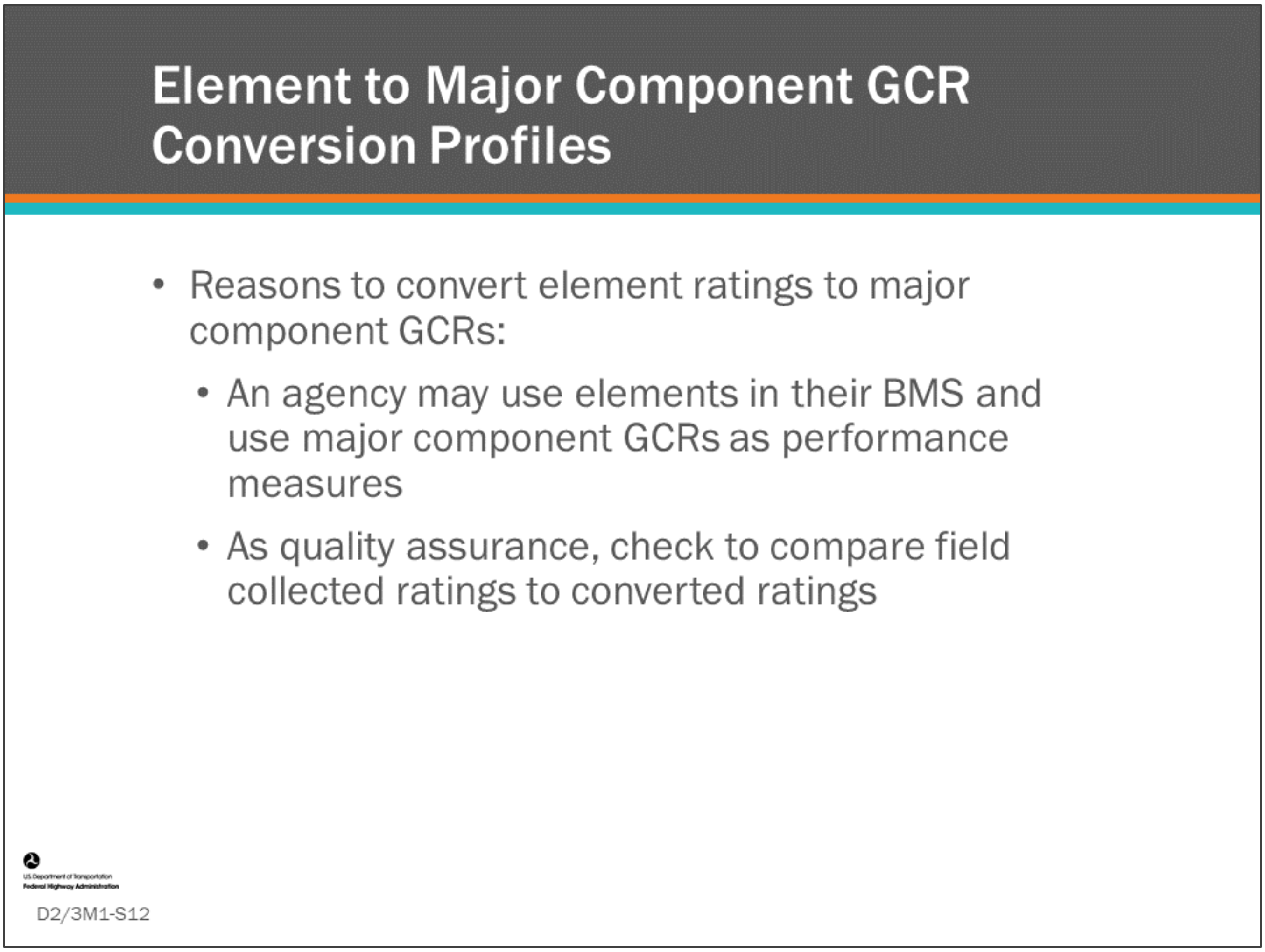
D2/3M1-Slide 11



Key Message

Although we do not have time in this module to discuss all the many BMS implementation steps in more detail, we selected several steps that we will discuss further. These include creating decision trees, action effects (benefits), and the cost of those actions.

D2/3M1-Slide 12



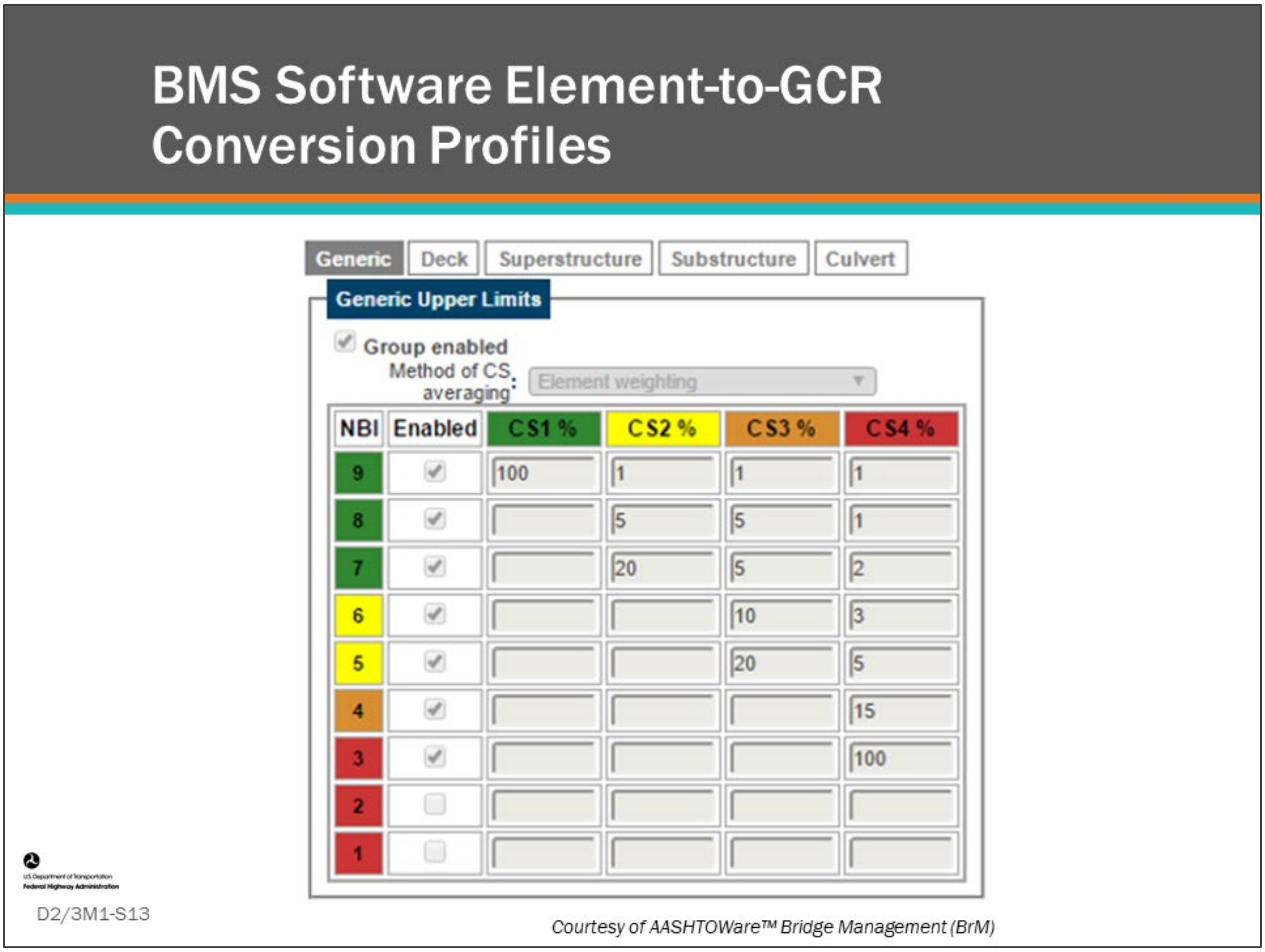
Key Message

Reasons to convert element ratings to major component GCRs include the following:

- An agency may use elements in their BMS and use major component GCRs as performance measures.

As quality assurance, check to compare field collected ratings to converted ratings. This QC check can be used to identify potentially inaccurate data.

D2/3M1-Slide 13



NBI	Enabled	CS1 %	CS2 %	CS3 %	CS4 %
9	✓	100	1	1	1
8	✓		5	5	1
7	✓		20	5	2
6	✓			10	3
5	✓			20	5
4	✓				15
3	✓				100
2					
1					

Key Message

BMS software often allow entering rules for doing element-to-GCR (shown as NBI on the slide) conversion profiles. These will apply to the primary structural elements that make up the major component. For example, Element 107 – Steel Open Girder converts to a superstructure rating.

In the screenshot shown on the slide, GCRs (NBI) are shown as the row labels. Condition State percentage is shown as column labels. The conversion values are entered in a grid referenced from the GCR(NBI) and Condition States. The values in the cells are the upper limit for element condition state values. For example, if Element 107 - Steel Open Girder has 21 percent in CS2, using the profile on the slide, the highest possible GCR is 7 because CS2 quantity that is 20 percent or greater is 7.

D2/3M1-Slide 14

Creating Element-to-GCR Conversion Profiles

GCR	CS1	CS2	CS3	CS4
9	98	2	0	0
8	99	1	0	0
7	94	6	0	0
6	79	19	2	0
5	65	29	6	0
4	41	43	15	1
3	37	35	19	9

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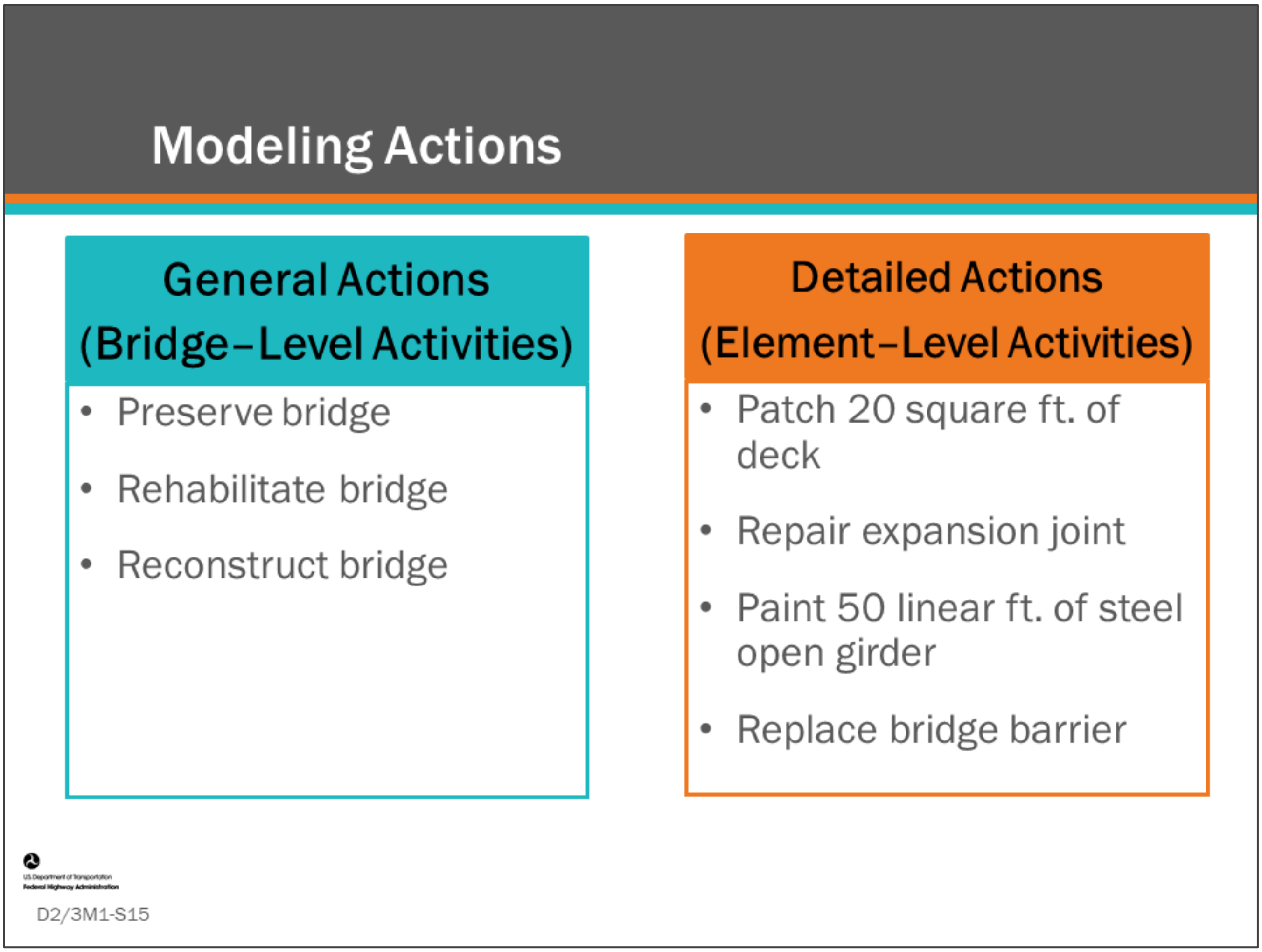
D2/3M1-S14

Key Message

An agency can review the average percentage of element condition states for each general condition by comparing how the element condition states are distributed on average when a comparable component GCR is reached. The table on this slide shows the GCR for a steel superstructure and the corresponding average percentage of the Steel Open Girder in each condition state. For example, for steel superstructures included in this study when the GCR is 6, on average:

- 79 percent of the steel open girder is in CS1;
- 19 percent is in CS2;
- 2 percent is in CS3;
- 0 percent is in CS4.

D2/3M1-Slide 15



Key Message

An important function of a BMS is modeling bridge actions and grouping these actions to form projects. We will take a closer look at how this is done in this section.

D2/3M1-Slide 16

Agency Actions - Decision Matrix

DECK CONDITION STATE				REPAIR OPTIONS
Top Surface		Bottom Surface		
BSIR #58a	Deficiencies % (a)	BSIR #58b	Deficiencies % (b)	
≥ 5	N/A	N/A	N/A	Hold (c) / Seal Cracks
				Silane
				Healer Sealer (d)
	≤ 10%	≥ 6	≤ 2%	Epoxy Overlay (f)
	≤ 10%	≥ 4	≤ 25%	Deck Patch (e, j)
4 or 5	10% to 25%	≥ 5	≤ 10%	Deep Concrete Overlay (h, j)
		4	10% to 25%	Shallow Concrete Overlay (h, i, j)
				HMA Overlay with water-proofing membrane (f, i)
		2 or 3	> 25%	HMA Cap (g, i)
≤ 3	>25%	≥ 6	< 2%	Deep Concrete Overlay (h, j)
		4 or 5	2% to 25%	Shallow Concrete Overlay (h, i, j)
				HMA Overlay with water-proofing membrane (f, i)
		2 or 3	>25%	HMA Cap (g, i)
				Replacement with Epoxy Coated or Stainless Rebar Deck

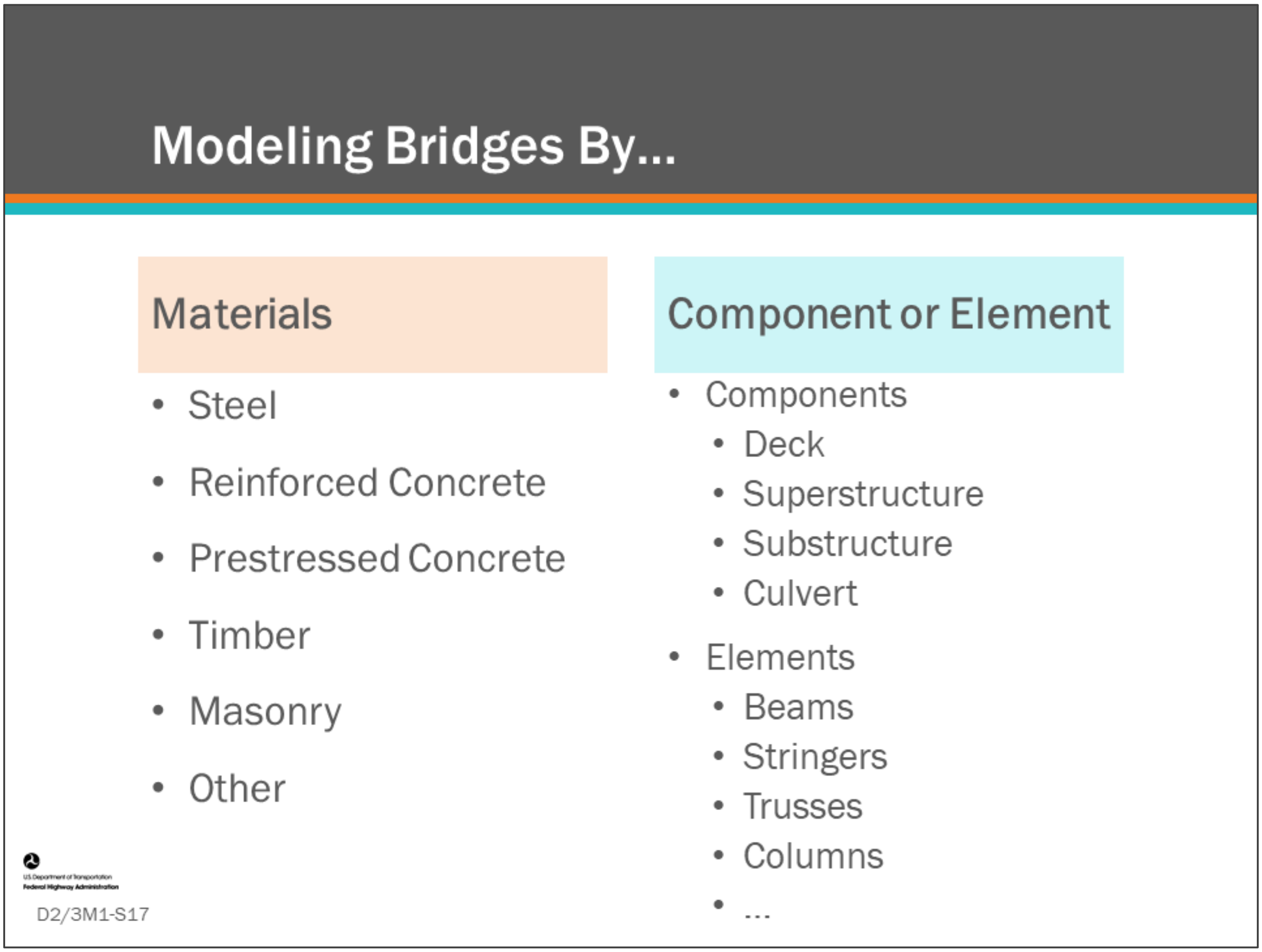
D2/3M1-S16

Key Message

Agency actions can be illustrated in table format, as a decision matrix. Shown here is an example of a State DOT decision matrix for bridge deck actions.

- Whether defined in tree or matrix format, these are all agency trigger rules that can be coded into your BMS.
    - Note: This slide does not show the footnotes that belong with the table shown here. In the original matrix, the footnotes provided more detailed guidance.

D2/3M1-Slide 17

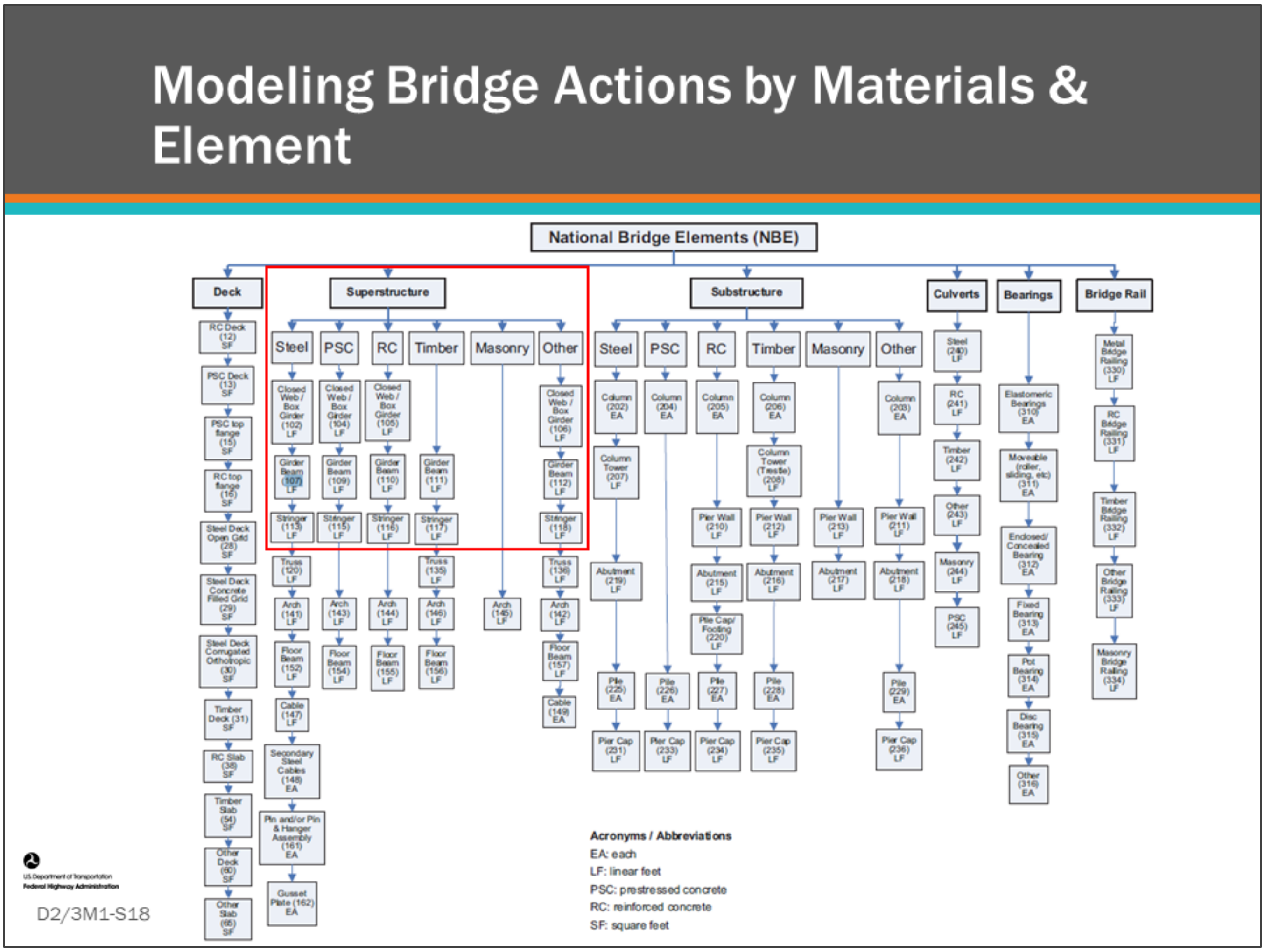


Key Message

Bridges actions are modeled by:

- Materials, such as steel, reinforced concrete, prestressed concrete, timber, masonry
- Components, as in, deck, superstructure, substructure, culvert
- Elements such as beams, stringers, trusses, columns

D2/3M1-Slide 18



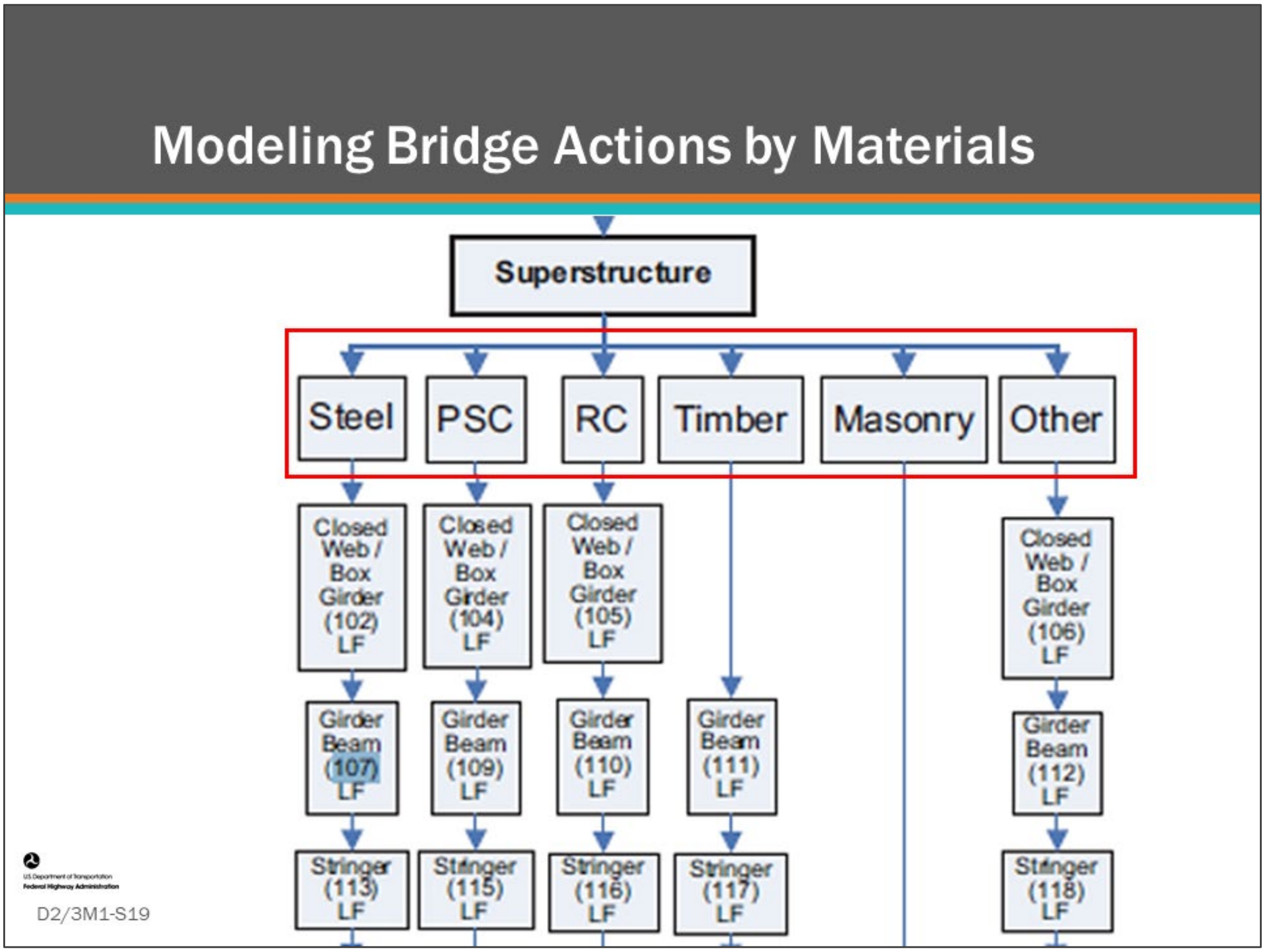
Key Message

There are over 90 AASHTO National Bridge Elements. These are all reported to FHWA for National Highway System bridges.

Actions need to be developed for the elements that an agency wants included within BMS needs assessment, benefit-cost analysis, and/or project planning.

Depending on the BMS and how it is set up, some elements may be included in automated modeling and project recommendations, while others may require manual inclusion in project recommendations.

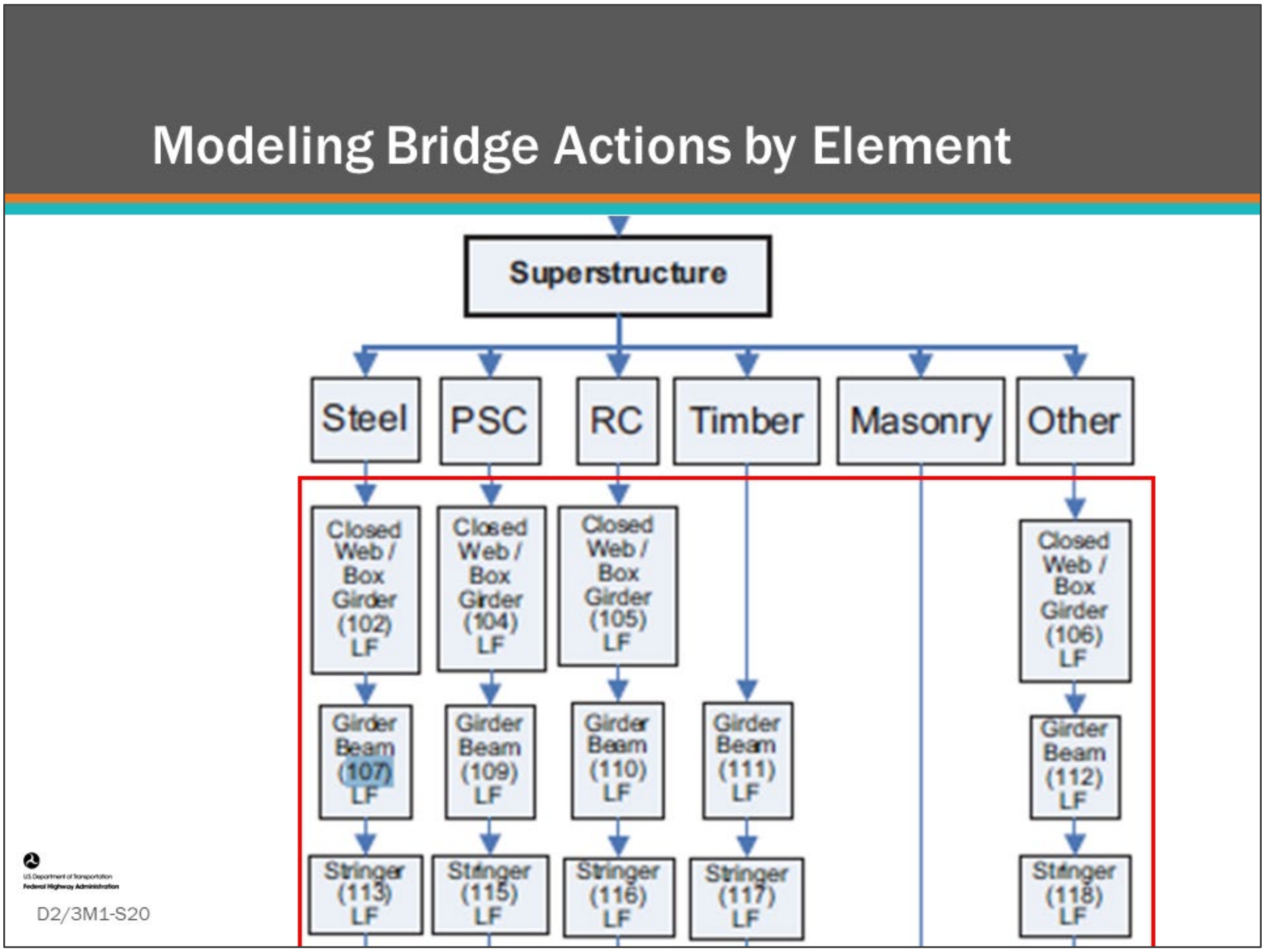
D2/3M1-Slide 19



Key Message

Under superstructure, we first see categories of materials including; Steel, Prestressed Concrete (PSC), Reinforced Concrete (RC), Timber, Masonry and Other.

D2/3M1-Slide 20



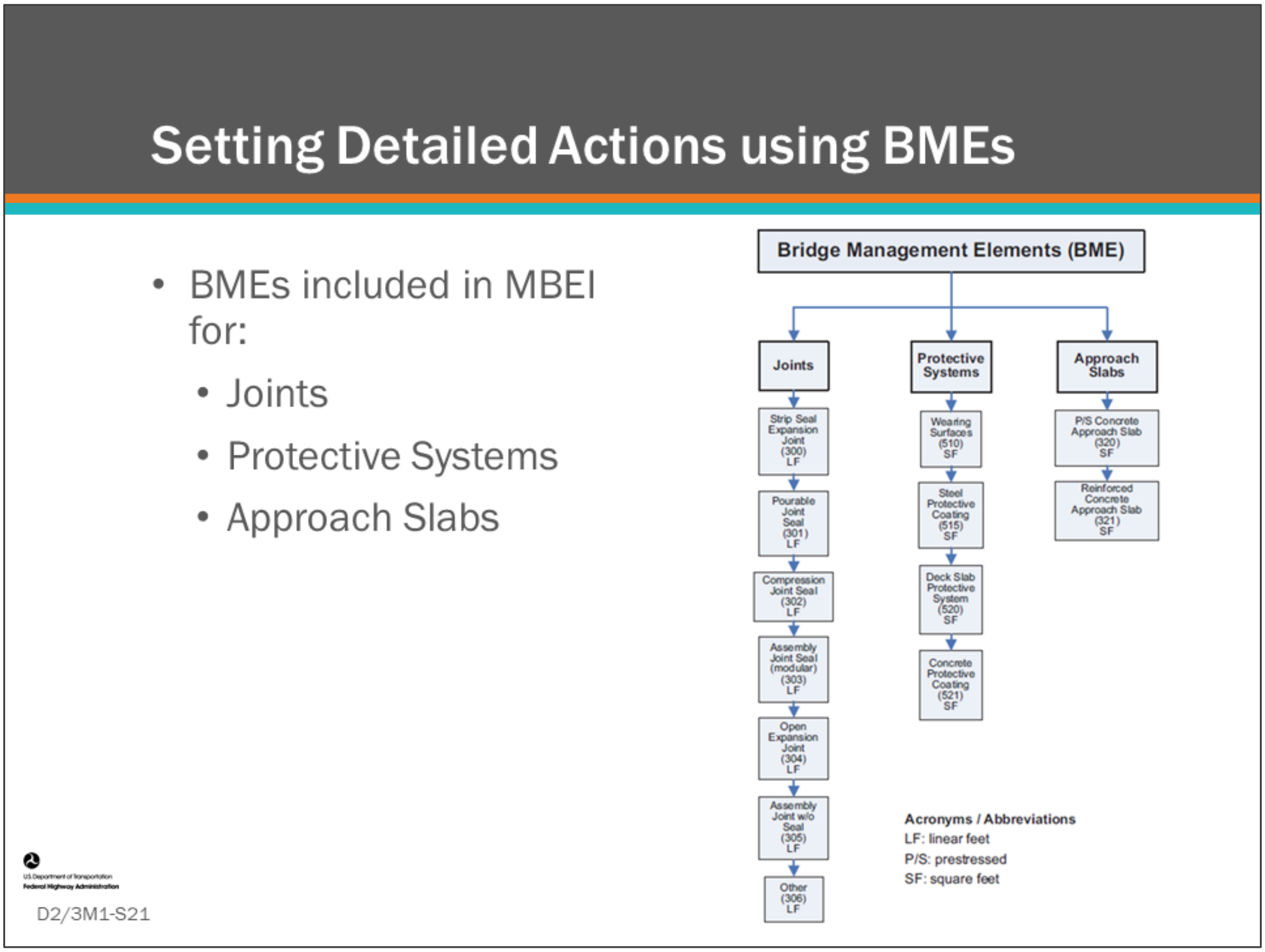
Key Message

Next, element members are categorized by their element type. Here we see the element types:

- Closed Web / Box Girders (102, 104, 105, 106)
- Girder / Beams (107, 109, 110, 111, 112)
- Stringers (113, 115, 116, 117, 118)

Additionally, not shown on this slide, we have superstructure element types for Truss, Arch, Floor Beam, Cable, Secondary Steel Cables, Pin and Hangers and Hanger Assemblies, and Gusset Plates.

D2/3M1-Slide 21

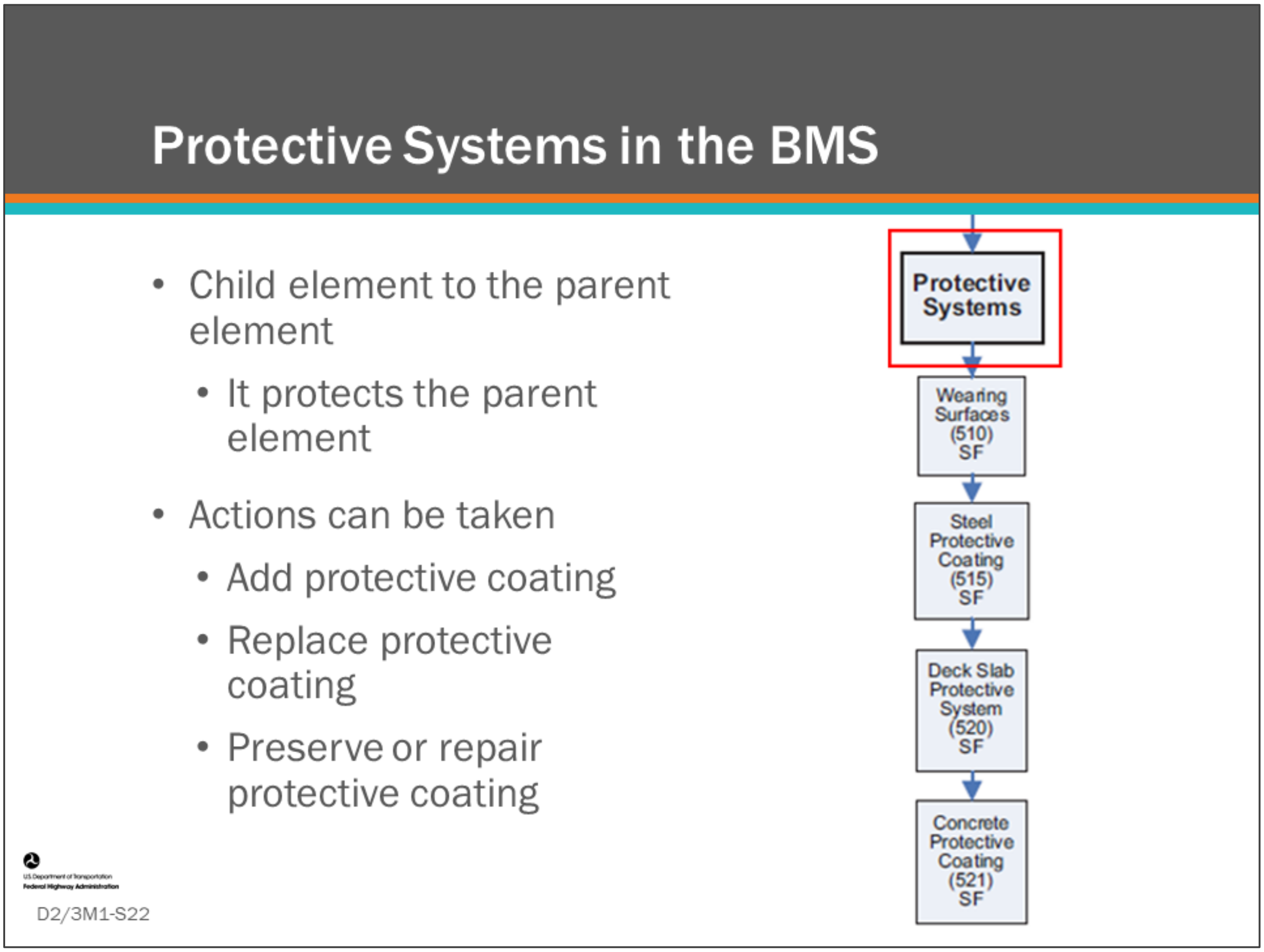


Key Message

The AASHTO's Manual for Bridge Element Inspection (MBEI) also includes Bridge Management Elements (BME) for joints, protective systems, and approach slabs. BMEs are also reported to FHWA for NHS bridges excluding the Approach Slabs and Concrete Reinforcing Steel Protective System (520).

Next, we will illustrate how protective systems, such as Element 515 – Steel Protective Coating can be used together with NBE elements, such as Element 107 – Steel Girder/Beam to set detailed actions.

D2/3M1-Slide 22

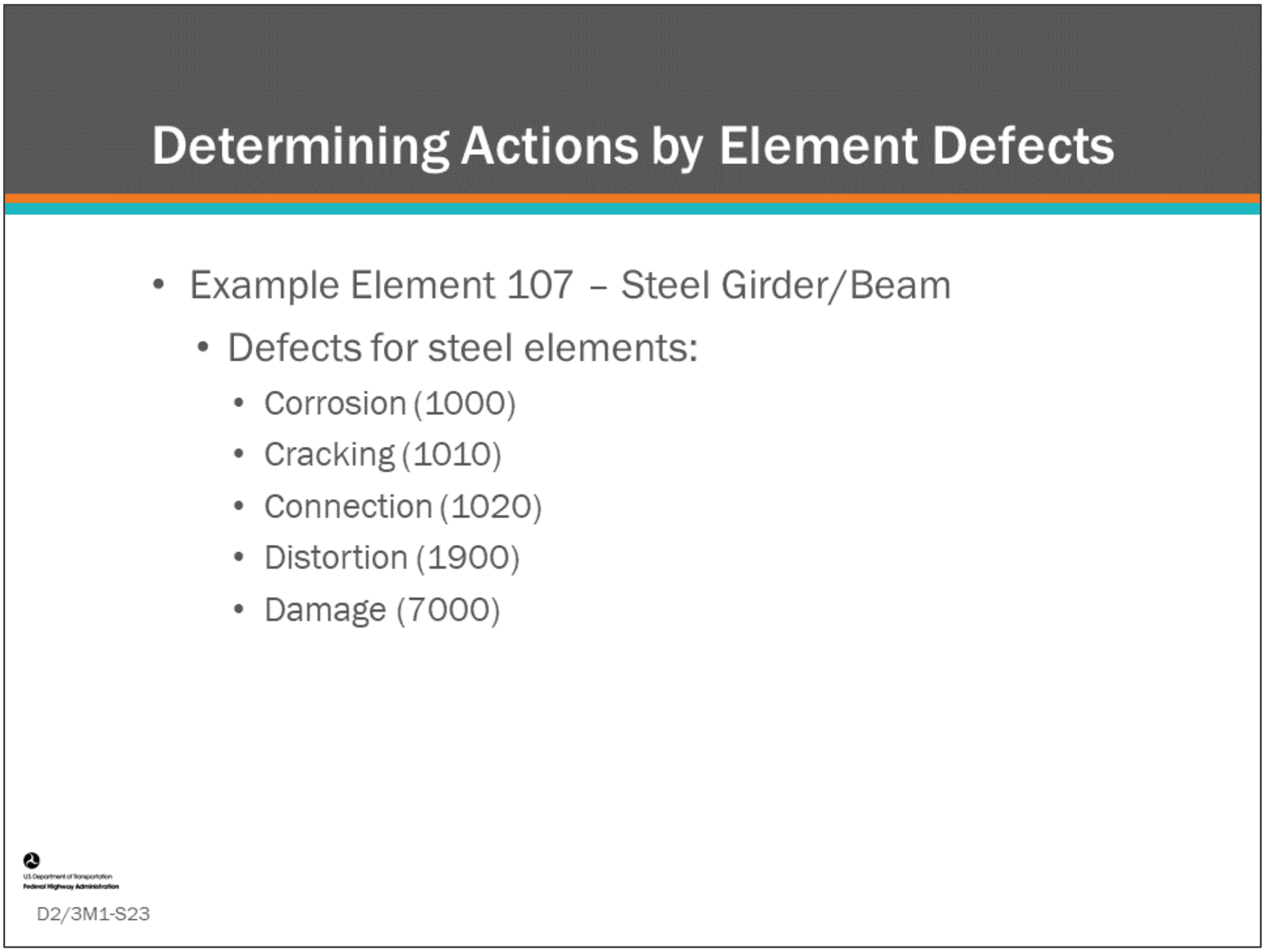


Key Message

BMEs include protective systems which are child elements that protect the parent element.

- This includes wearing surface for bridge decks, steel protective coatings, concrete reinforcing steel protective systems, and concrete protective coatings
  - Examples: epoxy-coated, galvanized, and stainless steel rebar, wearing surfaces, steel protective coatings, and cathodic protection
- Protective system child elements have condition states
- Actions (treatments) can be done to protective systems
- It is possible for the wearing surface to have a concrete protective coating, which introduces the “Grandparent” concept. Example: Reinforced concrete deck can be the grandparent for a wearing surface (parent) with a concrete protective coating (child)

D2/3M1-Slide 23

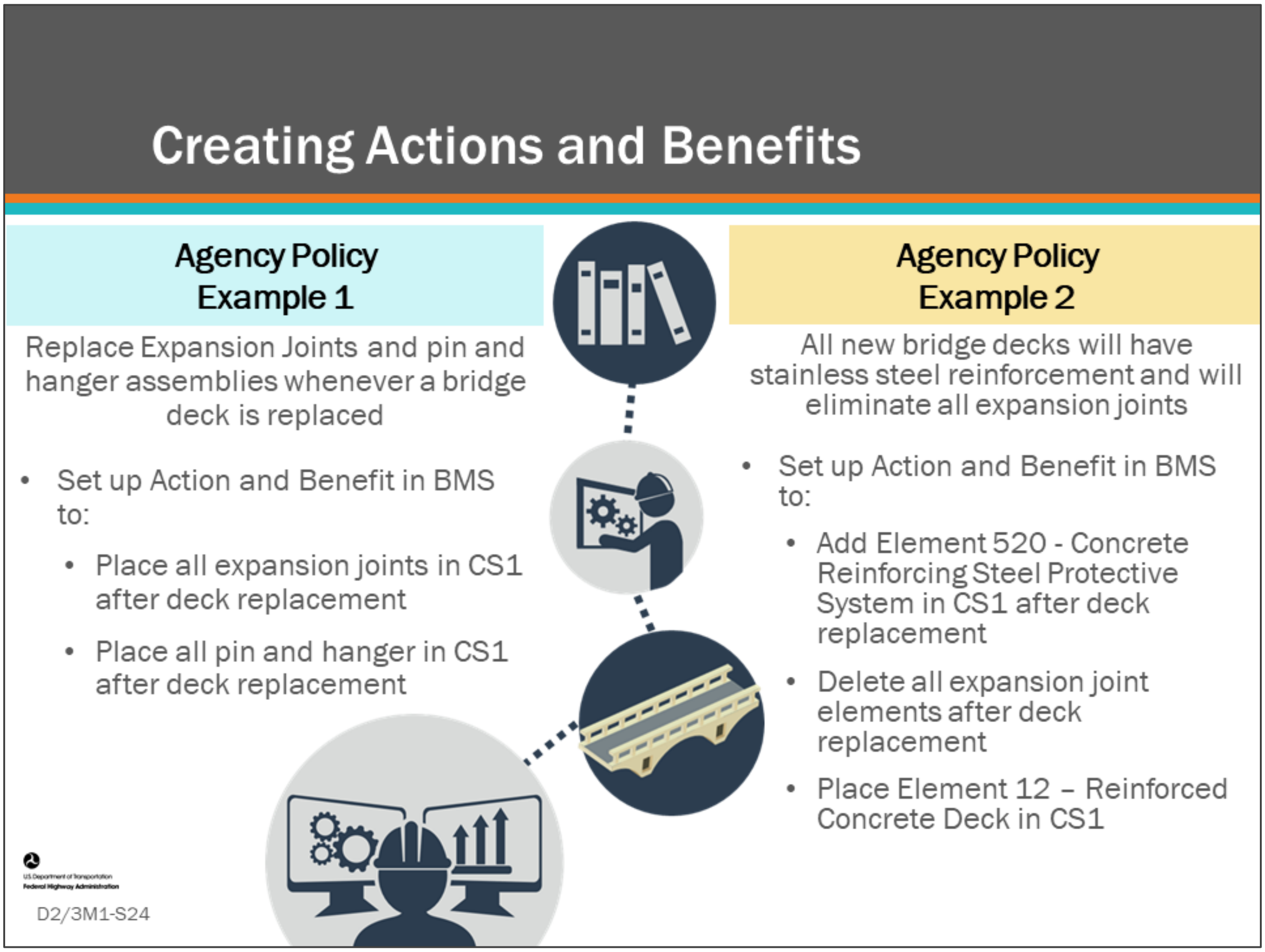


Key Message

Defects provide further detail regarding the condition state of the element in common terms that can be used in the BMS software.

- Using Defects with elements can provide even more refined decisions.
  - For example, Element 107 – Steel Girder/Beam with one lineal foot in CS3, with a defect of Corrosion (1000), could have a different action than one lineal foot of CS3 if the defect for this element was Cracking (1010)

D2/3M1-Slide 24

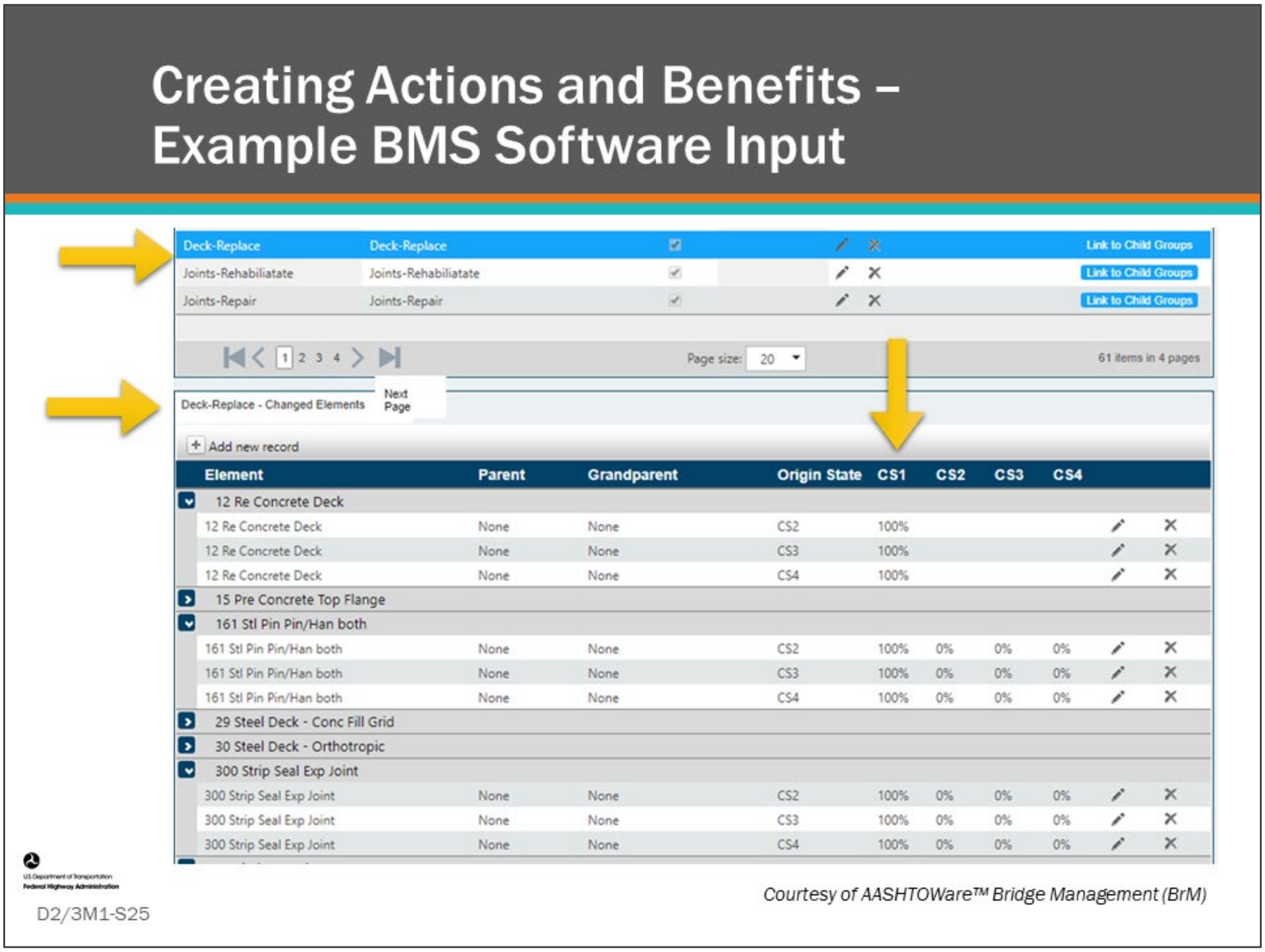


Key Message

Agencies have business practices that describe what actions are taken on certain bridge elements as a result of actions taken on other bridge elements. For the BMS to make project recommendations that align with agency practices and policies, these practices and policies must be input into the BMS.

- Example 1, it might be the agency policy to replace expansion joints and pin and hanger assemblies whenever a bridge deck is replaced.
    - In this case, you would program the BMS so that after a deck replacement action is done that all expansion joints will be in CS1, and all pin and hanger assemblies will be in CS1.
- Example 2, it might be the agency policy that the whenever a bridge deck is replaced it will have stainless steel reinforcement and all expansion joints will be eliminated.
    - In this case, you would program the BMS so that after a deck replacement action is done that Element 520 - Concrete Reinforcing Steel Protective System or an agency-defined element for stainless steel concrete reinforcing steel protective system will be added and will be in CS1. In addition, the Element 12 - Concrete Deck will be in CS1, and all expansion joint elements will be deleted.

D2/3M1-Slide 25

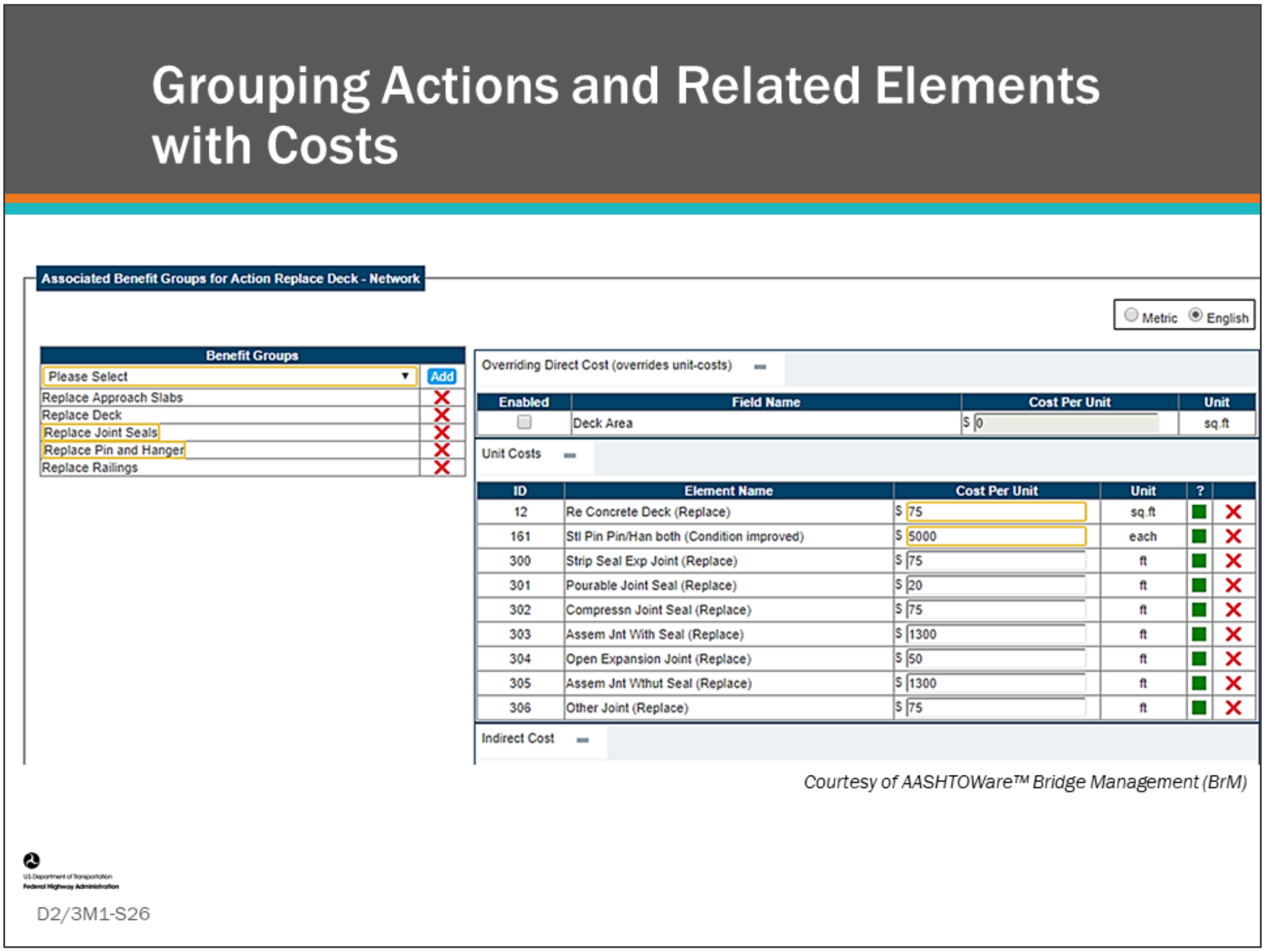


Key Message

Let's look at Example 1, from the previous slide inside a BMS.

- This input example is from AASHTOWare™ Bridge Management (BrM), illustrating the actions and benefits associated with Deck Replacement.
  - Notice, under "Changed Elements" that all of Element 12 – Reinforced Concrete Deck in CS2, CS3, and CS4, will change to CS1 when the deck is replaced.
  - It is implied that that portion of the deck in CS1 will remain CS1.

D2/3M1-Slide 26

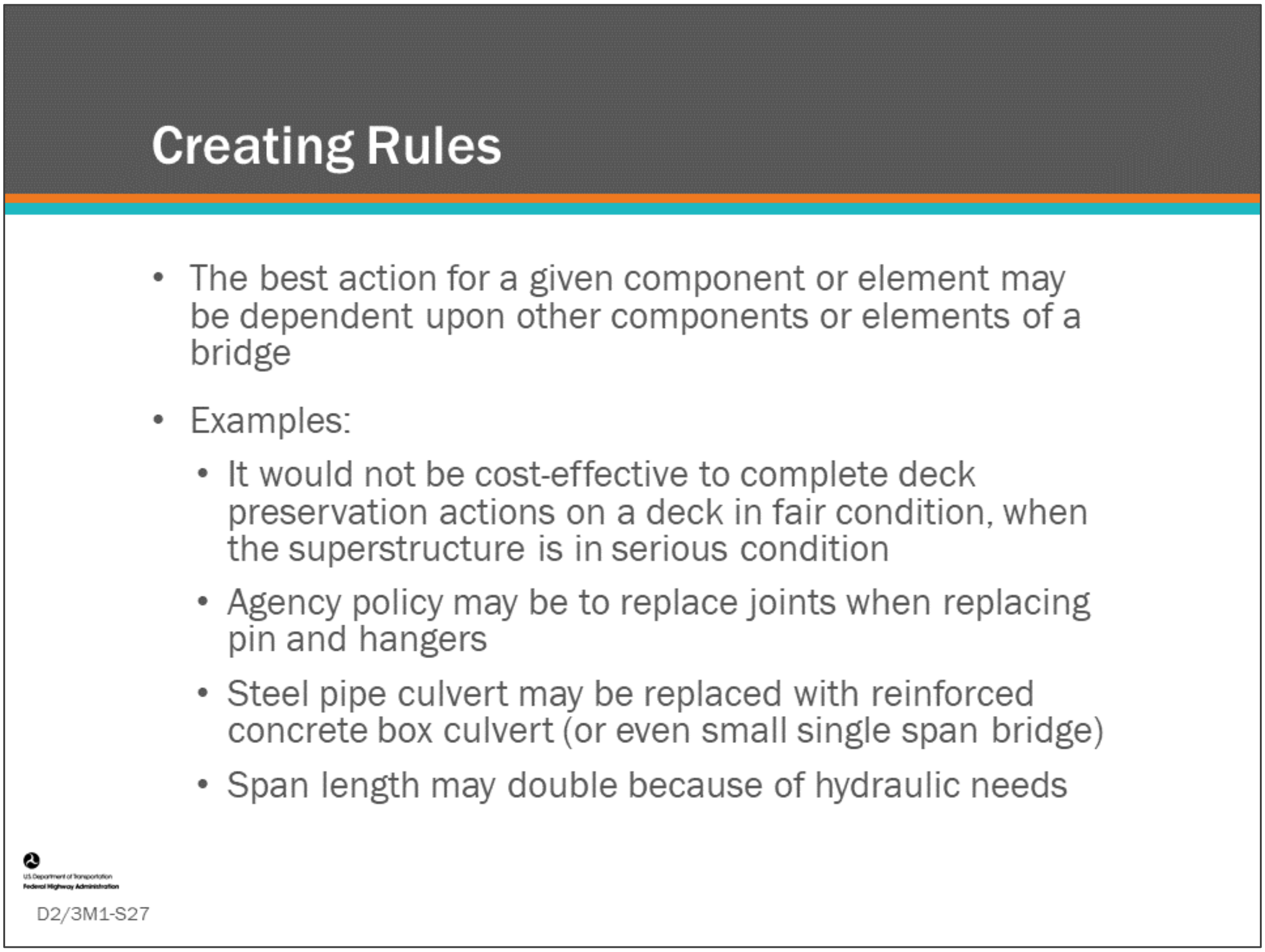


Key Message

When actions are grouped in the BMS to reflect agency rules and policies, the costs of these grouped actions must be input as well.

- In this example, the agency will replace approach slabs, pin and hangers, joints, and railings when replacing decks.

D2/3M1-Slide 27



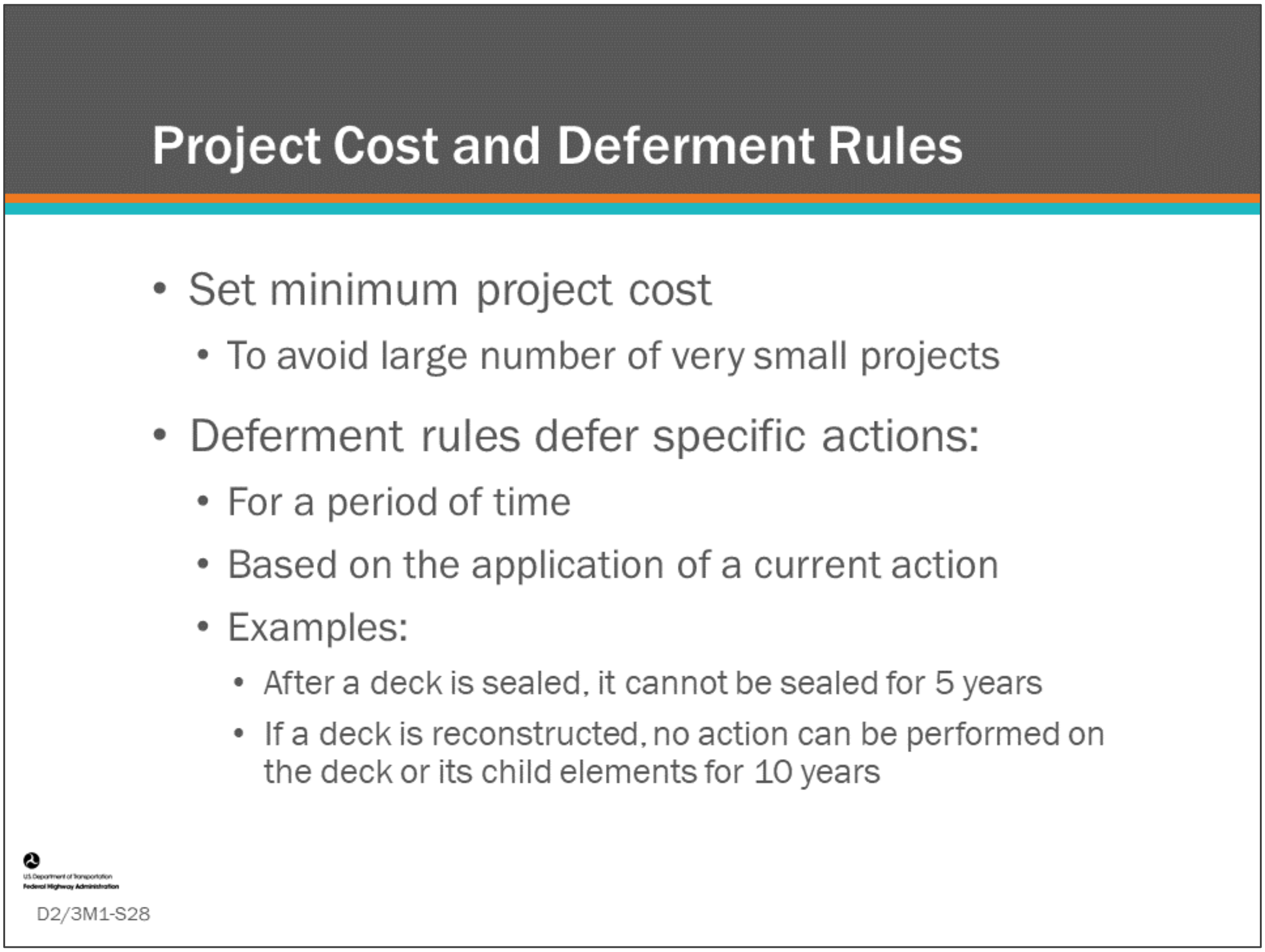
Key Message

When an element or component is replaced, an agency often has rules regarding what the replacement will be and how that replacement effects adjacent or dependent elements or components. You can input restrictions and effects such as these into the BMS, as trigger rules

For example:

- You normally wouldn’t only perform a deck replacement on a bridge whose superstructure GCR is 4 (poor) or less.
- You may replace the expansion joints in the deck whenever pin and hanger assemblies are replaced. Often, it is leaking joints that lead to pin and hangers becoming deteriorated, so it makes sense to protect the new pin and hanger assemblies.
- Agencies may also have policies that elements and components are to be replaced with a different type of element, or the replacement element may have a protective system added.
    - For example, deck replacement can lead to the addition of a deck protection element, such as coated or stainless steel rebars.
    - Deck replacement usually requires new railings, which may be of a different type, such as steel railings replaced with concrete barriers.
    - Joints may either be replaced with different types of joints or eliminated altogether.

D2/3M1-Slide 28



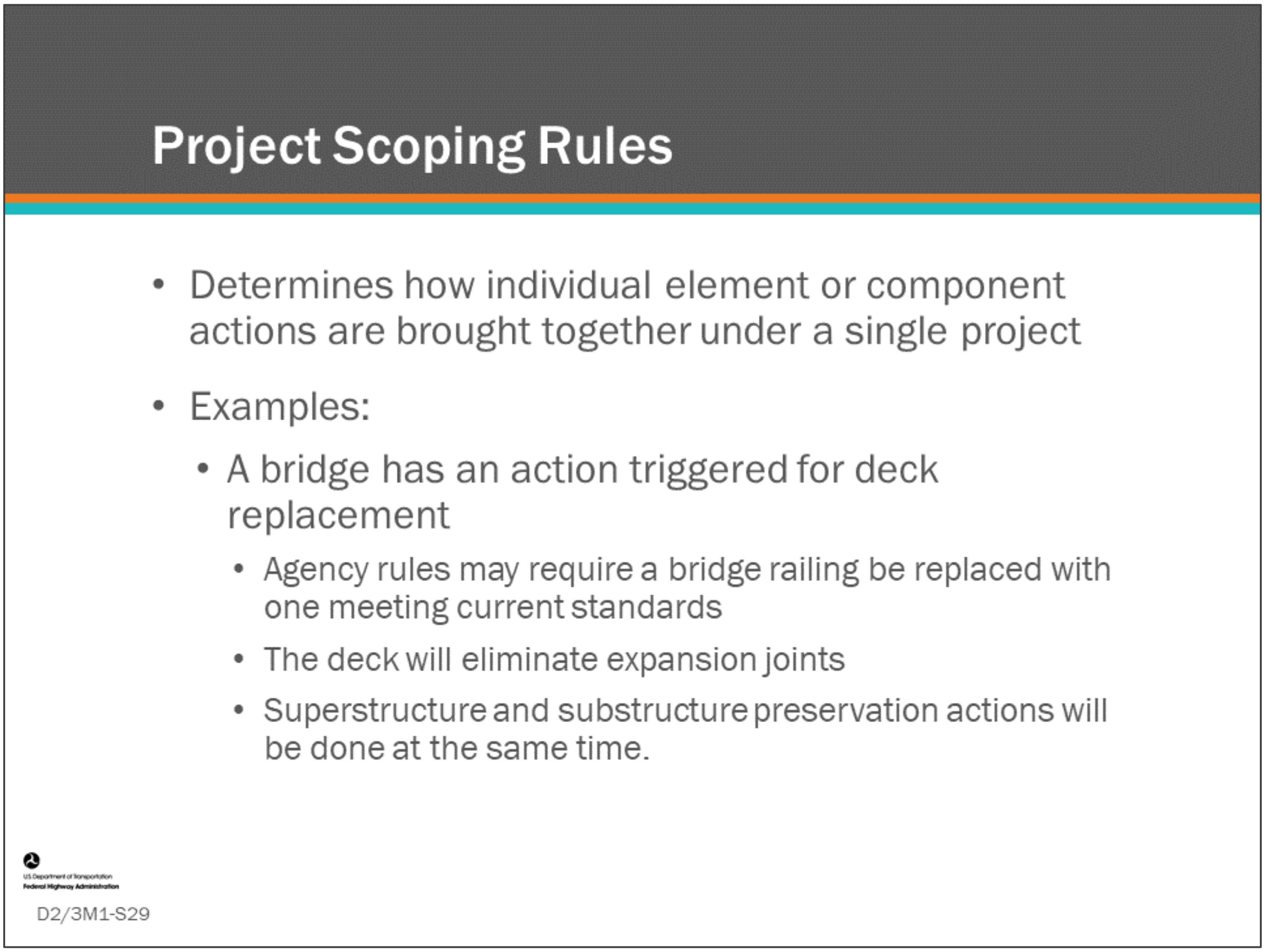
Key Message

A "Deferment Rule" is programmed into a BMS to defer specific actions for a period of time based on the application of the current action.

- For example, if a bridge deck receives a preservation action, such as sealing the deck, the BMS may contain a deferment rule that prevents the same action of sealing the deck from being performed for 5 years.

Deferment rules are often set so that the optimization routine cannot select actions in adjacent years. Deferment rules are often part of network policies for determining life-cycle actions.

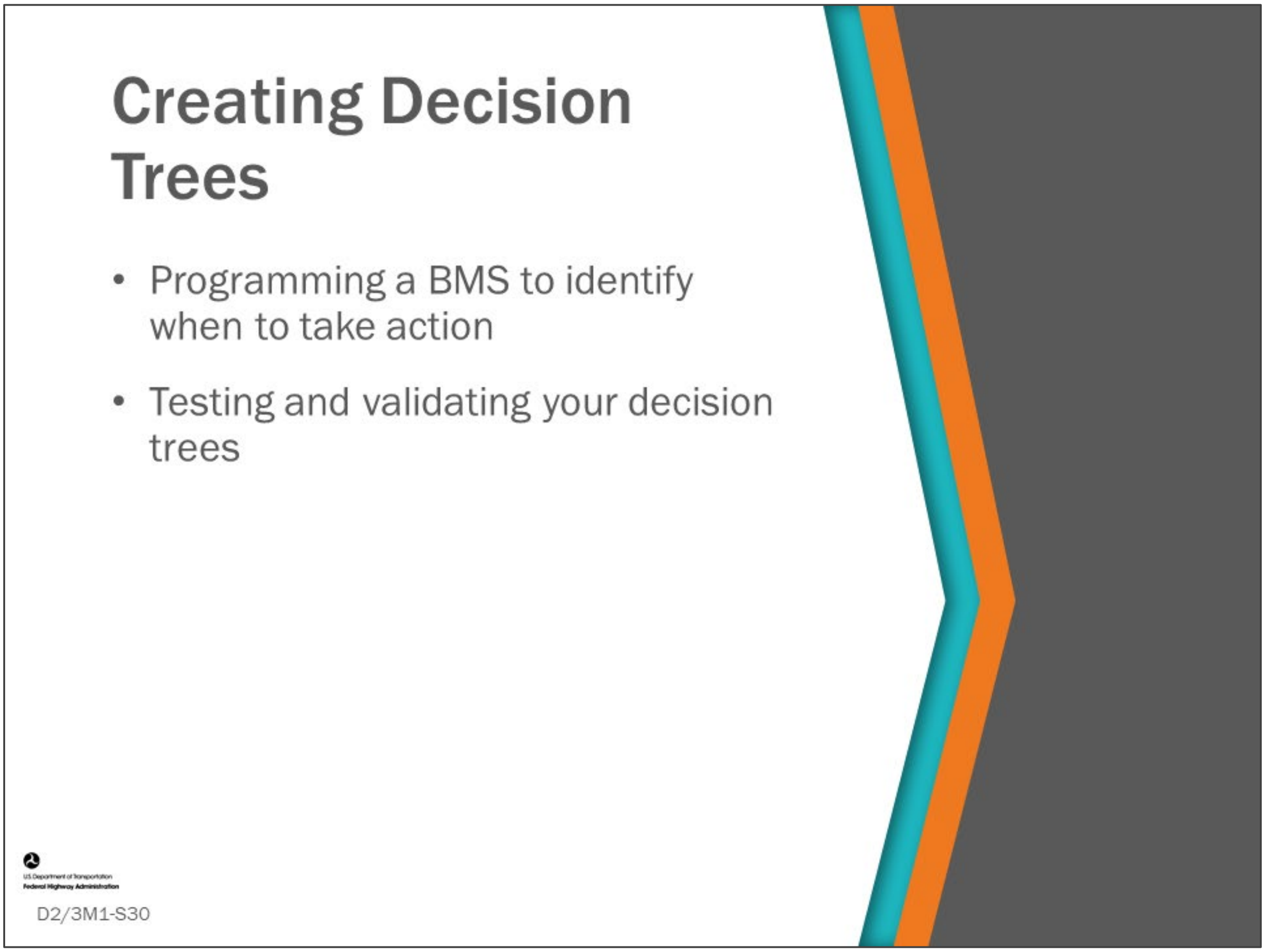
D2/3M1-Slide 29



Key Message

Project scoping rules determine how individual element or component actions are brought together to form a project. This is a very important function of a BMS for it to give realistic projects. It takes the collection of individual element actions and forms a reasonable project that the agency would perform.

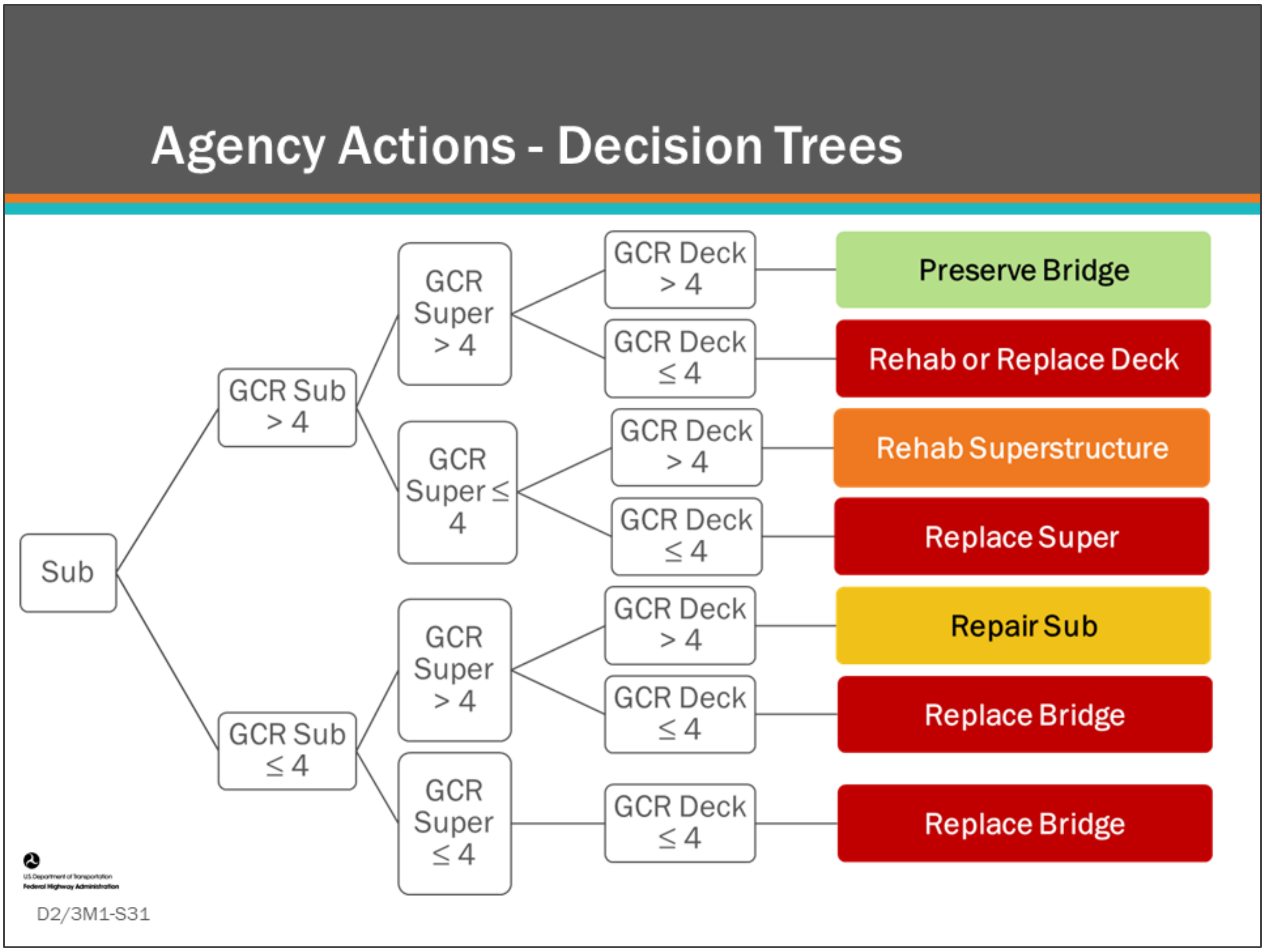
D2/3M1-Slide 30



Key Message

Decision trees are a very important part of a BMS as they indicate when to take action. They can be very challenging to create; and, testing and validation should be completed on your decision trees before they are programmed into your BMS.

D2/3M1-Slide 31



Key Message

Decision trees are used in some BMS to organize and set order to agency actions. For your BMS to give good answers, you need to build decision trees for all bridge component and/or element types and materials. This is because decision trees instruct the BMS to systematically follow agency MR&R and Reconstruction practices.

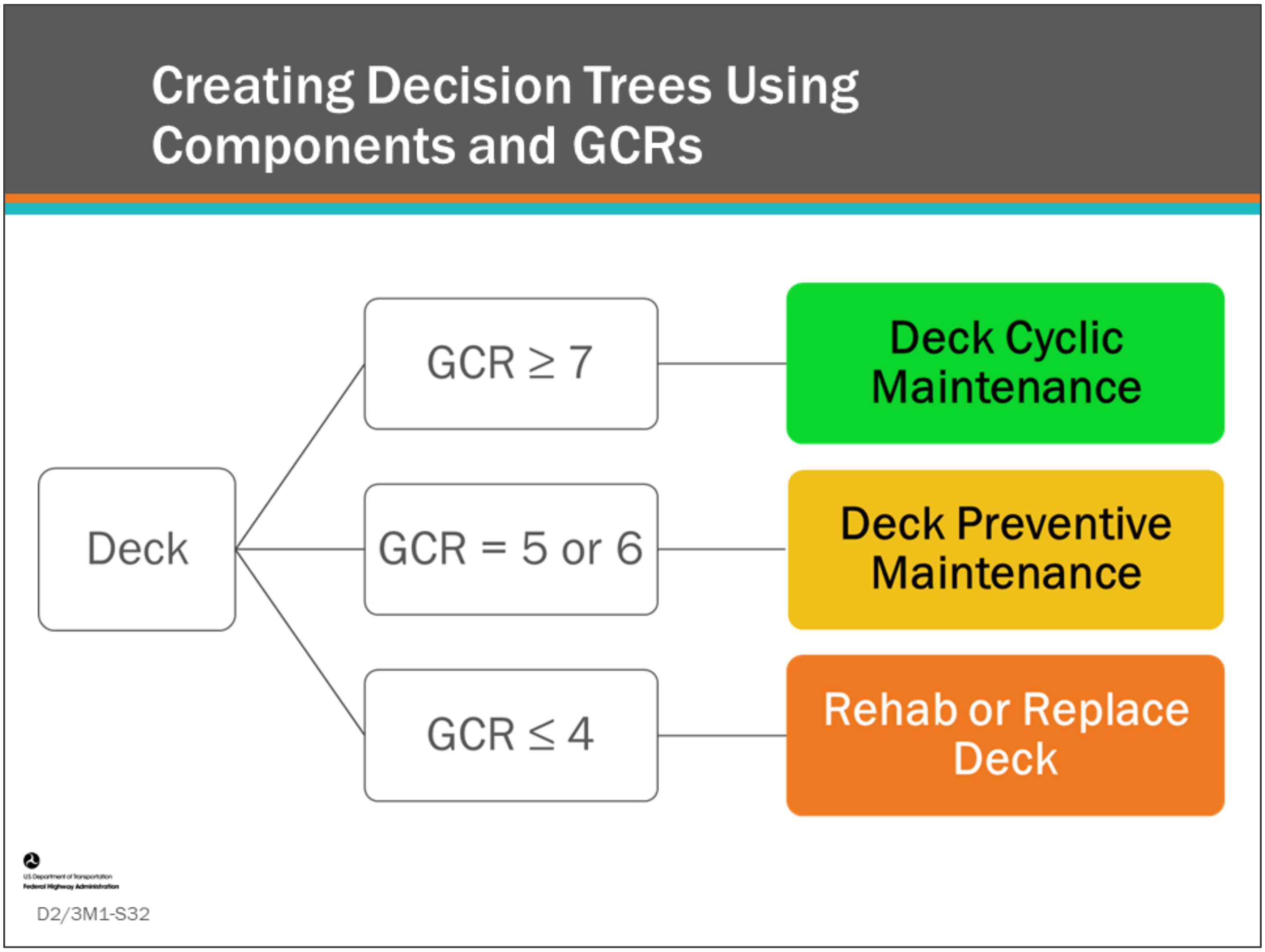
- Shown on this slide is an example decision tree illustrating simple substructure (sub), superstructure (super), and deck decisions depending upon if the components are in poor (GCR less than or equal to 4) or good or fair (GCR greater than 4) condition.

To build a decision tree, one strategy is to begin with the major components and identify all the rehabilitation and reconstruction candidates.

- To start, begin with the substructure because if the substructure is poor, you may need to replace the bridge.
- Then, move up to the superstructure to determine if it needs rehabilitation or replacement.
  - Note, in the decision tree on the slide, when the deck is poor and the superstructure and substructure are good or fair, the action shown is "Rehab or Replace Deck." Typically, a good decision tree only has one possible action, however if your decision tree is at a high level (like the one shown), rehab and replacement actions may be grouped together. A later procedure (for example, using element data or remaining life of superstructure and substructure) may determine a more specific action to the deck.
- Finally, examine the deck to determine its needs.

- Notice, the uppermost box on the right of the example decision tree on this slide says, “Preserve Bridge” in the green box.
- When the substructure, superstructure, and deck are all in good or fair condition, the bridge is a good candidate for preservation, and there can be an entirely new decision tree or management process for setting order for preservation actions.

D2/3M1-Slide 32



Key Message

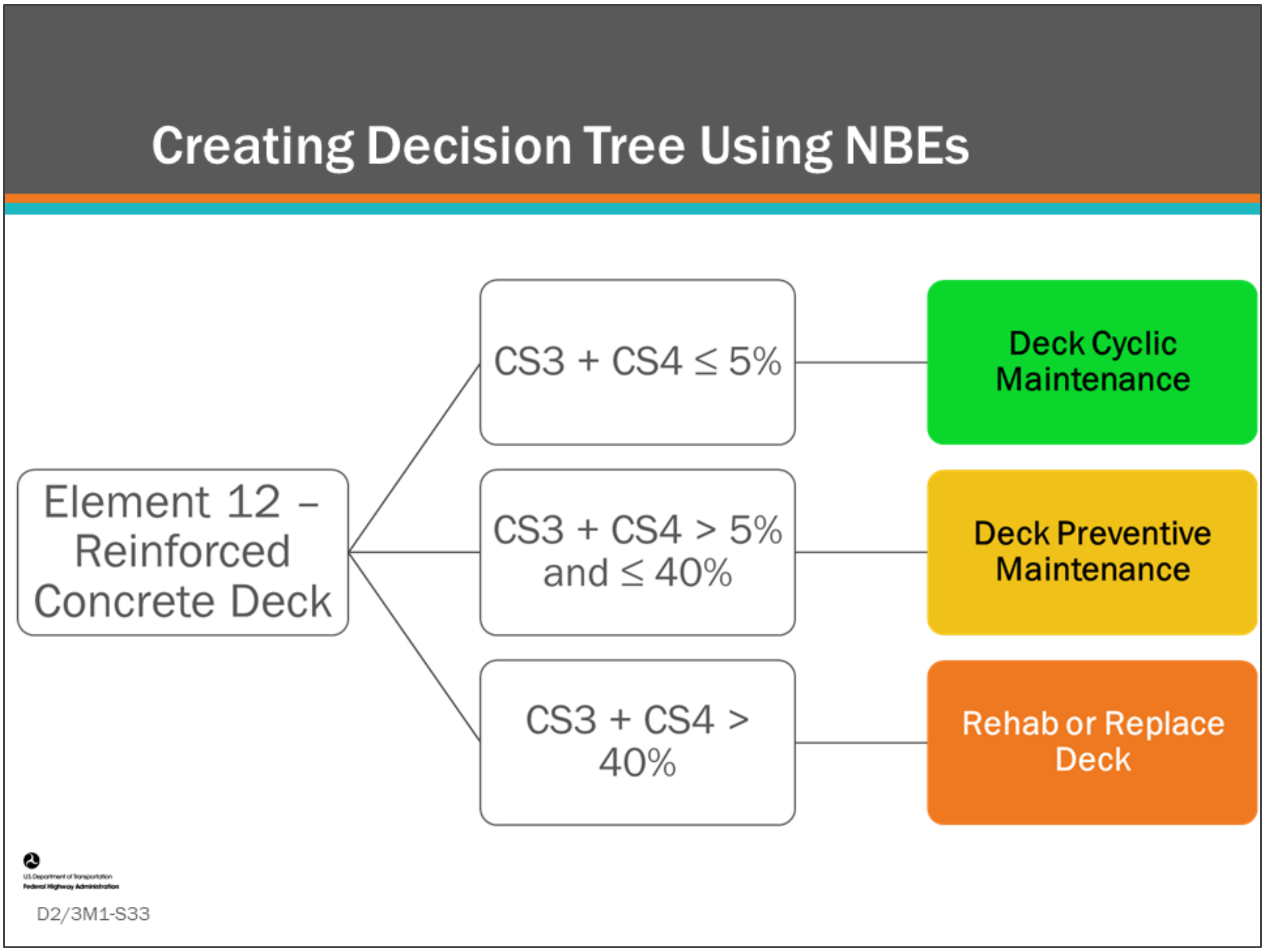
If you want to set up your BMS to only use components and GCRs, then the recommended actions will be general, as shown in this simple decision tree.

Recommendations will be general in nature such as:

- Do Nothing
- Deck Cyclic Maintenance
- Deck Preventive Maintenance
- Rehabilitate or Replace Deck.

This may be adequate for doing long-term budget needs analysis or categorizing general action needs, but GCRs would likely not be used for doing detailed analysis to determine short term preservation needs.

D2/3M1-Slide 33



Key Message

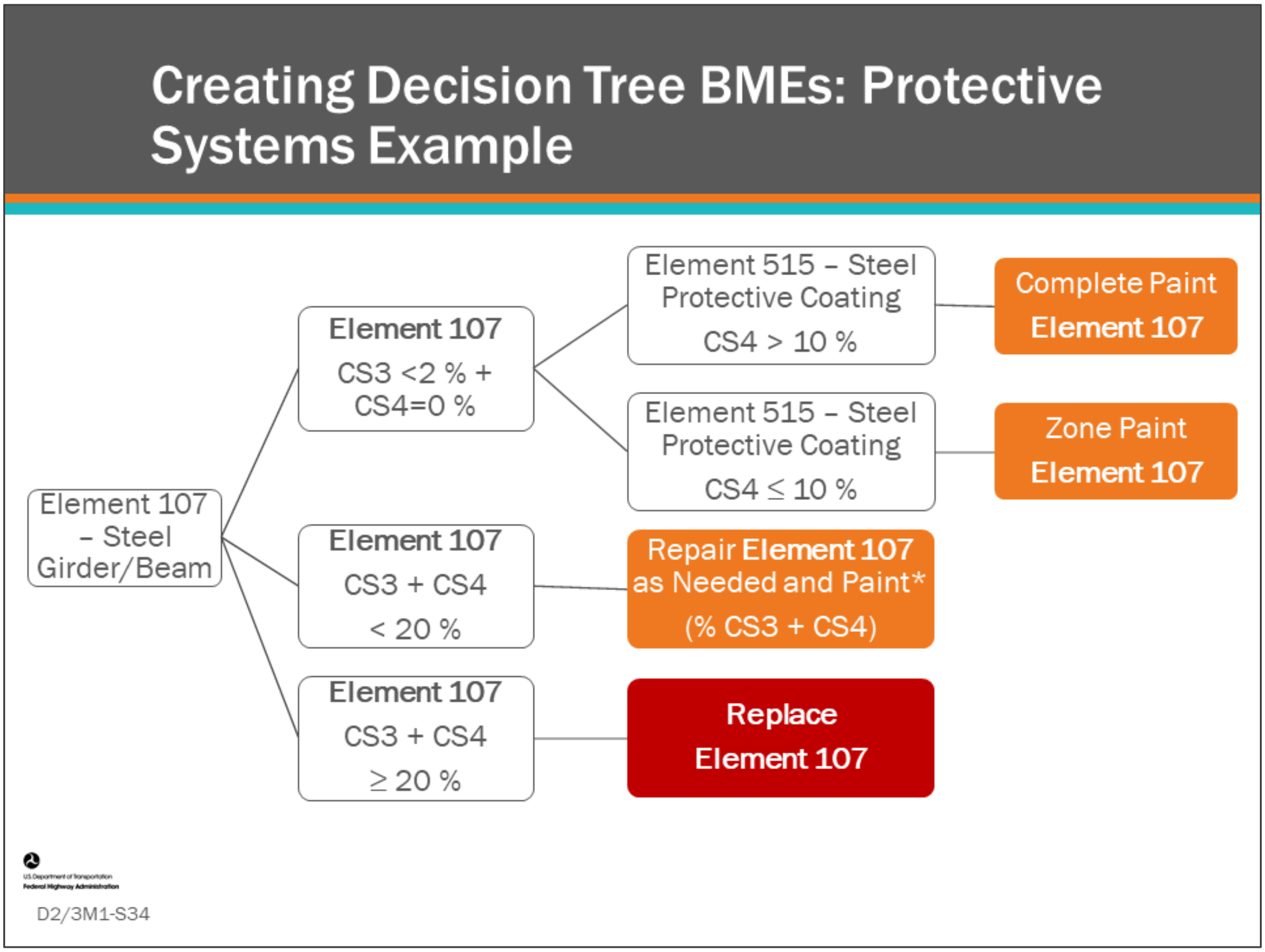
If you want to set up your BMS to only use National Bridge Elements, then you can refine your list of recommended actions. Recommendations may still be general but there will be actions for the specific elements which can be grouped to produce more refined projects. For example, follow-up procedures could look at other decision factors such as age of deck, whether there was a prior rehab, element defect types, etc. to determine more specific actions.

The criteria shown here are still very general. With elements and defects, the actions can be defined much better. For example, if there is abrasion/wear that exceeds 2 percent CS2, then deck cyclic maintenance may still be the most feasible action.

There is also opportunity to use deck Health Index to determine when replacement is needed so that localized deficiencies alone do not dictate. For example, a deck could be CS4 near expansion joint headers but CS2 and CS1 everywhere else which would not warrant replacement. Designation of a multi-criteria rule for replacement such as CS4 greater than 5 percent and HI less than 60 percent can help address this issue.

The rehabilitate or replace deck decision will have follow-on BMS procedures to look at other decision factors such as age of deck, prior deck rehabilitation, element defect types, etc. to determine which is the more feasible action.

D2/3M1-Slide 34



Key Message

Protective systems provide the ability to manage even more detailed actions such as zone painting or complete painting of steel bridge elements.

Shown on this slide is a decision tree for Element 107 – Steel Girder/Beam.

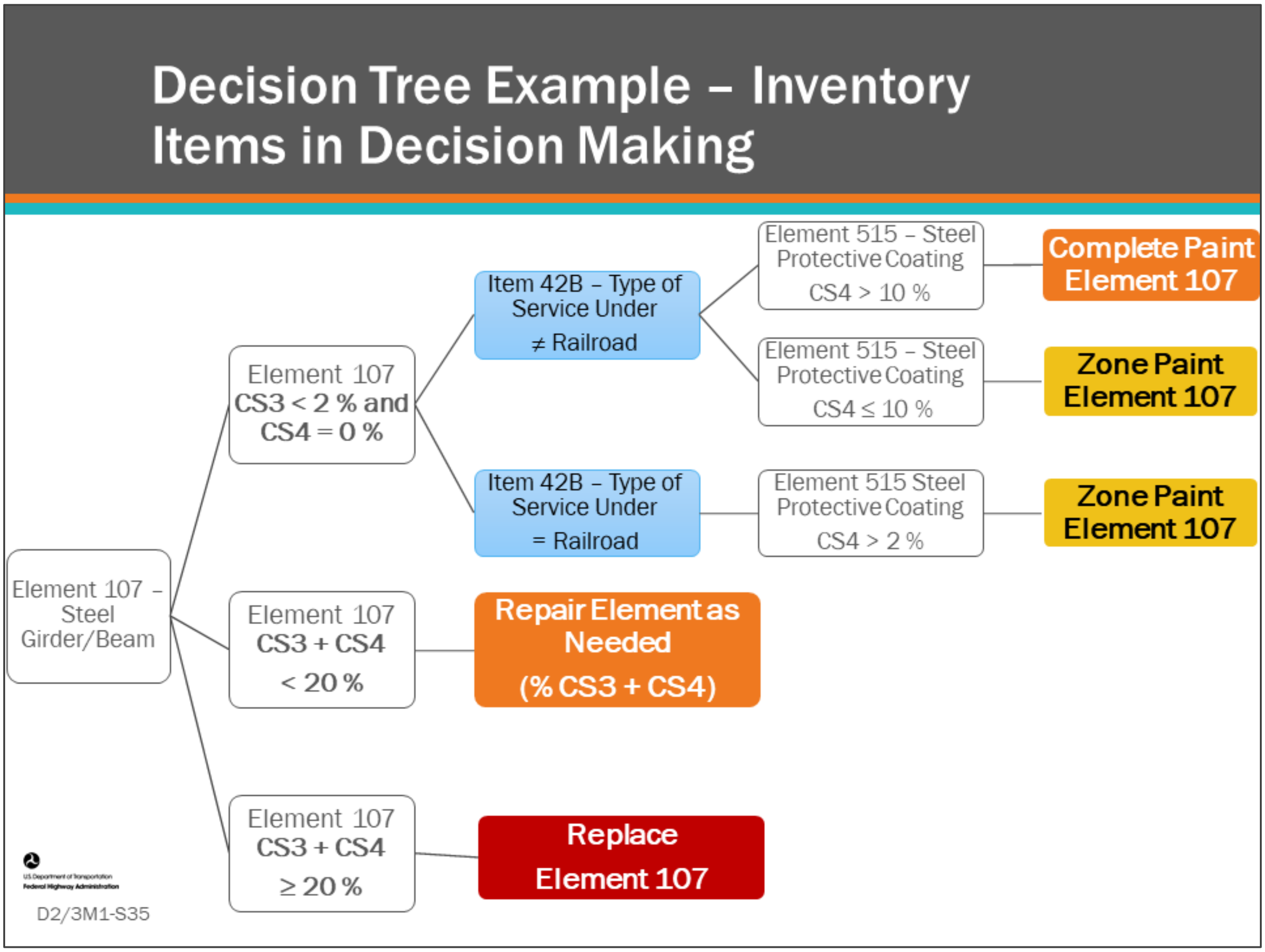
- If 20 percent or more of the beam is CS3 or CS4, then the beam should be replaced.
- If less than 20 percent of the beam is CS3 or CS4, then the beam can be repaired, as needed.
    - Not shown here (lack of space on slide) is Element 515 – Steel Protective Coating criteria. It could be the same criteria shown for element 515 in the slide when Element 107 CS is less than 2 percent and CS4 is equal to 0 percent.

Also shown in the slide is criteria for painting using Protective System Element 515 – Steel Protective Coating.

- If less than or equal to 10 percent of the protective coating is in CS4, then zone paint the area that is deficient.
- If more than 10 percent is in CS4, then perform a complete paint replacement.

Agencies can perform an economic analysis to determine what percentage of the coating system is deficient before it is more cost effective or beneficial to do a complete paint replacement.

D2/3M1-Slide 35



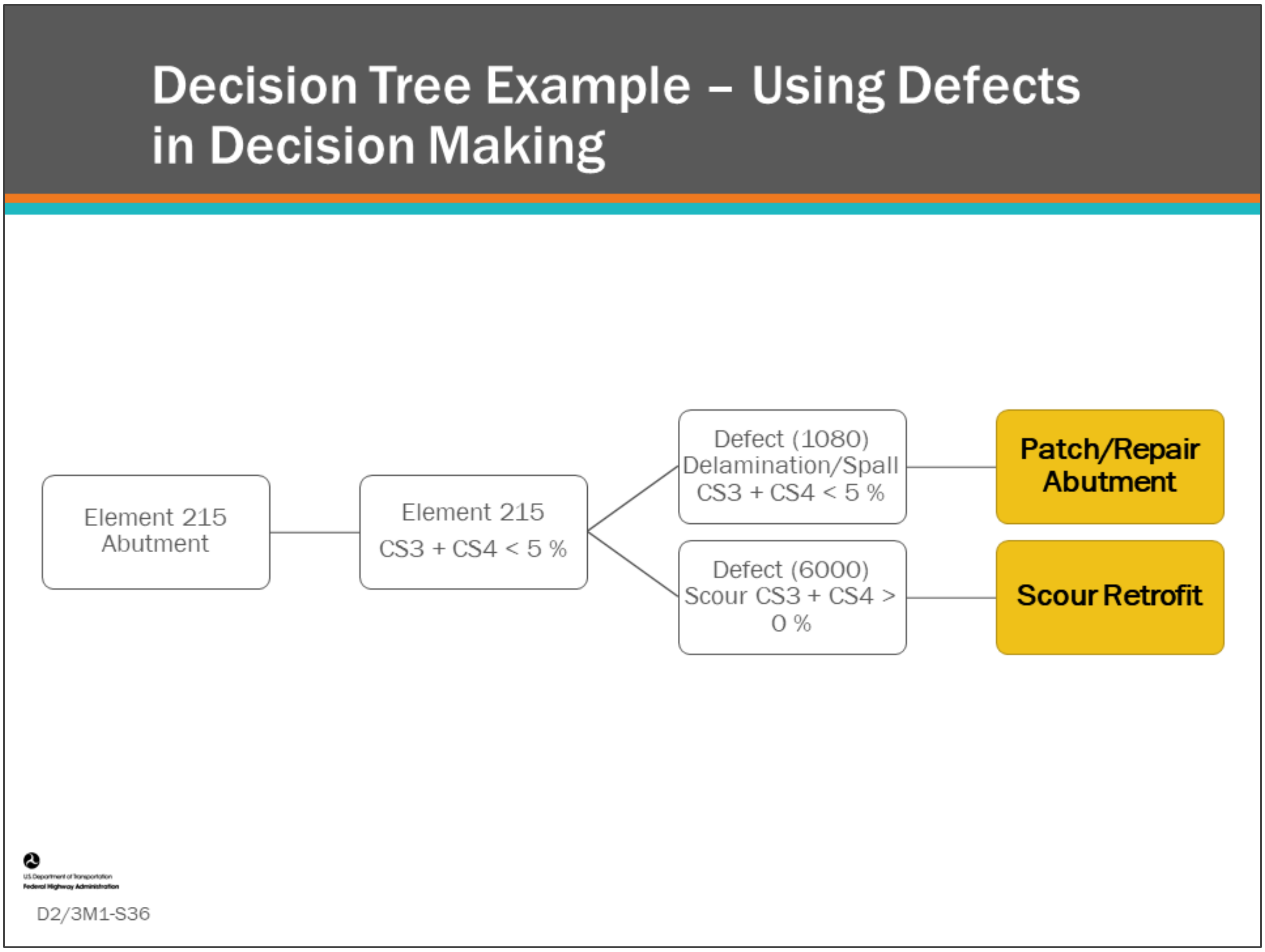
Key Message

Inventory items are often used to set network policies and agency actions.

For example, this can include:

- Item 29 – Average Daily Traffic
- Item 41 – Open, Posted, Closed to Traffic,
- Item 42B – Type of Service On or Under the Bridge

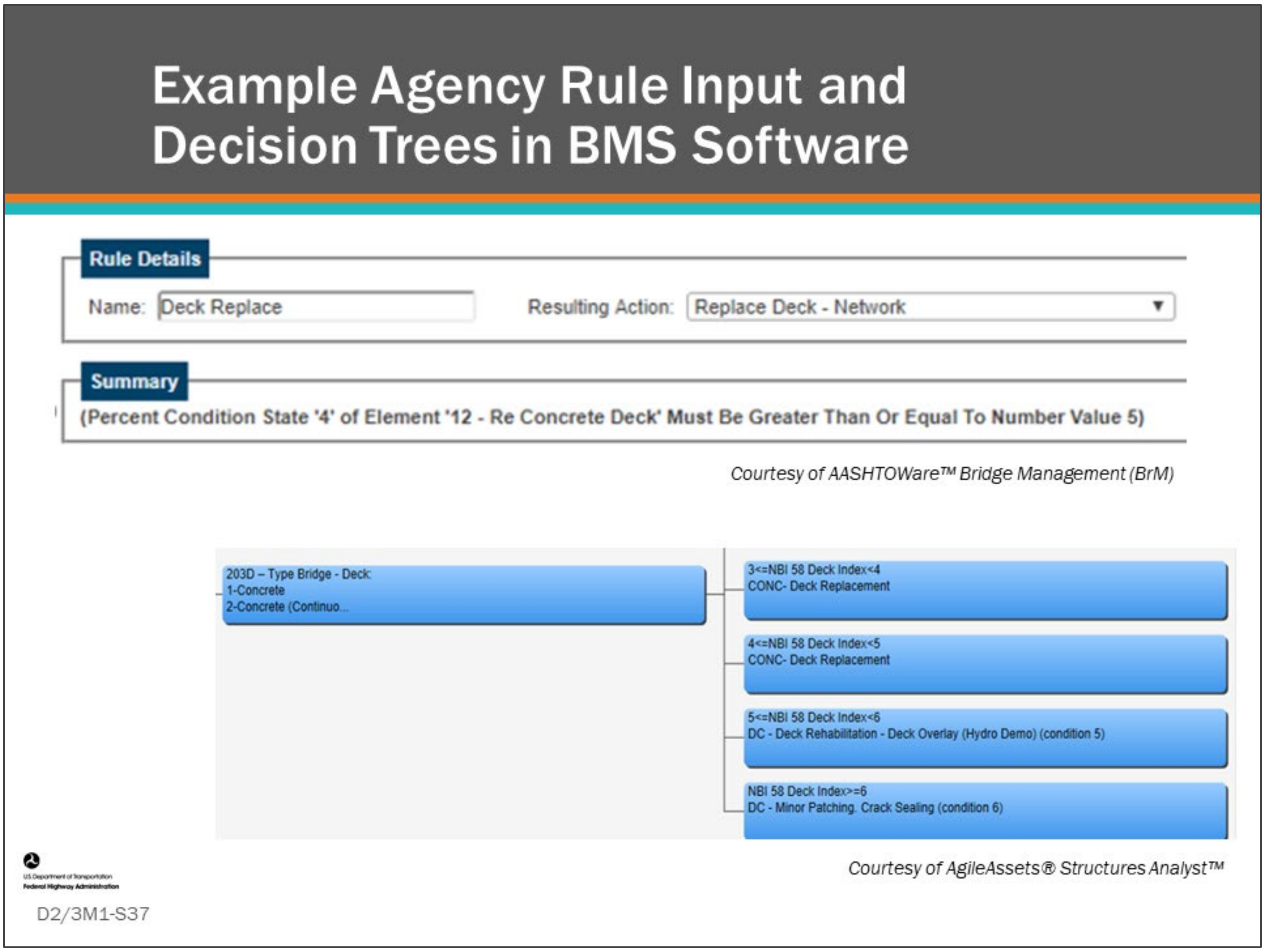
D2/3M1-Slide 36



Key Message

If defects are collected for elements, they also can be used to make MR&R or reconstruction action decisions. Shown in this example decision tree is Element 215 – Abutment having less than 5 percent combined CS3 (poor) and CS4 (severe) ratings. If the defect in CS3 and/or CS4 is Defect 1080 – Delamination/Spall, the MR&R action could be patch/repair abutment wall. However, if the defect is 6000 – Scour, then the action may be a scour retrofit.

D2/3M1-Slide 37

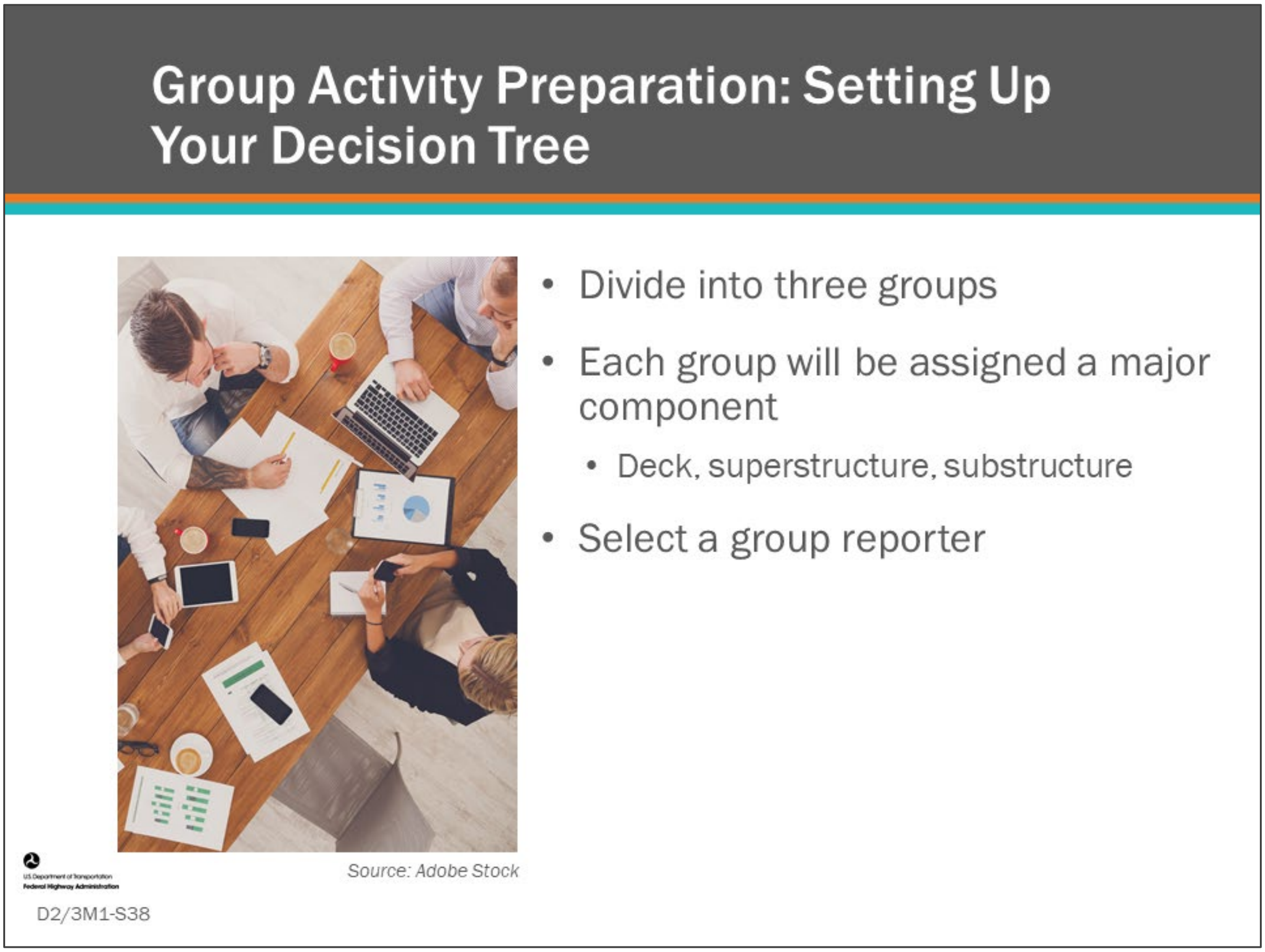


Key Message

BMS software provide agency action rule building screens and decision trees to help visualize agency action rules.

- Some software allows rules to be written directly.

D2/3M1-Slide 38

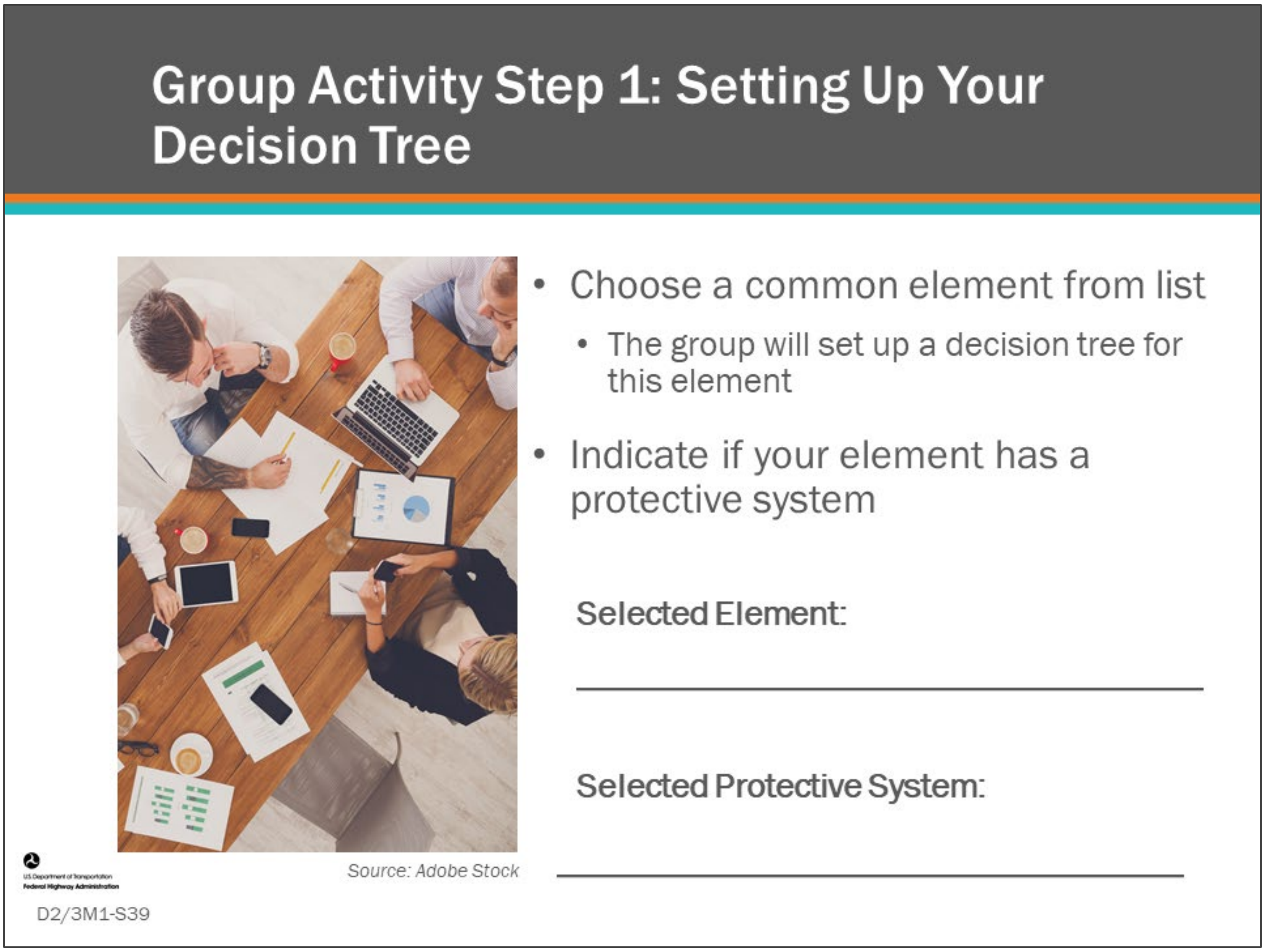


Key Message

In this group activity we are going to build a decision tree for commonly used deck, superstructure, and substructure elements. This will be done in multiple steps as shown on the following slides.

- Get into your groups
- Assign a group note taker and reporter

D2/3M1-Slide 39



Key Message

Given your assigned component:

- Choose a common element for your major component that you will create a decision tree for. If multiple groups have the same major component the instructor will assist picking sperate elements and materials for that component.
- Indicate if there is a protective system for the element.
- Record your element and its protective system on your flip chart.

D2/3M1 - Slide 39: Setting Up Your Decision Tree – Step 1

Your Selected Element.

Your Selected Protective System (If Appropriate)

D2/3M1-Slide 40

Group Activity Step 2: Setting Up Your Decision Tree

Source: Adobe Stock

List all actions performed to your group's chosen element and protective system:

- ______________________
- ______________________
- ______________________
- ______________________
- ______________________

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Key Message

Given your chosen element, list all actions performed to the element and its protective system on your flip chart.

D2/3M1 - Slide 40: Setting Up Your Decision Tree – Step 2

List all actions performed to your group's chosen element and protective system.

D2/3M1-Slide 41

Group Activity Step 3: Setting Up Your Decision Tree

Source: Adobe Stock

Set trigger values for each action for your element and protective system.

D2/3M1-S41

Key Message

Using your chosen element, set trigger values for each action for your element and protective system and record them on your flip chart.

D2/3M1 - Slide 41: Setting Up Your Decision Tree – Step 3

Set trigger values for each action for your element and protective system.

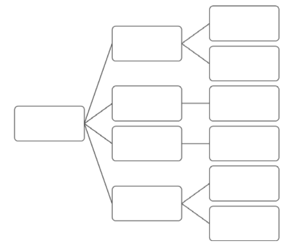
D2/3M1-Slide 42

Key Message

Group exercise:

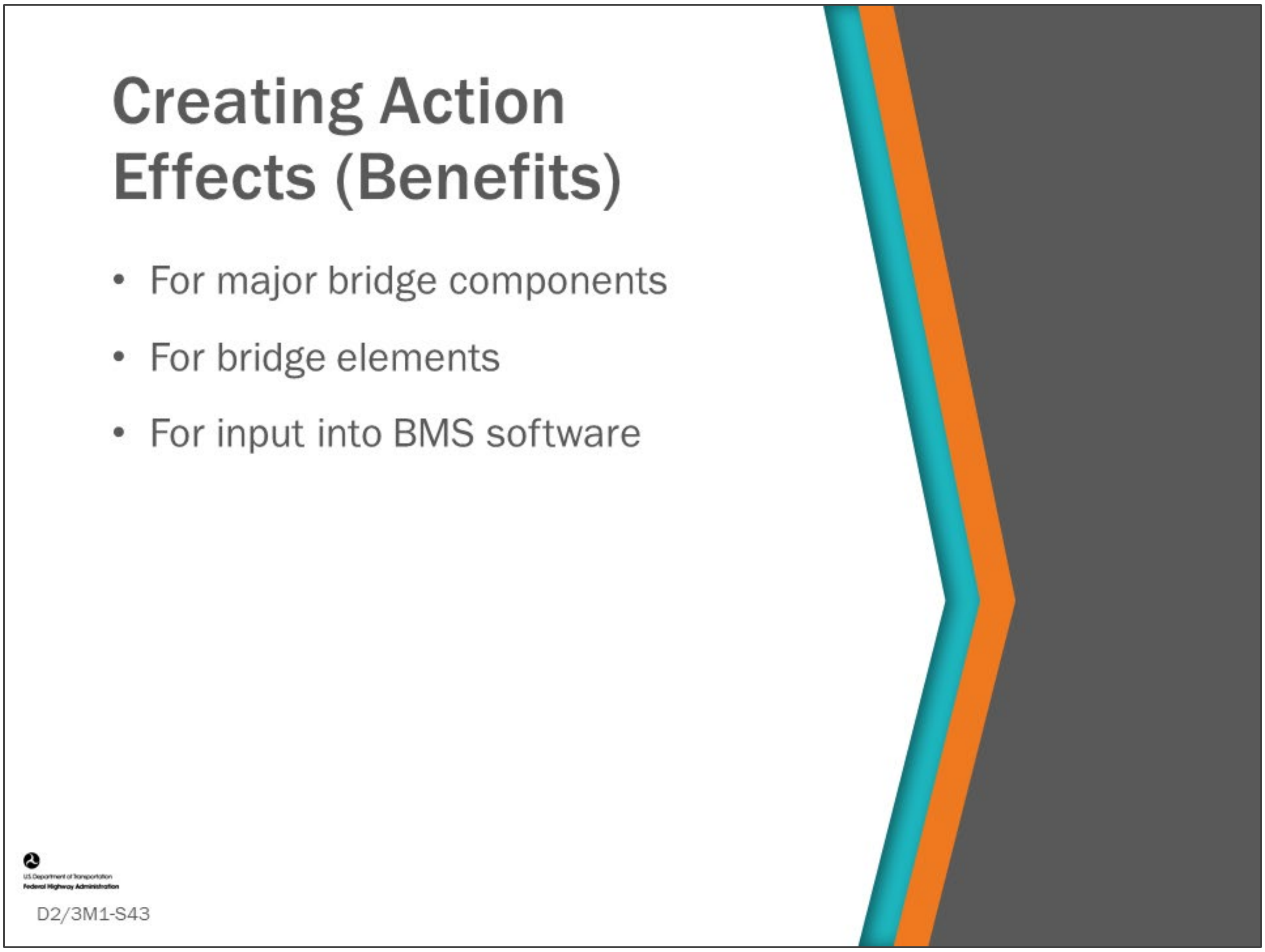
- Develop a decision tree for your groups assigned element

D2/3M1 - Slide 42: Setting Up Your Decision Tree – Step 4



Create a decision tree for your groups assigned element.

D2/3M1-Slide 43



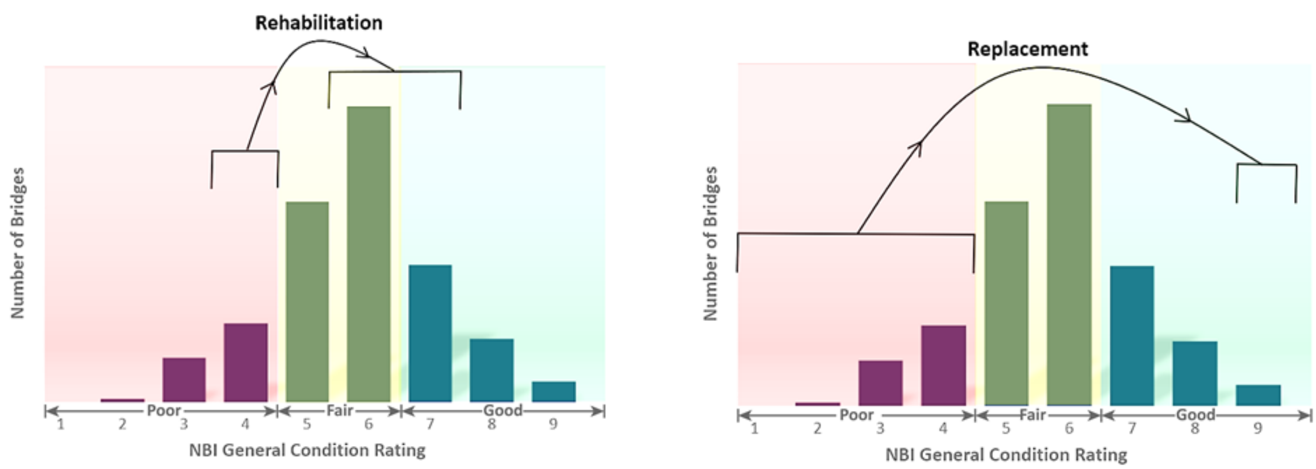
Key Message

In this section, we will discuss action benefits:

- For major bridge components
- For bridge elements
- For input into BMS software

D2/3M1-Slide 44

Creating Action Effects (Benefits) – For Bridge Major Components



	General Condition Rating (GCR)		
	Deck	Superstructure	Substructure
Prior To Action	3	4	7
After Action	9	9	7

D2/3M1-S44

Key Message

Component benefit from actions is easy to track. The table on this slide provides an example of a bridge that had a deck GCR of 3 (serious), a superstructure GCR of 4 (poor), and a substructure GCR of 7 (good).

- Following the rehabilitation action to the bridge, the GCRs improved resulting in the deck GCR of 9 (excellent), superstructure GCR of 9 (excellent), and substructure GCR of 7 (good).

An action effectiveness model can be developed by monitoring action benefits trends from many projects. The effect on condition can be expressed in a matrix of probabilities.

- This can be updated periodically.

Action benefit rules can be input in the BMS software indicating estimated improvement for rehabilitation and reconstruction (replacement) projects, but components rating improvements often do not result from preservation projects for bridges already in good or fair condition.

D2/3M1-Slide 45

Creating Action Effects (Benefits) – For Bridge Elements

Element Condition State Ratings Before Action (Project)

Element Number	Element Name	Total Quantity	Units	CS1	CS2	CS3	CS4
12	Concrete Deck	300	SFT	0	300		
107	Steel Girder/Beam	100	LFT	61	34	5	
215	Concrete Abutment	24	LFT	24			
300	Strip Seal Expansion Joint	24	LFT	0			24
515	Steel Protective Coating	1200	SFT	0	600	400	200

Element Condition State Ratings After Action (Project)

Element Number	Element Name	Total Quantity	Units	CS1	CS2	CS3	CS4
12	Concrete Deck	300	SFT	0	300		
107	Steel Girder/Beam	100	LFT	66	34	0	
215	Concrete Abutment	24	LFT	24			
300	Strip Seal Expansion Joint	24	LFT	24			0
515	Steel Protective Coating	1200	SFT	1200	0	0	0

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D2/3M1-S45

Key Message

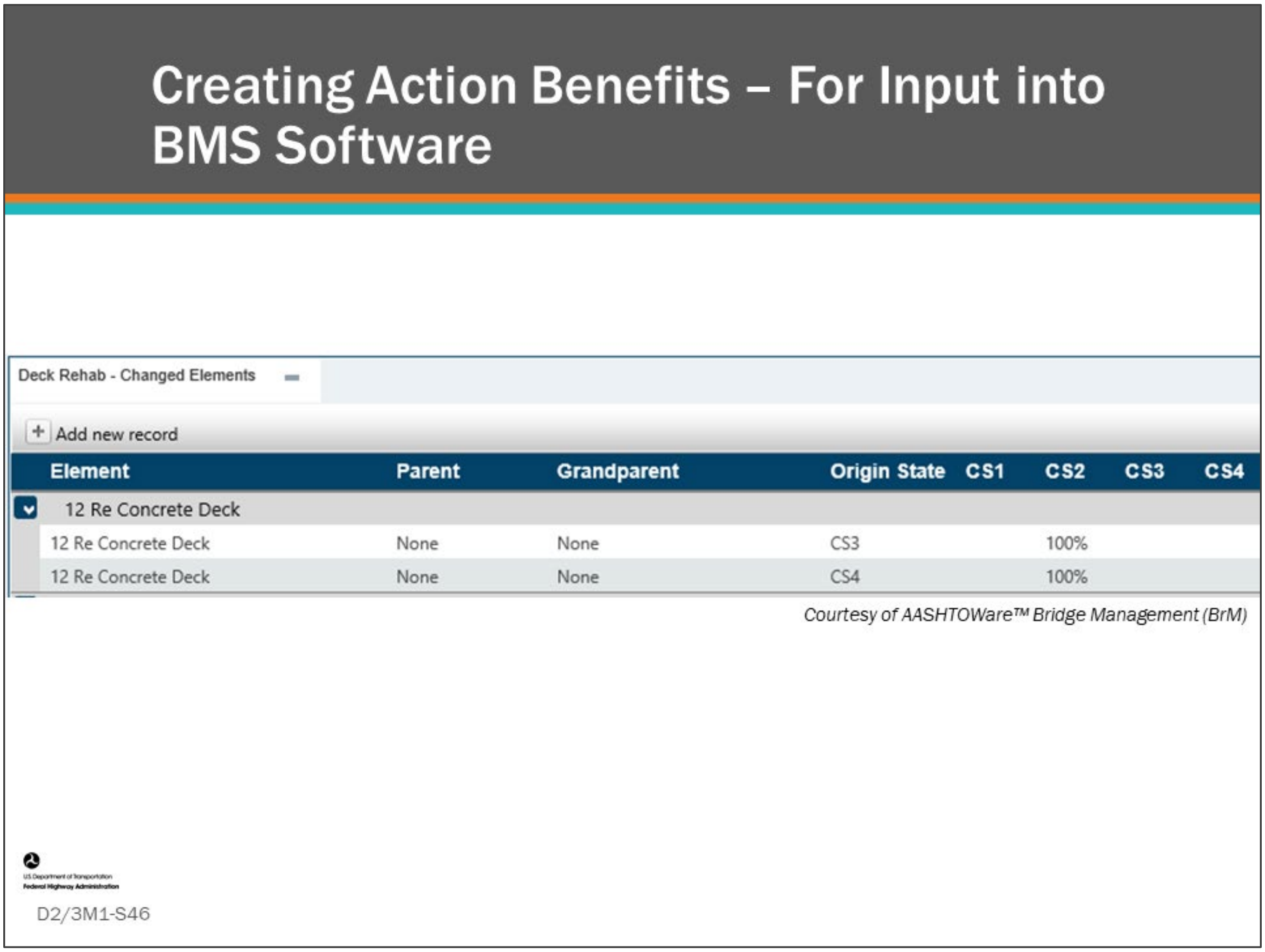
Estimating element improvements from actions is simple, when you have the data. The two tables in this slide show element condition ratings before and after an action. We can see that:

- 5 lineal ft. of Element 107 – Steel Girder/Beam improved form CS3 to CS1;
- 24 lineal ft. of Element 300 – Strip Seal Expansion Joint improved from CS4 to CS1; and,
- 1,200 square ft. of Element 515 – Steel Protective Coating improved from various quantities of CS2, CS3 and CS4 to CS1.

An action effectiveness model can be developed by monitoring action benefits trends from many projects. The effect on condition can be expressed in a matrix of probabilities.

- This can be updated each year.

D2/3M1-Slide 46



Key Message

In AASHTOWare™ Bridge Management (BrM), benefits from action are entered into the Admin > Modeling Config > Benefit Groups screen, as shown on this slide. On this screen of the BMS, you can program the effect of a specific action or actions applied to a structure.

- This screenshot shows that when a deck is rehabilitated, 100 percent of Element 12 – Reinforced Concrete Deck will be placed in CS2. Example - 100 percent of CS3 and CS4 will go to CS2. CS2 will stay in CS2 and CS1 will remain in CS1.
    - This type of programming needs to be completed for every action and every element

D2/3M1-Slide 47

Group Activity and Class Discussion: Setting Element Benefits Resulting From Actions

Source: Adobe Stock

Assign benefits for all of the actions identified for your group's chosen element:

- ____________________
- ____________________
- ____________________
- ____________________
- ____________________

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D2/3M1-S47

Key Message

Group exercise:

- Using the same groups from the Decision Tree Activity, assign benefits for all the actions identified for your group's chosen element.

D2/3M1 - Slide 47: Setting Element Benefits Resulting From Actions

Assign benefits for all actions identified for your group's chosen element.

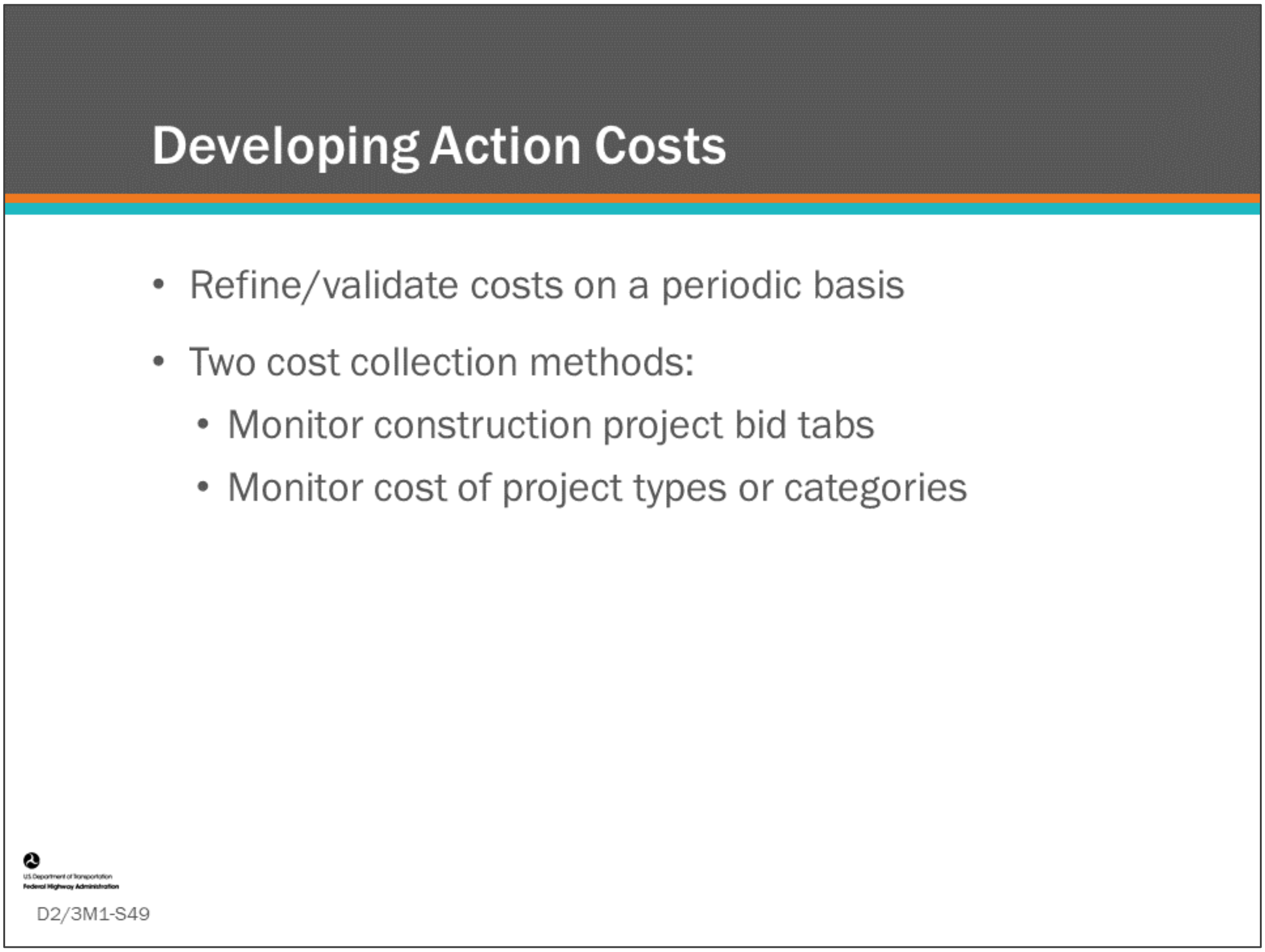
D2/3M1-Slide 48

Key Message

In this section of the module, we will discuss direct and indirect agency costs, including:

- Development of action costs
- Direct and indirect costs in bid tabs

D2/3M1-Slide 49



Key Message

It is important that the action costs or treatment costs, are routinely monitored and analyzed as they are a key component in a BMS decision making methodology.

- It is necessary to get the best available unit costs input into the BMS initially and refine/validate those costs on a periodic basis
    - This is not a straight-forward task as construction project pay items rarely match units used for BMS elements
    - Also, indirect costs such as traffic control and mobilization can be a large percentage of the action cost, especially for preservation projects
- Two methods for collecting agency direct and indirect action costs include:
    - Monitor construction project bid tabs
    - Monitor cost of project types or categories

Some states have used spreadsheets linked to bid cost data that is updated periodically and produces scripts to update database cost tables

D2/3M1-Slide 50

Direct Costs – Bid Tabs

Line	Item /Description	Quantity	Estimated Price	Bid Price /Units	Estimated Amount
SECTION: 0001 BID ITEMS					
0285	507-00100 Concrete Slope and Ditch Paving (Reinforced)	200.00	450.00	425.00 CY	90,000.00
0290	515-00120 Waterproofing (Membrane)	3,066.00	25.00	16.00 SY	76,650.00
0295	518-01004 Bridge Expansion Device (0-4 Inch)	196.00	200.00	225.00 LF	39,200
0300	601-03040 Concrete Class D (Bridge)	1,488.00	500.00	575.00 CY	744,000.00
0305	601-03050 601-Concrete Class D (Wall)	6.00	1,300.00	730.00 CY	7,800.00
0310	602-0020 Reinforcing Steel (Epoxy Coated)	380,000.00	1.00	1.15 LB	0.00
0315	604-00505 Inlet Type D (5 Foot)	2.00	5,000.00	4,000.00 EACH	10,000.00
0320	604-25000 Vane Grate Inlet Special	2.00	8, 000.00	14,000.00 EACH	16,000.00

D2/3M1-S50

Key Message

In the first day of this workshop, we learned about direct and indirect agency costs

- Direct costs are those that can be attributed directly to components and elements in their unit of measure and indirect cost are those costs that cannot be easily attributed to a component or element.
- Even when a pay item is considered a direct cost, it can be difficult to directly link it to a bridge element because the unit of measures are different.
    - For example, the bid tab shown on this slide identifies quantities for "Concrete Class D" deck concrete in cubic yards (CY) and "Reinforcing Steel (Epoxy Coated)" in pounds, while deck elements are measured in square feet and include the concrete and reinforcing steel direct costs.

D2/3M1-Slide 51

Indirect Costs – Bid Tabs

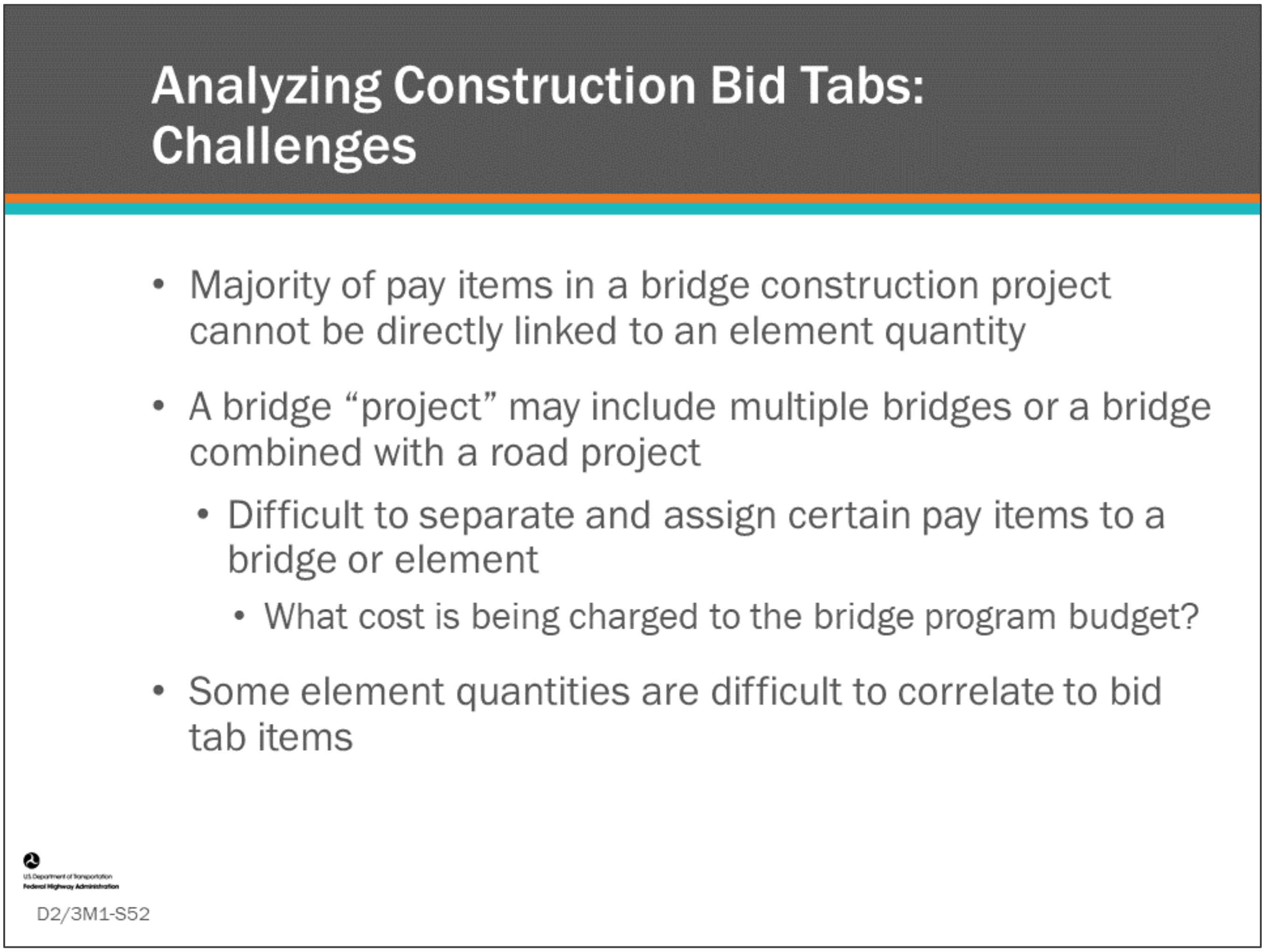
Line	Item /Description	Quantity	Estimated Price	Bid Price /Units	Estimated Amount
SECTION: 0001 BID ITEMS					
0445	621-00425 Detour	2.0	420,000.00	1,000,000.00 LS	420,000.00
0450	624-30037 36 Inch Drainage Pipe	290.0	120.00	150.00.00 LF	36,250.00
0455	625-00000 Construction Surveying	1.0	150,000.00	85,000.00 LS	150,000.00
0460	626-00000 Mobilization	1.0	432,000.00	430,000.00 LS	432,000.00
0465	626-01103 Public Information Services (Tier III)	1.0	10,000.00	33,000.00 LS	10,000.00
0470	627-00009 Modified Epoxy Pavement Marking (Inlaid)	45.0	180.00	180,00 GAL	8100.00
0475	627-00013 Pavement Marking Paint (High Build)	940.0	38.00	45.00 GAL	35,720.00
0480	627-01010 Preformed Plastic Pavement Marking (Type I) (Inlaid)	800.0	20.00	18.00 SF	16,000

D2/3M1-S51

Key Message

Another approach to setting unit cost for elements and indirect cost multipliers for a BMS is to relate overall project to categories of work as shown in the slide which can be separated into actions. An agency may have cost templates for various types of work, including separating the bridge program into categories as shown in this slide. Projects should be analyzed each year to track trends for project costs. This can be as simple as dividing the overall project cost to the deck area of the existing bridge, or the cost can be assigned to the element conditions that improved as discussed in the Action effects (benefits) section.

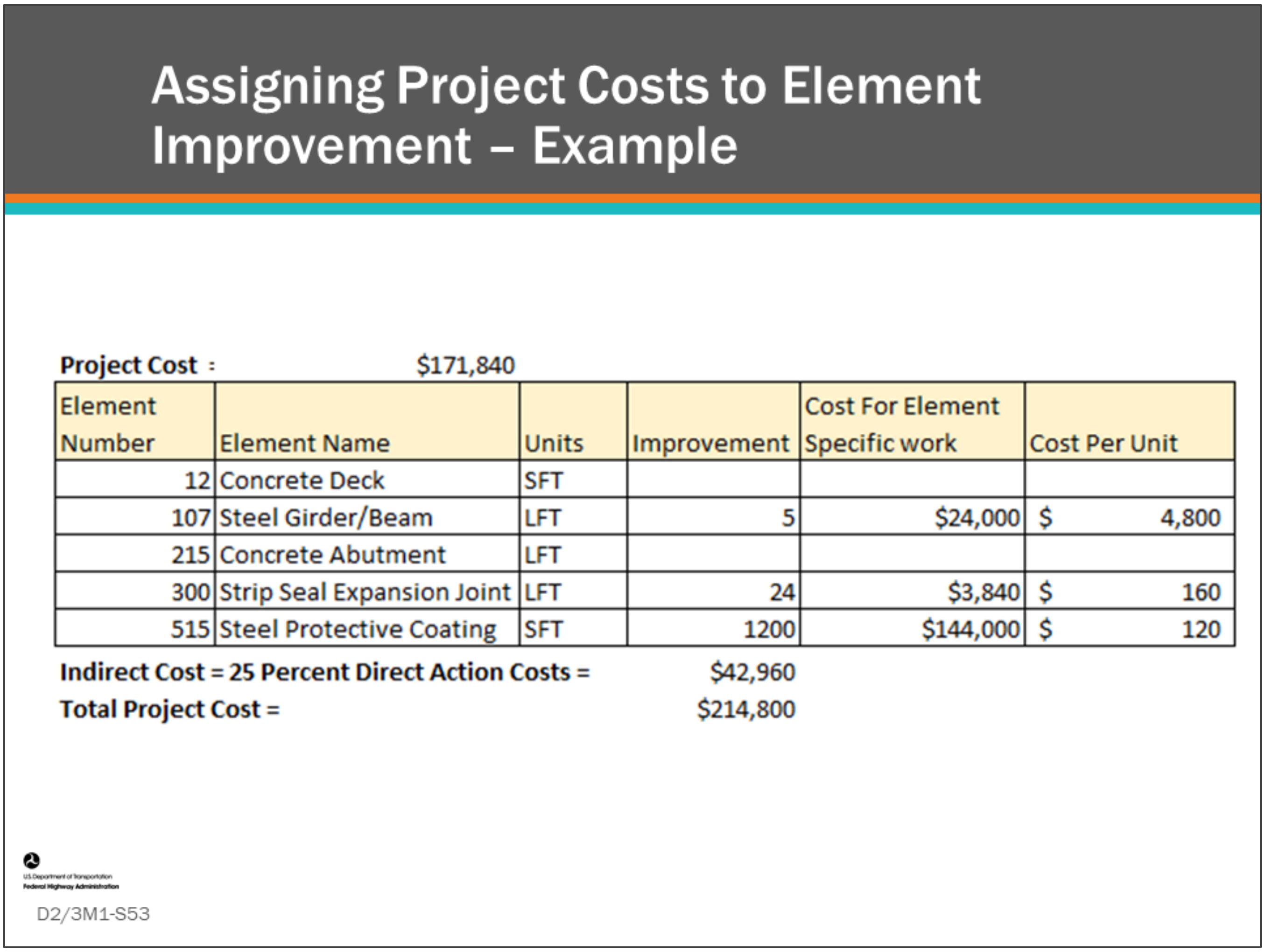
D2/3M1-Slide 52



Key Message

Although some construction item and element quantities do not match, a correlation can often be derived. For example, if the common deck thickness is 9 inches, then the area of a deck can be estimated by converting the volume of concrete to cubic feet and dividing by 0.75. A correlation cannot be obtained for many elements however; and, one may need to apply a largely manual process to identify unit costs.

D2/3M1-Slide 53



Project Cost : $171,840

Element Number	Element Name	Units	Improvement	Cost For Element Specific work	Cost Per Unit
12	Concrete Deck	SFT			
107	Steel Girder/Beam	LFT	5	$24,000	$ 4,800
215	Concrete Abutment	LFT			
300	Strip Seal Expansion Joint	LFT	24	$3,840	$ 160
515	Steel Protective Coating	SFT	1200	$144,000	$ 120

Indirect Cost = 25 Percent Direct Action Costs = $42,960

Total Project Cost = $214,800

Key Message

An analysis of project costs can also be used to estimate cost per unit of measure for elements, as demonstrated on this slide.

The steps to do this are as follows:

1. For a project, using bid tabs, estimate what the average percentage of the total cost is indirect cost. This is shown as 25 percent in the slide.
2. For the remaining bid tab costs, assign the appropriate portion to each element that was included in the project.
    - For example: $24,000 was allocated to Element 107 – Steel Girder/Beam
3. Calculate the unit cost for each element by dividing the cost apportioned to the element by the quantity of the element that was improved.
    - For example, for Steel Girder/Beam: $24,000 divided by 5 is equal to $4,800 per unit

Alternatively, if using unit costs for actions based on the deck area alone, the above reduces to:

1. For each of the chosen set of projects in the sample, for a specific action type, calculate the total cost divided by the bridge deck area as the unit cost per square ft. of deck area.
2. Take the average (or weighted average, if preferred) of these unit costs as the unit cost to be used in the BMS for that action.

Keep in mind that costs per unit deck area generally can only be applied accurately when the full quantity of the element on the bridge has work performed, for example deck overlay or patch and overlay, beam painting, beam replacement, and deck replacement. This is not an accurate approach to cost estimating when the element varies widely in quantity from bridge to bridge and a relation with deck area cannot be accurately established (for example quantity of deck joints, substructure, rail, etc.).

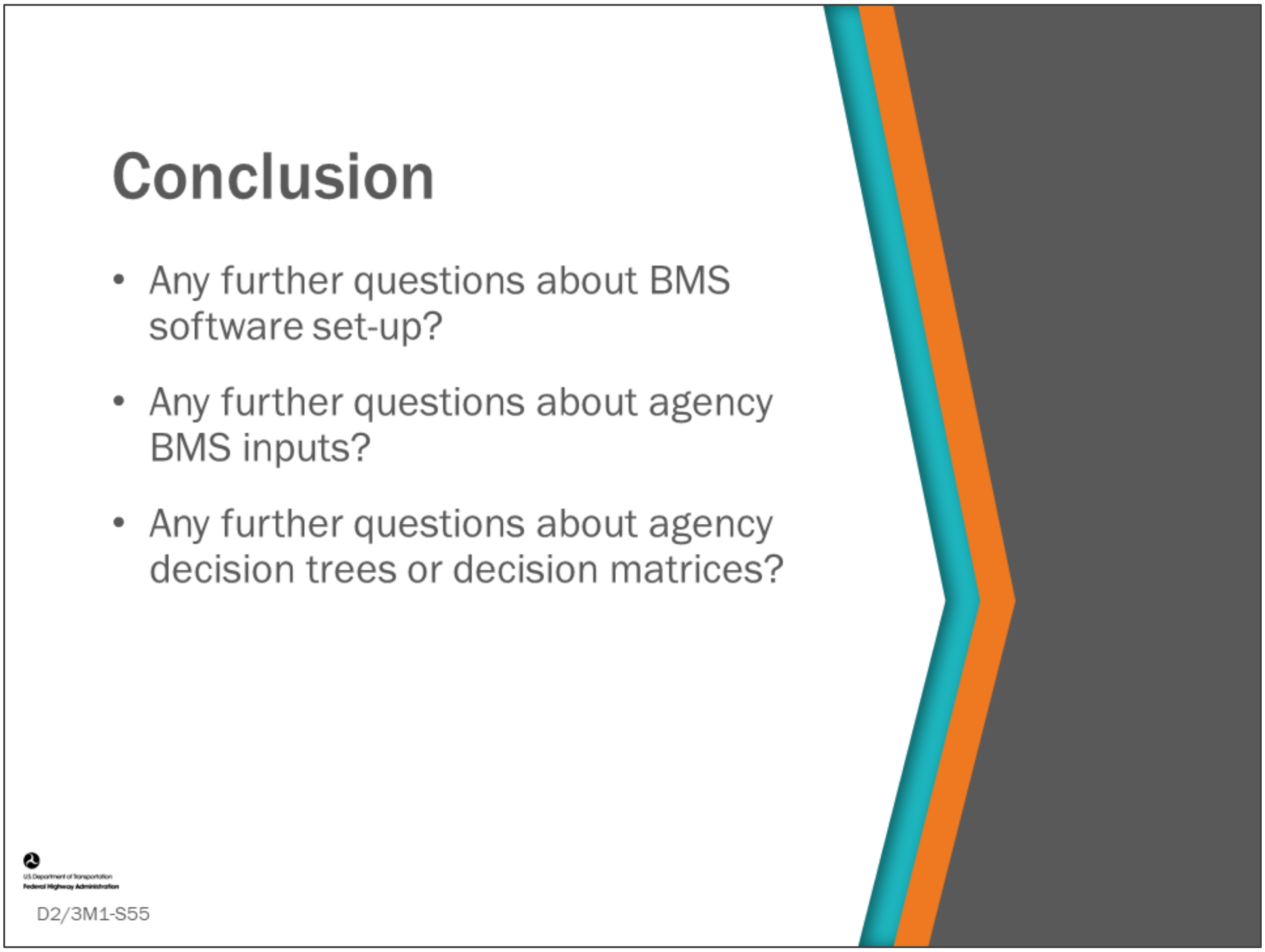
D2/3M1-Slide 54

Key Message

An agency can collect construction history information when work is performed on a bridge to help estimate cost for future actions.

- Shown on this slide is an example of what data could be collected. Construction history is valuable in several ways, including cost estimating, life cycle plan monitoring, and setting timing and benefit life for different actions. One of the major ways in which construction history is useful is decision rules. If good construction history records are kept and input into the system, rules can be set up that are time based (e.g., seal deck X years after replacement). Time based rules are especially valuable when accurate deterioration models are not available.

D2/3M1-Slide 55



Key Message

This concludes Day 2, Module 1: BMS Software Implementation Steps

D2/3M1-Slide 56

Slide #	Image Description	Source Information
6	Bridge management workflow diagram.	This Workshop.
13	Screenshot showing GCRs (NBI) are shown as the row labels. Condition State percentage is shown as column labels. The conversion values are entered in a grid referenced from the GCR(NBI) and Condition States.	AASHTOWare™ Bridge Management (BrM).
14	Table comparing NBI condition ratings to percentages of elements in each condition state.	This Workshop.
16	An example deck decision matrix with the repair options highlighted in blue.	Michigan DOT. *Bridge Deck Preservation Matrix*. 2017.
18	A workflow diagram for the National Bridge Elements with a red box containing superstructure elements and materials.	FHWA. *Specification for the National Bridge Inventory Bridge Elements.* Washington, DC, 2014.
19	A workflow diagram for superstructure showing materials and element types. Materials are contained in a red box.	FHWA. *Specification for the National Bridge Inventory Bridge Elements.* Washington, DC, 2014.
20	A workflow diagram for superstructure showing materials and element types. Element types are contained in a red box.	FHWA. *Specification for the National Bridge Inventory Bridge Elements.* Washington, DC, 2014.

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D2/3M1-S56

D2/3M1 Figure Source List

D2/3M1-Slide 57

Slide #	Image Description	Source Information
21	A workflow diagram for Bridge Management Elements (BMEs).	*FHWA. Specification for the National Bridge Inventory Bridge Elements. Washington, DC, 2014.*
22	A workflow diagram for protective system.	FHWA. *Specification for the National Bridge Inventory Bridge Elements.* Washington, DC, 2014.
25	AASHTOWare™ Bridge Management (BrM) screenshot example BMS software input.	AASHTOWare™ Bridge Management (BrM).
26	Screenshot of AASHTOWare™ Bridge Management (BrM) for Associated Benefit Groups for Replace Deck.	AASHTOWare™ Bridge Management (BrM).
31	Workflow diagram of an example decision tree.	This Workshop.
32	Workflow diagram creating decision trees using components and CGR's.	This Workshop.
33	Workflow diagram for creating a decision tree using NBE's.	This Workshop.
34	Workflow diagram for creating decision tree BMEs: Protective Systems Example.	This Workshop.
35	Workflow diagram for decision tree example for inventory items in decision making.	This Workshop.
36	Workflow diagram showing how defects can be used to make decisions on actions.	This Workshop.

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D2/3M1-S57

D2/3M1 Figure Source List

D2/3M1-Slide 58

Slide #	Image Description	Source Information
37	Screenshot of AASHTOWare™ Bridge Management (BrM) agency rules for deck replacement.	AASHTOWare™ Bridge Management (BrM).
37	Screenshot of portion of an AgileAssets® Structures Analyst™ decision tree indicating that when the GCR deck rating is equal to or less than 4, deck replacement is a feasible action.	AgileAssets® Structures Analyst™.
46	Screenshot of AASHTOWare™ Bridge Management (BrM) deck rehab benefits.	AASHTOWare™ Bridge Management (BrM).
50	A portion of a bid tabs shows work items, quantities, estimated price, bid price, and estimated amount.	This Workshop.
51	A portion of a bid tabs shows work items, quantities, estimated price, bid price, and estimated amount. Examples of indirect cost items are shown.	This Workshop.
53	Screenshot of a spreadsheet showing example element quantity unit costs and indirect cost as percentage of the total cost.	This Workshop.

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D2/3M1-S58

D2/3M1 Figure Source List

Module Title: D2/3M2 – Deterioration Model Development, Use, and Maintenance

Module Time: 120 minutes

Module Summary

All BMS applications require the user to enter deterioration models. This can be intimidating if the user does not have a good understanding how deterioration models are used in the system. This module will provide more detailed education about several methods of creating deterioration models including stochastic and deterministic methods. It will review Markov Chain transition probabilities, age of structure, time in condition state, and expert elicitation. It will demonstrate how these models are calculated and are input into BMS software. It will show how deterioration modeling is used for network level analysis and forecasting future bridge conditions.

Expected Outcome(s)

The expected outcome for this topic will be that participants understand the reasons for modeling deterioration, the different types of deterioration models, and some of the advantages and reasons for using one type over another. They will understand how to do basic calculations for each method, and they will learn how to input deterioration models in BMS software.

Resource List

Slide	Reference Information
8	Statista.com. Definition of confidence level.
8	Statista.com. Definition of margin of error.
12	Businessdictionary.com. Definition of deterministic model.
13	Investopedia.com. Definition of stochastic modeling.
15	Morcous, G. *Developing Deterioration Models for Nebraska Bridges*. Page 44. University of Nebraska-Lincoln.
18	Morcous, G., et al. *Deterioration Models and LCCA For Nebraska Bridge Decks,* 2012 Midwest Bridge Preservation Partnership, Council Bluffs, IA. October 17, 2012.
19	Chyad, A., *Deterioration Prediction Modeling for the Condition Assessment of Concrete Bridge Decks*, Ph.D. Dissertation, Western Michigan University, June 2018.
28	Dekalbab, W., et al. *History Lessons From the National Bridge Inventory*. Public Roads. Publication Number: FHWA-HRT-08-004. Issue No: Vol. 71 No. 6. Washington, DC, May/June 2008.
31	NCHRP. *Report 782, Proposed Guideline for Reliability-Based Bridge Inspection Practices*. Transportation Research Board. Washington, DC, 2014.
50	AASHTO. *Manual for Bridge Element Inspection.* Washington, DC, 2013.
50, 65	MDOT. *Michigan Bridge Element Inspection Manual*, March 2015.

72	NCHRP. *Report 713, Estimating Life Expectancies of Highway Assets, Volume 1: Guidebook.* Transportation Research Board. Washington, DC, 2012.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D2/3M2-Slide 1

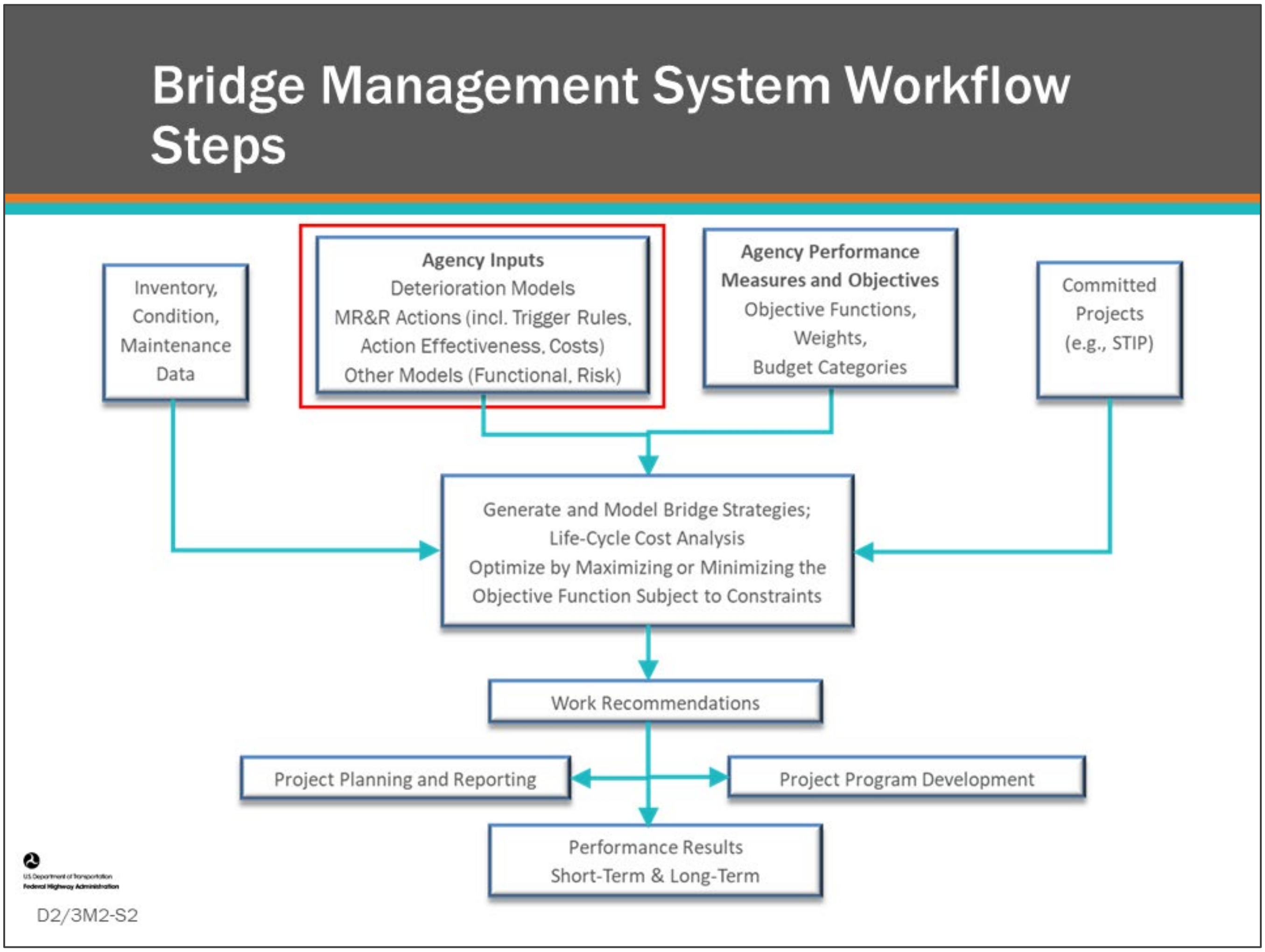
Key Message

This module will go over deterioration model development, use and maintenance.

Disclaimer

FHWA does not promote or endorse patented and proprietary products. Bridge management software is largely proprietary. Workshop content pertaining to proprietary software is included only to illustrate how bridge management system concepts and analyses are applied in practice. The included content shall not be construed as promotion or endorsement of specific software.

D2/3M2-Slide 2



Key Message

BMS workflow steps are shown on the slide. Agency inputs including deterioration models are highlighted by the red box.

D2/3M2-Slide 3

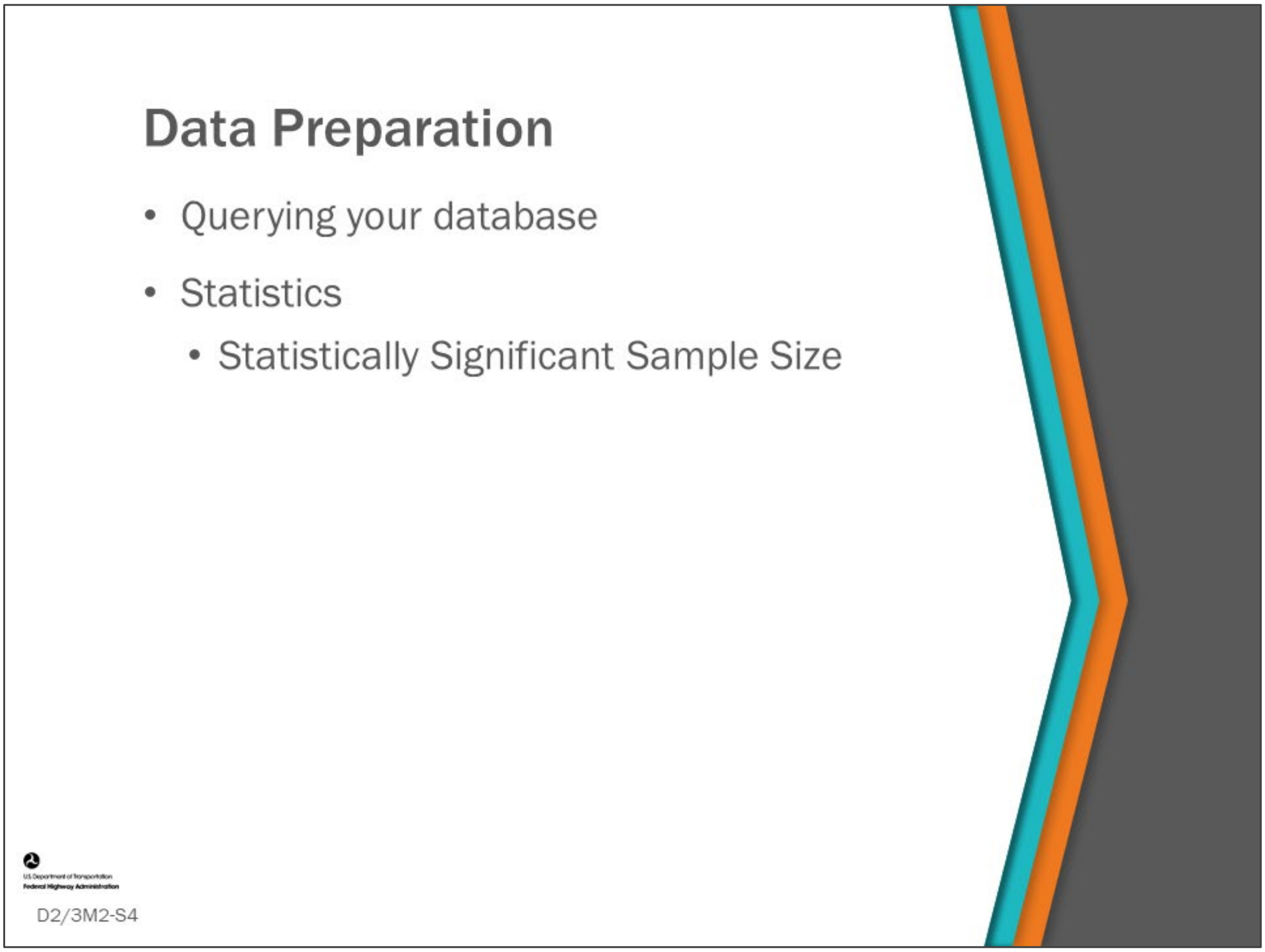
Key Message

This module will provide guidance on ways you can create deterioration model(s) input into your BMS.

- You may do this with your own staff.
- You may use a university or hire a consultant.

Hopefully, this module help you ask the right questions, avoid stumbling blocks, guide you to query and prepare the right data, as well as analyze it in a way that will produce accurate deterioration models - suitable for input into your BMS.

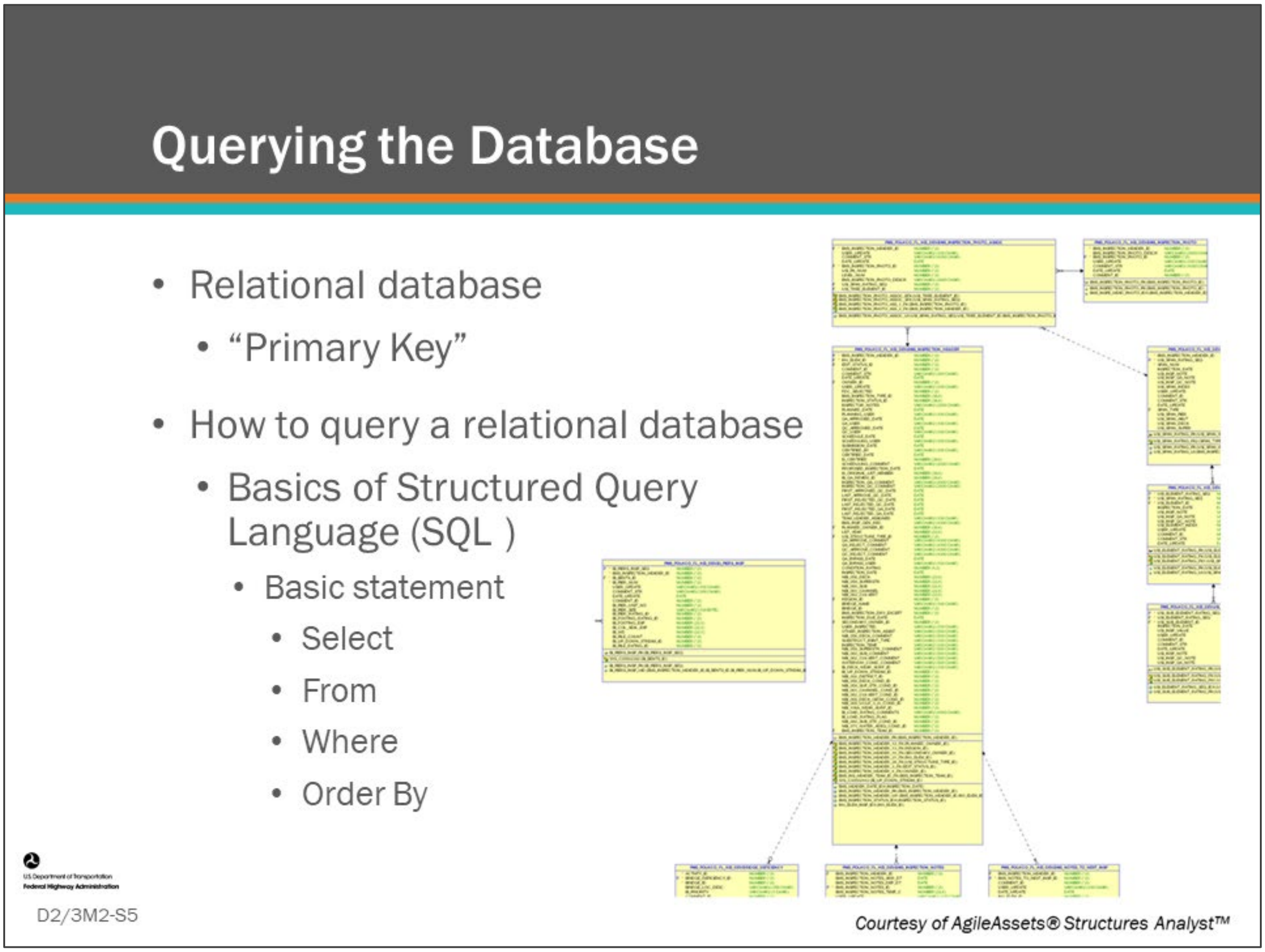
D2/3M2-Slide 4



Key Message

In this section, we will cover how to get the data you need to create your deterioration model. We will also review the importance of statistics in this process.

D2/3M2-Slide 5



Key Message

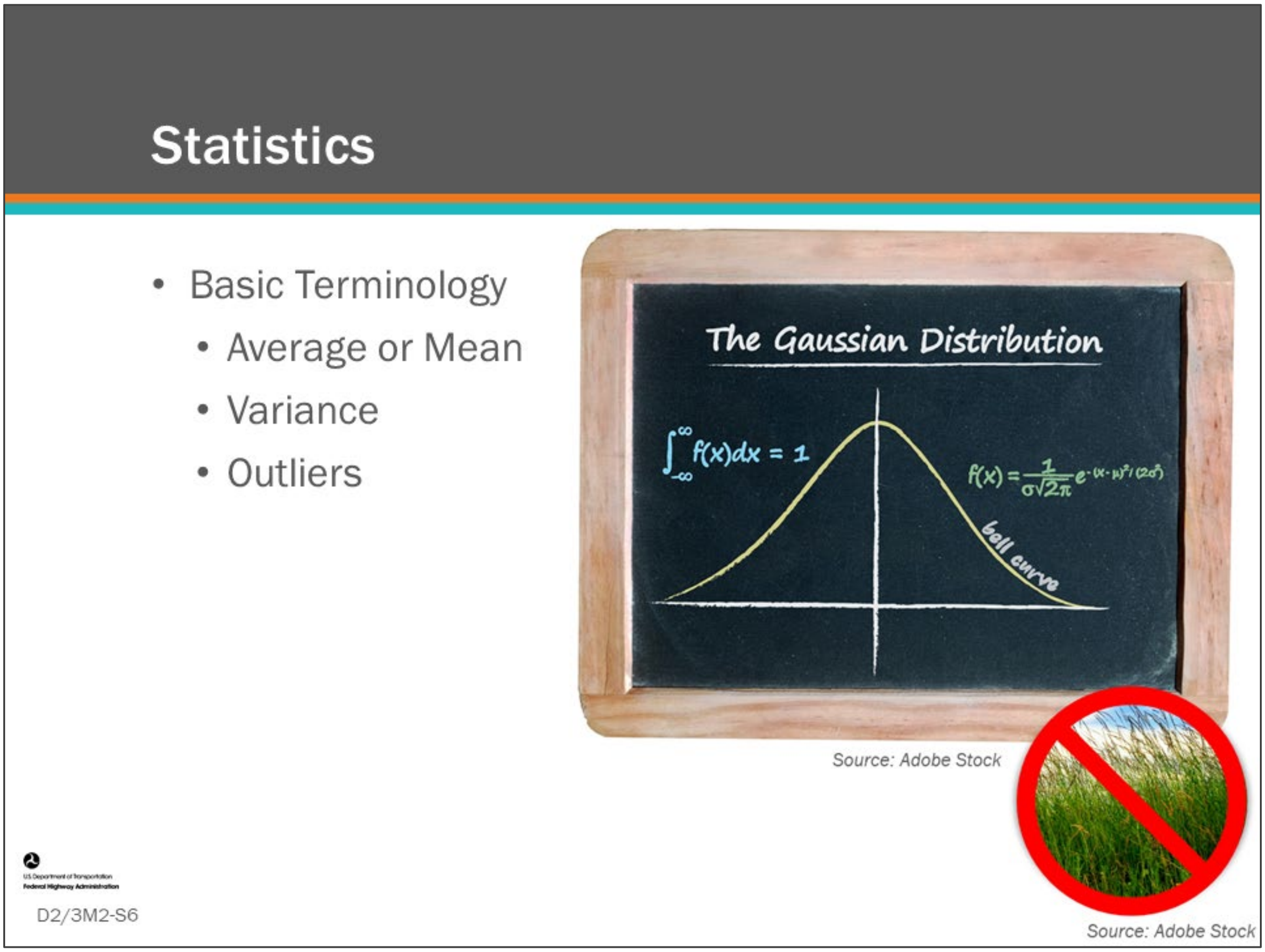
Relational databases are the foundation of a BMS, so it is important to understand the basics of this powerful way of storing data and making it available for use in many ways.

- The database shown on the slide is a snap-shot of a small portion of the AgileAssets® Structures Analyst™ relational database.
- A database is queried using structured query language, or SQL. Simply, this is telling what to select, from where, and how to order it.
- Your software may have ways to retrieve and review your bridge data. There are standard reports and the ability to create custom reports.
- Some software provide tools to do custom queries without having to write SQL script. You can also export data in several formats for further analysis in other desk top software, such as Microsoft Excel.

A database schema is the skeleton structure that represents the logical view of the entire database. It defines how the data is organized and how the relations among them are associated.

- It formulates all the constraints that are to be applied on the data (e.g., data type and size). It defines tables, views, and integrity constraints.

D2/3M2-Slide 6



Key Message

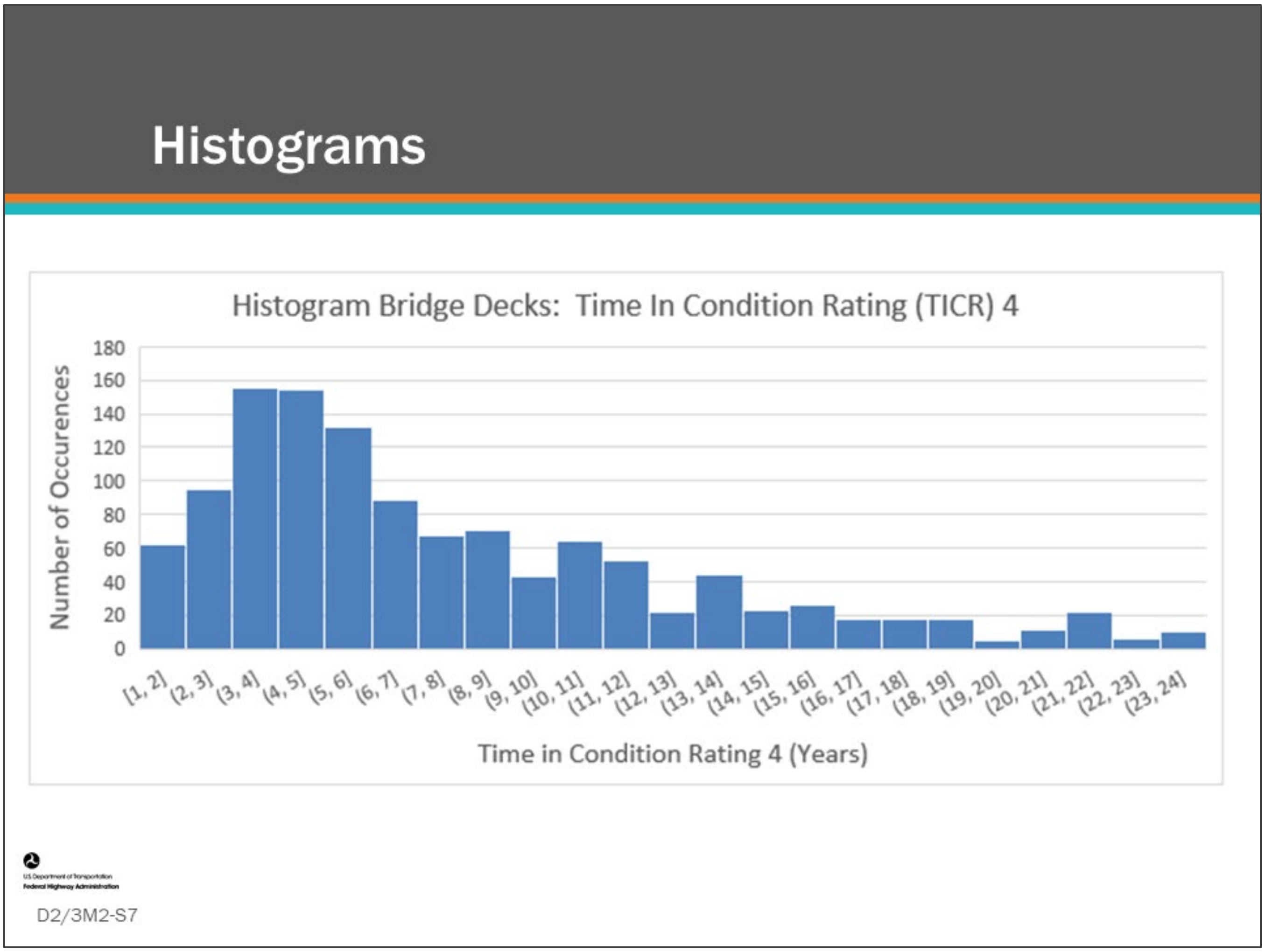
When developing deterioration models statistics will play a very important role. Anytime you collect, prepare, and analyze data statistics are used.

- Average (or mean) is a number expressing the “expected” value in a set of data.
- Statistical variance, in probability theory and statistics, is the expectation of the squared deviation of a random variable from its mean. Informally, it measures how far a set of (random) numbers are spread out from their average value. The standard deviation is the square root of the variance.
- A statistically significant sample is one the you have confidence represents the overall dataset.
- An outlier is an observation that lies an abnormal distance from other values in a random sample from a population. In a sense, this definition leaves it up to the analyst (or a consensus process) to decide what will be considered abnormal. Before abnormal observations can be singled out, it is necessary to characterize normal observations.
- The Normal (or Gaussian) Distribution (often called the Bell Curve) is a common way to visualize the distribution of your data, a visual representation is shown on the slide.
- In addition to the well-known Normal distribution, data may follow many other statistical distributions that we will not discuss in depth here.

During this module we will use some very basic statistics terminology, as described above, but this only scratches at the surface of statistics. Unfortunately, we will not have enough time in this workshop to delve deeply into the methods and procedures to do good statistical analysis.

- However, if you look up just about any of the research reports referenced in this workshop you will see a dizzying amount of statistical analysis.
- Word of warning, it is easy to get “lost in the weeds” of statistical analysis, as implied by the graphic in the lower right corner of this slide. Always keep focus on your original objectives.
- More details on the Gaussian Distribution will be covered on the following slides.

D2/3M2-Slide 7

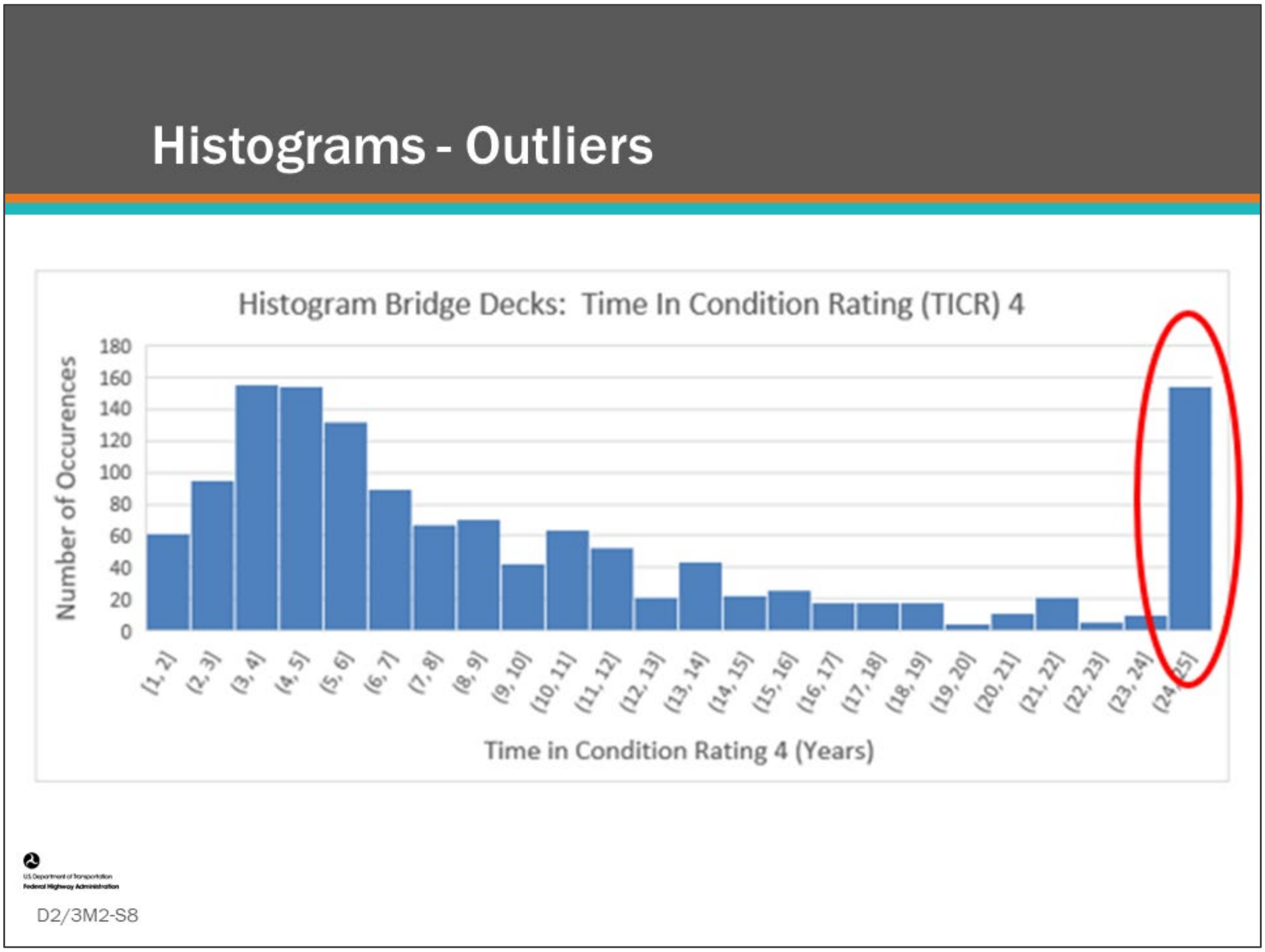


Key Message

A helpful way to view data is in a histogram. This slide shows a histogram of a population of bridge decks and the time spent in CS4.

- The x-axis shows the division of equal ranges of values collected in “bins”.
- For example, the bin farthest to the left on the graph show values from 1.0 to 1.9999 (rounded to show 1 to 2).
- The y-axis is number of occurrences for values falling in this range.

D2/3M2-Slide 8



Key Message

What if there is an anomaly in the data, such as the one shown on this slide? The data on this slide indicates that over 140 bridge decks remained in CS4 for 25 years.

- It is easy to see when reviewing the histogram for this data that these occurrences may be outliers.

D2/3M2-Slide 9

Statistically Significant Sample Size

- Confidence Level
  - Probability with which the estimation of the location of a statistical parameter (e.g. arithmetic mean) in a sample survey is also true for the population
- Margin of Error (MOE)
  - Maximum deviation of the sample results from the real values.

Population	Confidence Level	MOE	Size
100	95%	5%	80
1,000	95%	5%	278
10,000	95%	5%	370

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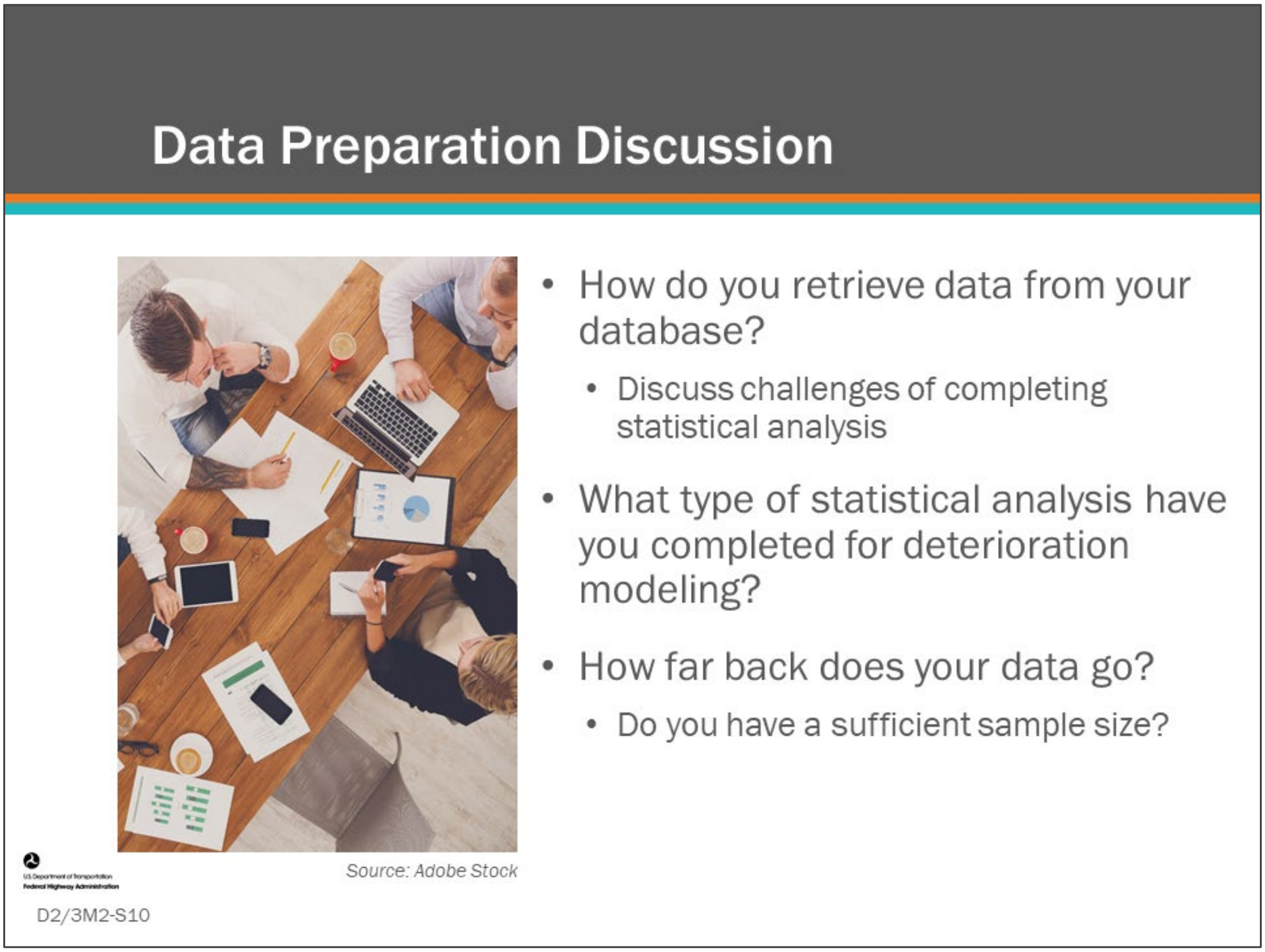
D2/3M2-S9

Key Message

When completing deterioration modeling it is very important to be aware of the size of your data set, and it is always good to work with someone familiar with statistical analysis.

- When does your dataset become too small for you to have confidence that it is representative of the population?
- There are methods to determine if you have a statistically significant sample size and determining your confidence level.
- The table in the slide shows some typical sample sizes necessary to have a 95 percent confidence level in the accuracy of your results.

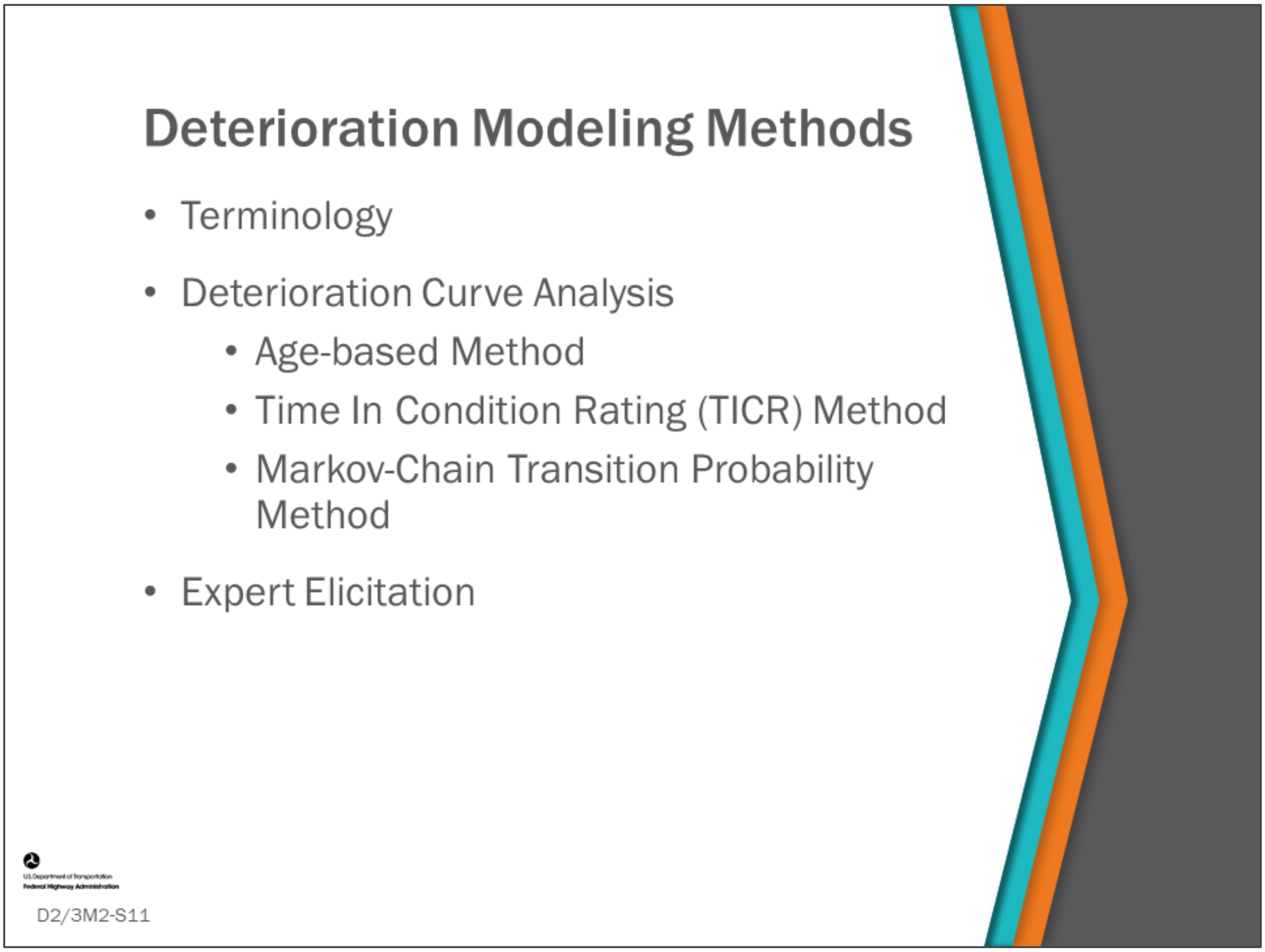
D2/3M2-Slide 10



Key Message

Discuss the questions on this slide.

D2/3M2-Slide 11

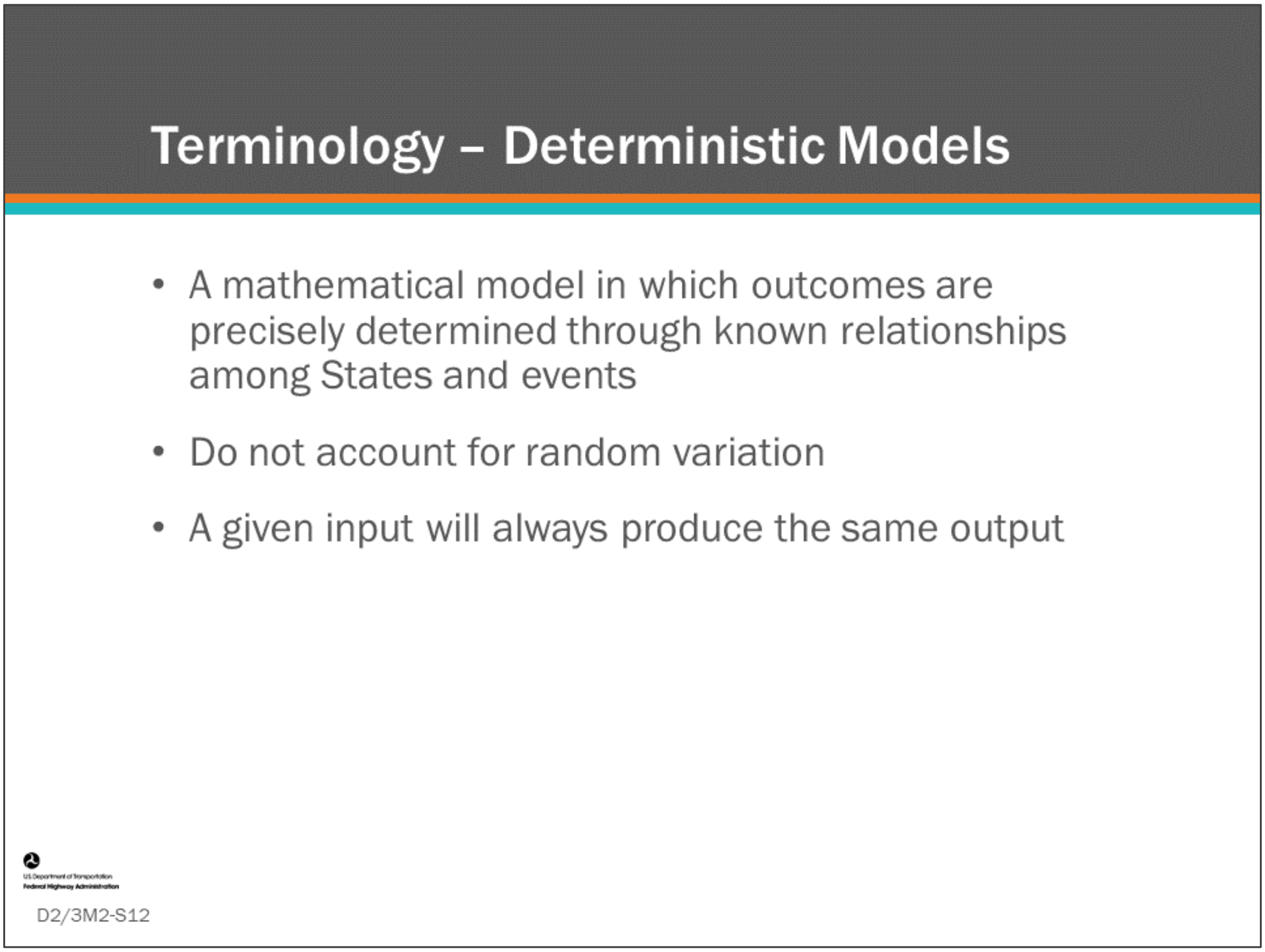


Key Message

There are several methods by which bridge condition date is counted and analyzed to develop deterioration models.

- In this section of the module, we will first define common terms and then will introduce three methods of creating deterioration models used by researchers and bridge owners.
- Finally, expert elicitation will be introduced to help fill any gaps in data using expert judgment from knowledgeable bridge engineers, inspectors, and managers.

D2/3M2-Slide 12

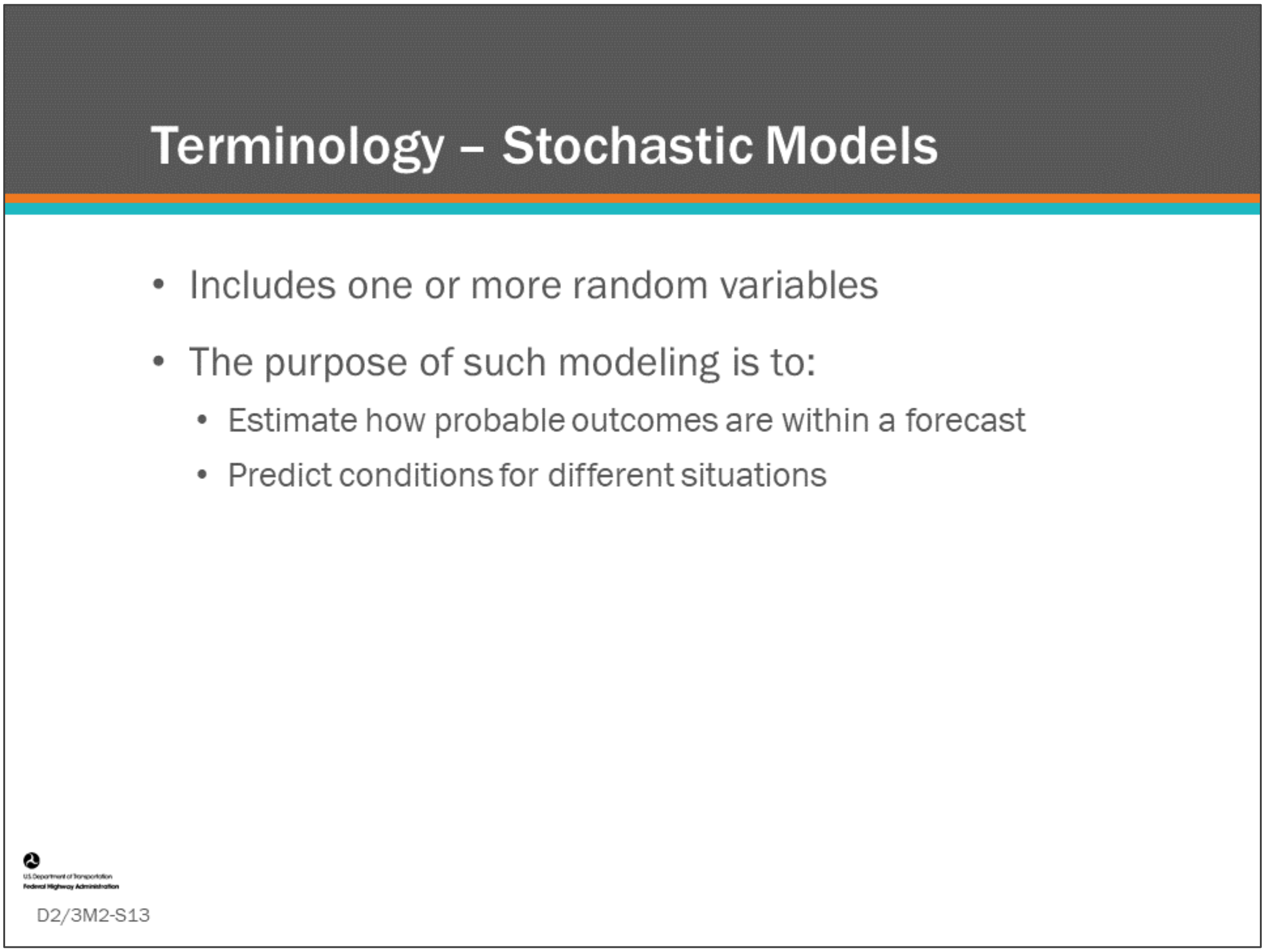


Key Message

Define deterministic models.

- An example of deterioration modeling is a researcher who analyzes many years of bridge condition data and develops a family of deterioration curves which are defined by equations.

D2/3M2-Slide 13



Key Message

Define stochastic models.

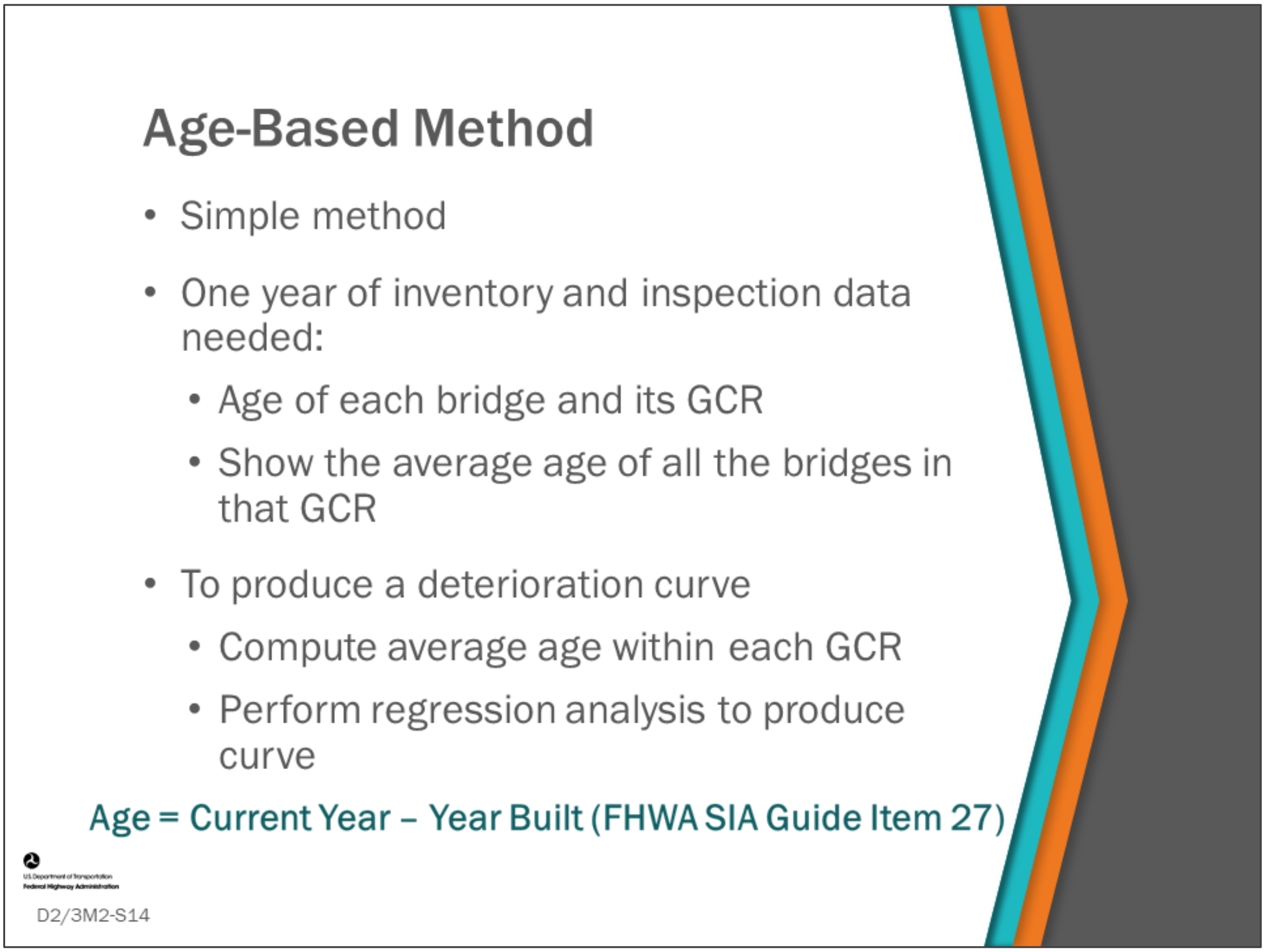
- A good example of a stochastic method is the Markov Chain Transition Probability method, which was discussed briefly on the first day of this workshop and will be discussed in greater detail in this module.

The Markov Chain Transition Probability method uses statistics to estimate the mean survival time of a component or element in a condition rating or condition state, respectively.

Although definitions are provided, actual modeling often involves a mix of these two methods.

- Agency use of Markov Chain Transition Probability method in a BMS is a good example of combining stochastic and deterministic modeling, because it calculates the probability of the component or element staying the same.
- By formula, the transition probability is converted to mean time in condition rating (component) or condition state (element) and those values are:
    - Input into the software as a piecewise linear distribution for component deterioration, which is a deterministic model; or,
    - Entered as an exponential equation for element quantity in a condition state with time, which is also entered and used as a deterministic model.

D2/3M2-Slide 14



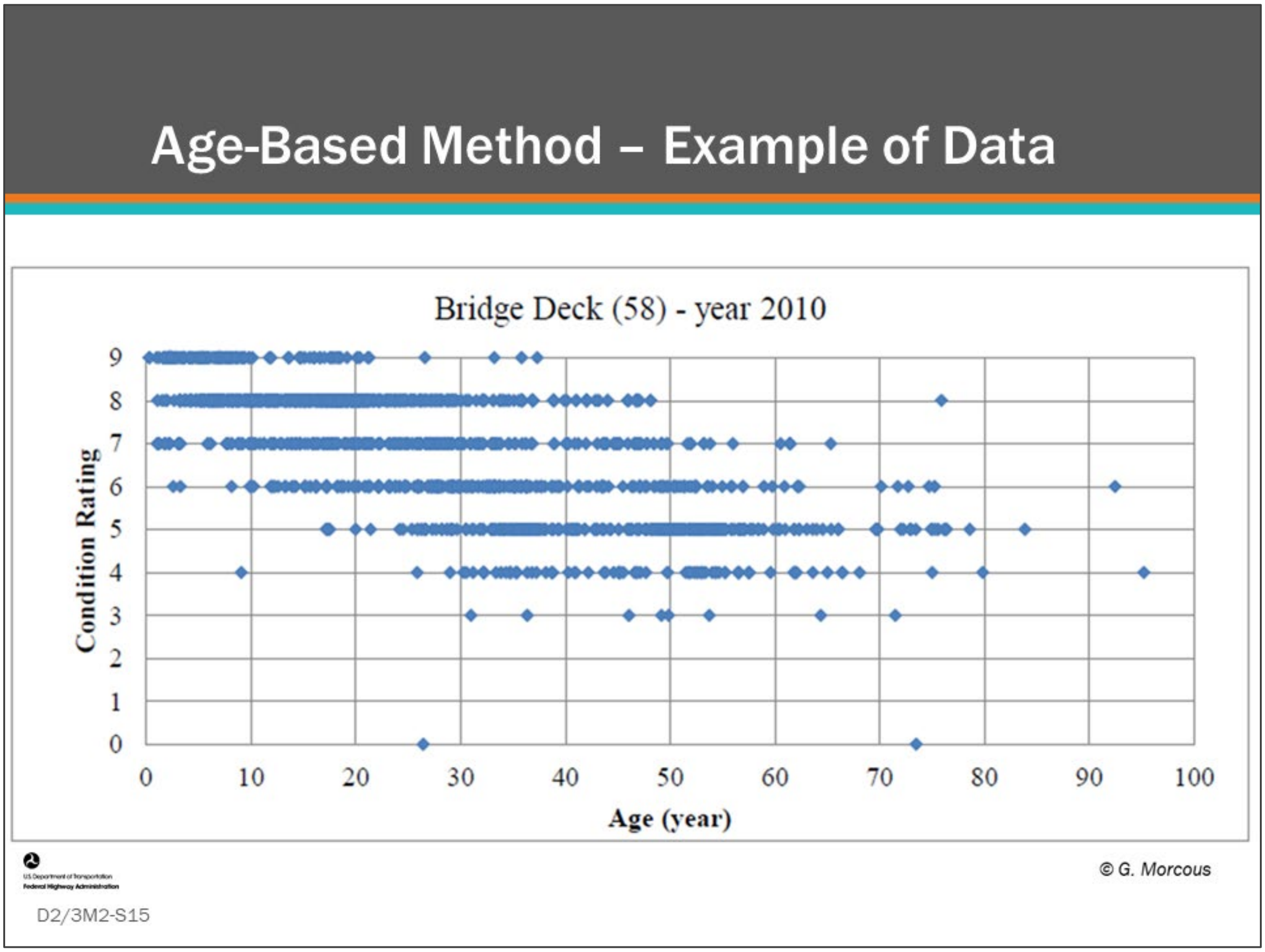
Key Message

The Age-based Method creates a deterioration curve by comparing the age of bridges in each of the condition ratings at a chosen point in time.

This is a simple method that can be completed with one year of inventory and inspection data.

- Often bridges that have been reconstructed as indicated by NBI Item 106 are removed from the data set. For the year of the analysis, count the age of each bridge noting what condition rating it is in.
- For each condition rating, show the average age of all the bridges in that condition rating and graph these values or do regression analysis to produce a deterioration curve.
- The equation on the slide shows the current year minus the year built as determined by NBI Item 27.

D2/3M2-Slide 15

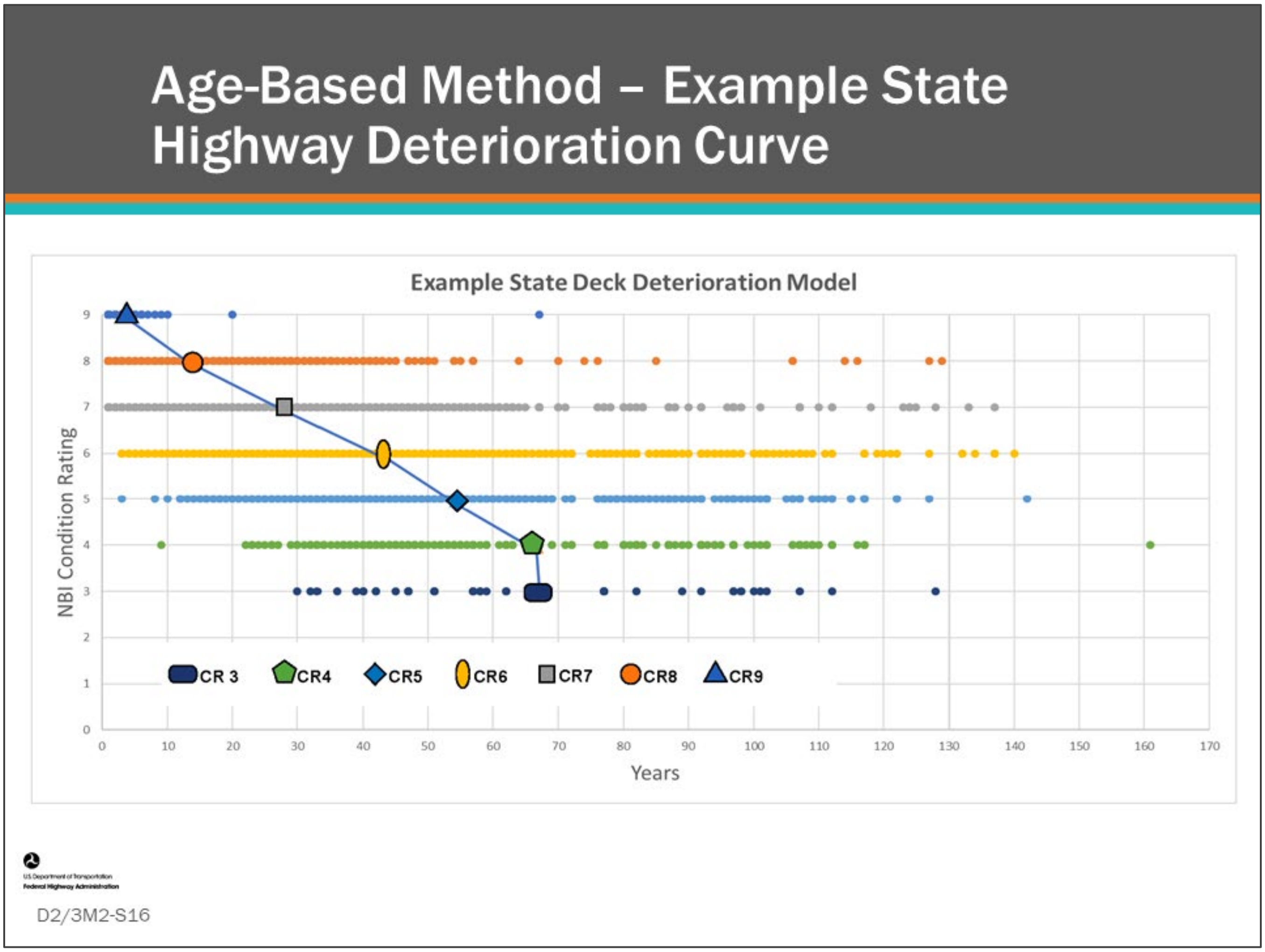


Key Message

This slide shows the age of bridges in Nebraska in the various deck condition ratings.

- Each blue dot represents a bridge, showing its age from year built, and deck condition rating.
- Displaying it this way you can see how the age of bridges in a given condition rating are clustered and the variance of age data for each condition rating.

D2/3M2-Slide 16

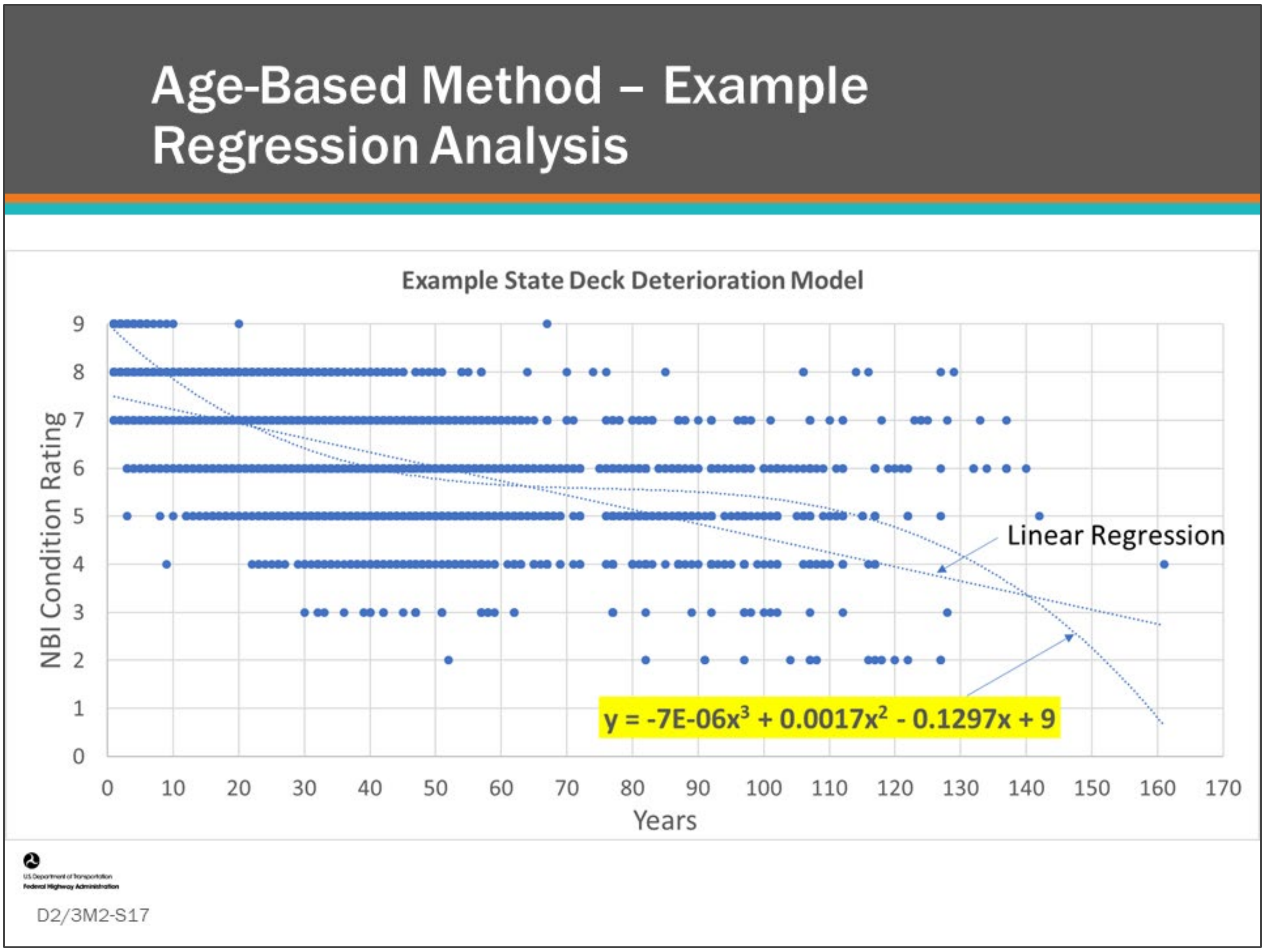


Key Message

This slide shows a similar scatter chart for deck condition ratings for an example state highway bridge population.

- The number of occurrences is shown for each condition rating.
- Average age for each condition rating is shown as a triangle marker and lines are drawn to simulate a deterioration curve.
- Connecting straight lines between points is called a piecewise linear model.

D2/3M2-Slide 17



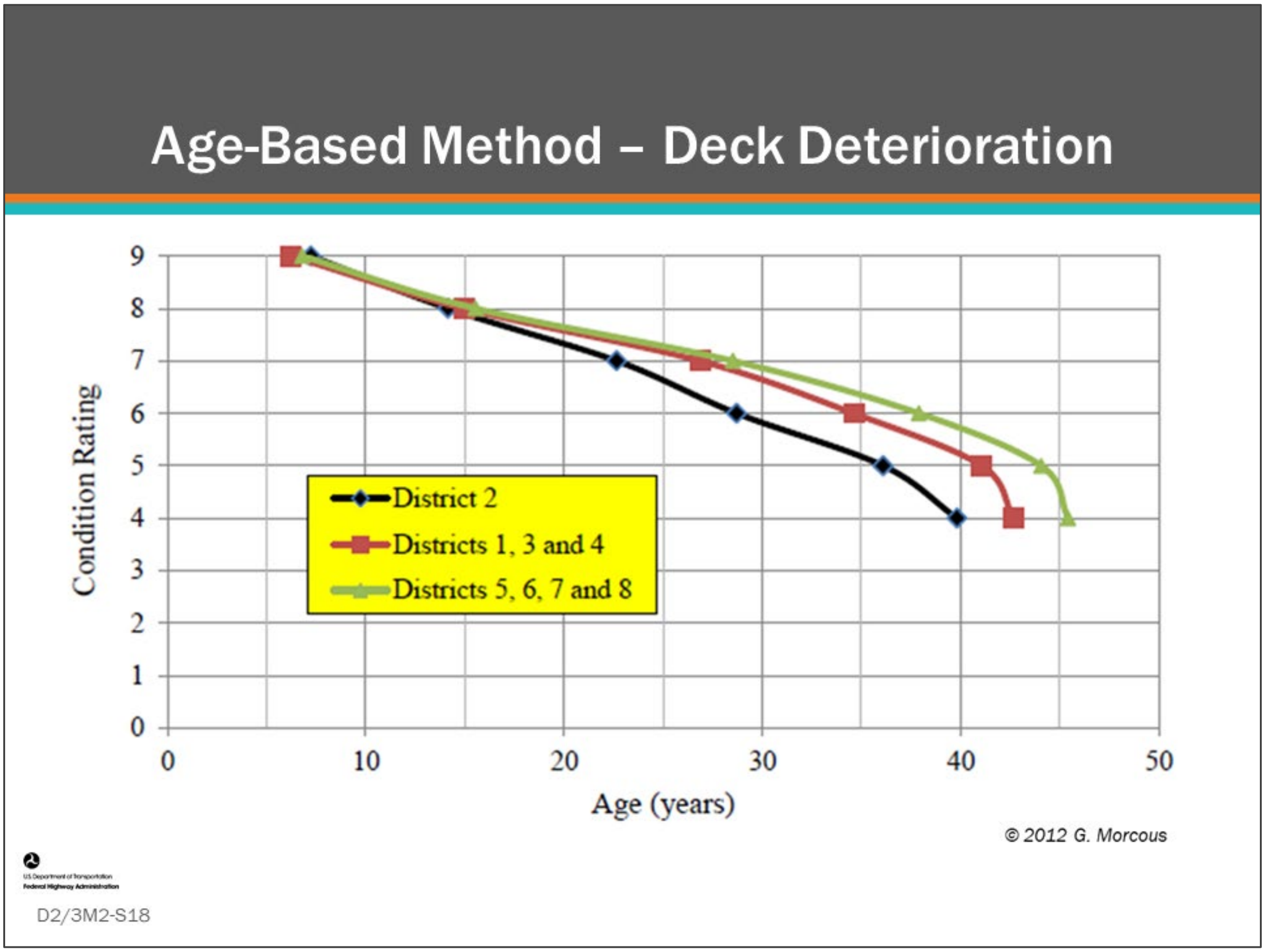
Key Message

A regression analysis can also be done for the data shown in the previous slide. Shown on this slide are two examples of regression analysis;

- A simple linear regression; and
- A data-fitting equation.

BMS software allow deterioration models to be represented by equations.

D2/3M2-Slide 18



Key Message

This slide shows another example of deterioration curves developed using this method.

- This was completed as part of a study for the Nebraska DOT.
- Three deterioration curves show how bridge decks deteriorate differently in Nebraska highway districts.

D2/3M2-Slide 19

Age-Based Method – Average Age in Condition Ratings

Condition Ratings for Michigan Concrete Bridge Decks, 2015

Condition Rating	Description	No. of Bridges	Average Age (year)
9	Excellent Condition	229	5.67
8	Very Good Condition	1606	18.31
7	Good Condition	3272	32.25
6	Satisfactory Condition	2598	43.16
5	Fair Condition	1029	53.97
4	Poor Condition	375	58.98
3	Serious Condition	121	65.89
2	Critical Condition	18	72.39
1	Imminent Failure Condition	1	70
0	Failed Condition	6	102.5
Total		9225	

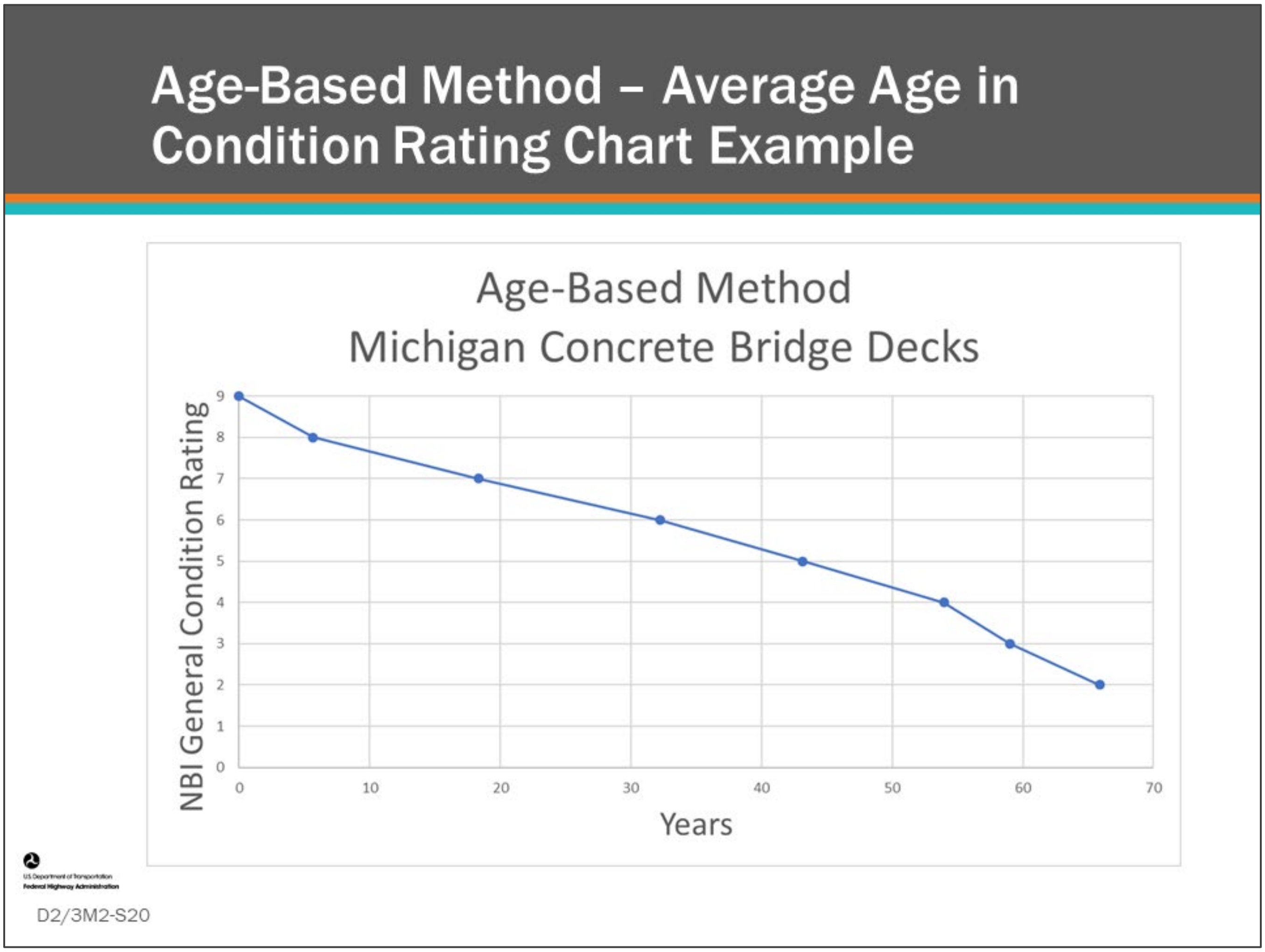
D2/3M2-S19

Key Message

This slide shows a count of Michigan DOT concrete bridge decks and the average age in each condition rating.

- The average age in each condition could be used to draw a deterioration curve by cumulative summation.

D2/3M2-Slide 20



Key Message

The average age in condition rating data from the previous slide was used to plot a deterioration curve for Michigan concrete bridge decks.

D2/3M2-Slide 21

Age-Based Method Discussion

Source: Adobe Stock

- What are benefits of the Age-Based method?
- What are the challenges?

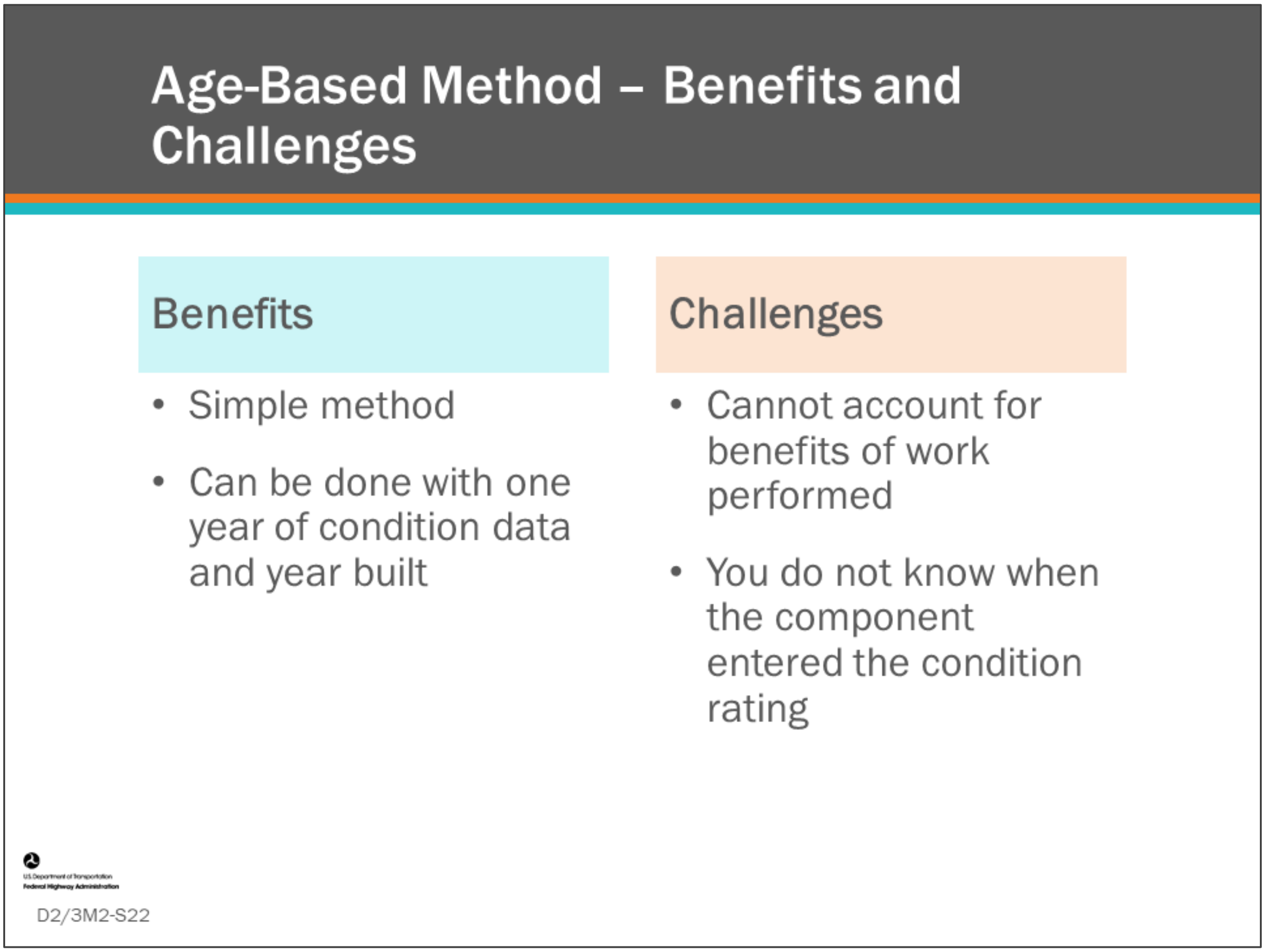
D2/3M2-S21

Key Message

Discuss the questions on this slide.

- What are benefits of the Age-Based method?
- What are the challenges?
    - What are concerns?
    - What do you think about the results?

D2/3M2-Slide 22



Key Message

Benefits and challenges of the Age-Based method are shown on the slide.

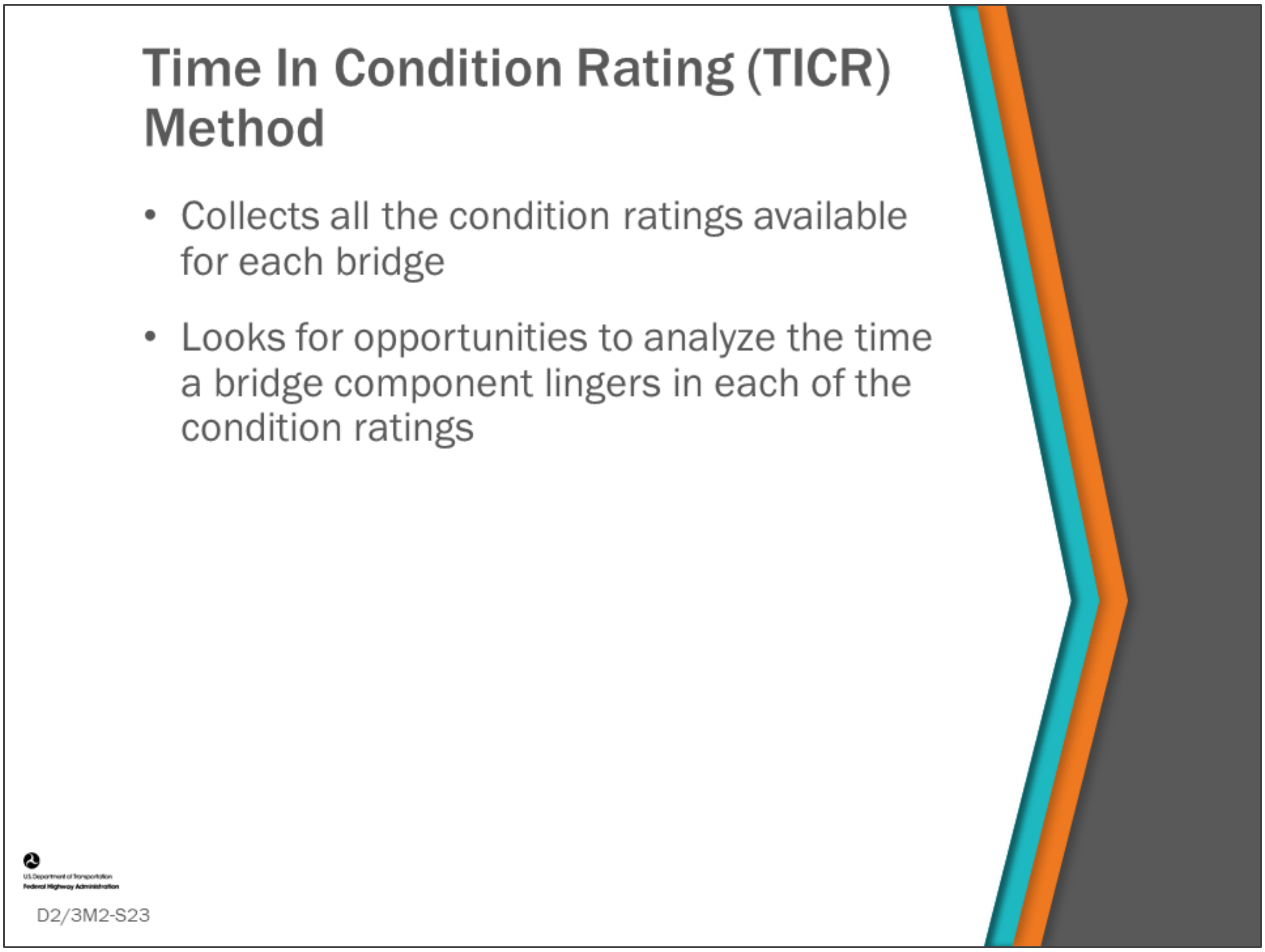
Benefits include:

- Simple method
- Can be done with one year of condition data and year built

Challenges include:

- Cannot account for benefits of work performed
- You do not know when the component entered the condition rating

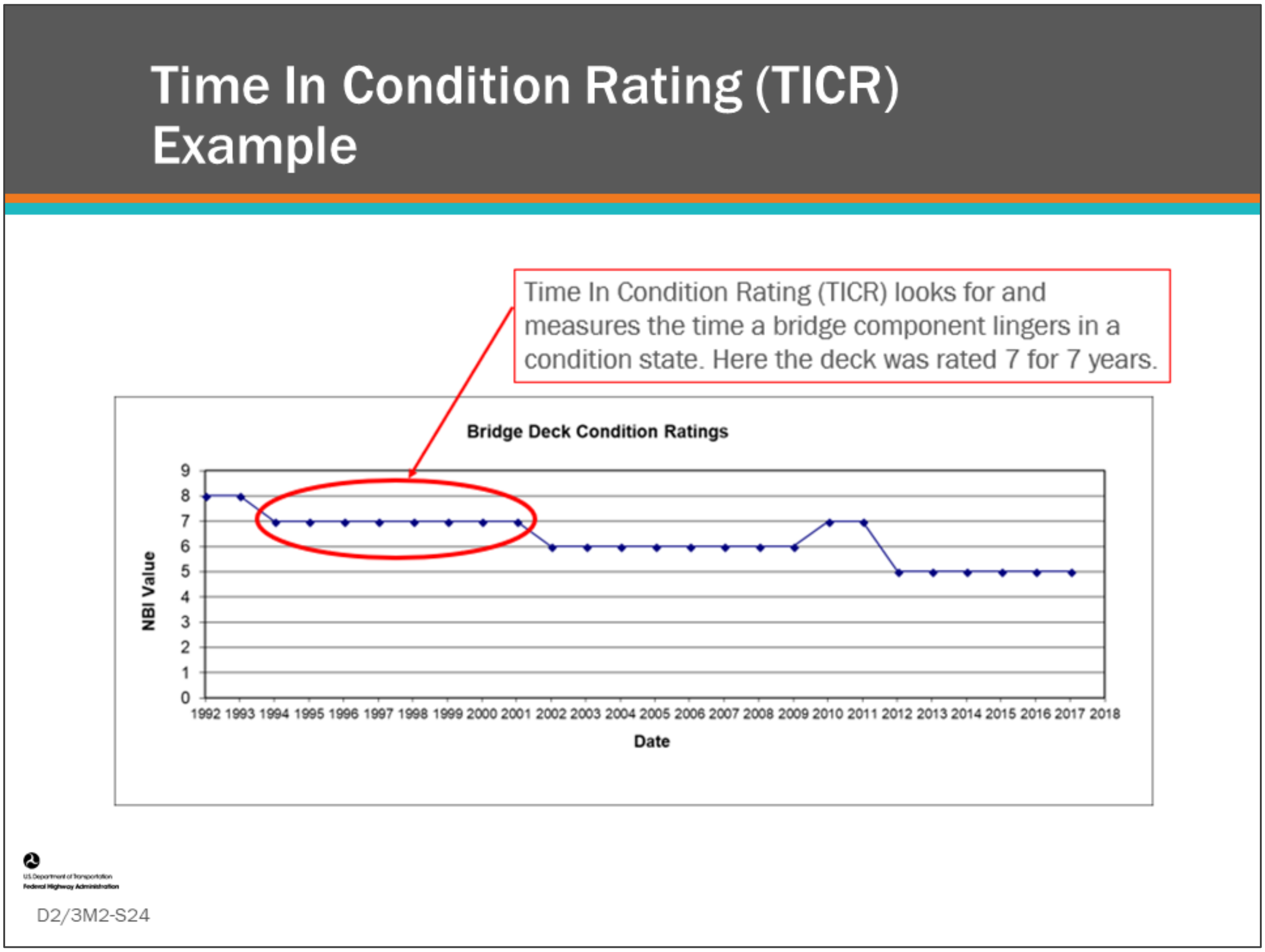
D2/3M2-Slide 23



Key Message

Another method for analyzing condition data to estimate deterioration of components is to measure the time the component lingers in a condition rating. We will learn how researchers and agencies go about creating deterioration models using this method.

D2/3M2-Slide 24

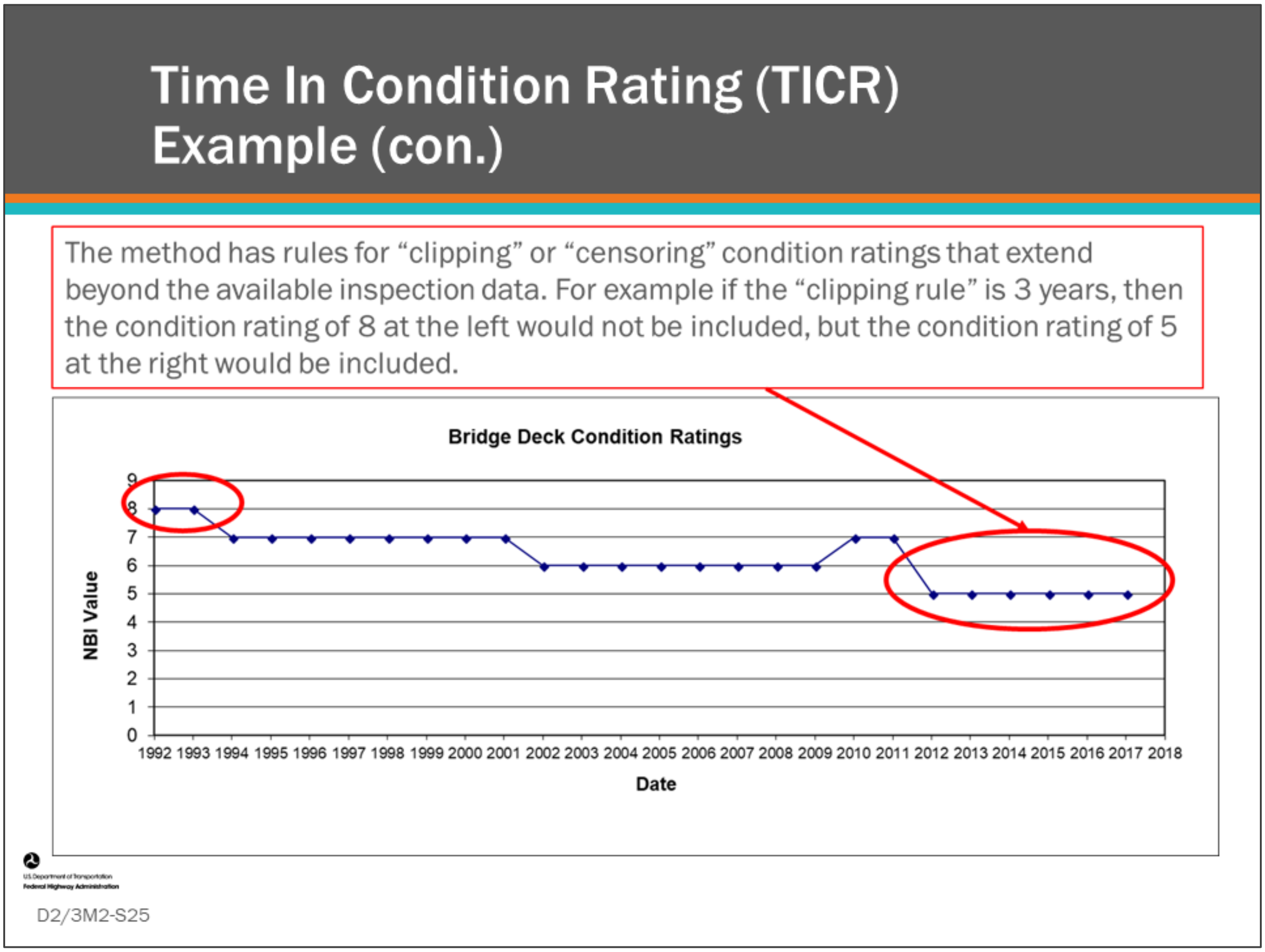


Key Message

NBI bridge major component condition data (GCR) is available going back to 1992 on the FHWA NBI website. For any bridge, this data can be used to show the condition of that component in each year or at each inspection.

- This is shown for a bridge in the above chart which shows GCRs for the bridge deck on the y-axis, and year on the x-axis.
    - Once this is plotted for a bridge, the data can be reviewed to find occurrences where a condition rating was entered and then exited to a lower condition rating as shown in the chart.

D2/3M2-Slide 25

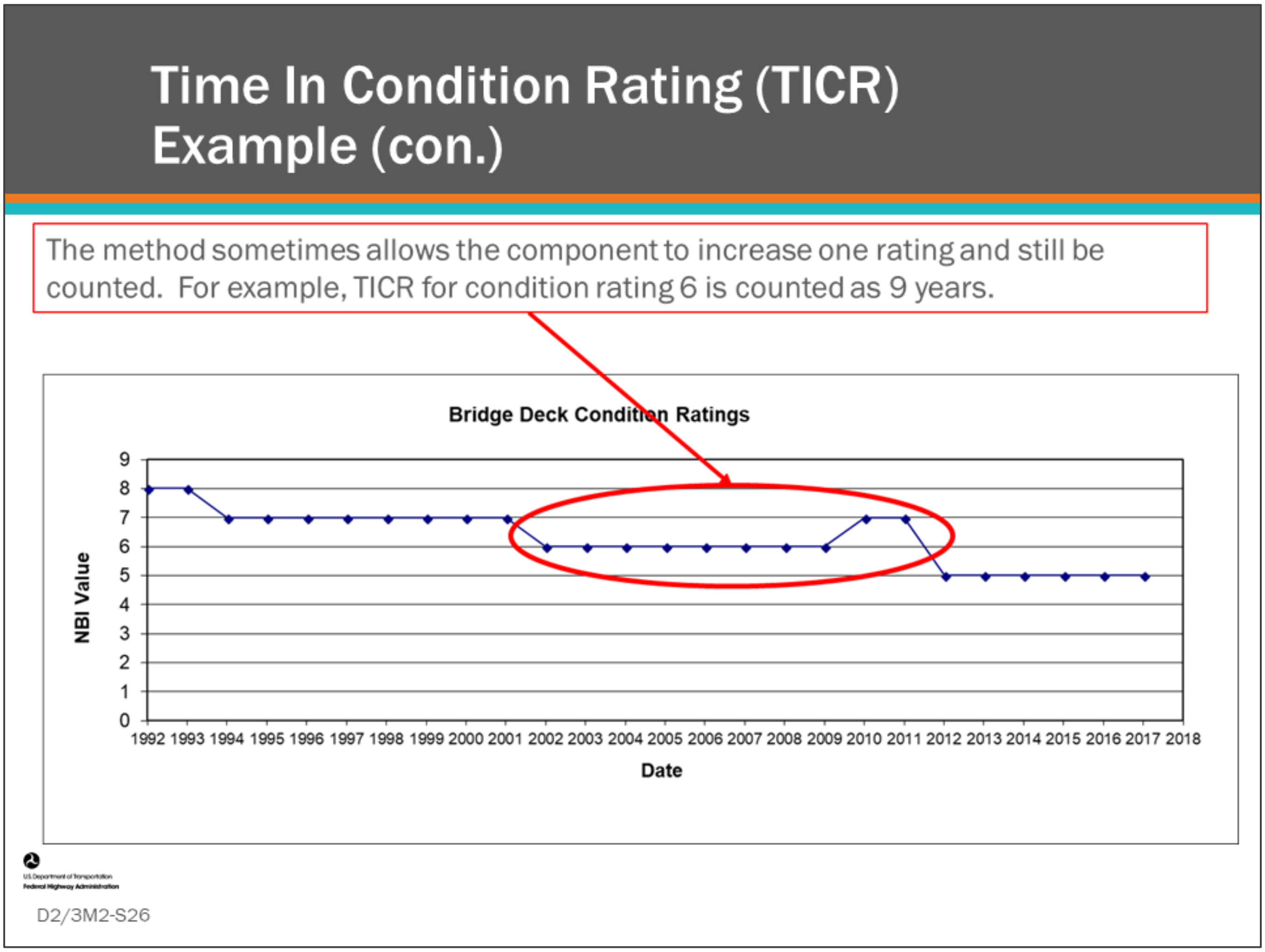


Key Message

The method has rules for “clipping” or “censoring” condition ratings that extend beyond the available inspection data and cannot be completely observed. A decision must be made to count or censor the data.

- For example, if the “clipping rule” is 3 years, then the GCR of 8 at the left would not be included, but the condition rating of 5 at the right would be included.

D2/3M2-Slide 26



Key Message

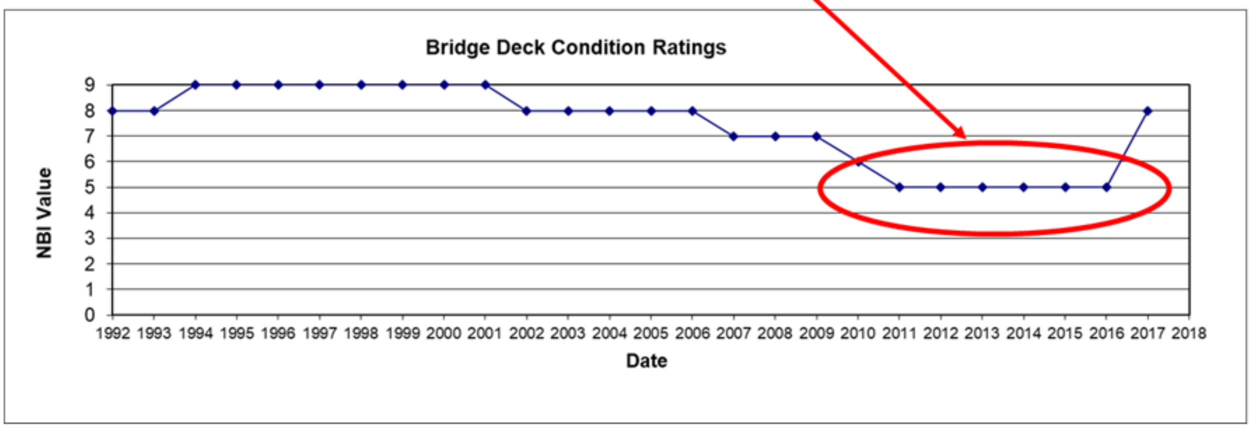
This method sometimes allows the component to increase one rating and still be counted.

- For example, TICR for GCR 6 is counted as 9 years when the last two years are counted as being in GCR 6, even though they are rated 7.

D2/3M2-Slide 27

Time In Condition Rating (TICR) Example (con.)

If a condition rating increases more than one value then the time spent in that condition cannot be counted. For the example shown here the deck was rated five for five years, but then the condition increased to 8.



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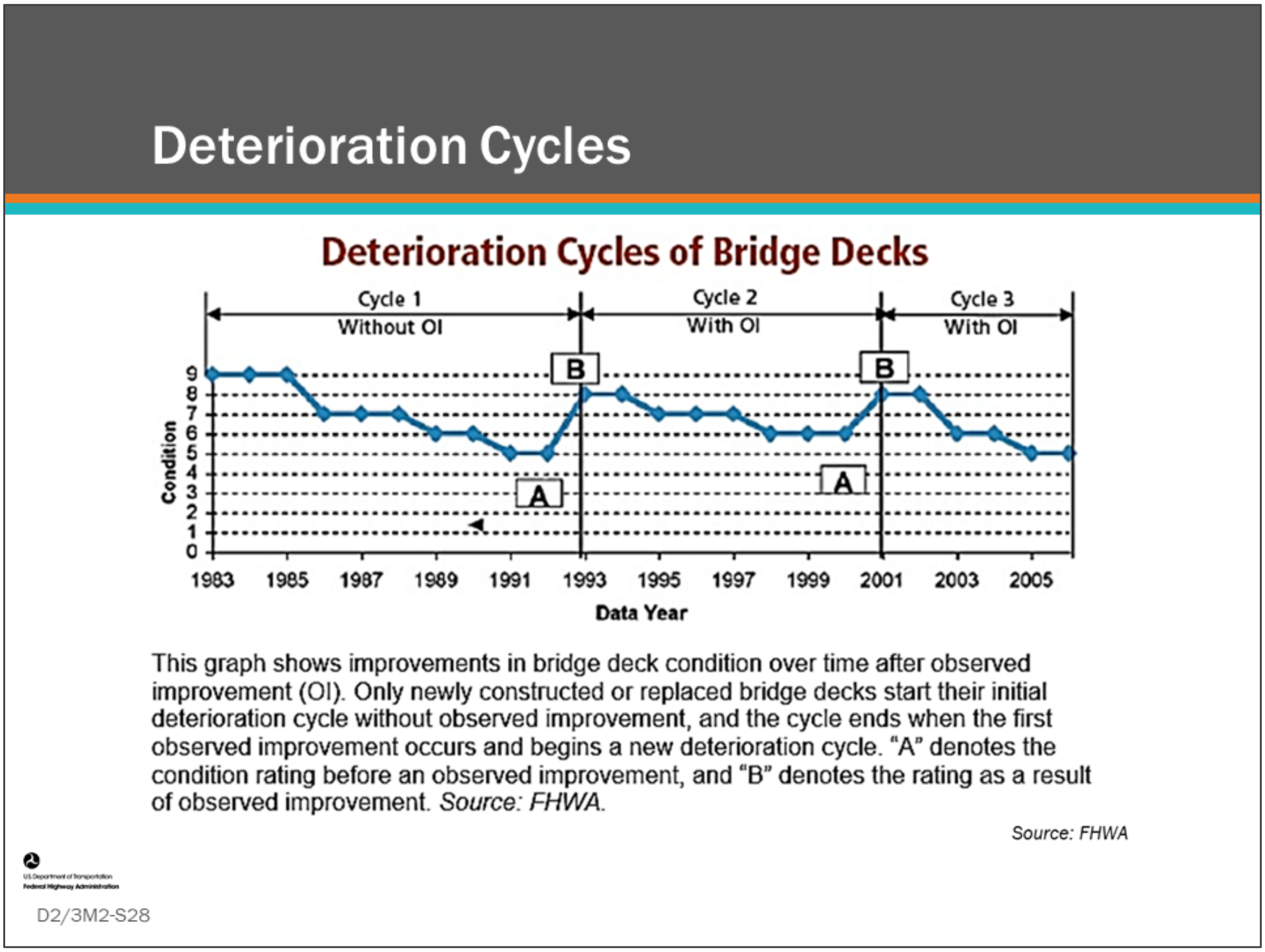
D2/3M2-S27

Key Message

When a condition rating goes up by more than one rating, it is assumed that an action was taken to improve the bridge. Because the condition was not allowed to naturally deteriorate to the next lower condition, it cannot be counted.

- For the example shown on this slide, the deck was in GCR 5 for five years, but then the condition increased to GCR 8, so the data could not be counted.

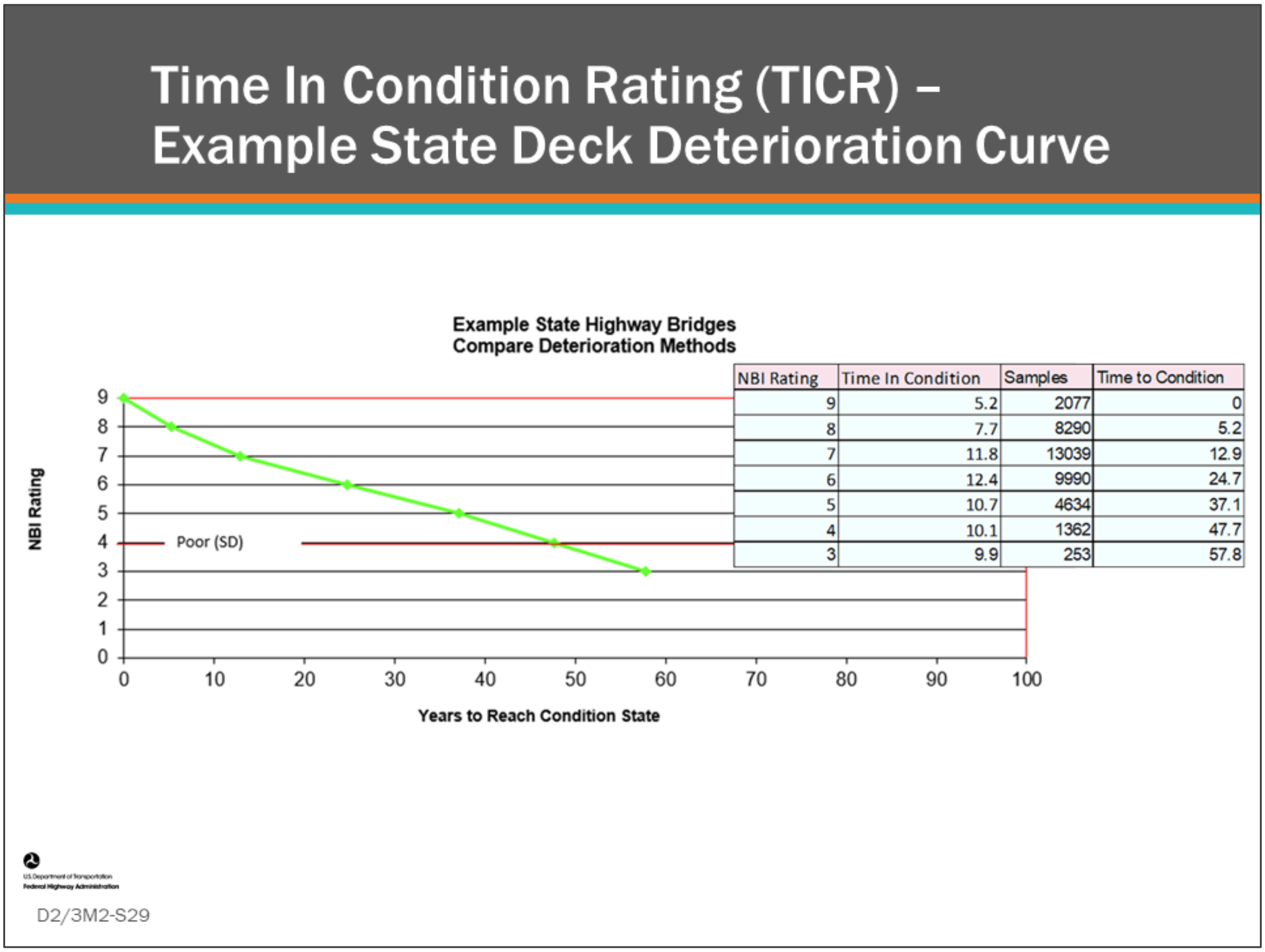
D2/3M2-Slide 28



Key Message

A bridge will often have two or three deterioration stages as shown here. Rehabilitation projects are done which improve the condition of elements, components or the entire bridge.

D2/3M2-Slide 29



NBI Rating	Time In Condition	Samples	Time to Condition
9	5.2	2077	0
8	7.7	8290	5.2
7	11.8	13039	12.9
6	12.4	9990	24.7
5	10.7	4634	37.1
4	10.1	1362	47.7
3	9.9	253	57.8

Key Message

Using the same example state highway bridges used for the Age-based method, a deterioration curve was derived using the TICR method.

- The table at the right side of the slide shows TICR, sample size, and the cumulative time to condition for the results of the analysis.
- The chart shows the resulting deterioration curve.

D2/3M2-Slide 30

Time In Condition Rating (TICR) Method – Discussion

Source: Adobe Stock

- What are benefits of Time In Condition Rating (TICR) method?
- What are the challenges?

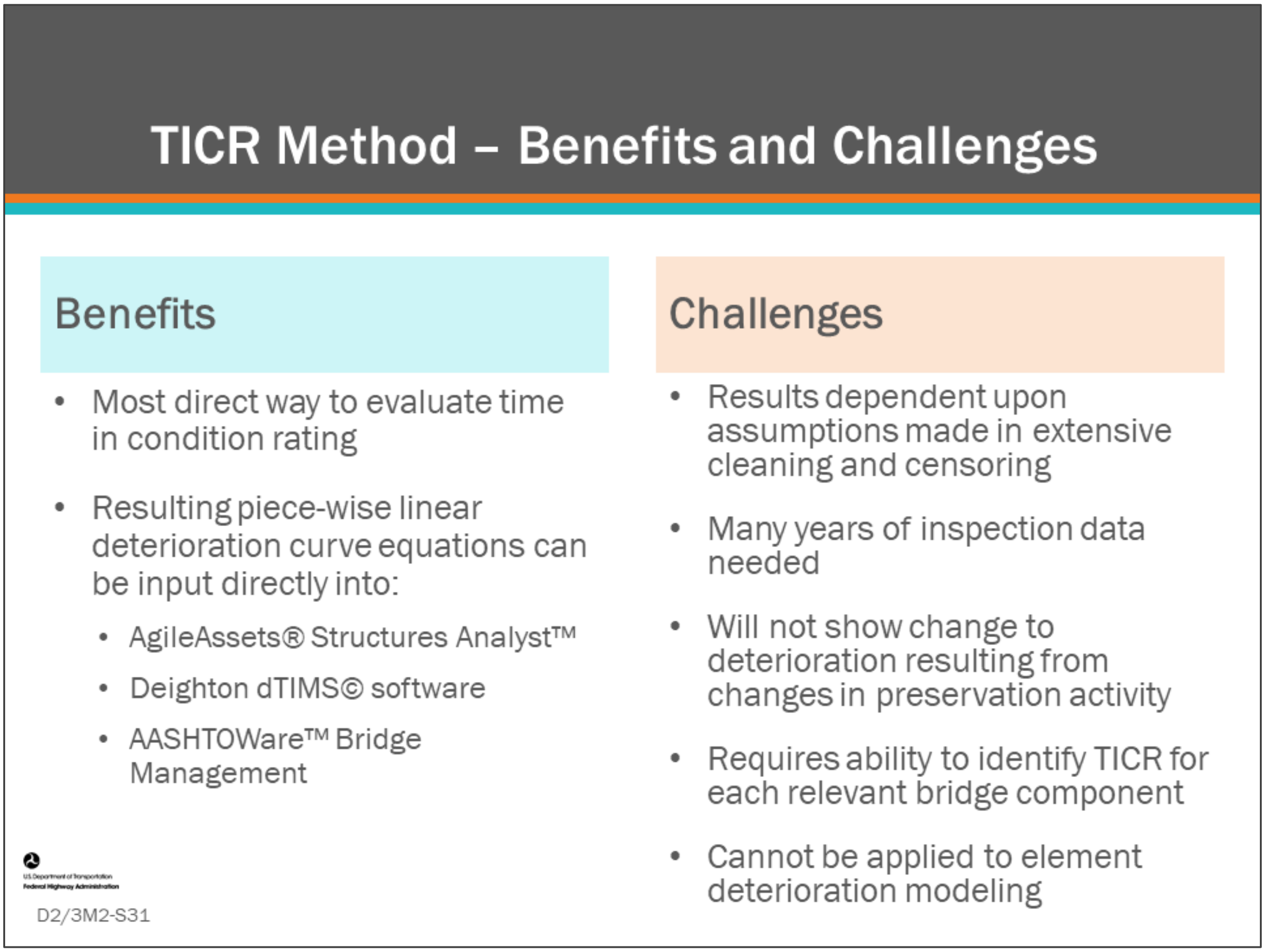
U.S. Department of Transportation Federal Highway Administration

D2/3M2-S30

Key Message

Discuss the questions on this slide.

D2/3M2-Slide 31



Key Message

Benefits and challenges of the TICR method are shown on this slide.

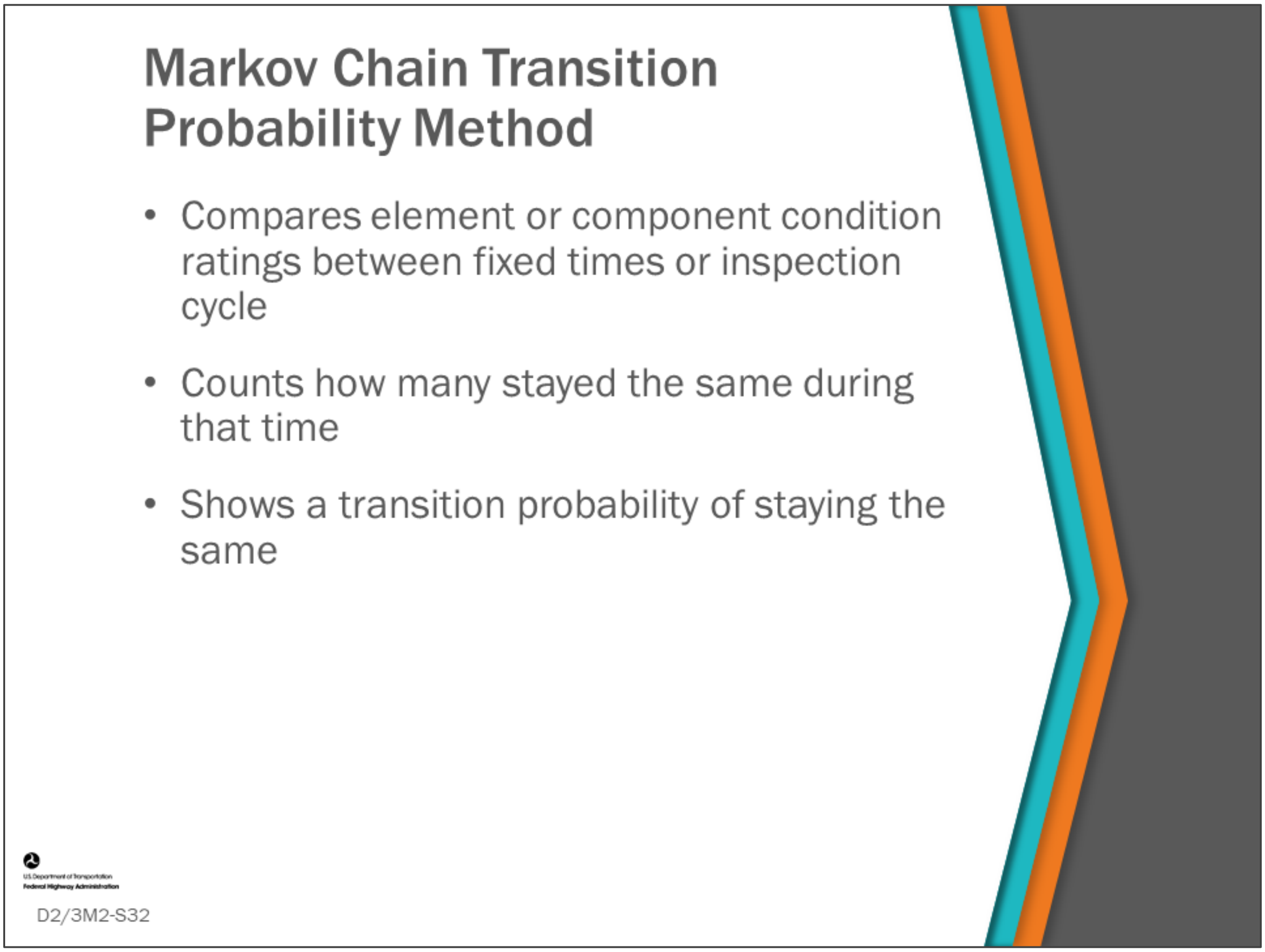
Benefits include:

- Most direct way to evaluate time in condition rating
- Resulting piece-wise linear deterioration curve equations can be input directly into:
  - AgileAssets® Structures Analyst™
  - Deighton dTIMS© software
  - AASHTOWare™ Bridge Management (BrM allows entry of transition times for each GCR which also resolves to the same piecewise deterioration curves)

Challenges include:

- That results are dependent upon assumptions made in extensive cleaning and censoring
- The method requires many years of inspection data
- Since the method uses data collected over many years, it will not show changes in deterioration that are the result of changes in agency policy and procedure, such as inspection guidance or preservation activity
- The method would need to be done for each relevant bridge component and it cannot be applied to element deterioration modeling

D2/3M2-Slide 32



Key Message

The third method analyzing condition data to estimate deterioration of components we will cover in this module is the Markov Chain Transition Probability.

- This method counts how many element or component condition ratings stayed the same during a fixed time frame and expresses the result as a transition probability of the condition ratings' likelihood of staying the same.
  - The fixed time frame used for the analyses, for example, could be per average inspection cycle, or a yearly snapshot - such as for Federal NBI data submittal.
- Transition probability can be converted to average TICR via calculation

D2/3M2-Slide 33

Transition Probability Matrix – Deck Deterioration Example

Deck Deterioration

	0	1	2	3	4	5	6	7	8	9
9	0	0	0	0	0	0	0	12	25	120
8	5	0	0	1	0	2	17	297	1691	7
7	10	0	0	0	3	22	290	6416	55	
6	19	0	0	1	5	156	4731	180	24	
5	5	0	0	0	34	1972	76	38	40	4
4	1	0	2	10	443	2	12	5	12	21
3	0	0	0	42					1	2
2	0	0	4							
1	0	4								
0	0									

D2/3M2-S33

Key Message

Shown on this slide is the transition probability matrix. We will review each part of it and learn how it is used.

- The example matrix shows bridge deck condition ratings using the NBI GCRs for bridge decks
- The matrix is produced by comparing bridge deck GCRs for individual bridges over a set time period
    - In this case, the ratings compare the NBI submittal from 2016 to 2017 (one year)

D2/3M2-Slide 34

Transition Probability Matrix – Deck Deterioration Example (con.)

- Bridge deck GCRs that dropped one or more GCR

Deck Deterioration

	0	1	2	3	4	5	6	7	8	9
9	0	0	0	0	0	0	0	12	25	120
8	5	0	0	1	0	2	17	297	1691	7
7	10	0	0	0	3	22	290	6416	55	
6	19	0	0	1	5	156	4731	180	24	
5	5	0	0	0	34	1972	76	38	40	4
4	1	0	2	10	443	2	12	5	12	21
3	0	0	0	42					1	2
2	0	0	4							
1	0	4								
0	0									

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D2/3M2-S34

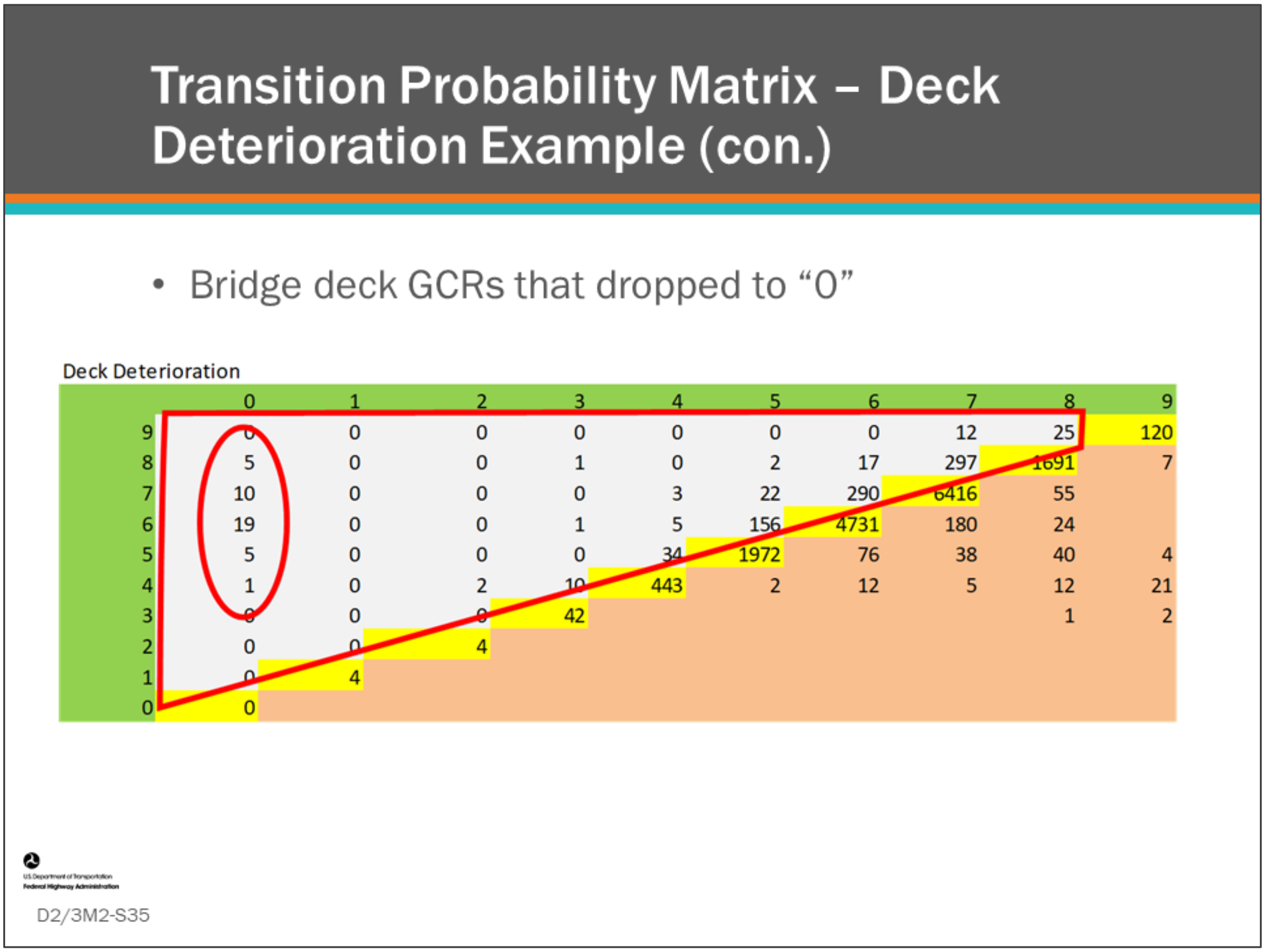
Key Message

The values to the left of the diagonal are bridge deck GCRs that went down one or more GCR during the time period.

For example:

- 25 bridge decks rated 9 dropped one rating to 8
- 12 bridge decks dropped two ratings to 7
- 297 bridge decks GCR 8 dropped to a GCR of 7
- 17 bridge decks dropped to a GCR of 6
- 2 bridge decks dropped to a GCR of 5
- 1 bridge deck dropped to a GCR of 3

D2/3M2-Slide 35



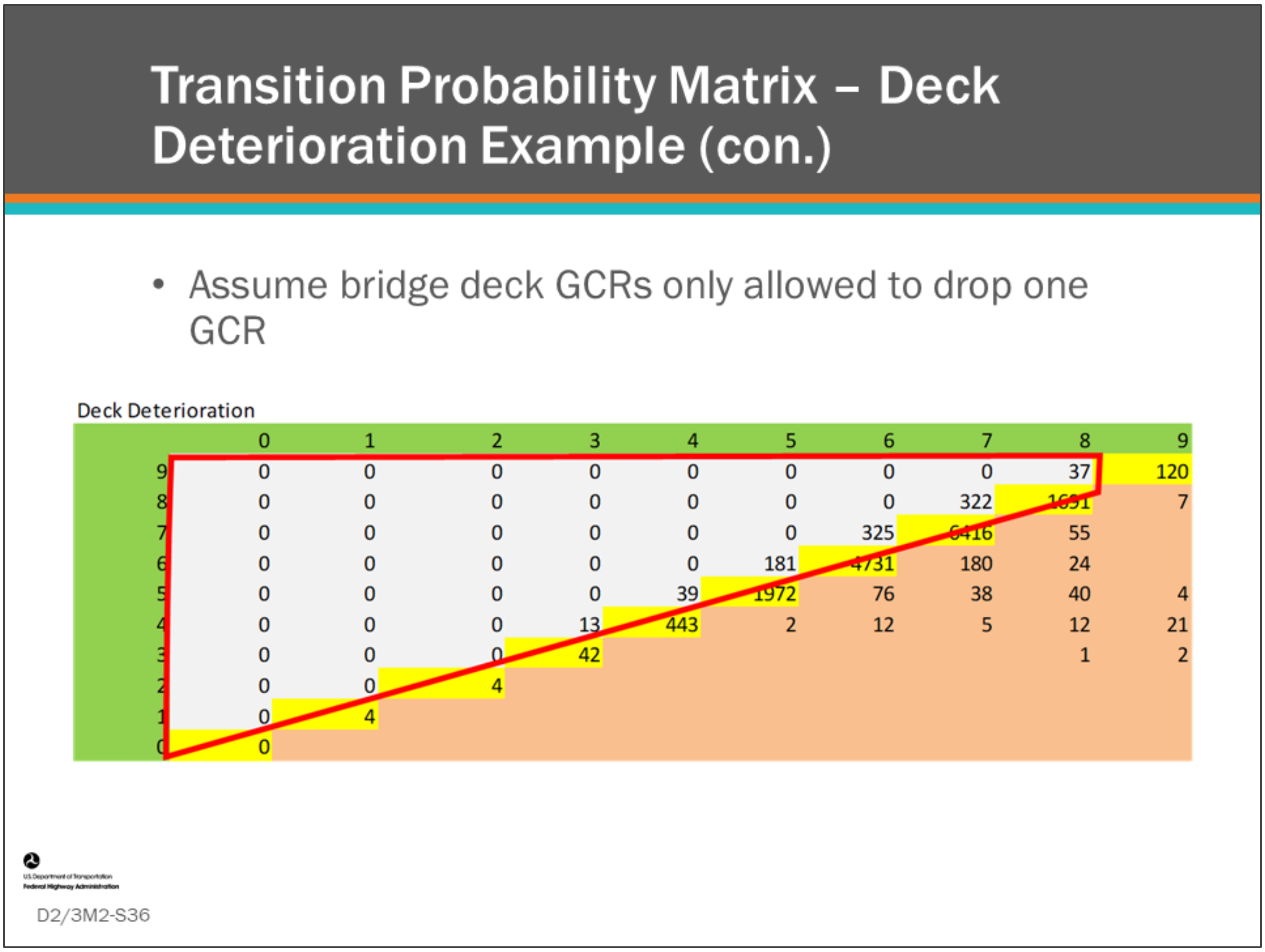
	0	1	2	3	4	5	6	7	8	9
9	0	0	0	0	0	0	0	12	25	120
8	5	0	0	1	0	2	17	297	1691	7
7	10	0	0	0	3	22	290	6416	55	
6	19	0	0	1	5	156	4731	180	24	
5	5	0	0	0	34	1972	76	38	40	4
4	1	0	2	10	443	2	12	5	12	21
3	0	0	0	42					1	2
2	0	0	4							
1	0	4								
0	0									

Key Message

Notice the deck GCRs that dropped all the way to GCR of zero, which is defined as the bridge failed and it is closed.

- This may be possible for a few of these bridges; however, it is also possible that these are being reconstructed, and, some agencies may rate the component as zero during this time.
    - This is an example of how reviewing this matrix can help bridge managers and inspection managers to perform quality assurance of bridge inspections and recording practice.

D2/3M2-Slide 36



	0	1	2	3	4	5	6	7	8	9
9	0	0	0	0	0	0	0	0	37	120
8	0	0	0	0	0	0	0	322	1691	7
7	0	0	0	0	0	0	325	6416	55	
6	0	0	0	0	0	181	4731	180	24	
5	0	0	0	0	39	1972	76	38	40	4
4	0	0	0	13	443	2	12	5	12	21
3	0	0	0	42					1	2
2	0	0	4							
1	0	4								
0	0									

Key Message

Often, for simplicity in calculations, researchers will only allow a GCR to drop only one rating at a time.

- The matrix above was adjusted to show all GCRs dropping only one rating; however, this step really is not necessary for further calculations.

D2/3M2-Slide 37

Transition Probability Matrix – Deck Deterioration Example (con.)

- Bridge deck GCRs that increased one or more

Deck Deterioration

	0	1	2	3	4	5	6	7	8	9
9	0	0	0	0	0	0	0	0	37	120
8	0	0	0	0	0	0	0	322	1601	7
7	0	0	0	0	0	0	325	6416	55	
6	0	0	0	0	0	181	4721	180	24	
5	0	0	0	0	39	1972	76	38	40	4
4	0	0	0	13	443	2	12	5	12	21
3	0	0	0	42					1	2
2	0	0	4							
1	0	4								
0	0									

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D2/3M2-S37

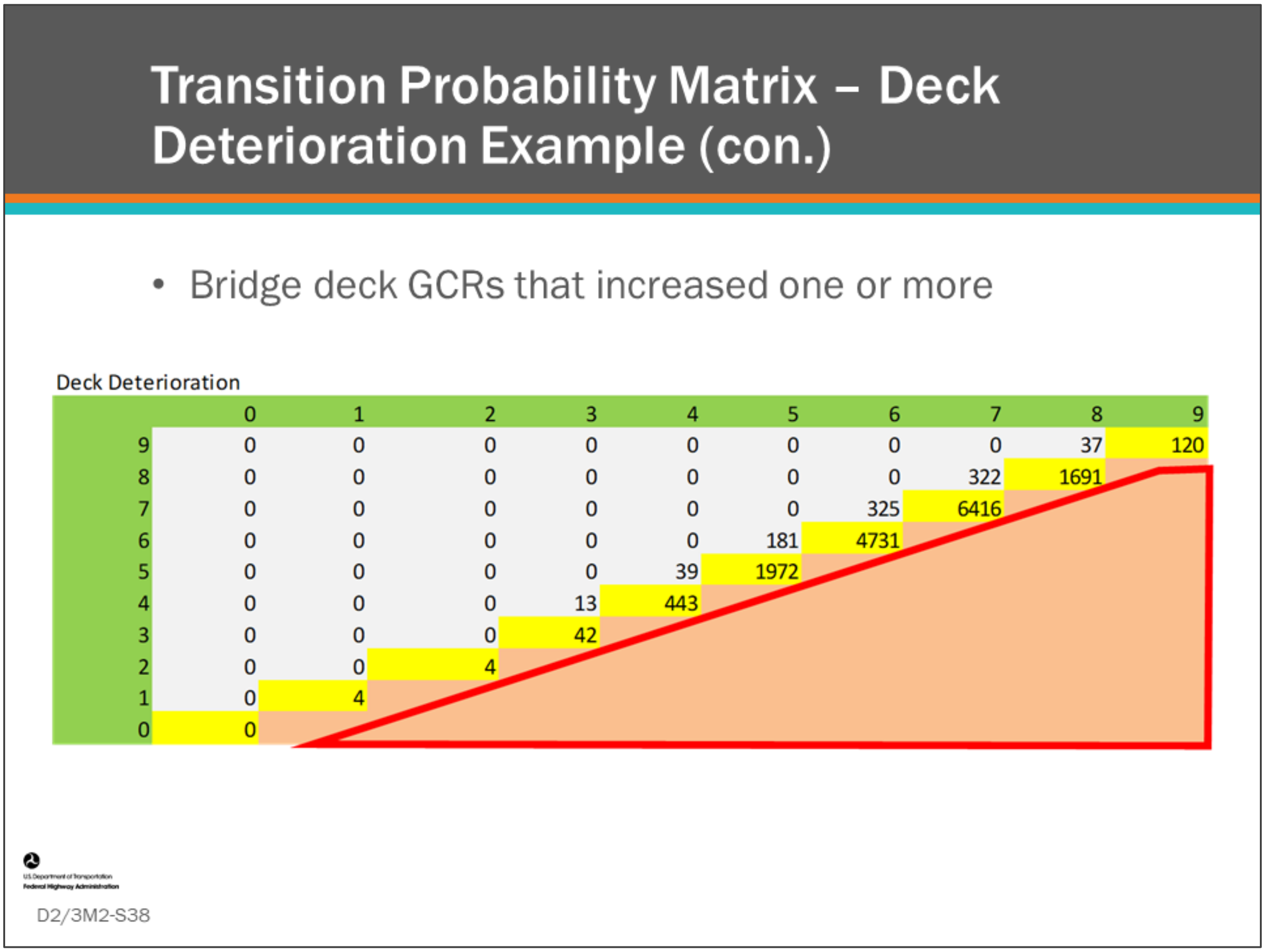
Key Message

The area to the right of the diagonal shows bridge decks that increased one or more ratings.

For example:

- 180 bridge decks with GCR 6 improved to 7
- 24 bridge decks increased to 8
- 1 bridge deck that was rated a 3 (serious condition) increased to 8
- 2 bridge decks increased to 9

D2/3M2-Slide 38



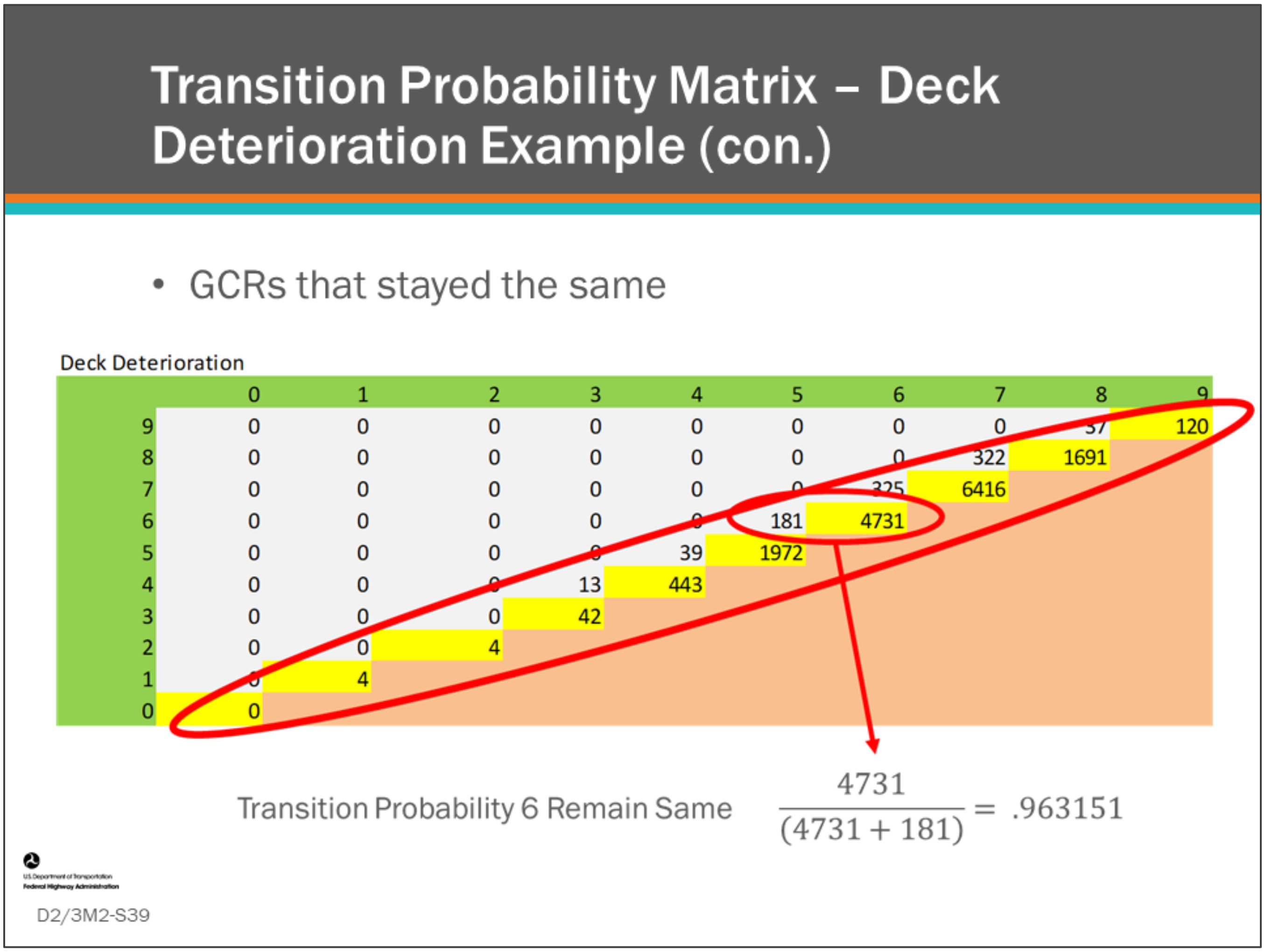
	0	1	2	3	4	5	6	7	8	9
9	0	0	0	0	0	0	0	0	37	120
8	0	0	0	0	0	0	0	322	1691	
7	0	0	0	0	0	0	325	6416		
6	0	0	0	0	0	181	4731			
5	0	0	0	0	39	1972				
4	0	0	0	13	443					
3	0	0	0	42						
2	0	0	4							
1	0	4								
0	0									

Key Message

When counting change for deterioration modeling improvement in condition ratings are removed from the matrix.

- Notice the values in the red box have been removed.

D2/3M2-Slide 39



	0	1	2	3	4	5	6	7	8	9
9	0	0	0	0	0	0	0	0	37	120
8	0	0	0	0	0	0	0	322	1691	
7	0	0	0	0	0	0	325	6416		
6	0	0	0	0	0	181	4731			
5	0	0	0	0	39	1972				
4	0	0	0	13	443					
3	0	0	0	42						
2	0	0	4							
1	0	4								
0	0									

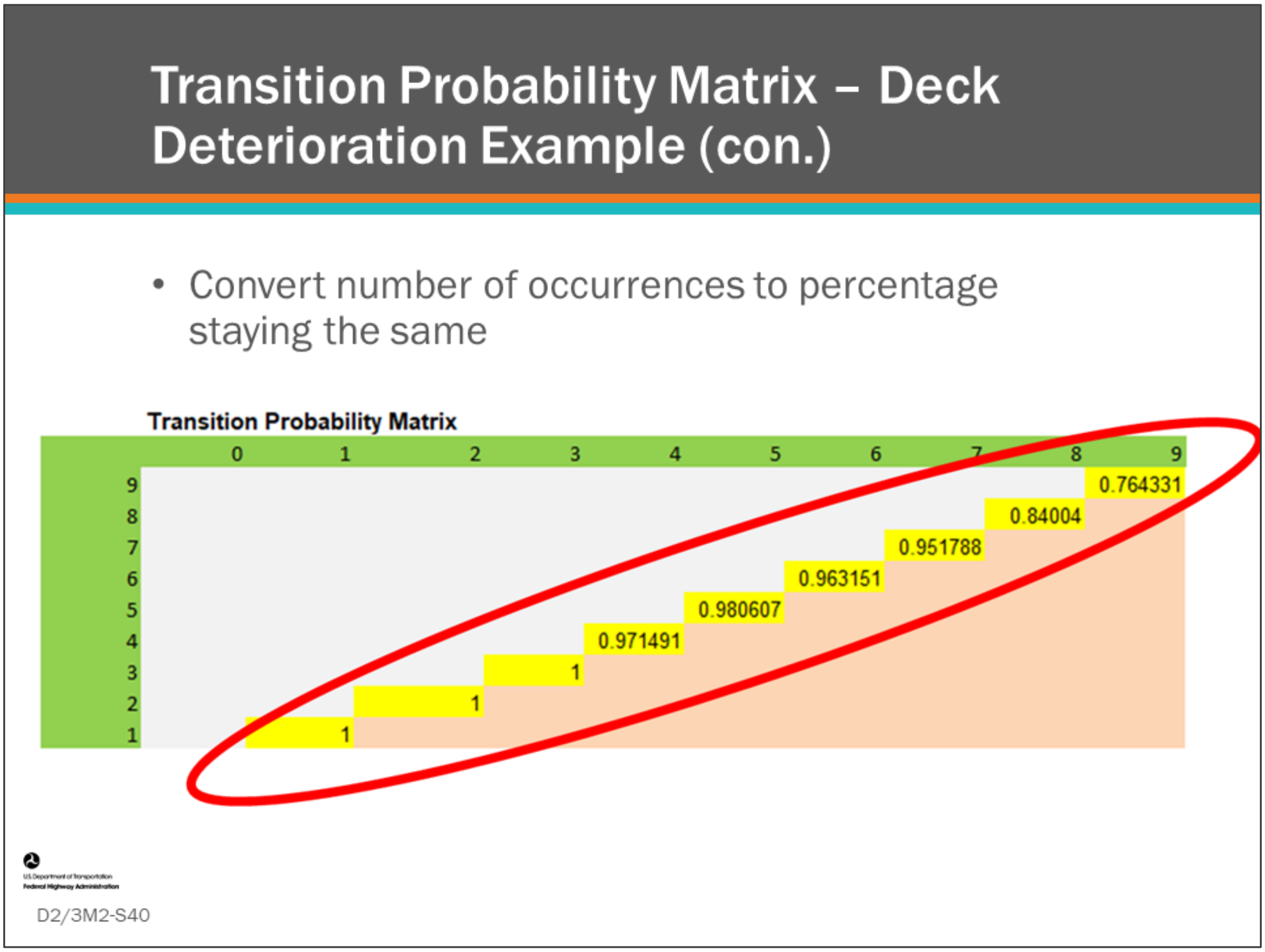
Key Message

The values along the diagonal are the deck ratings that stayed the same from the first year (2016) to the second year (2017). For example:

- 120 bridge decks with a GCR 9 remained 9
- 1,691 bridge decks with a 8 remained 8
- 6,416 bridge decks with a 7 remained 7

These are the values used for all deterioration modeling calculations. The values can be converted to transition probability by simply dividing the number that stayed the same over the total amount that was in that condition rating.

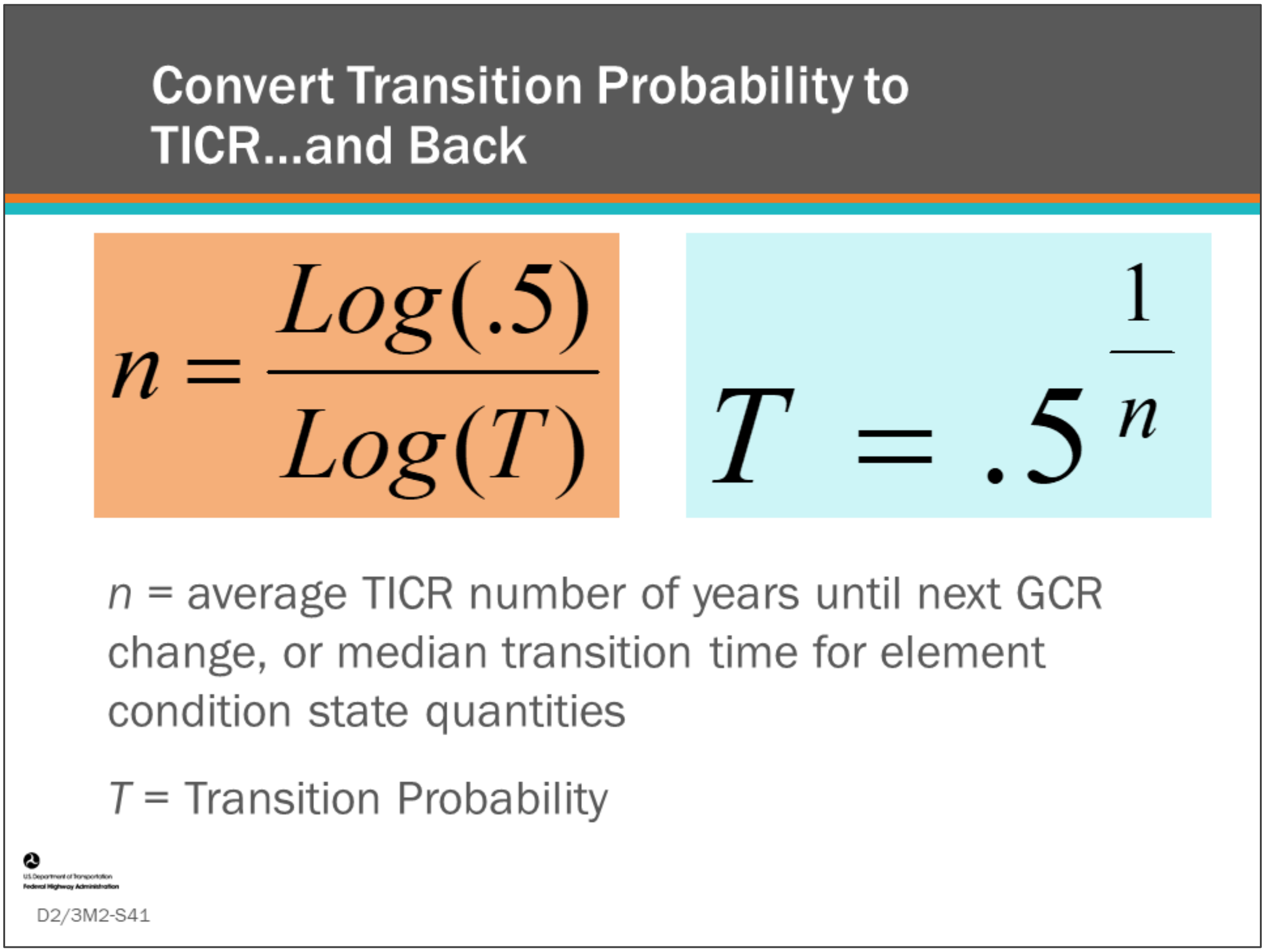
D2/3M2-Slide 40



Key Message

Finally, after completing this for each GCR, we have the transition probabilities for staying the same for each GCR.

D2/3M2-Slide 41



Key Message

These are the two most important equations if you use transition probabilities for deterioration modeling:

- The equation on the left, converts transition probability to average TICR, or median time in an element condition state
- The equation on the right, converts average TICR, or median time in an element condition state, into a transition probability
    - Median time in an element condition state is the time for 50 percent of the condition state quantity to move out of the condition state

D2/3M2-Slide 42

Markov Chain Transition Probability Calculation For Successive Years

Probability CS1 Remains CS1, when t = .9828

t = Time (years)	Future Probability by Multiplication	Future Probability by Exponential Equation
0	1.0	$t^0 = 1.0$
1	t = 0.9828	$t^1 = 0.9828$
2	t x t = 0.9659	$t^2 = 0.9659$
3	t x t x t = 0.9493	$t^3 = 0.9493$
4	t x t x t x t = 0.9330	$t^4 = 0.9330$

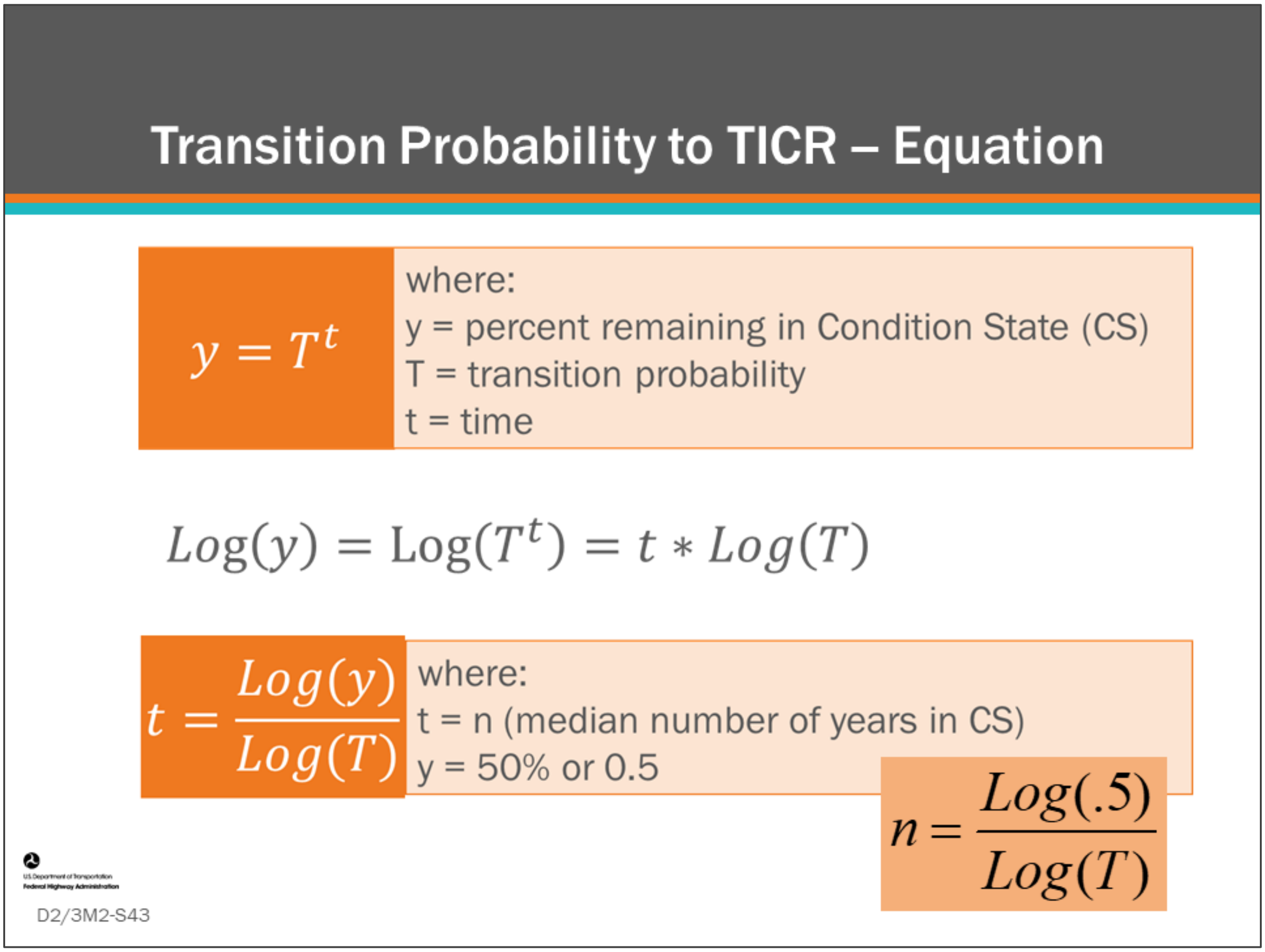
D2/3M2-S42

Key Message

Probability for change is only applicable when no action is taken to the bridge.

- With this equation, you can calculate the expected quantity or percentage that will remain in a given condition state in future years.

D2/3M2-Slide 43



Key Message

This slide shows how the transition probability to time in condition rating equation is derived.

D2/3M2-Slide 44

Calculating TICR For Each Condition Rating

Rating	Transition Probability	Time In Condition Rating
9	0.764331	3
8	0.840040	4
7	0.951788	14
6	0.963151	18
5	0.980607	35
4	0.971491	24

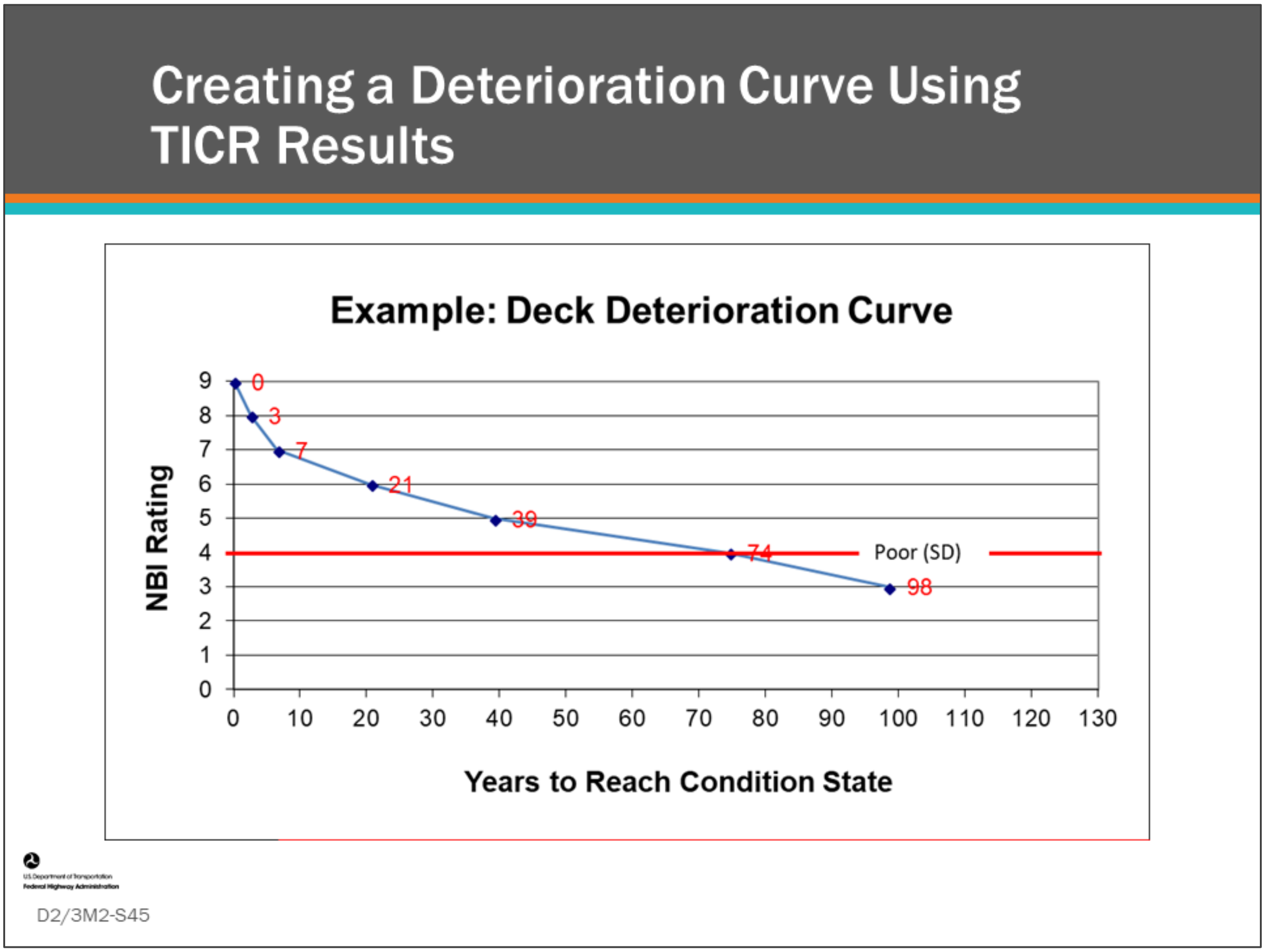
$$T = .5^{\frac{1}{n}}$$

D2/3M2-S44

Key Message

Here we see the transition probabilities from the previous example converted to average TICR, for GCRs 9 through 4.

D2/3M2-Slide 45

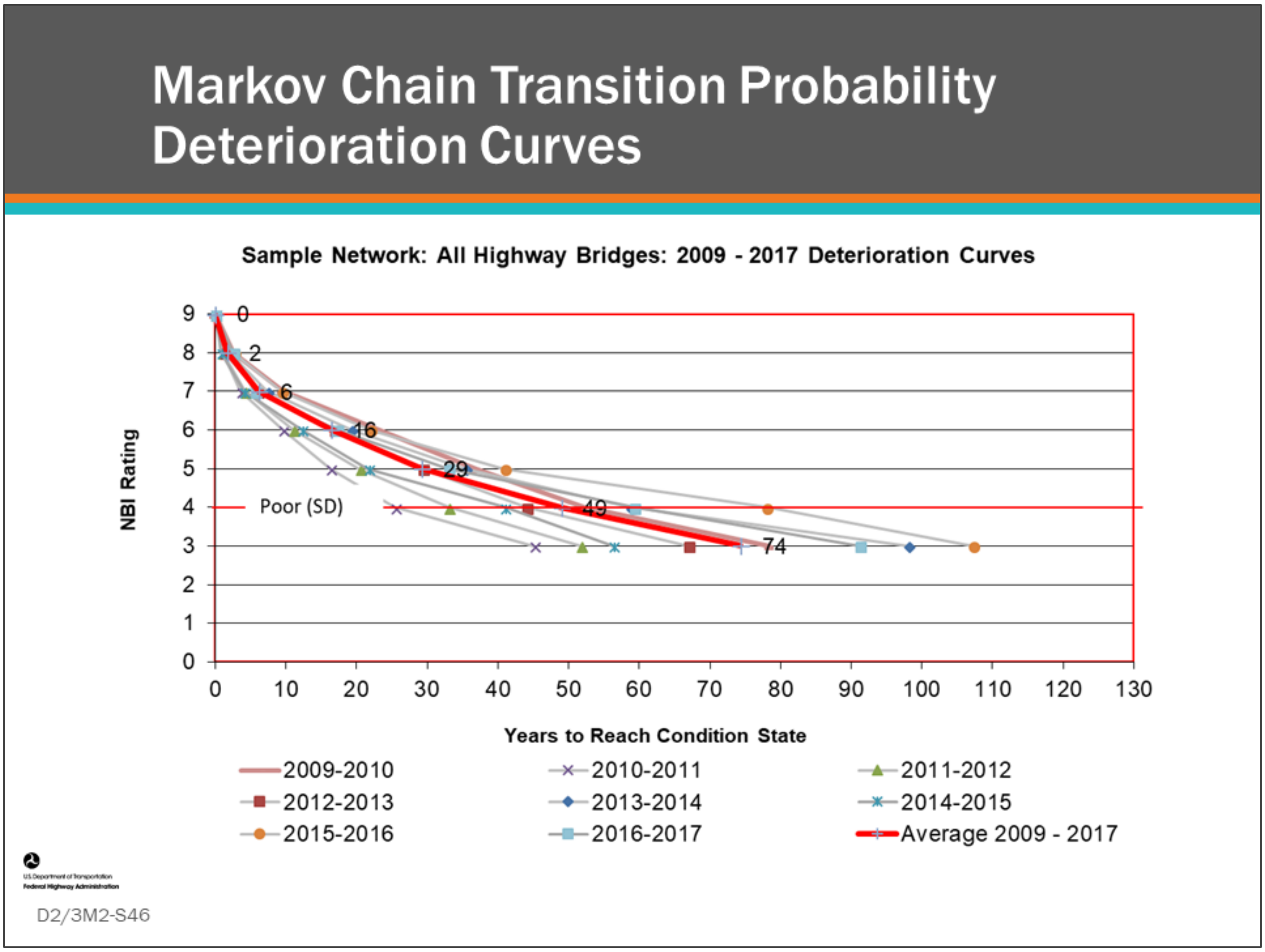


Key Message

The results can be shown as a deterioration curve by plotting the cumulative TICR values, as shown in the chart on this slide.

- A helpful measure is to show how long a new bridge component takes before it becomes poor condition, or Time To Poor (TTP).
- Time to Poor can also be called remaining service life.

D2/3M2-Slide 46



Key Message

Theoretically, Markov transition probabilities only need one inspection cycle (two inspections) in order to create a deterioration model; however, it has been shown that transition probabilities can vary from year to year, thus affecting the curves calculated using this method.

- Shown in the chart are multiple deterioration curves created using the Markov transition probability method for our sample network of bridges.
    - Notice how from year to year the curves change.
    - The modeler should choose wisely how many inspection cycles are used to create the average or representative deterioration model.
    - A minimum of four inspection cycles has been practiced.

Data mining for creating deterioration models for a BMS is also affected by the need to develop native deterioration curves that exclude the effects of work that improves condition.

- When developing deterioration models for input into a BMS, effort should be made to use native (no action was performed on the bridge) deterioration models as much as possible.
    - For example, major component or element improvement are always removed from the dataset, and an agency can also try to identify and remove bridges which have had recent preservation activity.

D2/3M2-Slide 47

Markov Chain Transition Probability Method Discussion

Source: Adobe Stock

- What are benefits of the Markov Chain Transition Probability method?
- What are the challenges?

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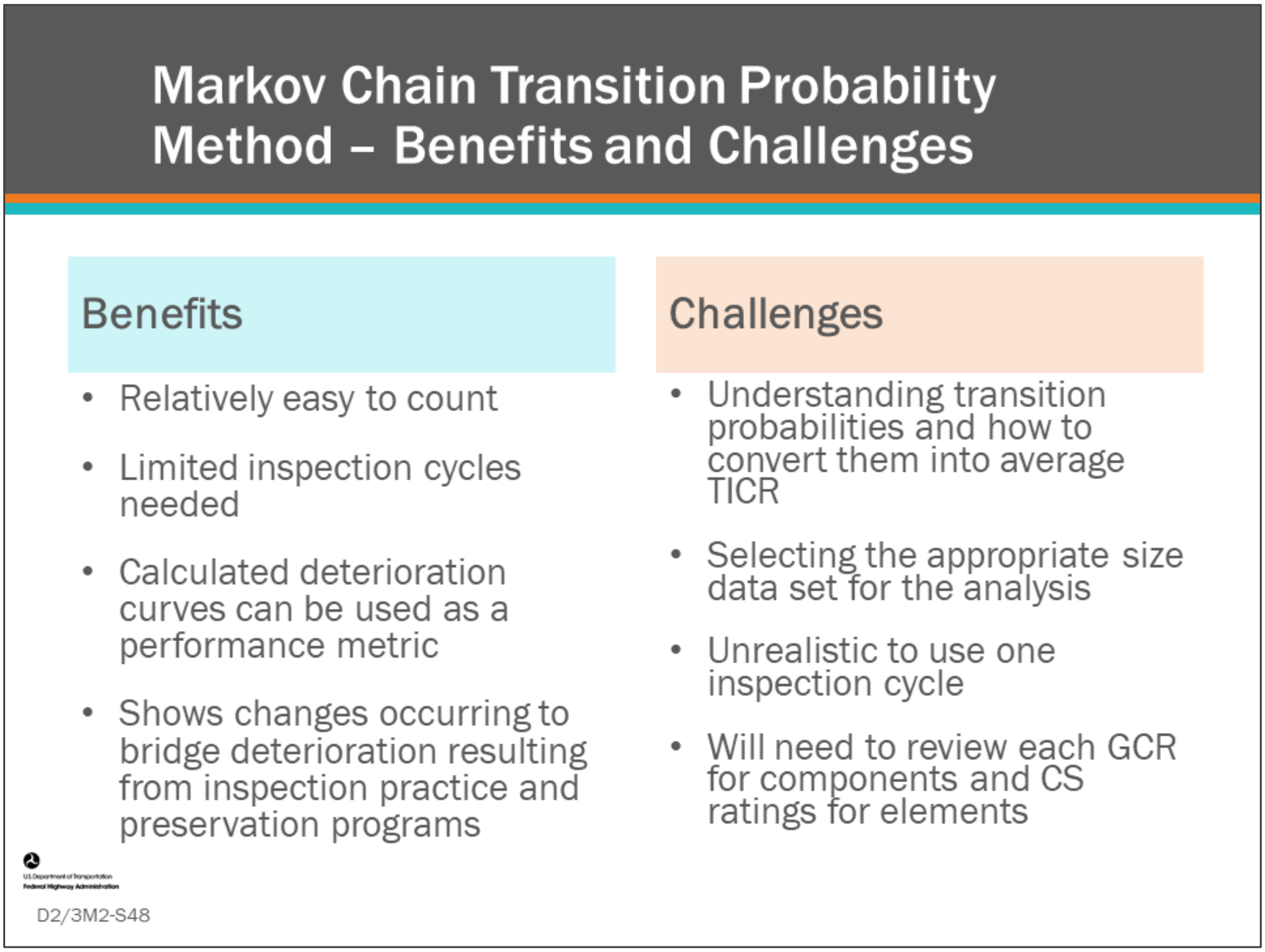
Federal Highway Administration

D2/3M2-S47

Key Message

Discuss the questions on this slide.

D2/3M2-Slide 48



Key Message

Benefits and challenges of the Markov method are shown on the slide.

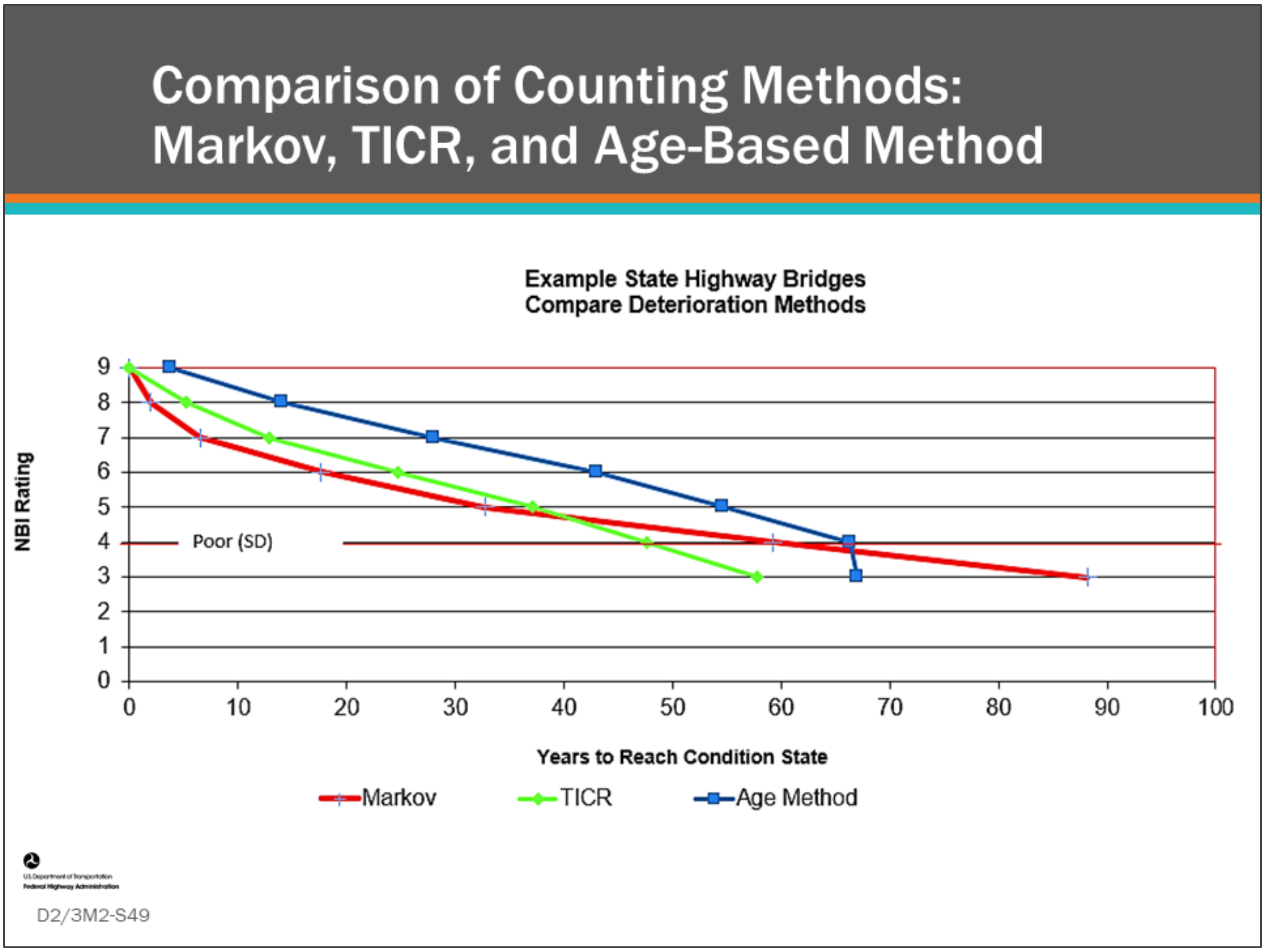
Benefits include:

- It is relatively easy to count.
- Limited inspection cycles needed to estimate deterioration curves. This is because the required data is percentage that transitions per year (at least one inspection cycle generating two data points is required). Including additional inspection cycles will increase the number of data points improving accuracy.
- Transition probabilities, or the calculated deterioration curves, can be used as a performance metric.
- For example, 2016-2017 can be compared to 2017-2018.

Challenges include:

- Understanding transition probabilities and how to convert them into average TICR
- Selecting the appropriate size data set for the analysis
- Unrealistic to use one inspection cycle
- Will need to review each GCR for components and CS ratings for elements

D2/3M2-Slide 49



Key Message

This chart shows a comparison of three data analysis methods: Markov Chain transition probability, TICR, and the Age-Based Method, for the same data set of example state highway bridges.

- Notice the different results and shape of deterioration curves.

The point of showing these together for the same data is to illustrate that depending upon how you count, what clipping, censoring, data preparation, and what analysis you perform, this will determine the form of the resulting deterioration models. In the end, you need to be comfortable in the results.

D2/3M2-Slide 50

Bridge Element Deterioration Overview

120 Steel Truss

104 Prestressed Closed Web/Box Girder (Segmental)

215 Reinforced Concrete Abutment

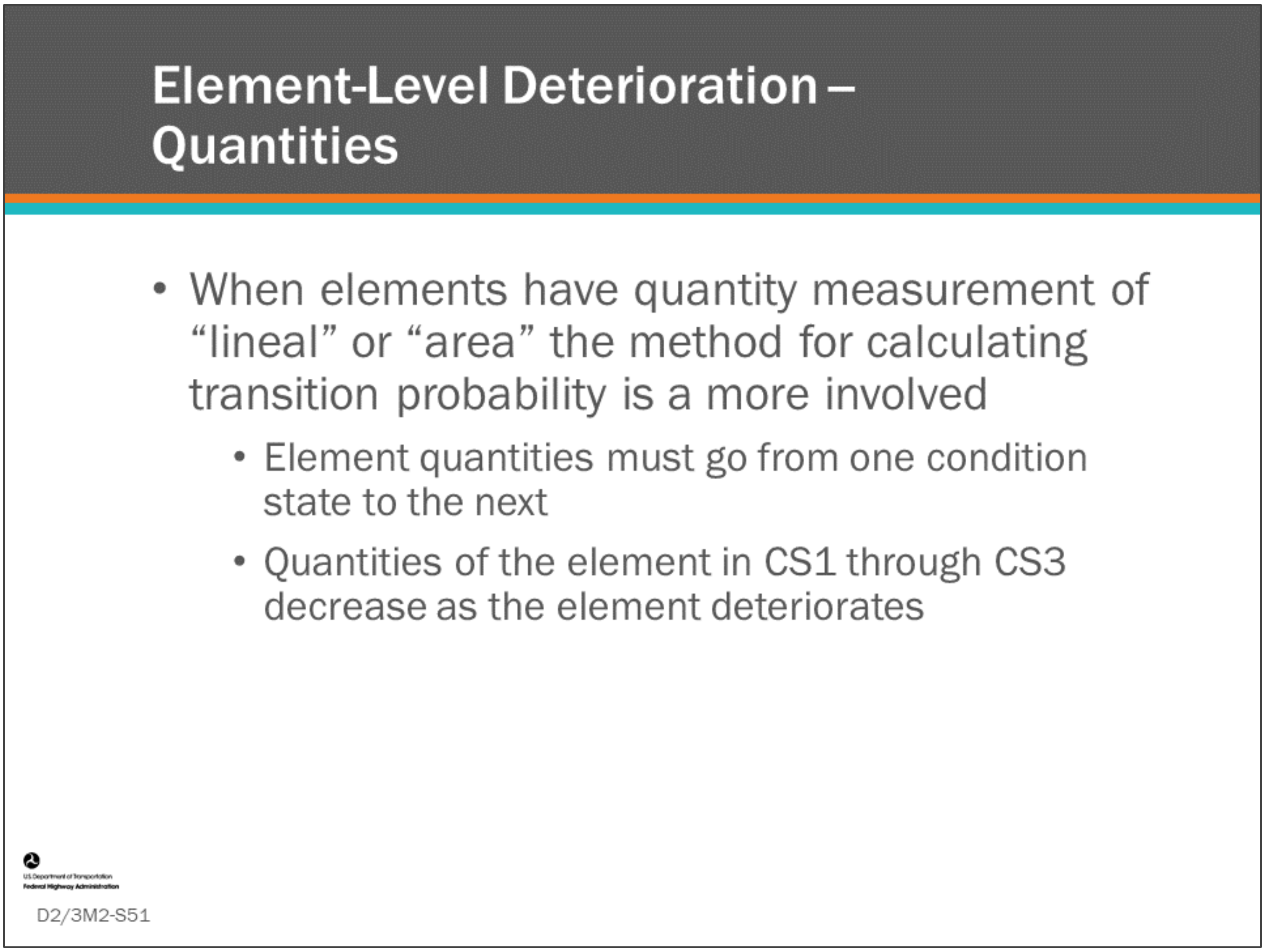
D2/3M2-S50

Key Message

Highway bridge owners realized that to advanced their bridge management programs, they would need to collect more detailed condition information at the element level.

- To support this, AASHTO created the MBEI, which provides guidance to bridge owners how to collect element condition data.

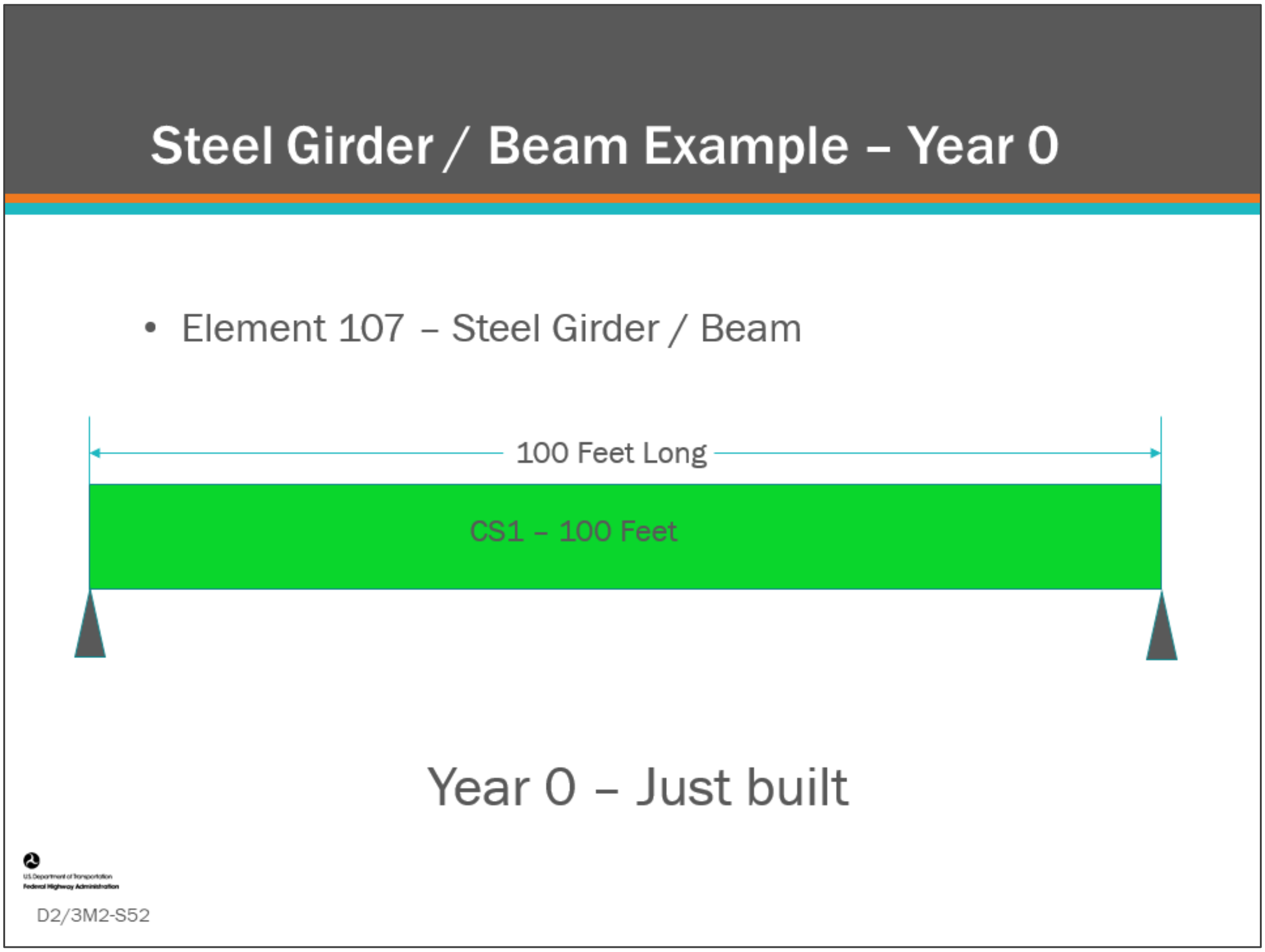
D2/3M2-Slide 51



Key Message

Because the element can have quantities of lineal feet and square feet in each of the condition states, some rules are needed to work with them – as discussed in the bullets.

D2/3M2-Slide 52

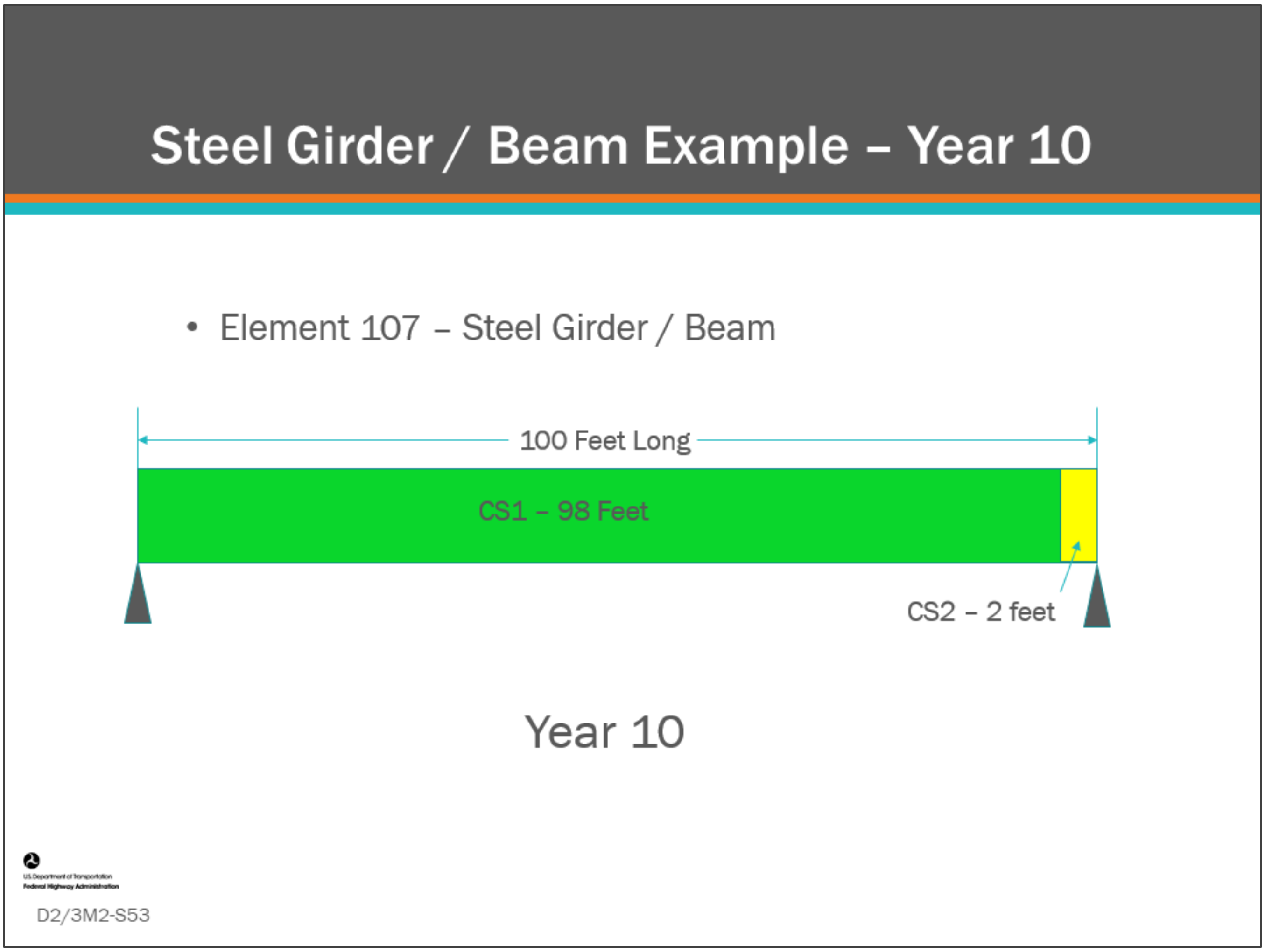


Key Message

In this section, we will show how element condition ratings are used to show deterioration on Element 107 – Steel Girder / Beam.

- When the bridge is first built, the beam is all in CS1 (good).

D2/3M2-Slide 53



Key Message

In 10 years, 2 ft of the beam deteriorates into CS2 (fair).

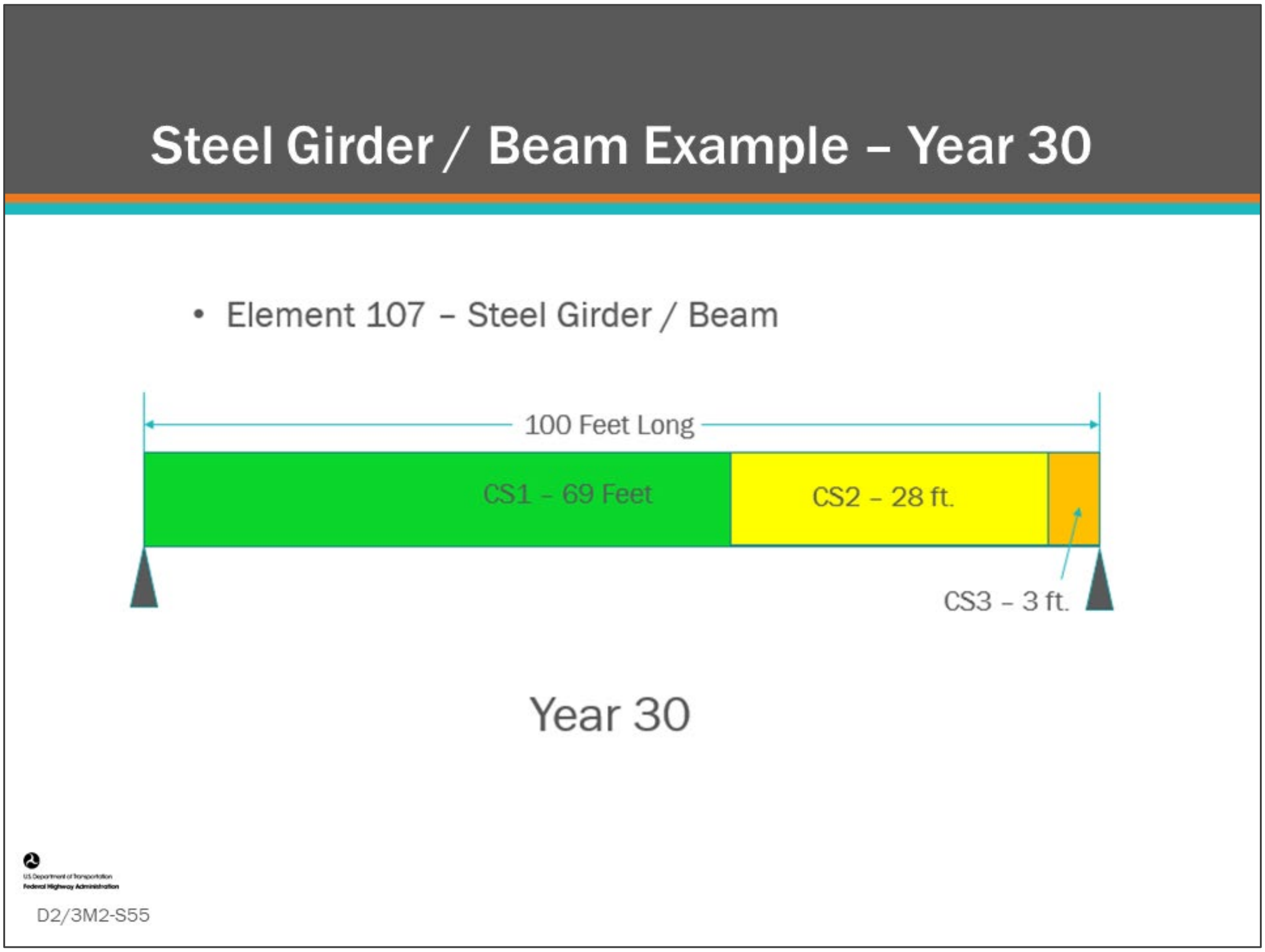
D2/3M2-Slide 54

Key Message

In 20 years:

- 81 ft of the beam is in CS1
- 18 ft in CS2
- 1 ft in CS3

D2/3M2-Slide 55



Key Message

After 30 years:

- 69 ft of the beam is in CS1
- 28 ft is in CS2
- 3 ft is in CS3

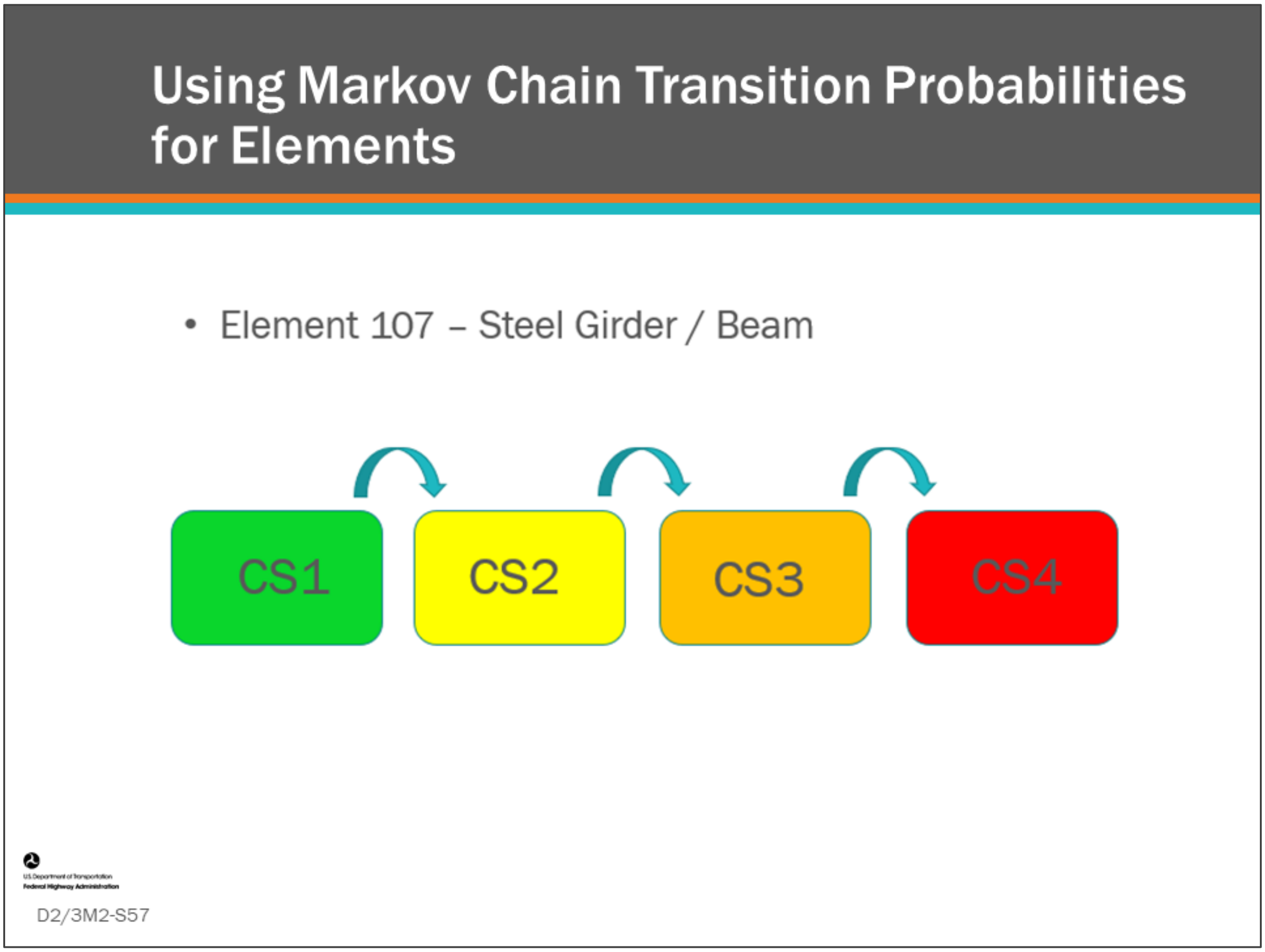
D2/3M2-Slide 56

Key Message

At 40 years:

- 67 ft of the beam is in CS1
- 28 ft is in CS2
- 4 ft is in CS3
- 1 ft is in CS4

D2/3M2-Slide 57

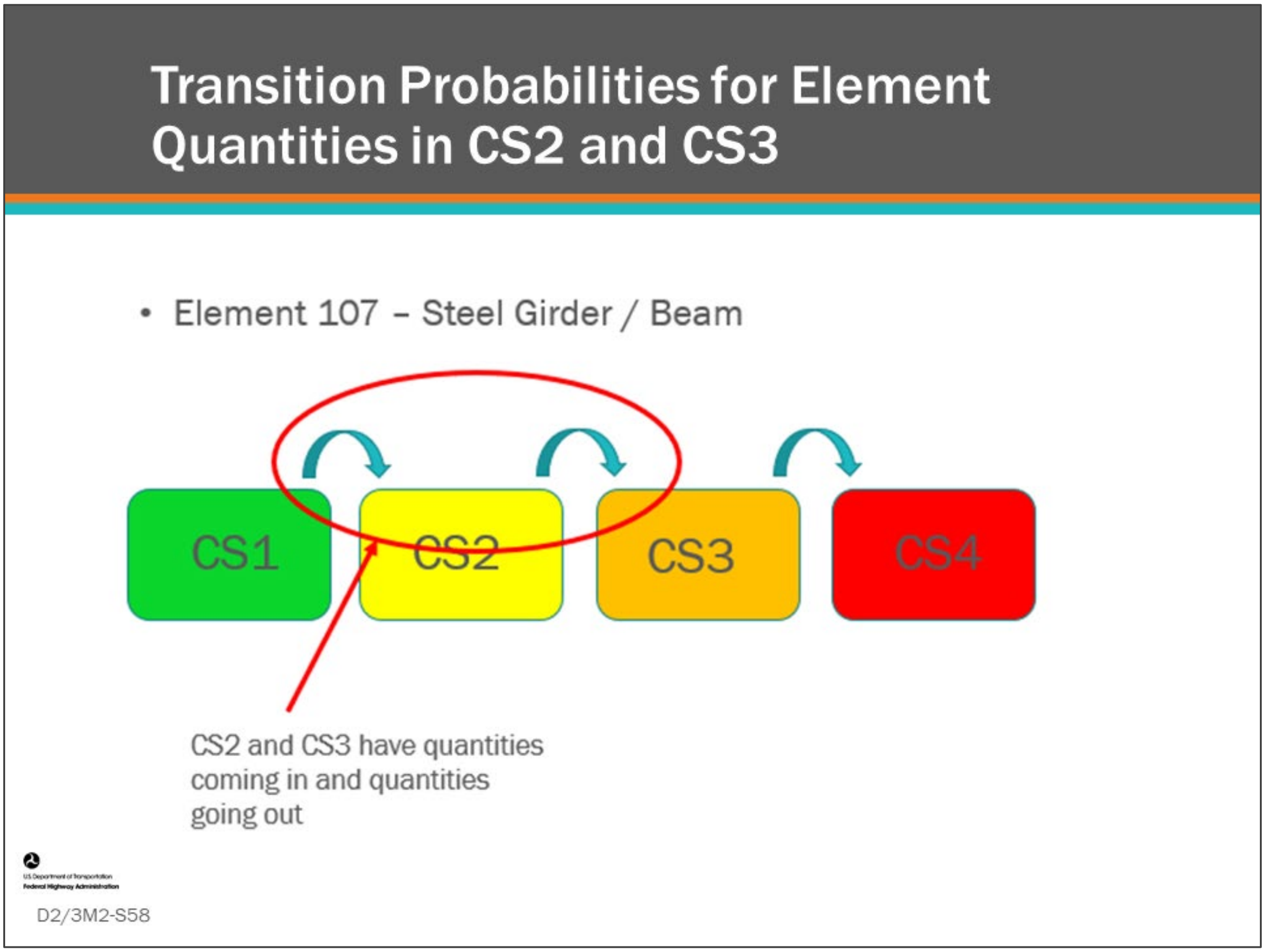


Key Message

We will now discuss how transition probability is measured for this beam.

- Again, portions of CS1 deteriorate to CS2, while portions of CS2 deteriorate to CS3, and a portion of CS3 deteriorates to CS4.

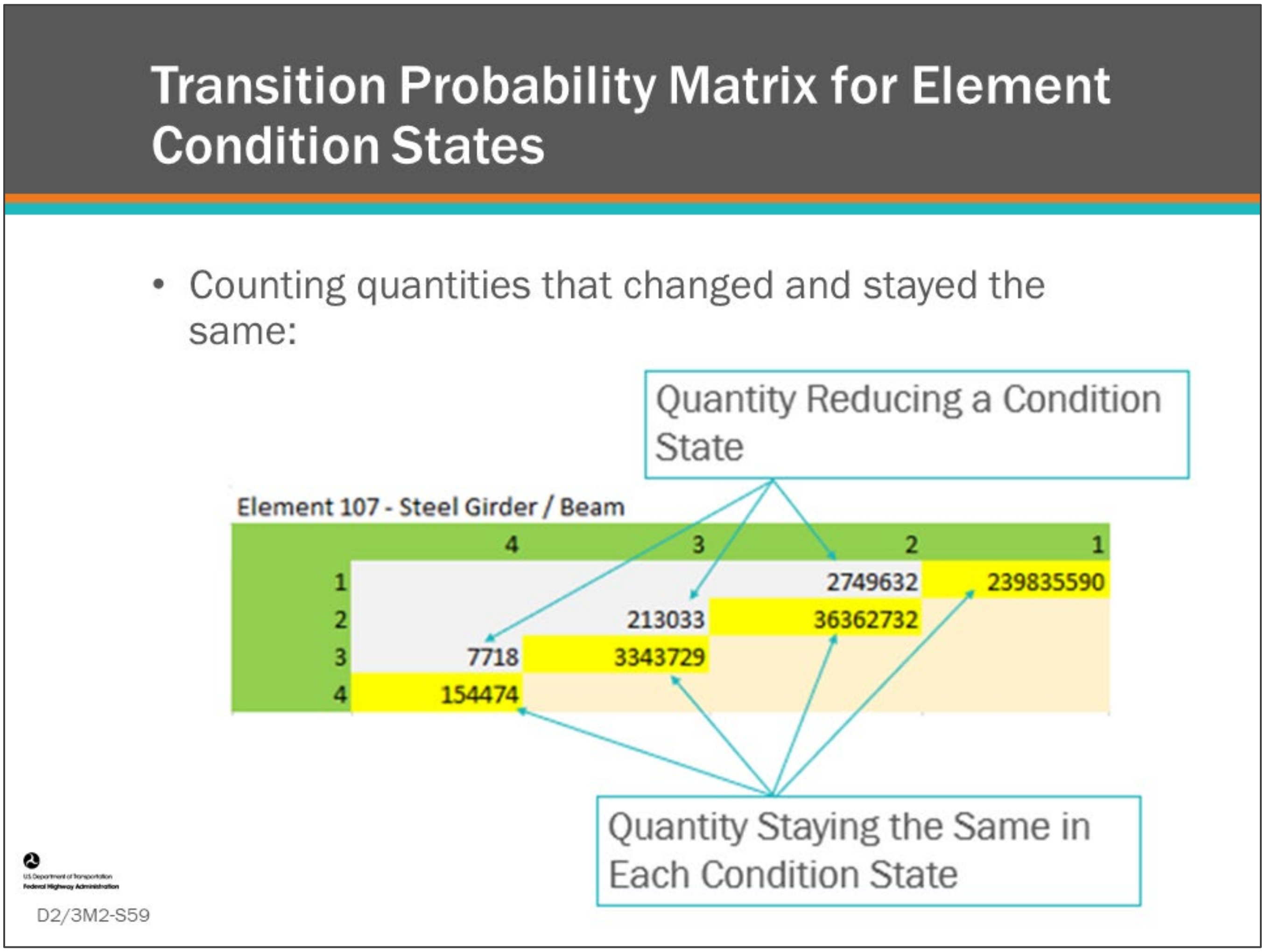
D2/3M2-Slide 58



Key Message

For CS2 and CS3, quantities are flowing in and flowing out.

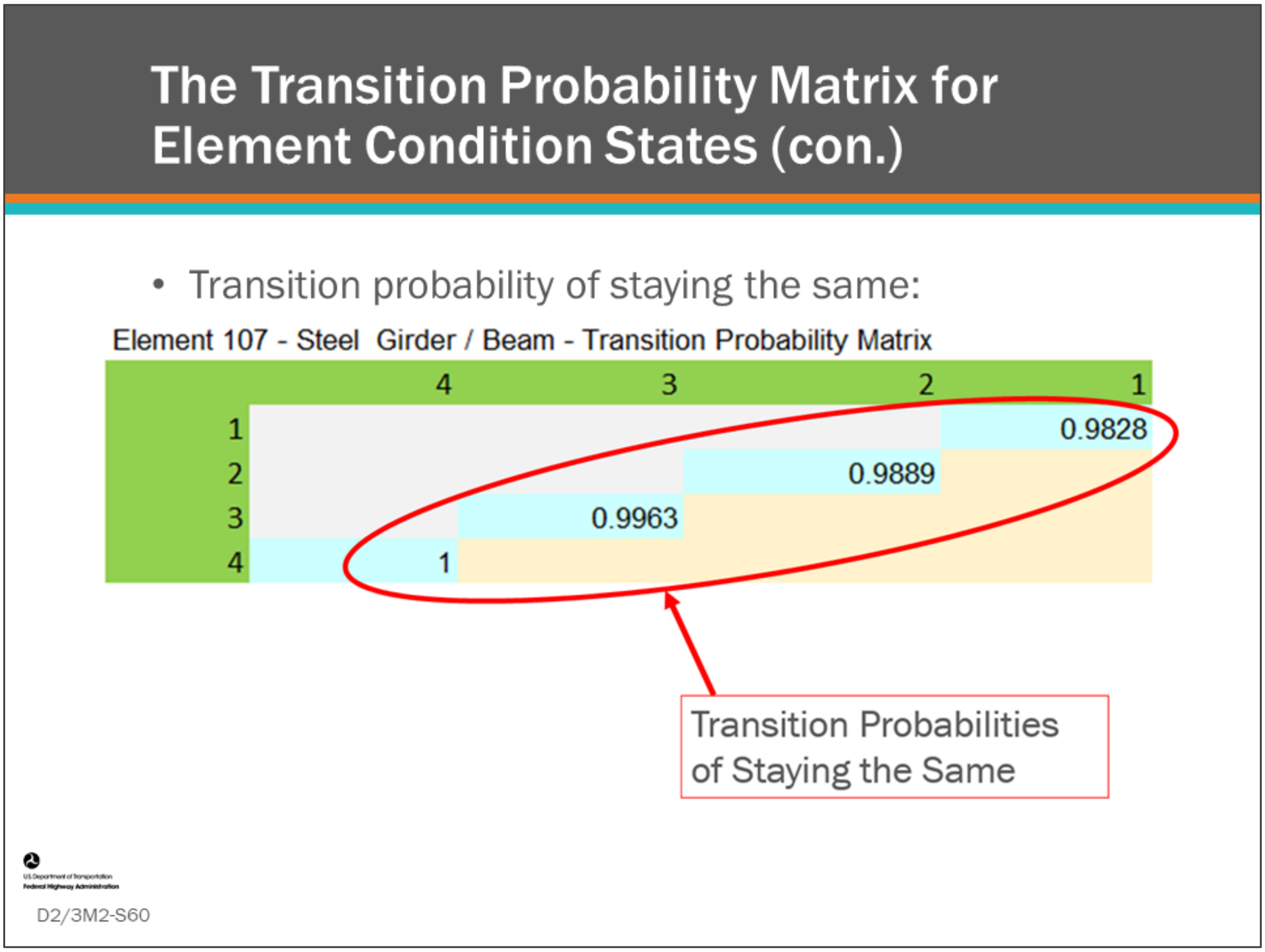
D2/3M2-Slide 59



Key Message

Similar to the counting procedure for bridge components shown earlier, you can count the quantity of each condition state that stay the same or change in a year or inspection cycle.

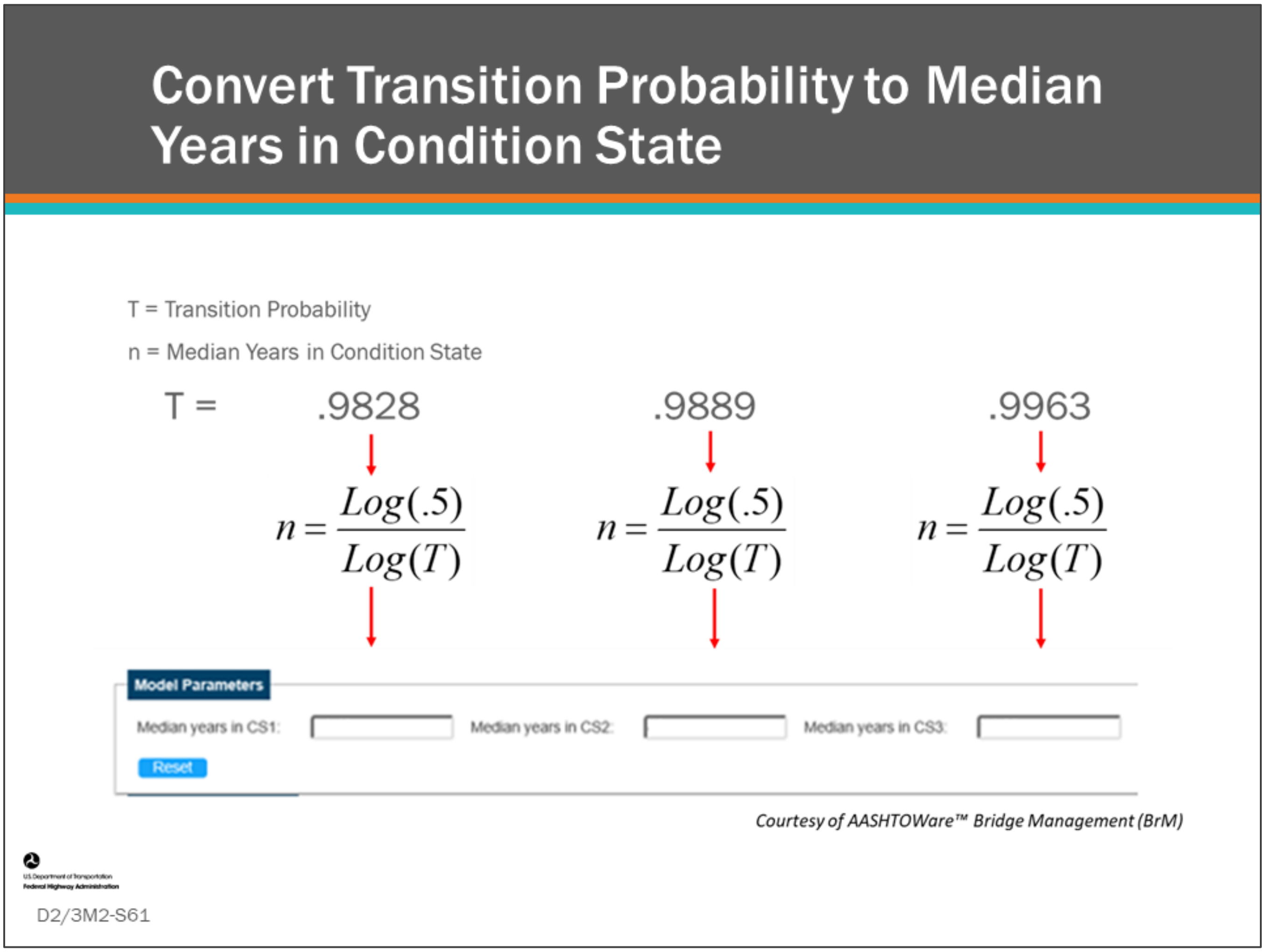
D2/3M2-Slide 60



Key Message

Quantity staying the same and reducing one condition rating are converted to transition probability.

D2/3M2-Slide 61

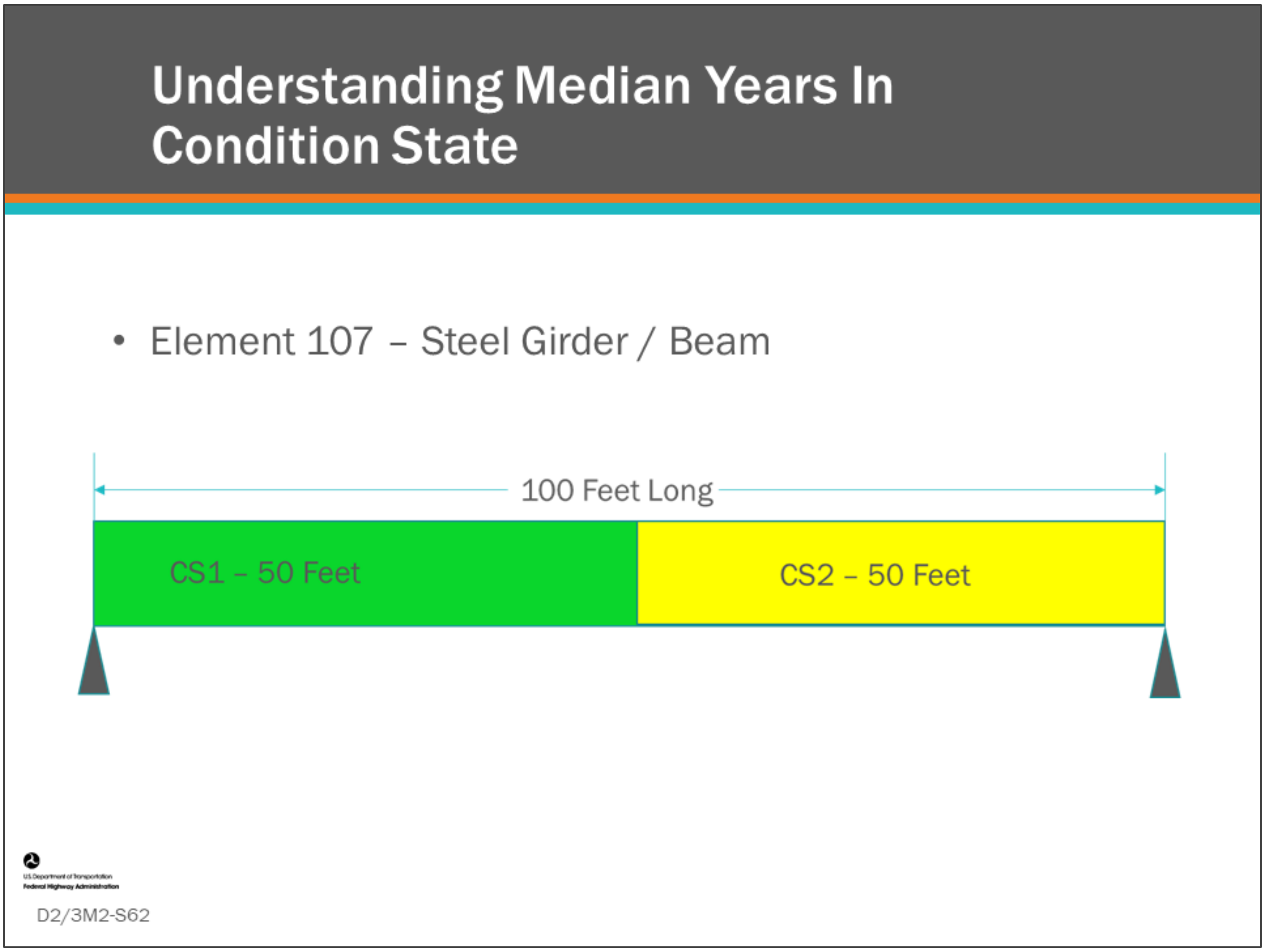


Key Message

Similar to components, transition probabilities can be converted to “median years in condition state” using the above equation.

- If you are using transition probabilities for modeling your elements, this may be what is input into your BMS software so that it can be converted to transition probabilities.
- Otherwise you may be able to program your transition probabilities directly into the software.

D2/3M2-Slide 62



Key Message

Median Years in Condition State is the time in years it takes for half of the element to transition out of the condition.

- It is important to note, this is a large quantity that typically takes a very long time to occur.

D2/3M2-Slide 63

GCR vs. Element Comparison

GCR	CS1	CS2	CS3	CS4
9	98	2	0	0
8	99	1	0	0
7	94	6	0	0
6	79	19	2	0
5	65	29	6	0
4	41	43	15	1
3	37	35	19	9

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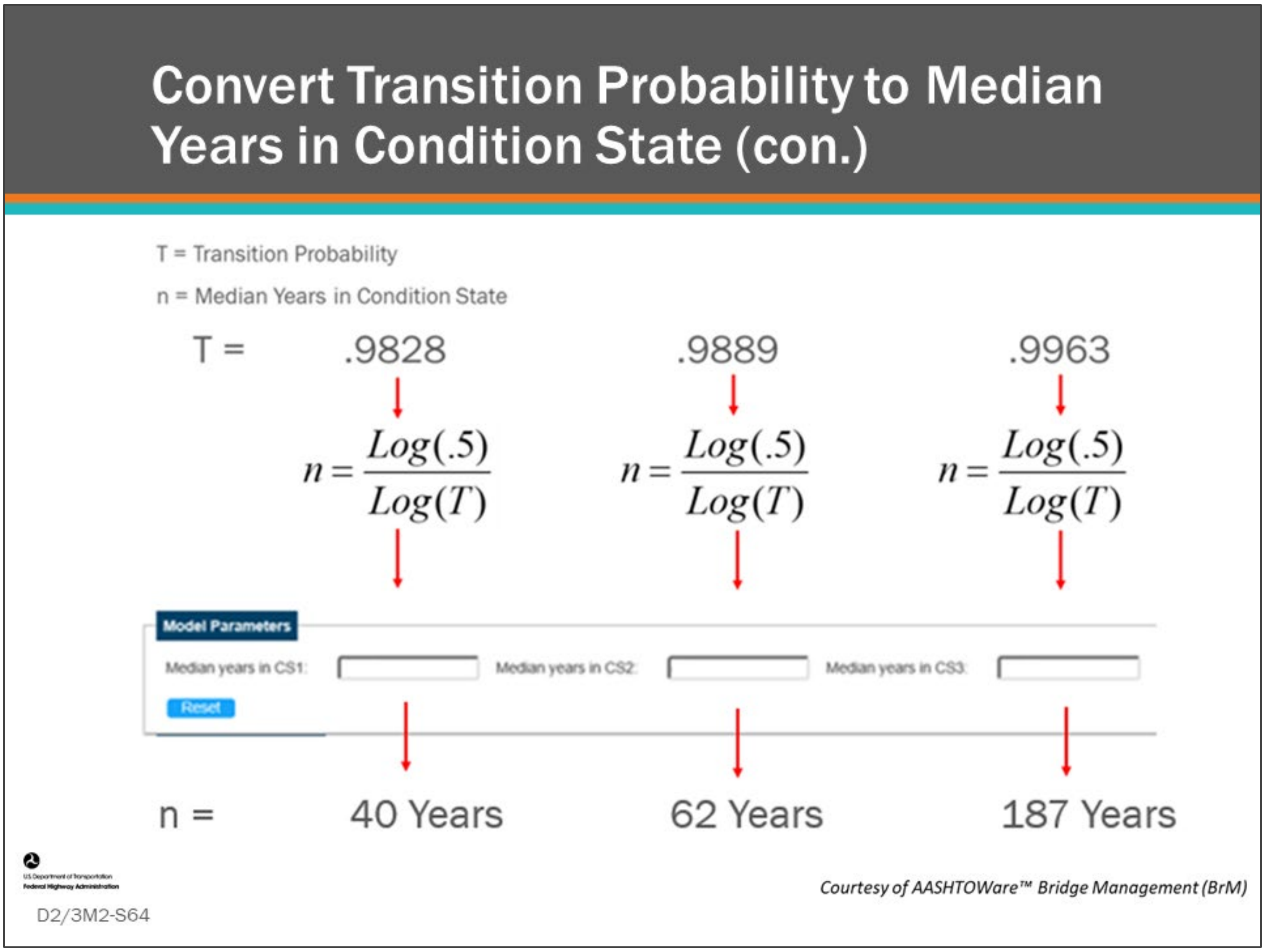
D2/3M2-S63

Key Message

One way to get a feel for how long it takes for an element to deteriorate is to compare how the element condition states are distributed on average when a comparable component GCR is reached.

- Shown here is DOT study where a comparison was made for several elements using NBE data.

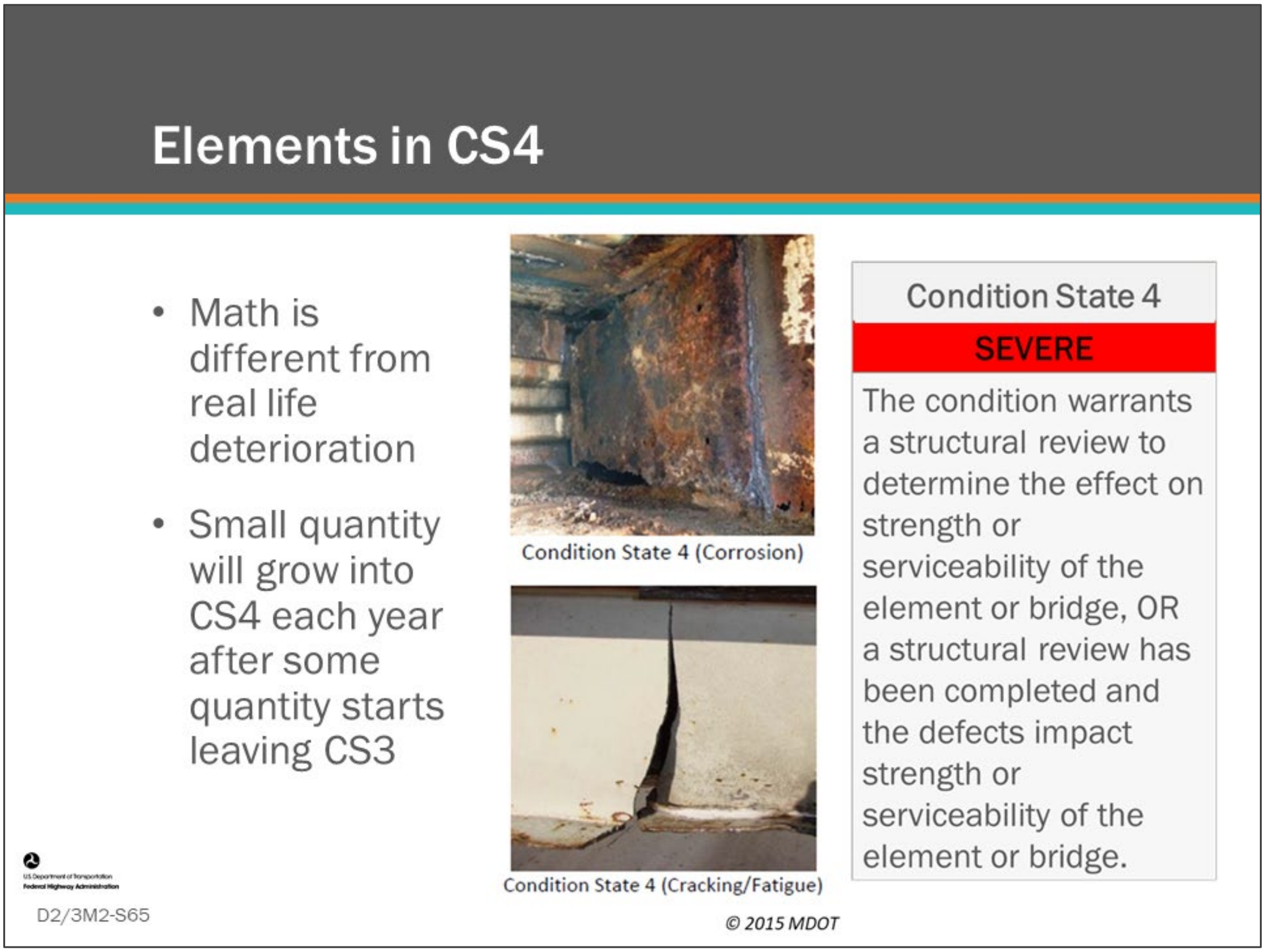
D2/3M2-Slide 64



Key Message

Finally, we see the results when we convert transition probability for CS1, CS2, and CS3 for the sample data to median years in each condition state.

D2/3M2-Slide 65



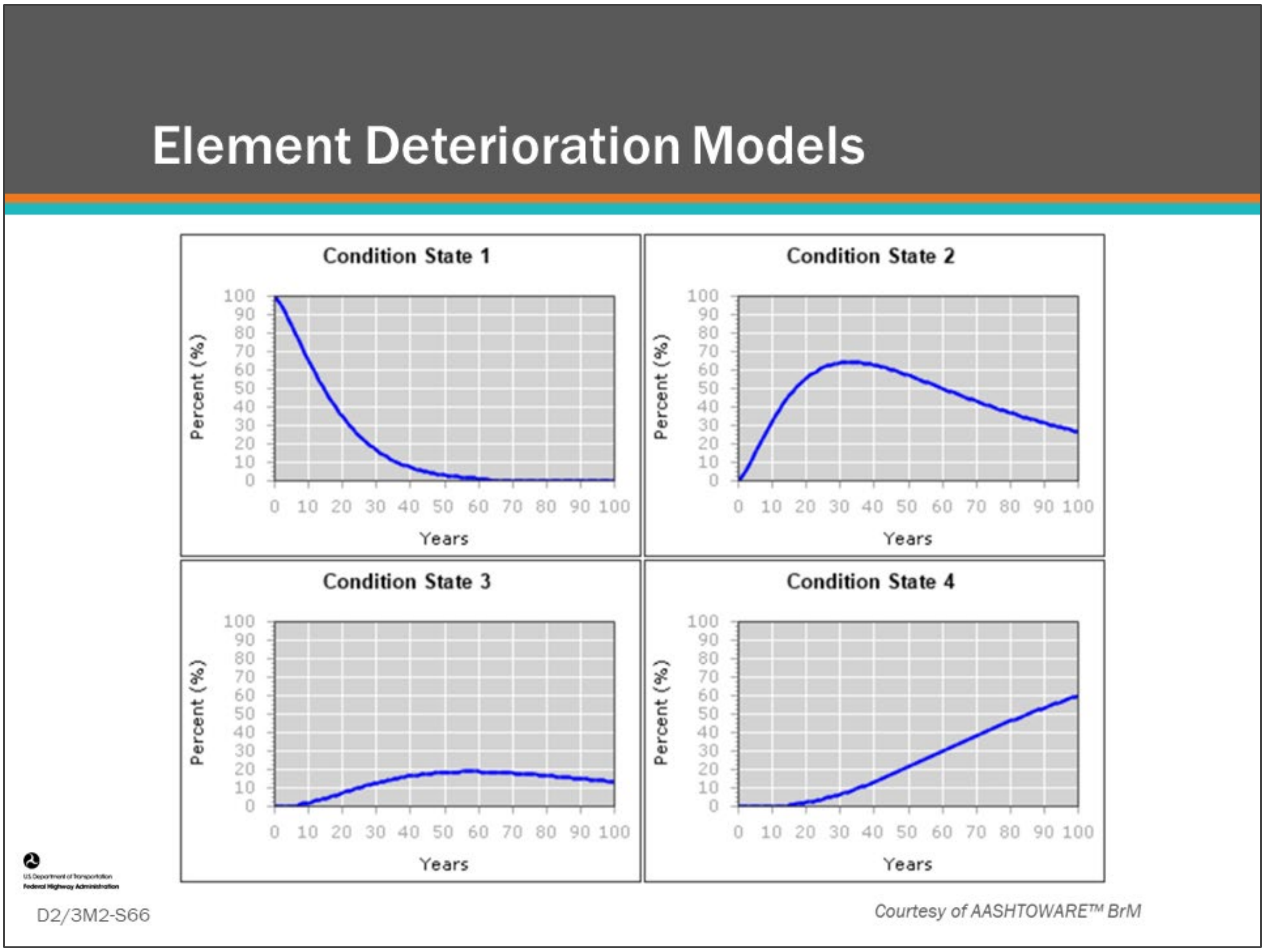
Key Message

When performing deterioration modeling of elements, using lineal feet and square feet as units of measure means you need to be aware that the mathematical models are different from real life deterioration.

- CS4 is a good example of this.
    - In reality, bridges rarely see quantities in CS4 and when a quantity is placed in this condition state, the bridge owner must perform a structural review and will often give a high priority to repair the damage.

Mathematically, deterioration models based on curvilinear functions gradually place very small quantities in CS4 because deterioration begins at onset.

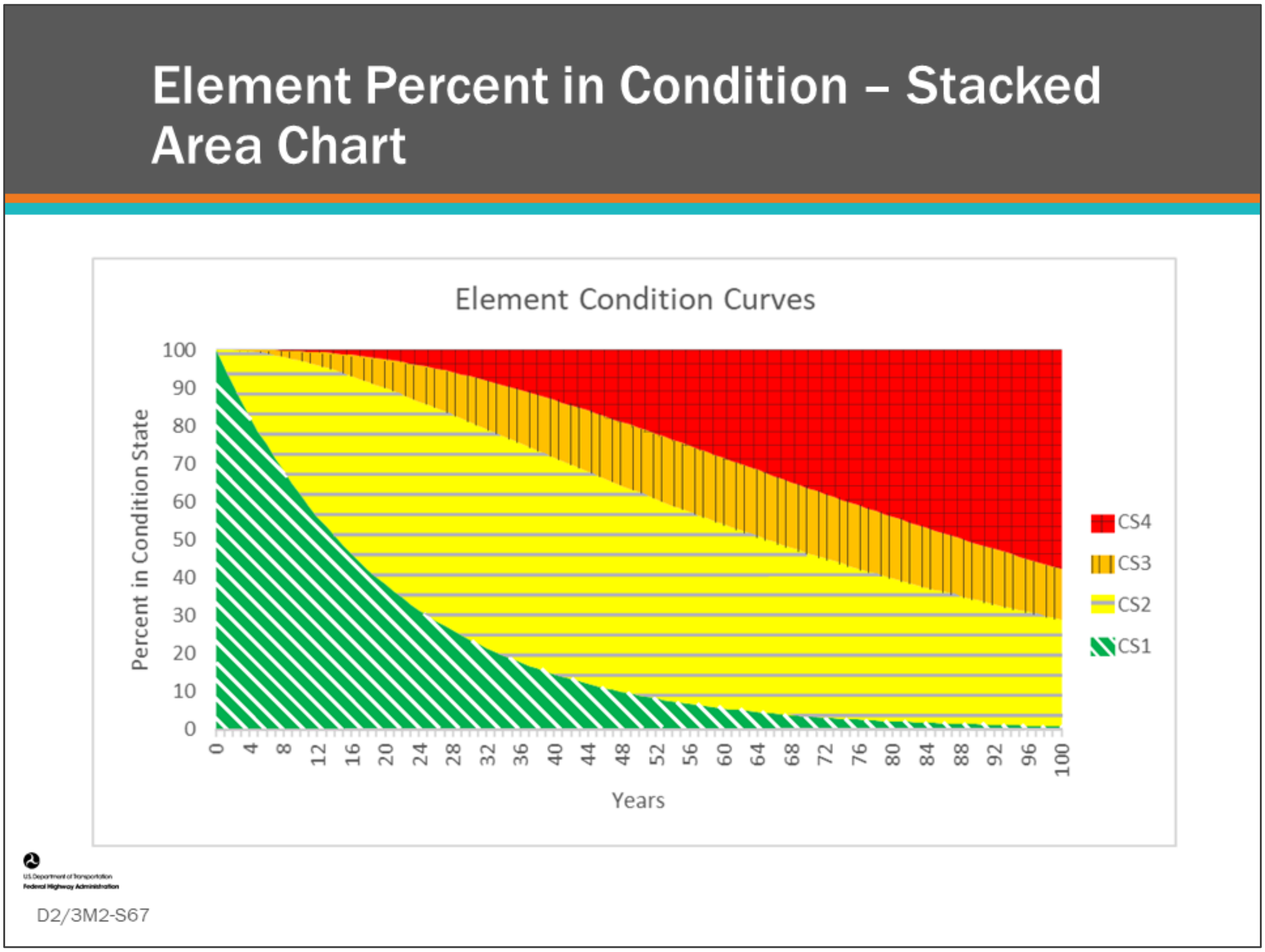
D2/3M2-Slide 66



Key Message

The BMS software will show element deterioration curves for each condition state.

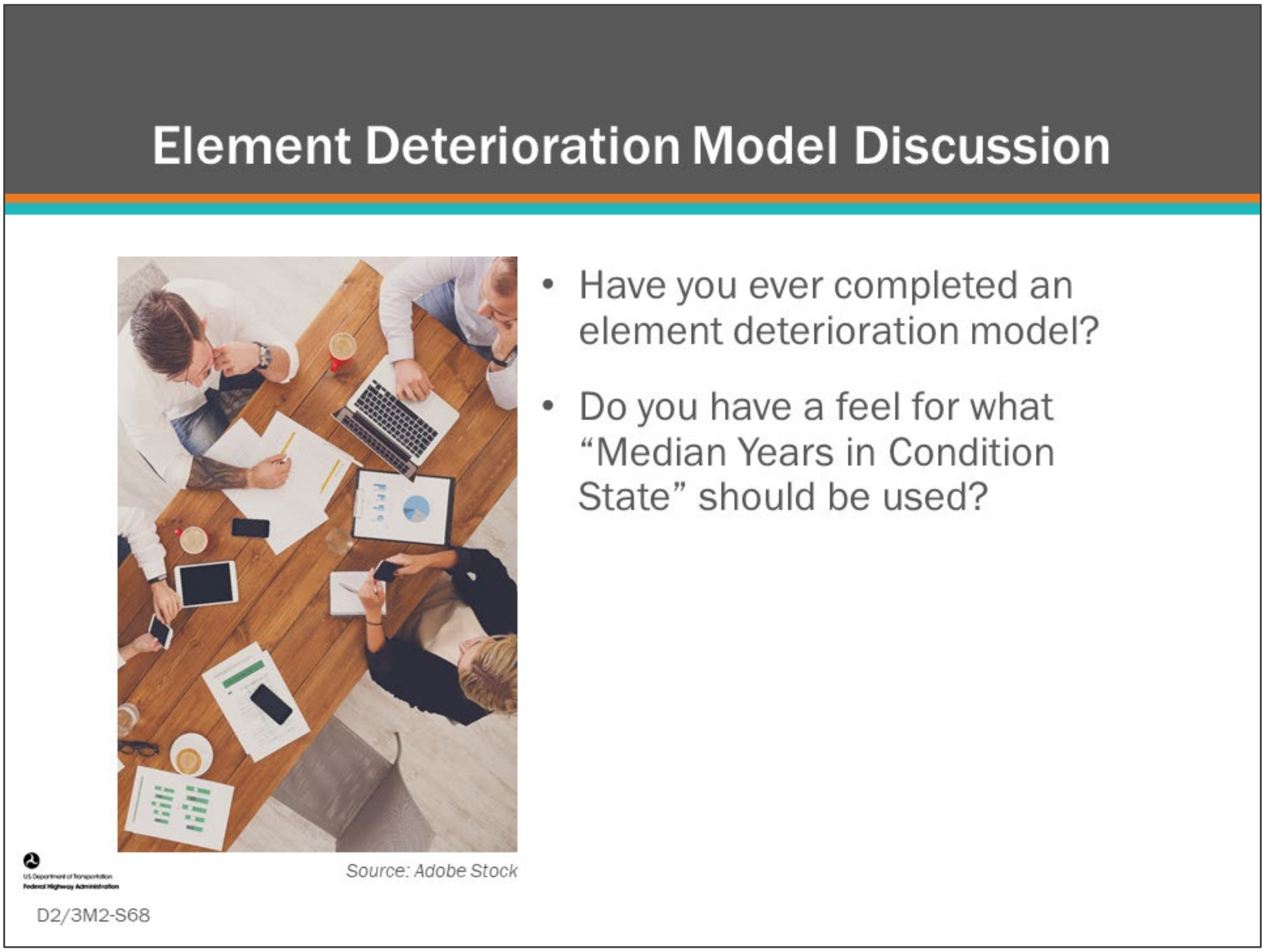
D2/3M2-Slide 67



Key Message

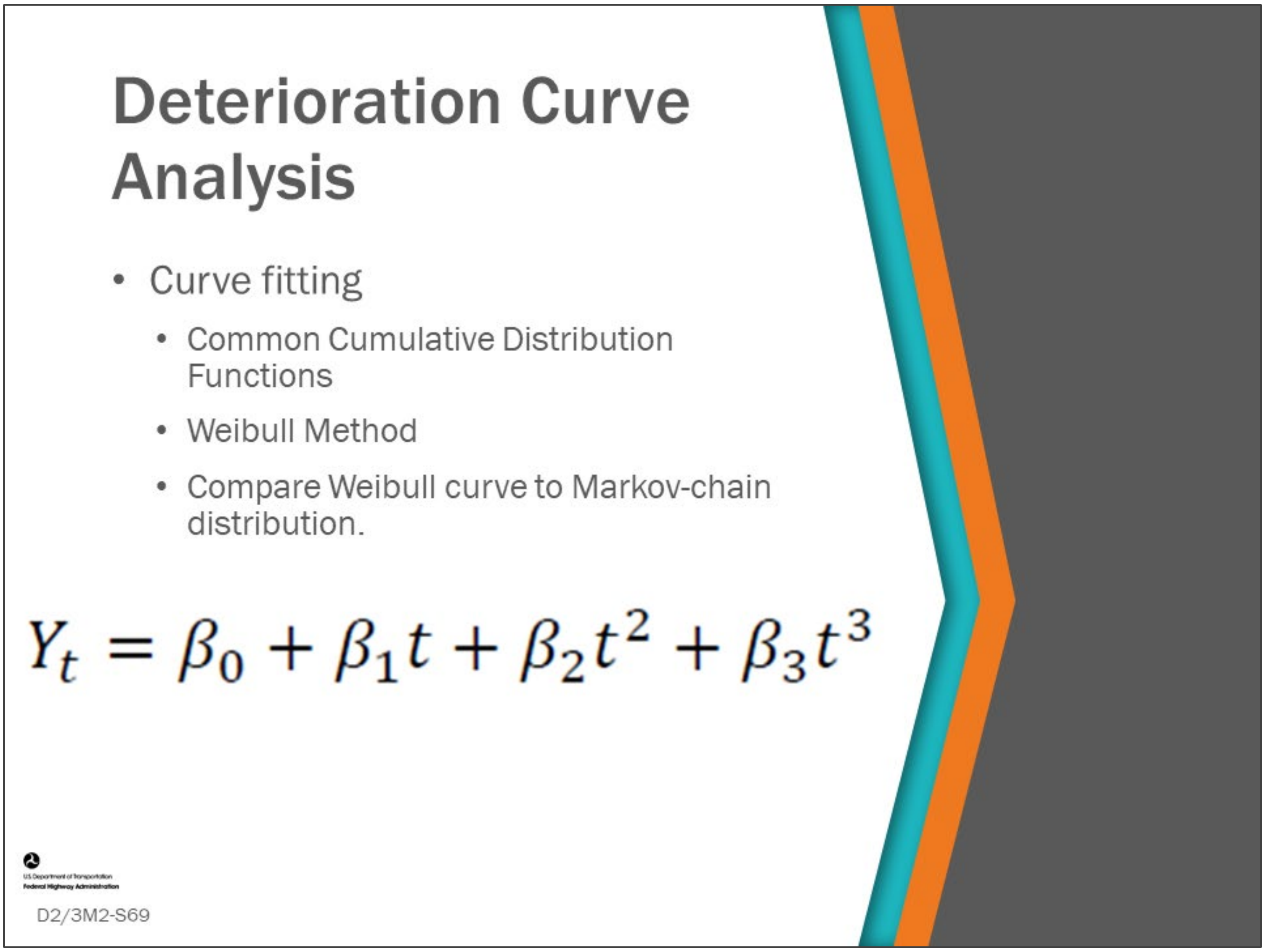
One way to show all the condition state curves in one chart is to use a "stacked area chart." Here, CS1 is shown as green; CS2 is shown as yellow; CS3 is shown as orange; and, CS4 is shown as red. The deterioration curve for CS1 is the line formed at the intersection of green and red.

D2/3M2-Slide 68



Key Message
Discuss the questions on this slide.

D2/3M2-Slide 69

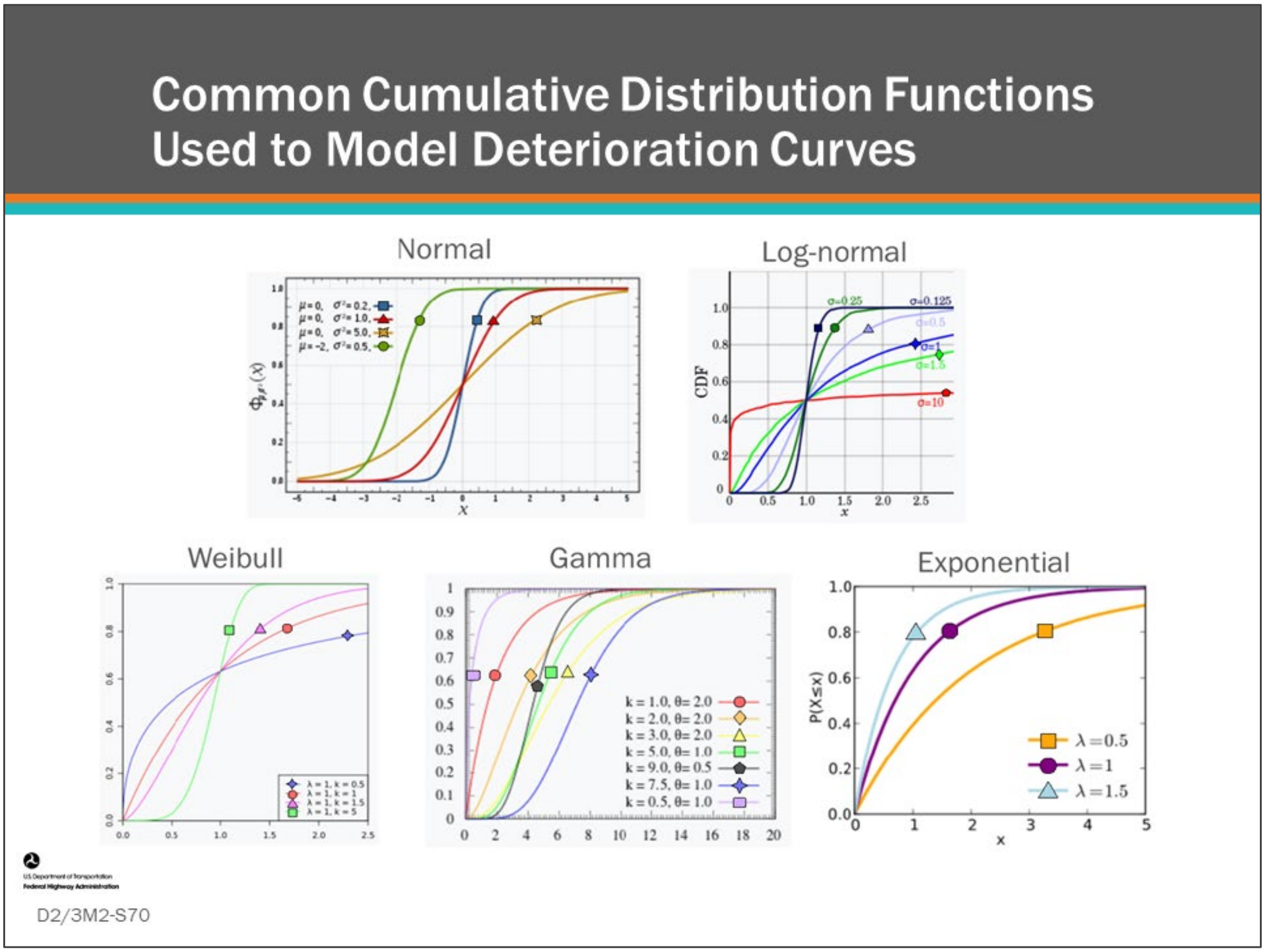


Key Message

When deterioration curves are developed using the TICR method or the Age-Based Method, researchers often “fit” a curve to the data for input into BMS software.

- The equation shown on this slide is a polynomial regression to the third degree. It is often used to describe the shape of deterioration curves.

D2/3M2-Slide 70



Key Message

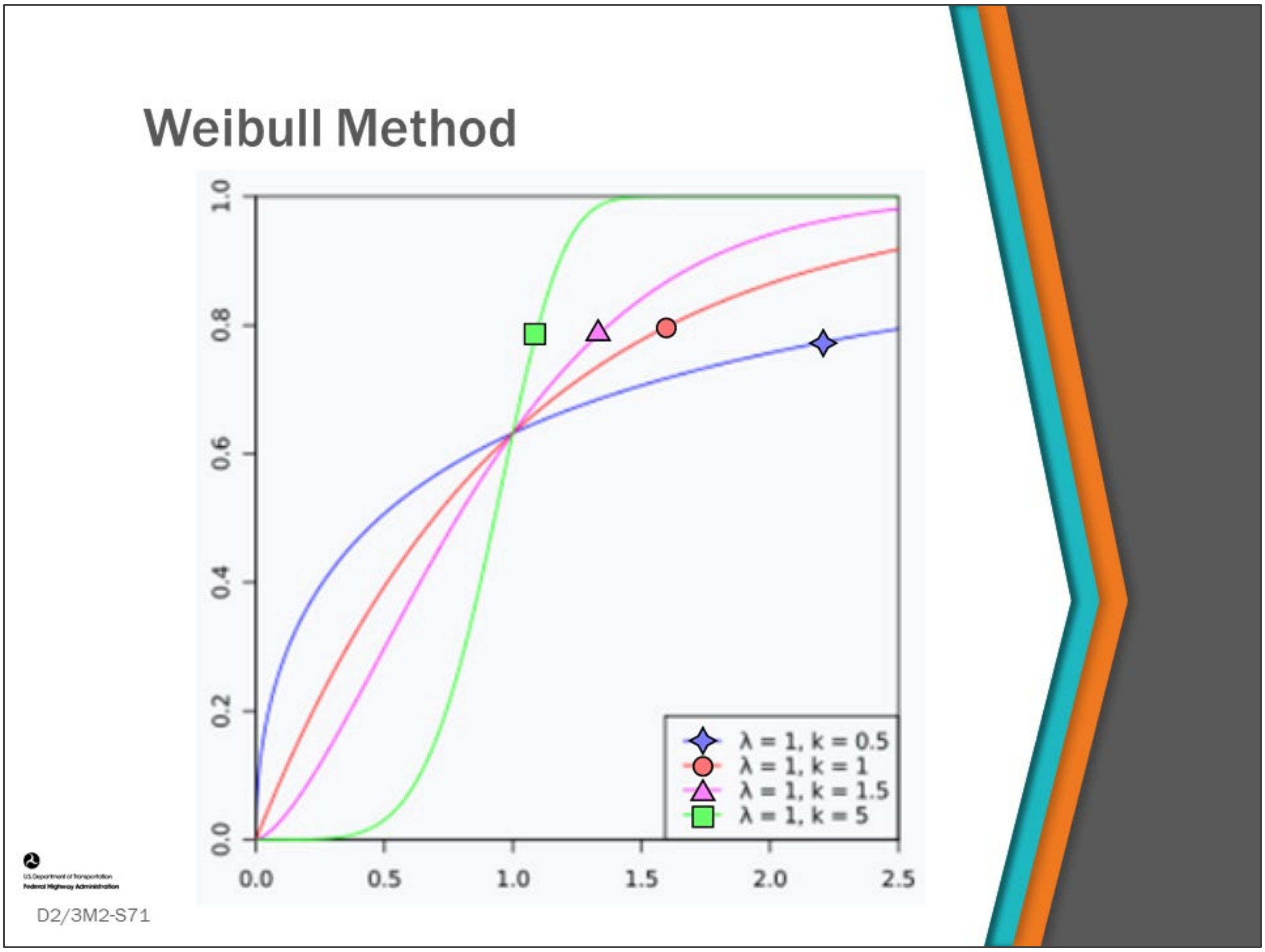
Researchers will evaluate inspection data over time to draw deterioration curves and then "fit" these curves into equations called cumulative distribution functions, or CDFs.

- Some examples of CDFs that research have found include normal, log-normal, Weibull, gamma, and exponential (Markov).

Researchers have fit curves to several of these distributions.

- One distribution function that is being used today is the Weibull method. The deterioration curve produced when converting Markov Chain transition probability to time in condition rating is an exponential cumulative distribution.

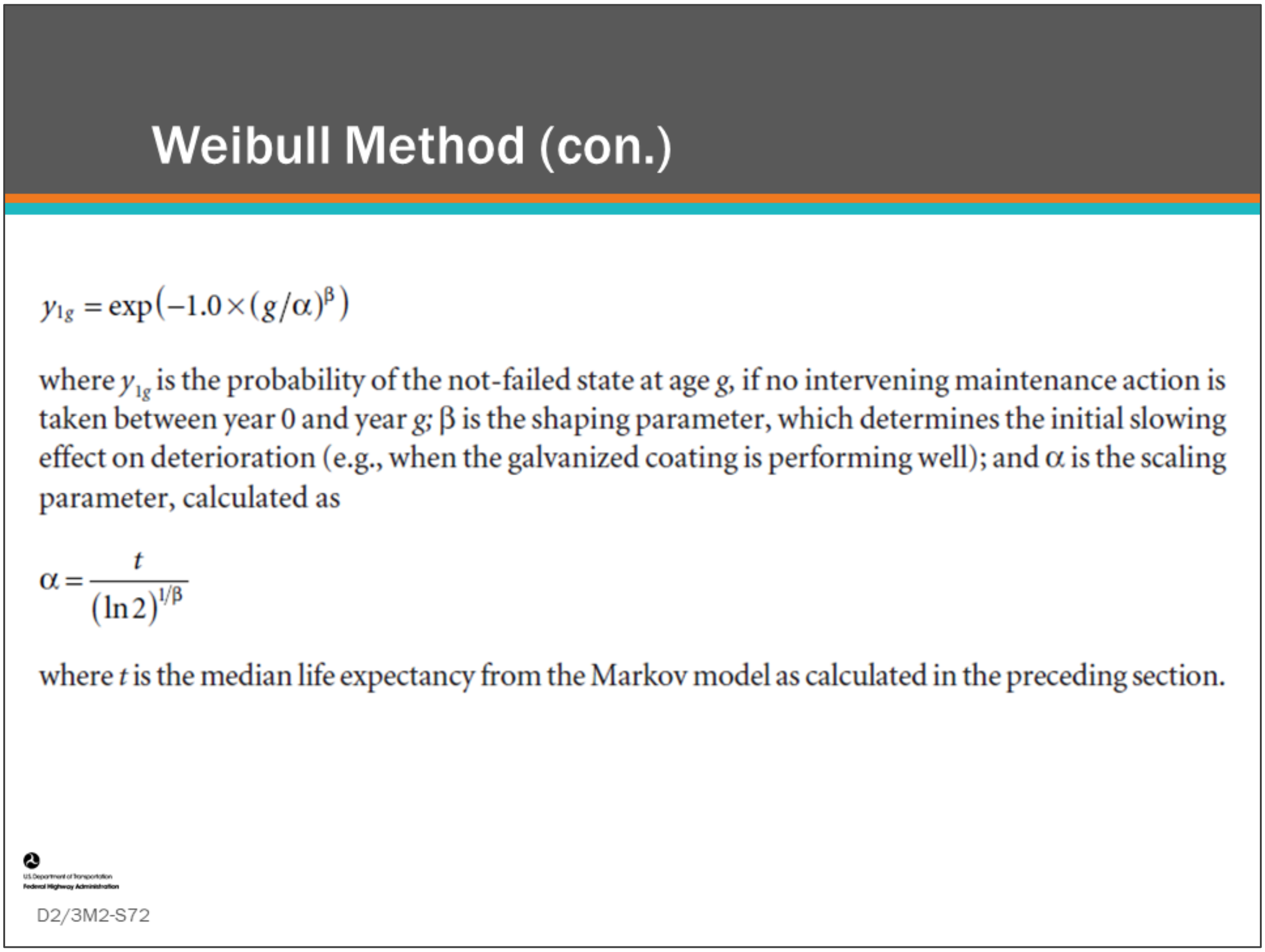
D2/3M2-Slide 71



Key Message

One cumulative distribution function that is being used more often, especially with elements, is the Weibull distribution. We will learn more about this method in this topic.

D2/3M2-Slide 72



Key Message

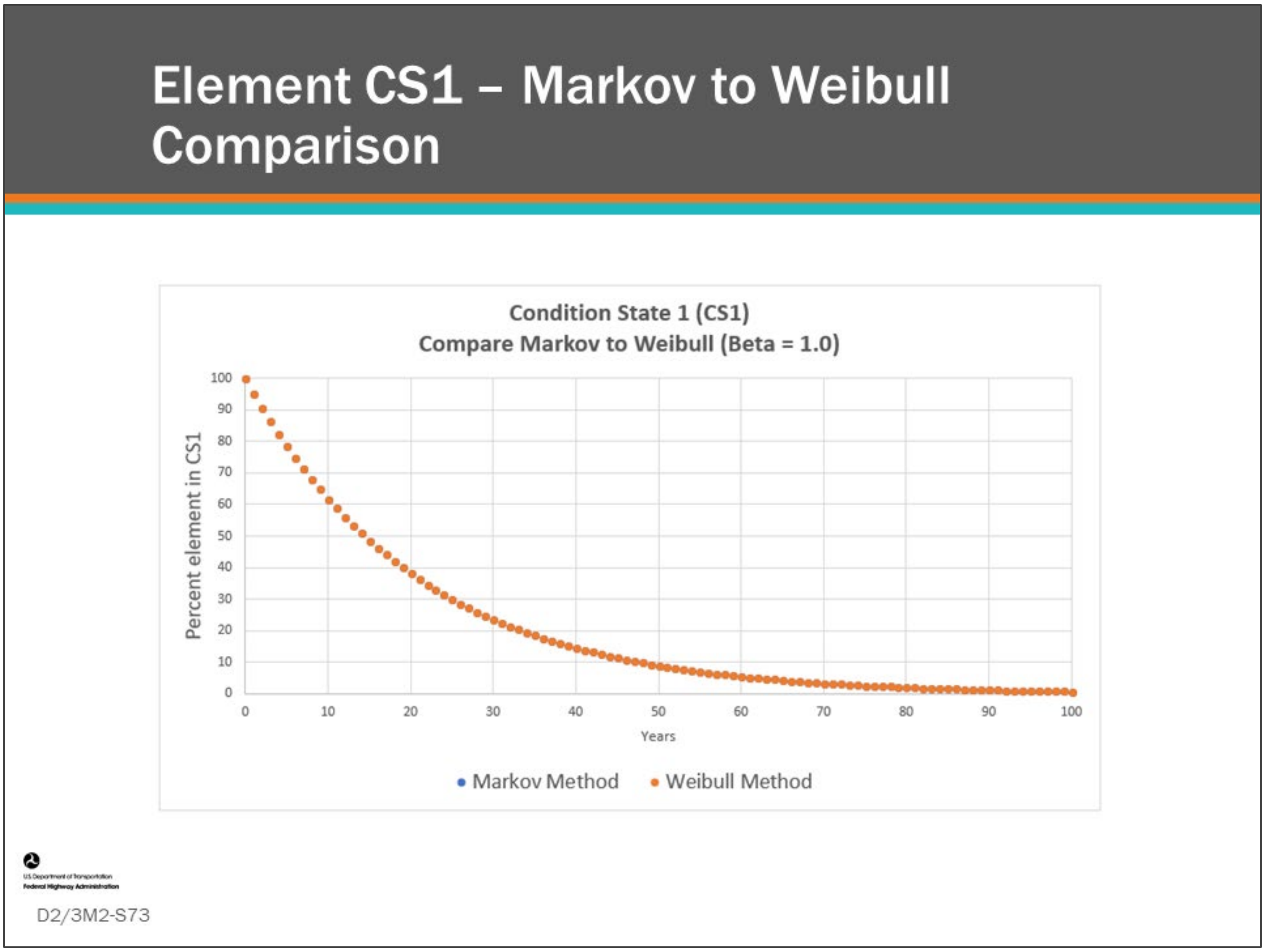
The information on this slide was taken from NCHRP, *Report 713, Estimating Life Expectancies of Highway Assets, Volume 1: Guidebook*.

- It shows the basic equations used for the Weibull cumulative distribution. When a combination of the “Shaping Factor” and the “Scaling Parameter” are set correctly, the curve takes on an “S-shape” that, when used to describe deterioration models, will show deterioration starting slowly at an early age and increasing with time.

The shaping parameter can often be adjusted in BMS software effecting how the deterioration curve is shaped at an early age. Higher shaping parameters slow the initial rate of deterioration, which then accelerates as the element gets older.

- A shaping factor equal to 1.0 produces the same deterioration curve as the Markov distribution.

D2/3M2-Slide 73

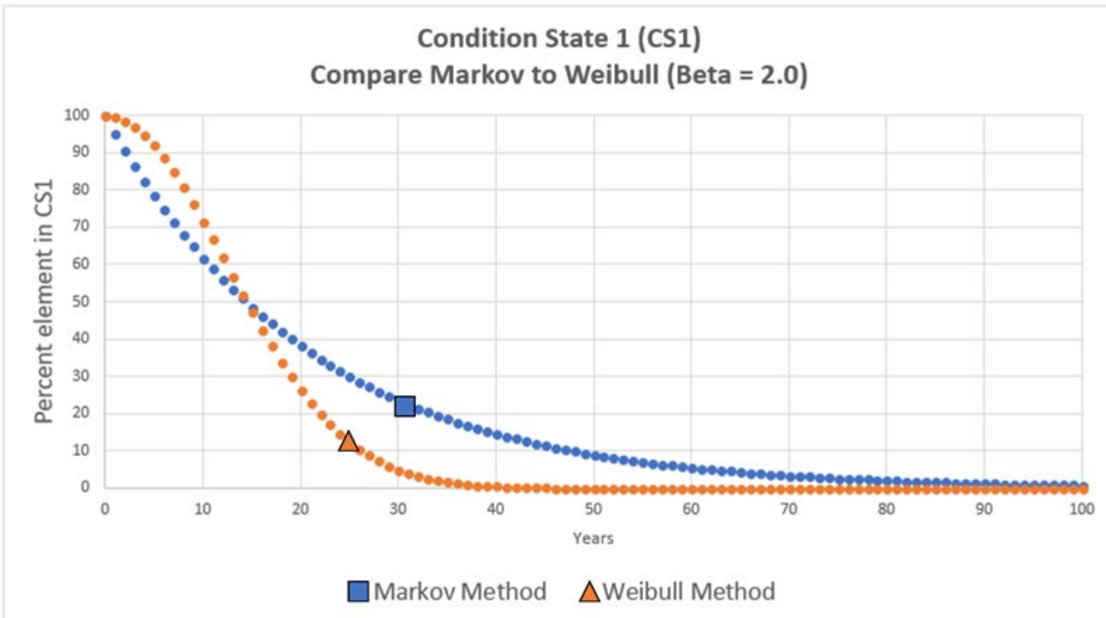


Key Message

When the “Shaping Factor” in BMS software is set to 1.0 the resulting deterioration curve will match the Markov cumulative distribution.

D2/3M2-Slide 74

Element CS1 – Markov to Weibull Comparison (con.)



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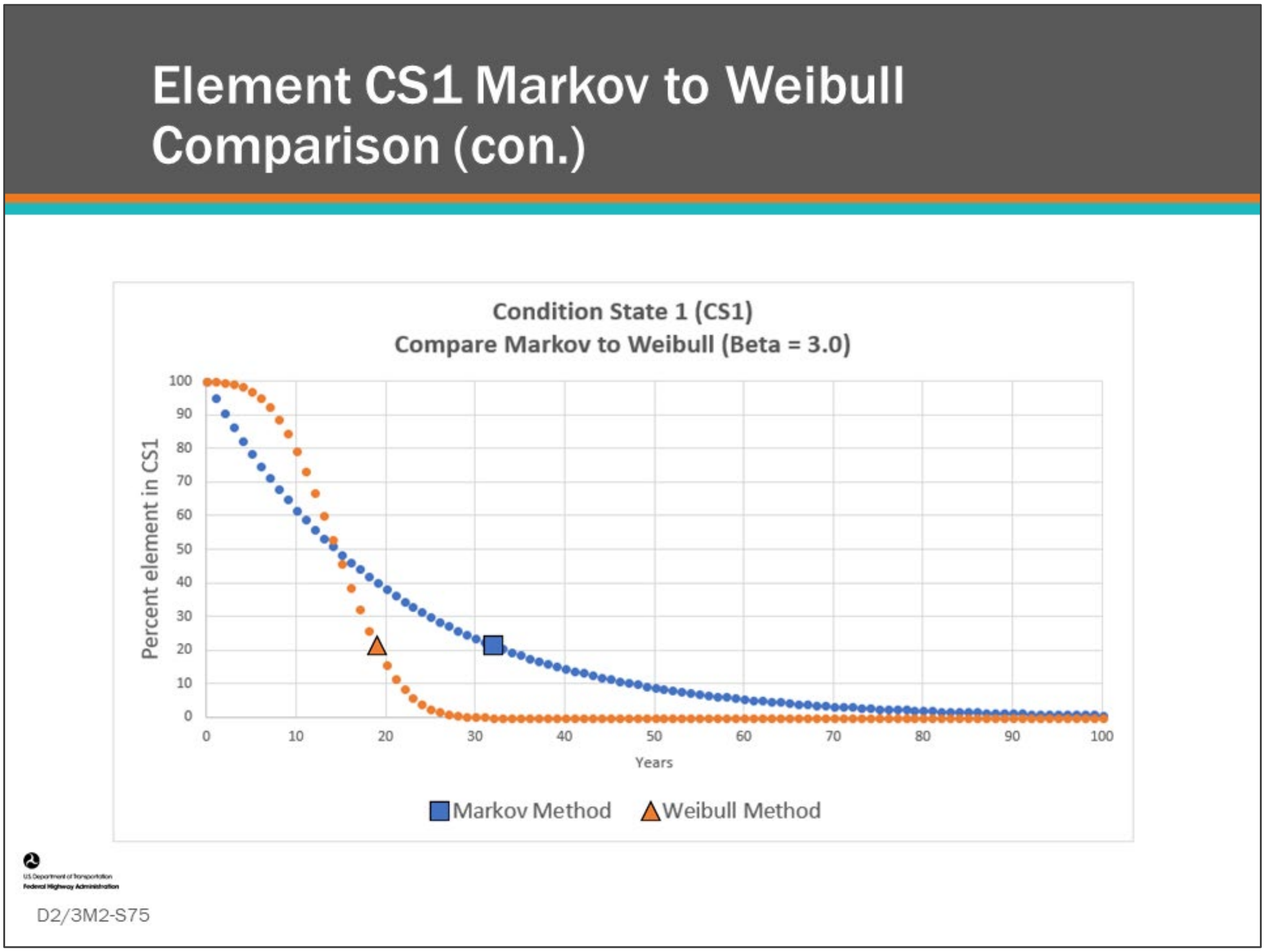
D2/3M2-S74

Key Message

As the Shaping Factor (Beta) is increased, deterioration slows at an early age but then steepens later.

- Notice, about 15 years in this example the deterioration curve of the Weibull curve is much steeper than the Markov curve, and beyond that point the deterioration is much more extensive than for the Markov curve.

D2/3M2-Slide 75



Key Message

Here, the Shaping Factor is set to 3.0.

D2/3M2-Slide 76

Weibull Method Discussion

Source: Adobe Stock

- What are benefits of this method?
- What are challenges?
- What do you think about the results?
- What do you think of the shape of the resulting curve?

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D2/3M2-S76

Key Message

Discuss the questions on this slide.

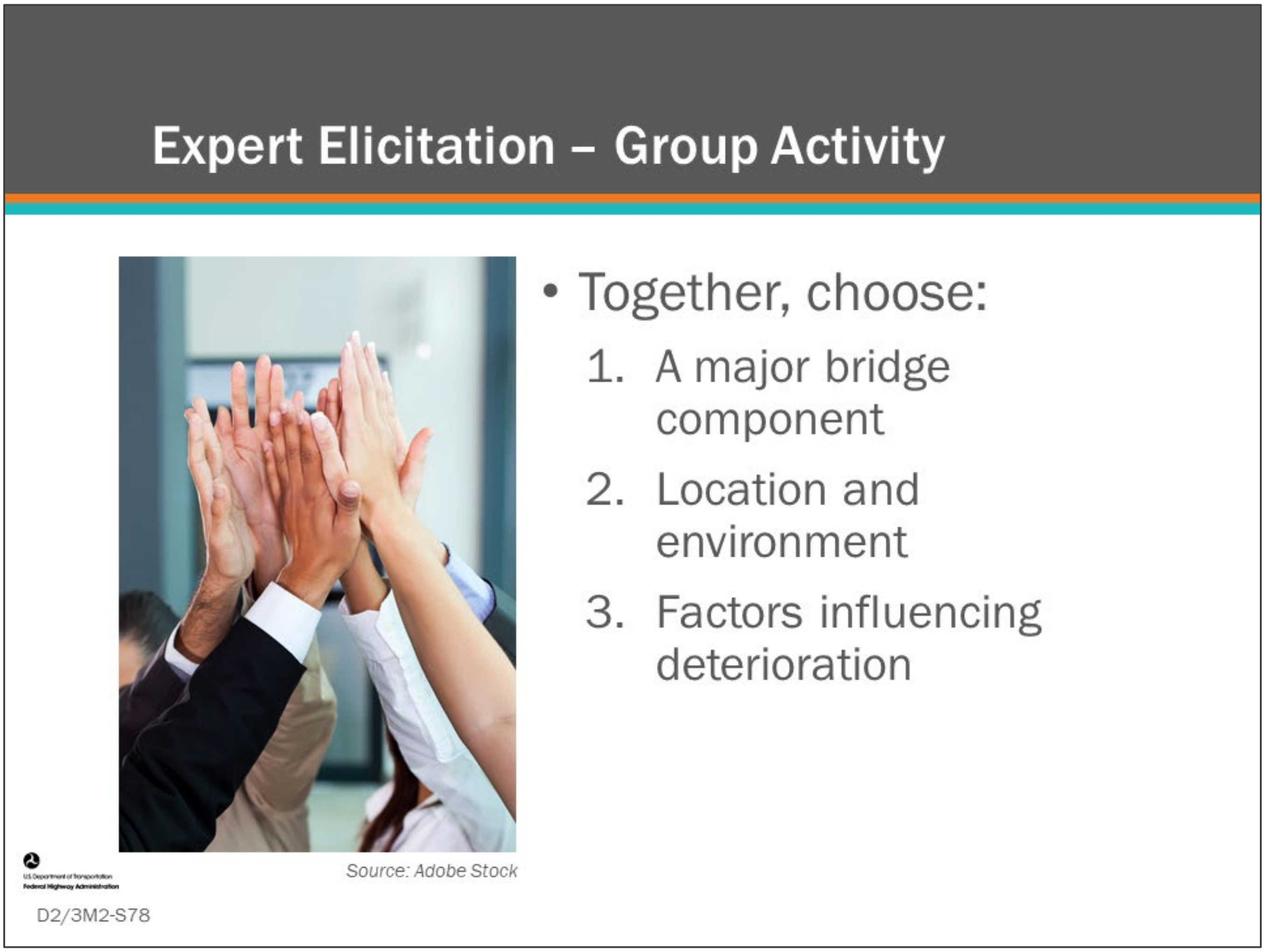
D2/3M2-Slide 77

Key Message

When data is inadequate to develop reliable deterioration curves, agencies can use expert elicitation to fill in the gaps.

- This is done by bringing together a team of experts, knowledgeable in how long the different bridge components and elements typically last.
- This team can include bridge inspectors, bridge managers, material engineers and anyone else who may be helpful.
- Judgements can be made separately and independently; then, the values are compiled and analyzed.
- Then, the team will come together to reach consensus.

D2/3M2-Slide 78



Key Message

Learn how to complete a simple expert elicitation for a bridge major component.

D2/3M2 - Slide 78: Deterioration Modeling Expert Elicitation

Together as a class, choose (and write down below):

1. A major bridge component

2. Location and environment

3. Factors influencing deterioration

D2/3M2-Slide 79

Expert Elicitation - Group Activity: Create a Major Component Deterioration Model

GCR	Transition Time
9	
8	
7	
6	
5	
4	
3	

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D2/3M2-S79

Key Message
Learn how to perform a simple expert elicitation for a bridge major component using NBI GCRs.

D2/3M2 - Slide 79: Create a Major Component Deterioration Model

Write in the table below what you feel the transition time (time the component lingers in that condition rating) is for each condition rating shown.

GCR	Transition Time
9	
8	
7	
6	
5	
4	
3	

D2/3M2-Slide 80

Expert Elicitation - Group Activity: Compare Element Percentage in Condition States

Condition State	Percentage in Condition State When Major Component Becomes Poor (GCR = 4)
CS1	
CS2	
CS3	
CS4	

D2/3M2-S80

Key Message

Estimate what they feel is the percentage of the element will be in CS1, CS2, CS3, and CS4, when the corresponding major component reaches a GCR of 4 (poor).

- Record your estimate in your workbook.
- This exercise will help you visualize the percentages in each condition state an element will have when the major component is in poor condition.

D2/3M2 - Slide 80: Compare Element Percentage in Condition States When Major Component Becomes Poor

Using the bridge element corresponding to the major component rating used in the first exercise, estimate what you feel the percentage of the element will be in CS1, CS2, CS3, and CS4, when the corresponding major component reaches a GCR of 4 (poor).

Condition State	Percentage in Condition State When Major Component Becomes Poor (GCR = 4)
CS1	
CS2	
CS3	
CS4	

D2/3M2-Slide 81

Expert Elicitation - Group Activity: Create an Element Deterioration Model

Condition State	Mean Time In Condition State
CS1	
CS2	
CS3	

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D2/3M2-S81

Key Message

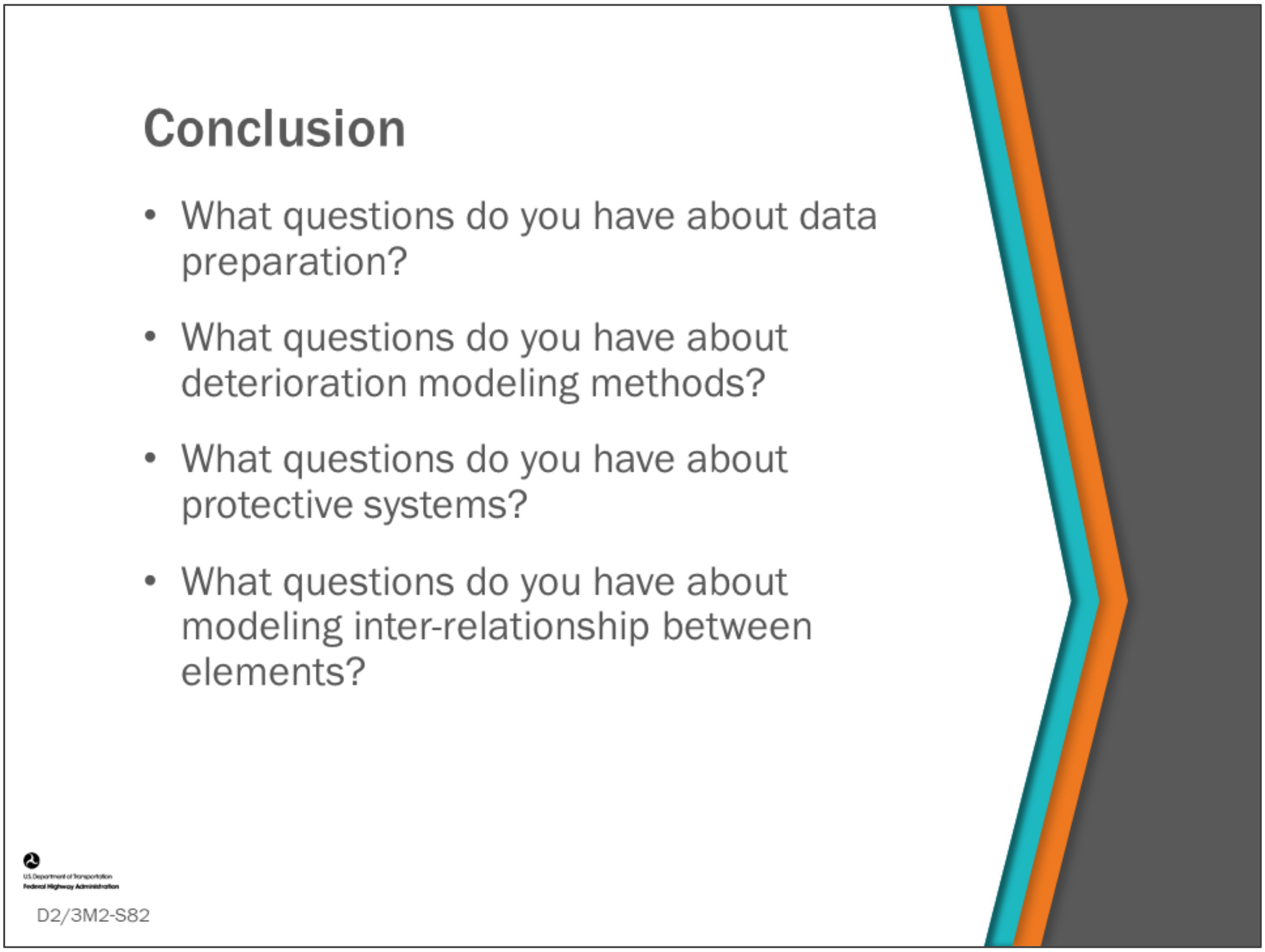
Complete a simple expert elicitation to create a deterioration model using a bridge element corresponding to the major component rating used in the first exercise.

D2/3M2 - Slide 81: Create an Element Deterioration Model

Using the bridge element corresponding to the major component rating used in the first exercise, estimate the median years in each condition rating CS1, CS2, and CS3, and write these values in table below.

Condition State	Estimated Median Years in Condition State
CS1	
CS2	
CS3	

D2/3M2-Slide 82



Key Message

What questions do you have about:

- Data Preparation?
- Deterioration Modeling Methods?
- Protective Systems?
- Modeling Inter-Relationship Between Elements?

D2/3M2-Slide 83

Slide #	Image Description	Source Information
2	Process flow diagram showing bridge management system workflow steps.	This Workshop.
5	Screenshot of a portion of a database schema.	AgileAssets® Structures Analyst™.
6	Photo of a chalk board displaying the Gaussian Distribution.	Adobe Stock.
6	A field of grass	Adobe Stock.
7-8	Chart showing a histogram with number of occurrences on the y axis (0 - 180) and time in condition rating 4 (years) on the x axis	This workshop.
9	Graphic of a table showing some typical sample sizes necessary to have a 95 percent confidence level in the accuracy of results.	This workshop.
15	A sample scatter chart for Bridge Deck (NBI Item 58) - Year 2010 shows condition rating (0 to 9) on the y axis and age (0 to 80) in years on the x axis	Morcous, G. *Developing Deterioration Models for Nebraska Bridges*. Page 44. University of Nebraska-Lincoln.
16	A scatter plot chart is shown with NBI condition ratings (1 to 9) on the y axis and years (0 to 170) on the x axis.	This Workshop.
17	A scatter chart shows NBI Condition Rating on the y-axis and Years on the x-axis.	This Workshop.
18	A chart showing condition rating on the y axis (0 - 9) and age in years (0 - 50) on the x axis.	Morcous, G., et al. *Deterioration Models and LCCA For Nebraska Bridge Decks,* 2012 Midwest Bridge Preservation Partnership, Council Bluffs, IA. October 17, 2012.

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D2/3M2-S83

D2/3M2 Figure Source List

D2/3M2-Slide 84

Slide #	Image Description	Source Information
19	A table shows condition rating, description of the condition rating, number of bridges, and average age for Michigan concrete bridge decks for each of the condition ratings (0 to 9).	Chyad, A., *Deterioration Prediction Modeling for the Condition Assessment of Concrete Bridge Decks*, Ph.D. Dissertation, Western Michigan University, June 2018.
20	A scatter charts shows NBI General Condition Rating on the y-axis and Years in the x-axis. A piece-wise linear line represents a deterioration curve.	This Workshop.
24-27	A chart is shown with NBI value shown on the y-axis (0 to 9) and year on the x-axis (1992 to 2018).	This Workshop.
28	Chart, titled, "Deterioration Cycles of Bridge Decks" showing deterioration cycles of bridge decks.	Dekelbab, W. et al. *History Lessons From the National Bridge Inventory*. Public Roads. Publication Number: FHWA-HRT-08-004. Issue No: Vol. 71 No. 6. Washington, DC, May/Jun 2008.
29	A chart is shown having NBI rating on the y axis (0 to 9) and years on the x axis (0 - 100).	This Workshop.
33-40	Shown are rows and columns from a spreadsheet showing a transition matrix for deck deterioration. Rows are labeled 9 to 0 from top down, and columns are labeled 0 to 0 from left to right.	This Workshop.

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D2/3M2-S84

D2/3M2 Figure Source List

D2/3M2-Slide 85

Slide #	Image Description	Source Information
42	A table uses the transition probability for Condition State 1 (CS1) for Element 107 Steel Girder / Beam shown in the previous slide.	This Workshop.
43	Graphic shows how the transition probability to time in condition rating equation is derived.	This Workshop.
44	A table shows columns for rating Transition Probability and Time in Condition Rating.	This Workshop.
45	A chart showing NBI rating on the y axis (0 - 9) and Years To Reach Condition State on the x axis (0 - 130	This Workshop.
46	A chart showing NBI rating on the y axis (0 - 9) and Years To Reach Condition State on the x axis (0 - 130).	This Workshop.
49	A chart showing NBI rating on the y axis (0 - 9) and Years To Reach Condition State on the x axis (0 - 130). Three deterioration curves are shown; Markov, TICR, and Age Method.	This Workshop.
50	Photo of a steel truss bridge.	MDOT. *Michigan Bridge Element Inspection Manual*, March 2015.

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D2/3M2-S85

D2/3M2 Figure Source List

D2/3M2-Slide 86

Slide #	Image Description	Source Information
50	Photo of prestressed closed web/box girder.	MDOT. *Michigan Bridge Element Inspection Manual*, March 2015.
50	Photo of reinforced concrete abutment.	MDOT. *Michigan Bridge Element Inspection Manual*, March 2015.
59	Table for Element 107 - Steel Girder / Beam. The rows of the table are labeled 1,2,3,4 (for condition states). The columns are labeled 4, 3, 2, 1. Values shown on the diagonal are quantity staying the same for each condition state. Values to the left of the diagonal are quantities reducing a condition state.	This Workshop.
60	Transition probability table. The rows of the table are labeled 1,2,3,4 . The columns are labeled 4, 3, 2, 1. Values shown on the diagonal are transition probabilities for each condition state.	This Workshop.
61	Graphic showing calculation of transition probabilities to median years in condition state. The equation shown reads n equals LOG(.5) divided by LOG(T)	AASHTOWare™ Bridge Management (BrM).
64	Graphic showing calculation of transition probabilities to median years in condition state. The equation shown reads n equals LOG(.5) divided by LOG(T).	AASHTOWare™ Bridge Management (BrM).

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D2/3M2-S86

D2/3M2 Figure Source List

D2/3M2-Slide 87

Slide #	Image Description	Source Information
65	Two photos showing examples of CS4. One for severe corrosion (top), one for a severe cracking (bottom).	MDOT. *Michigan Bridge Element Inspection Manual*, March 2015.
66	AASHTOWare Bridge Management software screenshot showing four deterioration curves; Condition State 1, condition state 2, condition state 3, and condition state 4. All curves show Percent in condition state (0 - 100) on the y axis and years (0 - 100) on the x axis.	AASHTOWare™ Bridge Management (BrM).
70	A collection of charts is shown showing shapes of five cumulative distribution function including; Normal, Log-normal, Weibull, Gamma, and Exponential.	This Workshop.
71	A chart showing possible curve shape for the Weibull distribution function.	This Workshop.
73	Chart titled Condition State 1 (CS1) Compare Markov to Weibull (Beta = 1.0). Y axis shows Parent Element in CS1 (0 - 100). Y axis shows years (0 - 100). Weibull and Markov curves are shown that match.	This Workshop.
74	Chart titled Condition State 1 (CS1) Compare Markov to Weibull (Beta = 2.0). Y axis shows Parent Element in CS1 (0 - 100). Y axis shows years (0 - 100). The Weibull curve now starts shallower than the Markov and then gets steeper.	This Workshop.

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D2/3M2-S87

D2/3M2 Figure Source List

D2/3M2-Slide 88

Slide #	Image Description	Source Information
75	Chart titled Condition State 1 (CS1) Compare Markov to Weibull (Beta = 3.0). Y axis shows Percent Element in CS1 (0 - 100). Y axis shows years (0 - 100). The Weibull curve now starts shallower than the Markov and then gets steeper.	This Workshop.

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D2/3M2-S88

D2/3M2 Figure Source List

Module Title: D2/3M3 – Life-Cycle Cost Analysis (LCCA) and Life-Cycle Modeling in a BMS

Module Time: 120 minutes

Module Summary

Day 1, Module 7 discussed Life-Cycle Cost analysis and Life-Cycle Modeling. This module will review Life-Cycle Cost Analysis (LCCA) and Life-Cycle Modeling and show how these models are created and used within the BMS, and how LCCA is performed within some BMS to determine life-cycle cost benefit of alternative present-day actions.

Expected Outcome(s)

The expected outcome of this module will be life-cycle model development.

Resource List

Slide	Reference Information
7,9,21	FHWA. *Life-Cycle Cost Analysis Primer*, Office of Asset Management USDOT. Washington, DC, 2002.
8	CRC Construction Innovation. *Whole of Life Cycle Cost Analysis in Bridge Rehabilitation*. Report 2002-005-C-03.
9,21	NCHRP. *Report 483 Bridge Life-Cycle Cost Analysis*. Washington, DC, 2003.
12	Minnesota DOT. *Fiscal Year 2016 through 2020 Bridge Preservation and Improvement Guidelines.* Bridge Office.
15	National Academies of Sciences, Engineering, and Medicine. *Design Guide for Bridges for Service Life*. Washington, DC, 2013.
21	Ehlen, M. *BridgeLCC 2.0 User's Manual, Life-Cycle Costing Software for the Preliminary Design of Bridges.* US Department of Commerce. NA1341-02-W-0884. September 2013.
22,24	National Institute of Standards and Technology (NIST). *Bridge LLC 2.0*. Software program. US Department of Commerce.
32	NCHRP. *Report 590 Multi-Objective Optimization for Bridge Management Systems.* Washington, DC, 2007.
32	AASHTO. *AASHTOWare™ Bridge Management (BrM) User's Manual*, version 5.2.3. Washington, DC, 2016.
37	Hulsey, J., et al., *Life Cycle Costs for Alaska Bridges.* Alaska University Transportation Center. Alaska DOT. Fairbanks, AK, 2015.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D2/3M3-Slide 1

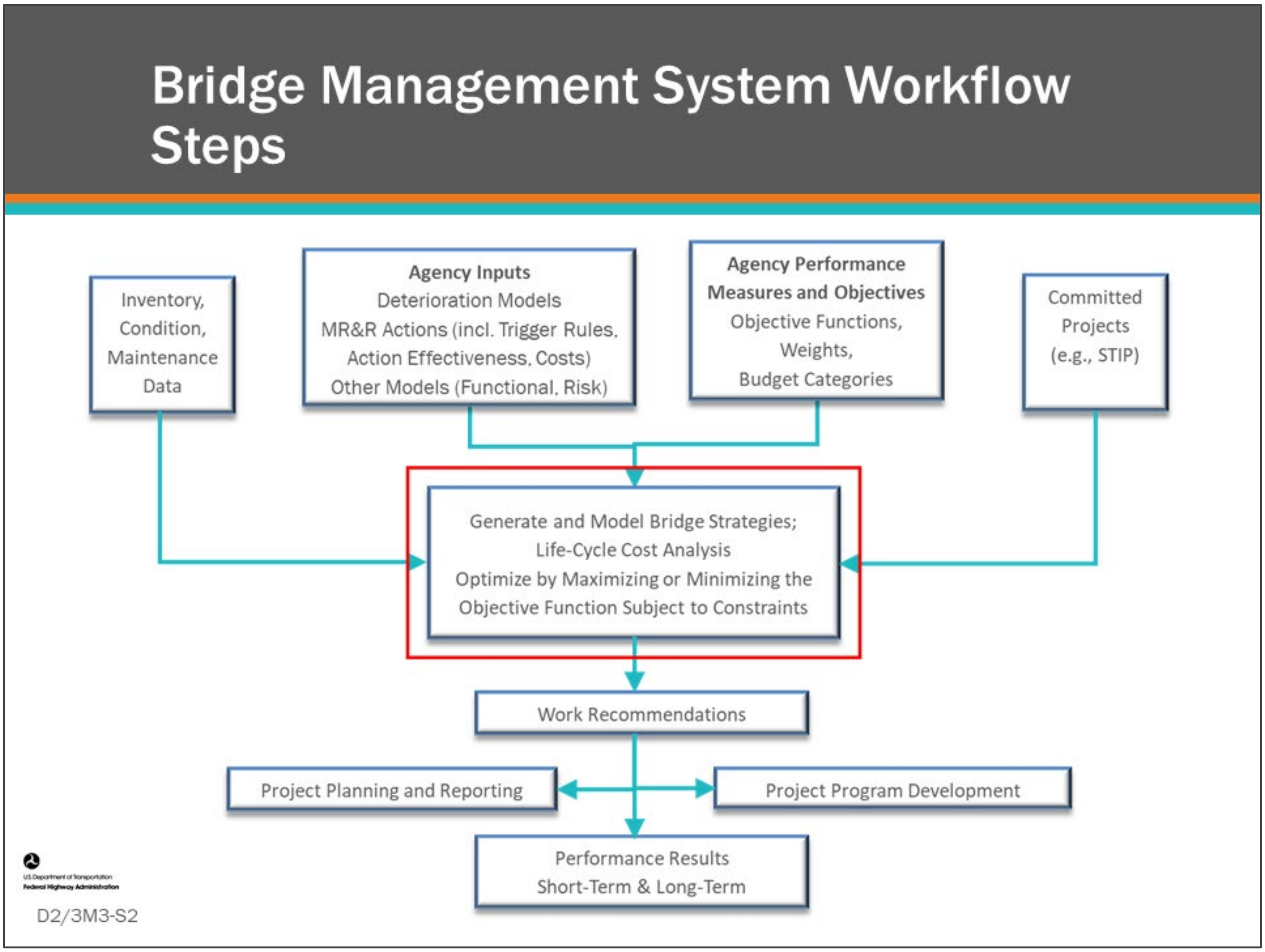
Key Message

This module will review Life-Cycle Cost Analysis (LCCA) and Life-Cycle Modeling and will show how these models are created and used within the BMS, and how LCCA is performed within some BMS to determine life-cycle cost benefit of alternative present-day actions.

Disclaimer

FHWA does not promote or endorse patented and proprietary products. Bridge management software is largely proprietary. Workshop content pertaining to proprietary software is included only to illustrate how bridge management system concepts and analyses are applied in practice. The included content shall not be construed as promotion or endorsement of specific software.

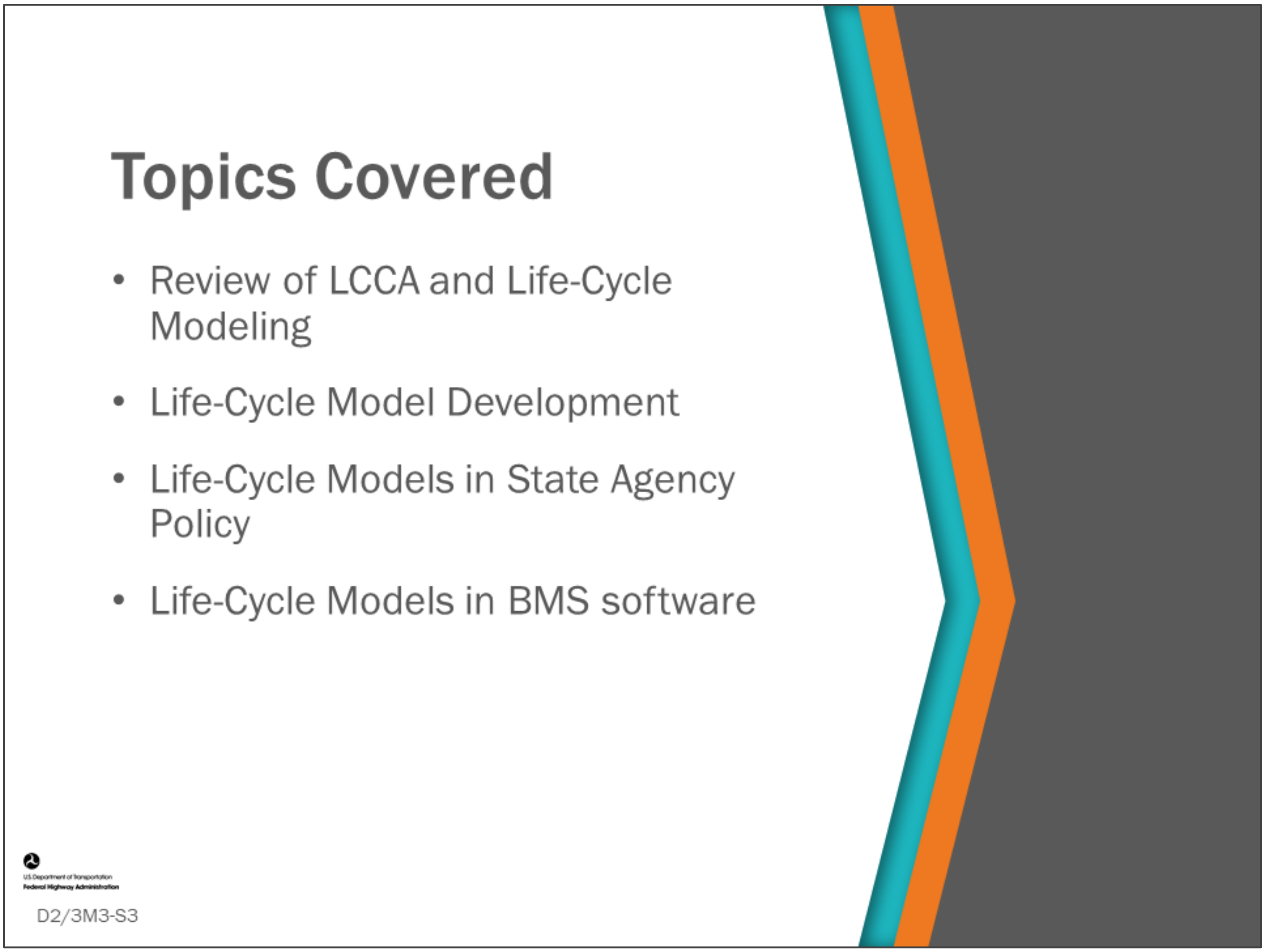
D2/3M3-Slide 2



Key Message

Common workflow steps and features are shown on the slide. In this module, we will review how to generate and model bridge strategies.

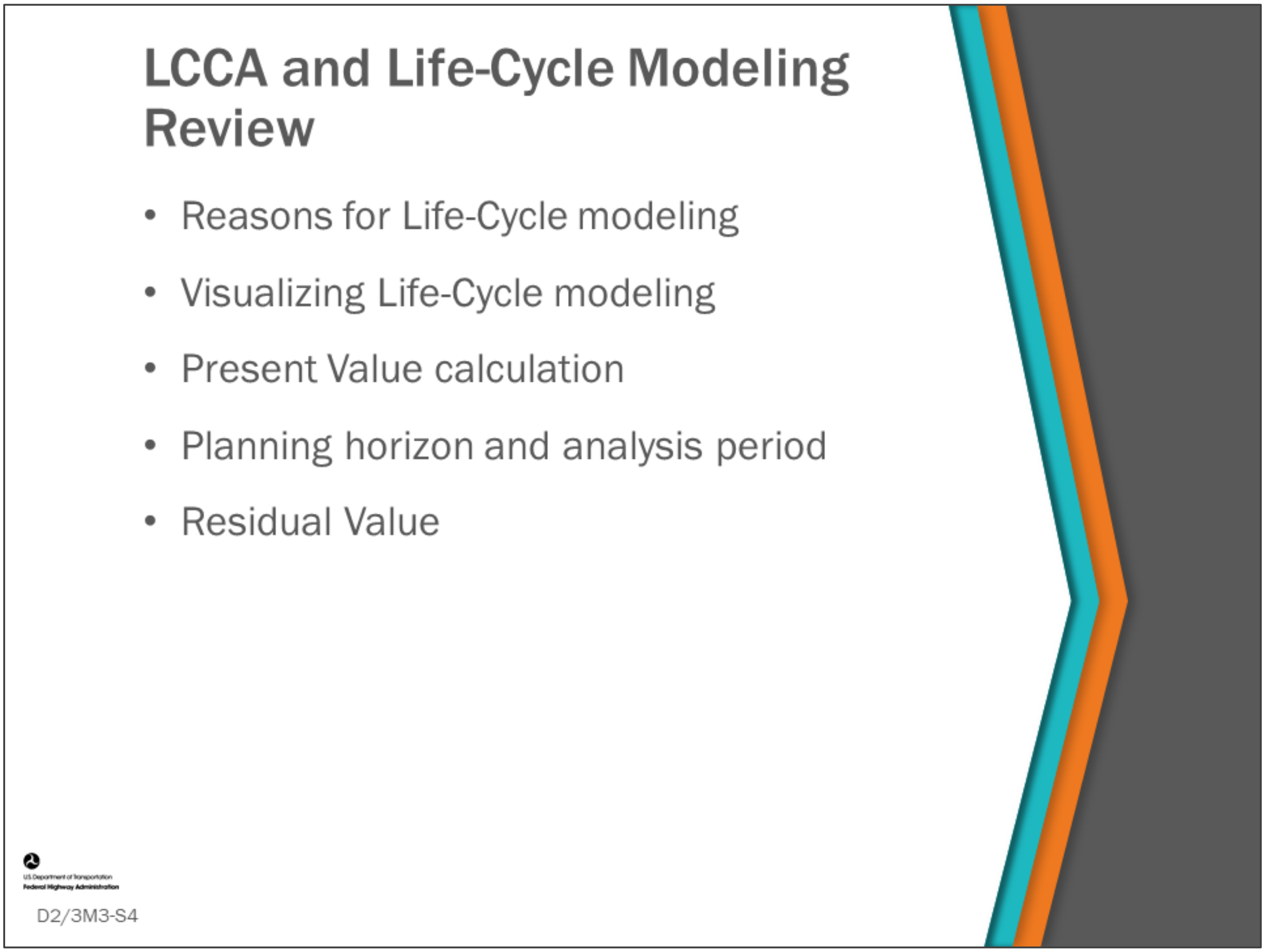
D2/3M3-Slide 3



Key Message

During Day 1, Module 7 discussed life-cycle agency cost and modeling and how they are used in life-cycle analysis. This module will delve into greater detail regarding how these models are created and used to help set network policy, and it will show how BMS software can be used to complete this type of analysis.

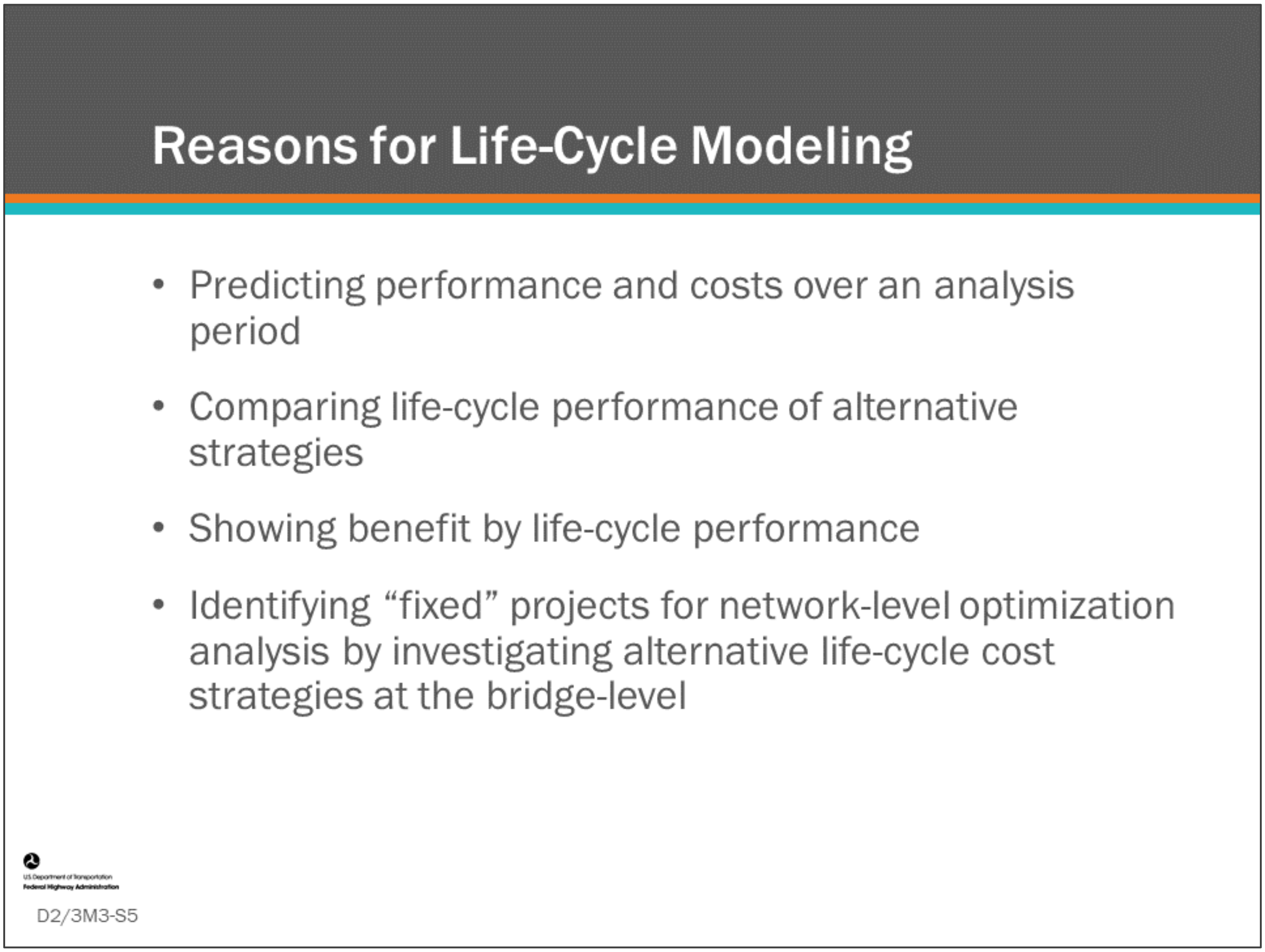
D2/3M3-Slide 4



Key Message

We will quickly review common LCCA that was presented on the first day of the workshop and prepare the class for hands-on activities.

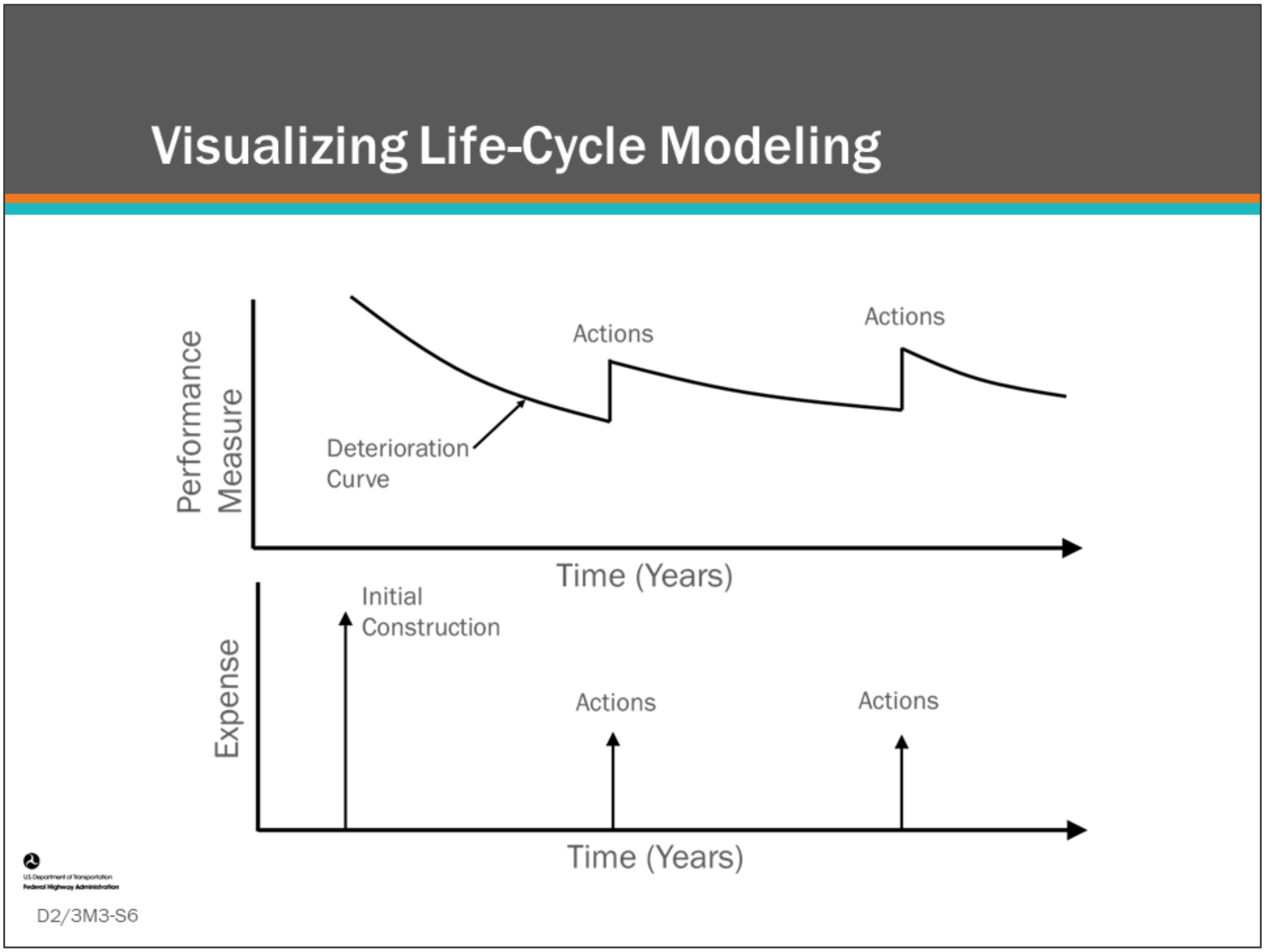
D2/3M3-Slide 5



Key Message

Modeling to predict the condition, performance and costs under any sequence of actions for a bridge is the fundamental analysis required for network level optimization, which is the ultimate goal of any BMS. However, it is instructive to break out life-cycle cost (LCC) modeling so that it can be understood independently, whether it is used at the bridge level, for so-called “bottom up” analysis; or, as a building block used in network-level optimization.

D2/3M3-Slide 6

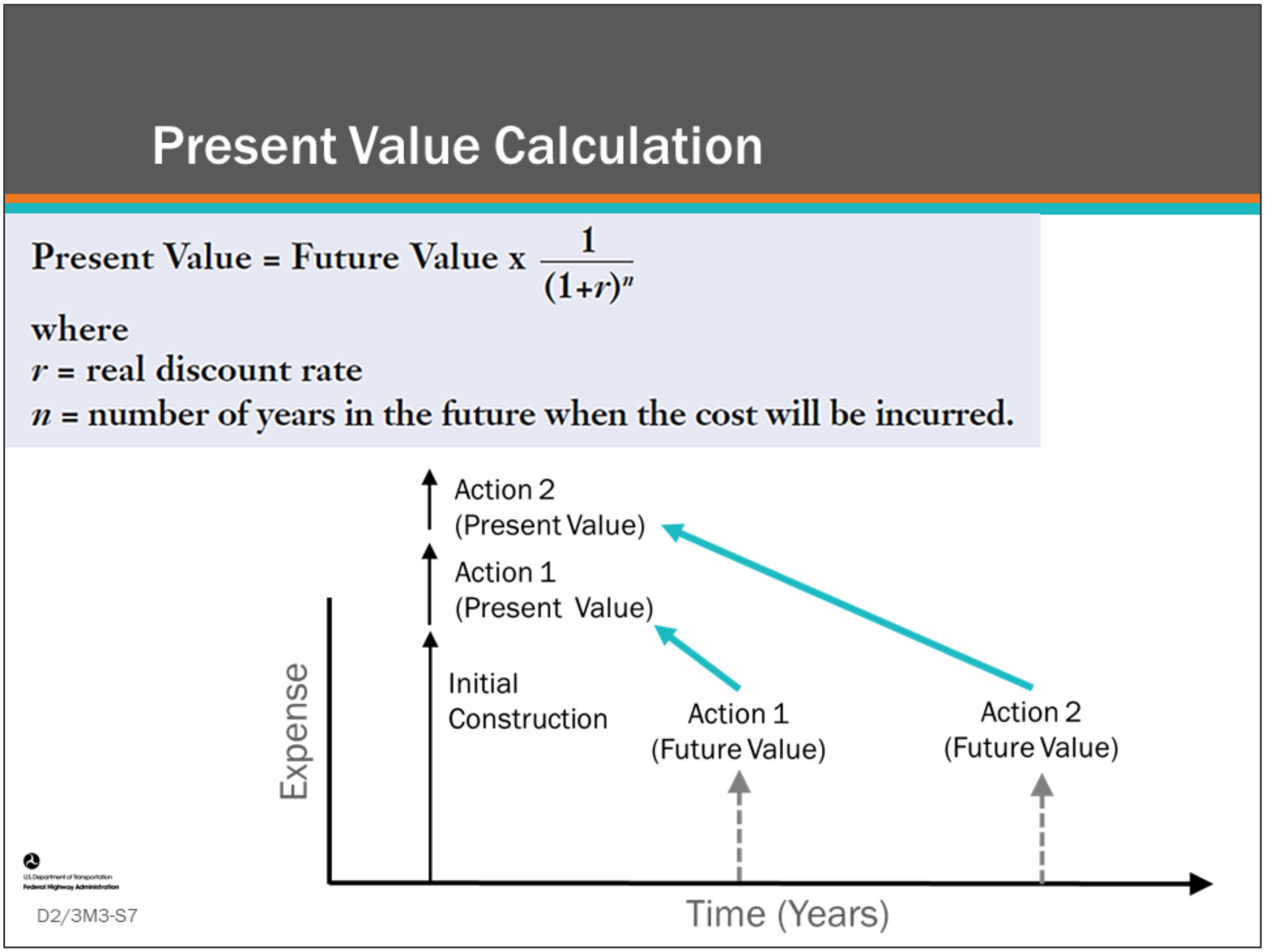


Key Message

The top chart shows a bridge deterioration curve with two actions that improve the agency's performance measure. The performance measures can use the GCR ratings, a health index developed using bridge elements, or a utility function. The bottom chart shows a cash-flow diagram with Expense on the y-axis, Time on the x-axis, and Actions shown at different times with the height of the arrow corresponding to the expense (cost) of each action.

- The two charts together, illustrate a Life Cycle Activity Profile (LCAP). The LCAP is the same as a life-cycle plan for an asset.
    - The life-cycle activity profile will be referenced and used extensively in this module.

D2/3M3-Slide 7



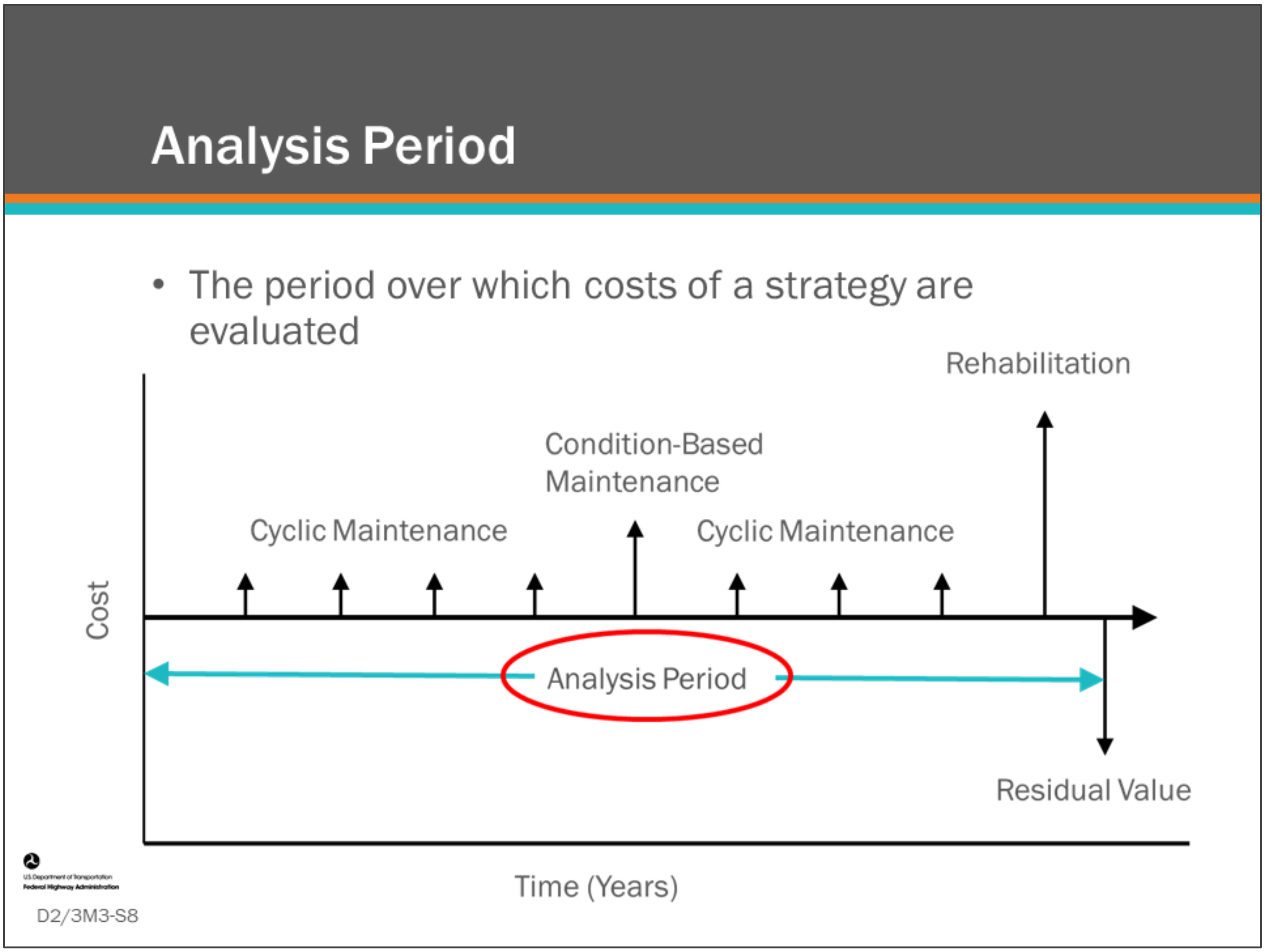
Key Message

LCCA compares different preservation strategies or life-cycle plans for a bridge by calculating Present Value (PV) for competing plans, as shown in the chart on this slide. This is done by representing all future actions as present value.

This slide shows the calculation for Present Value:

- "r" is the real discount rate
- "n" is the number of years in the future when the cost is incurred
- Net Present Value (NPV) is the summation of all present values

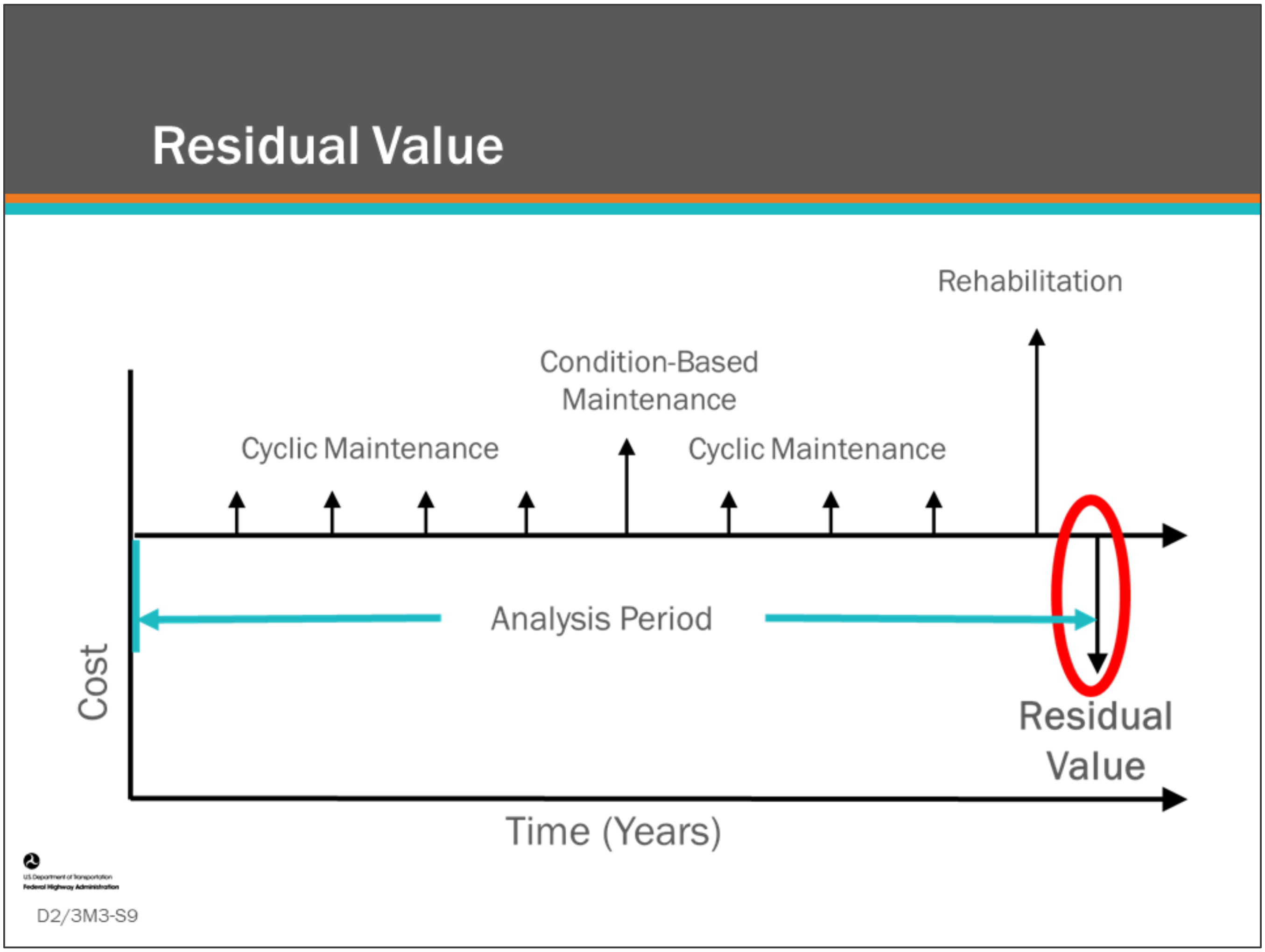
D2/3M3-Slide 8



Key Message

When comparing multiple strategies, a fixed analysis period needs to be selected over which costs of the strategies are evaluated. The analysis period needs to be long enough to provide a fair comparison between alternatives. For analysis of alternatives, the same population of bridges needs to be included.

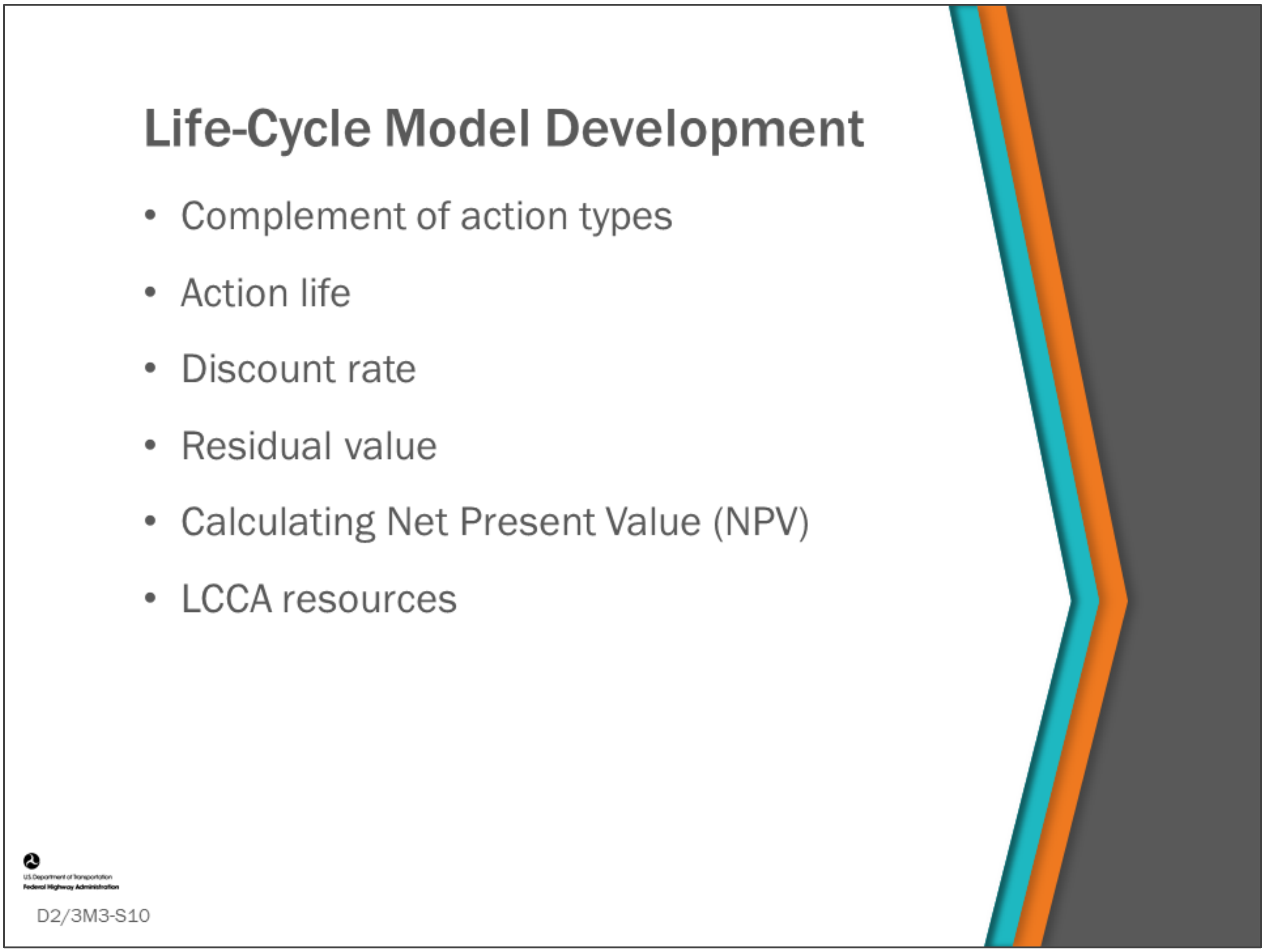
D2/3M3-Slide 9



Key Message

The LCAP for MR&R and reconstruction candidates in a BMS are most often bridges that are already in service at the beginning of the analysis period, and they will remain in service either in their present form or as replacement bridges after the analysis period. As a result, an initial construction cost may not be shown for the candidates. At the end of the analysis period, a "residual value" is calculated to equate the different Remaining Service Life (RSL) of competing candidates.

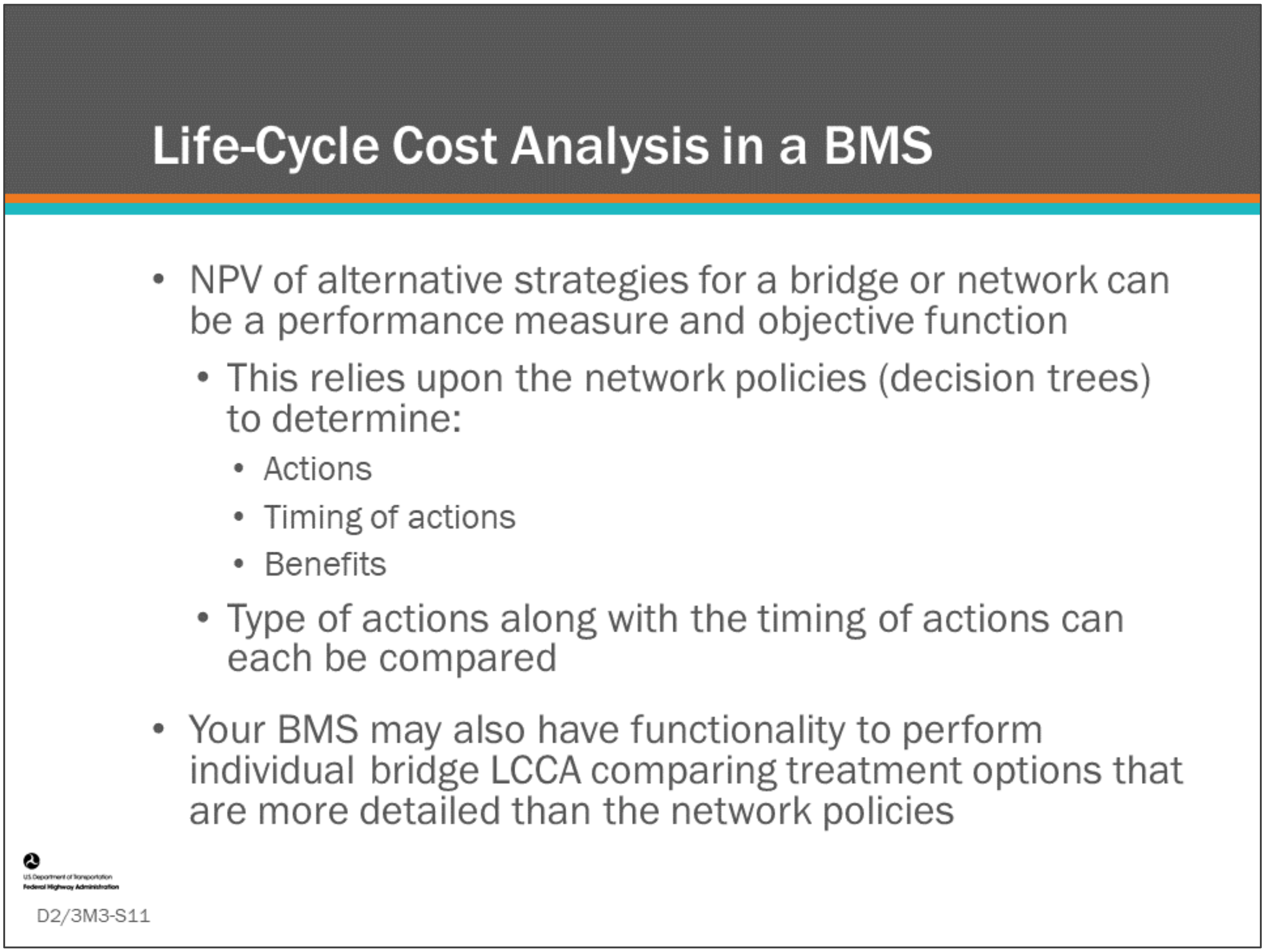
D2/3M3-Slide 10



Key Message

Life-cycle model development in a BMS involves using knowledge of actions (treatments), fix life of actions (treatments), and economic factors to compare life-cycle plan strategies. In this section, we will show how to set input values and do life-cycle cost calculations.

D2/3M3-Slide 11



Key Message

The purpose of life-cycle cost analysis in a BMS is to compare multiple life-cycle activity profiles (life-cycle plans). Life-cycle cost can be used in a BMS in several ways, two of which are shown on the slide.

- NPV of alternative strategies for a bridge or group of bridges can be a performance measure and objective function.
    - This relies upon the network policies (decision trees) to determine actions, timing of actions, and benefits.
    - Not only the type of actions can be compared, but the timing of these actions as well.
- Your BMS may also have functionality to perform individual bridge LCCA comparing treatment options that are more detailed than the network policies.

D2/3M3-Slide 12

Action Life

- Use agency guidance documents
- Use expert elicitation

Bridge Element	Expected Repair Service Life (yrs)	Bridge Element	Expected Repair Service Life (yrs)
• Joint repair	15	• Heat straightening of steel bridge members	-
• Joint replacement	25	• Full painting of structural steel members	15-25
• Elimination of deck joints	-		
• Deck patching	10-15		
• Deck overlays and re-overlays	20-25	• Zone and spot painting of structural steel members	10-15
• ADA improvements	20+		
• Approach panel repairs or replacement	20-25	• Bearing replacement or maintenance	50+
• Bridge barrier and end post repair, retrofit or replacement	20-30	• Installation of scour countermeasures	10+
• Curb ramp or sidewalk repairs	15-20	• Installation of cathodic protection	15-25
• Partial deck replacement	40+	• Chloride extraction	25+

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D2/3M3-S12

Key Message

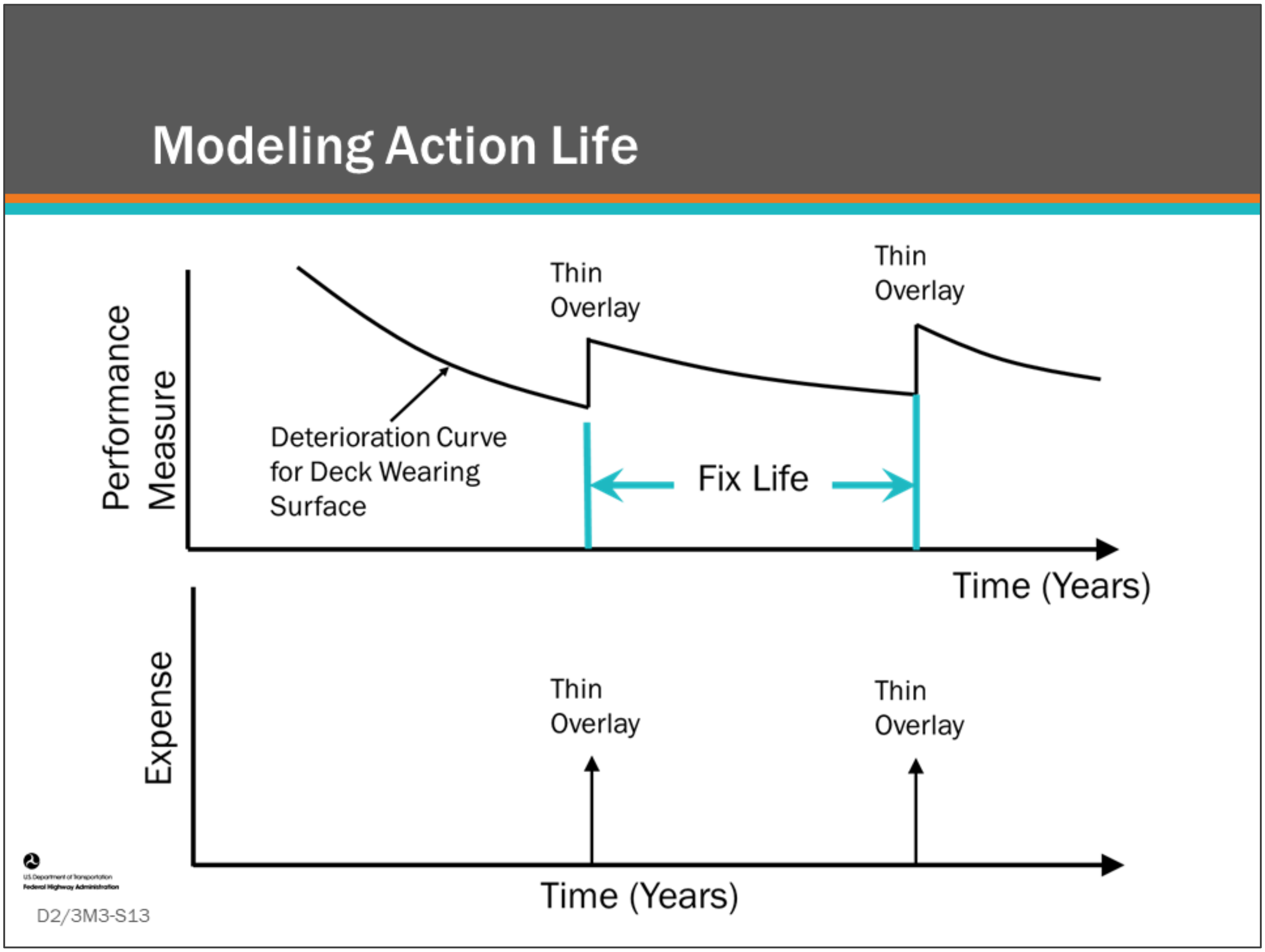
Knowing the estimated Action Life of different bridge actions is critical to a life cycle cost analysis. Note that some agencies may call this “fix life” or “expected service repair life.”

Your agency may have an agency guidance document with expected life for different treatments.

You can also use expert elicitation to come up with action life values.

Once you have expected action lives you will need to express these action lives in your BMS software. “Action Life” is likely not a value you input into your BMS, but it can be used as a starting point to model the benefit of the action in ways your BMS is set up to support, which depends on how your BMS performs deterioration modeling and how it shows benefit for actions.

D2/3M3-Slide 13



Key Message

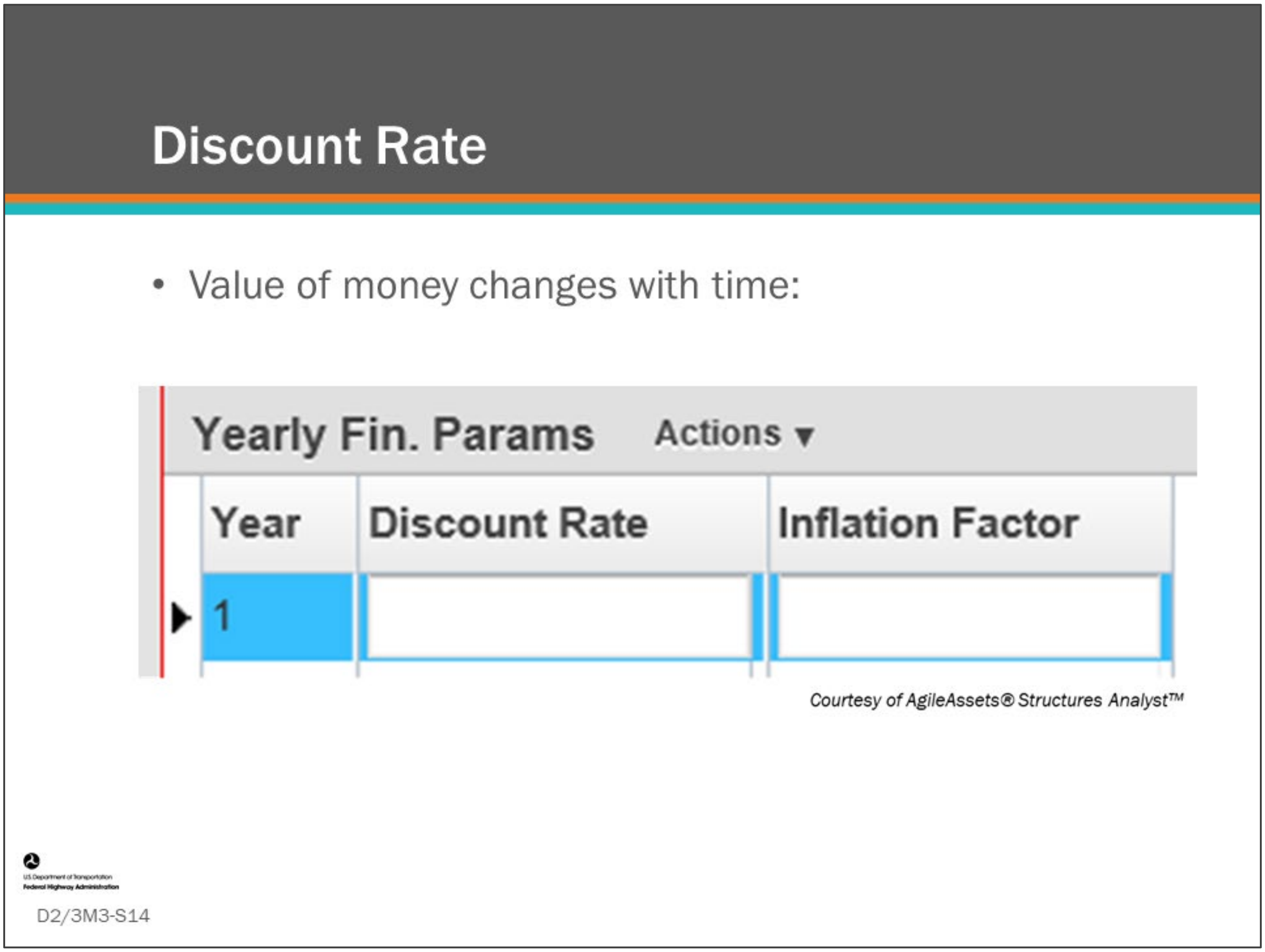
Action Life can be modeled at the same time deterioration modeling is performed.

Shown on this slide is the action life for a thin overlay for a bridge deck, which can be modeled using Element 510 – Deck Wearing Surface.

This slide also shows the relationship between action life and configuration of a BMS Network Policies. An action's "Action Life" is used to set timing of actions in a life cycle activity profile which sets actions that will be taken to the bridge during the analysis period as shown in the bottom graphic. There are several ways to set action life in a BMS.

- Deterioration modeling of the element or component are set for the material. This is used along with triggers set in the network polices, or decision trees, to decide when actions occur.
- Another way to set an action life in a BMS is to program the BMS to not allow the element to deteriorate for a set amount of years after the action.
- Yet another way, is to program the BMS to not allow the same action to take place for a set number of years.

D2/3M3-Slide 14

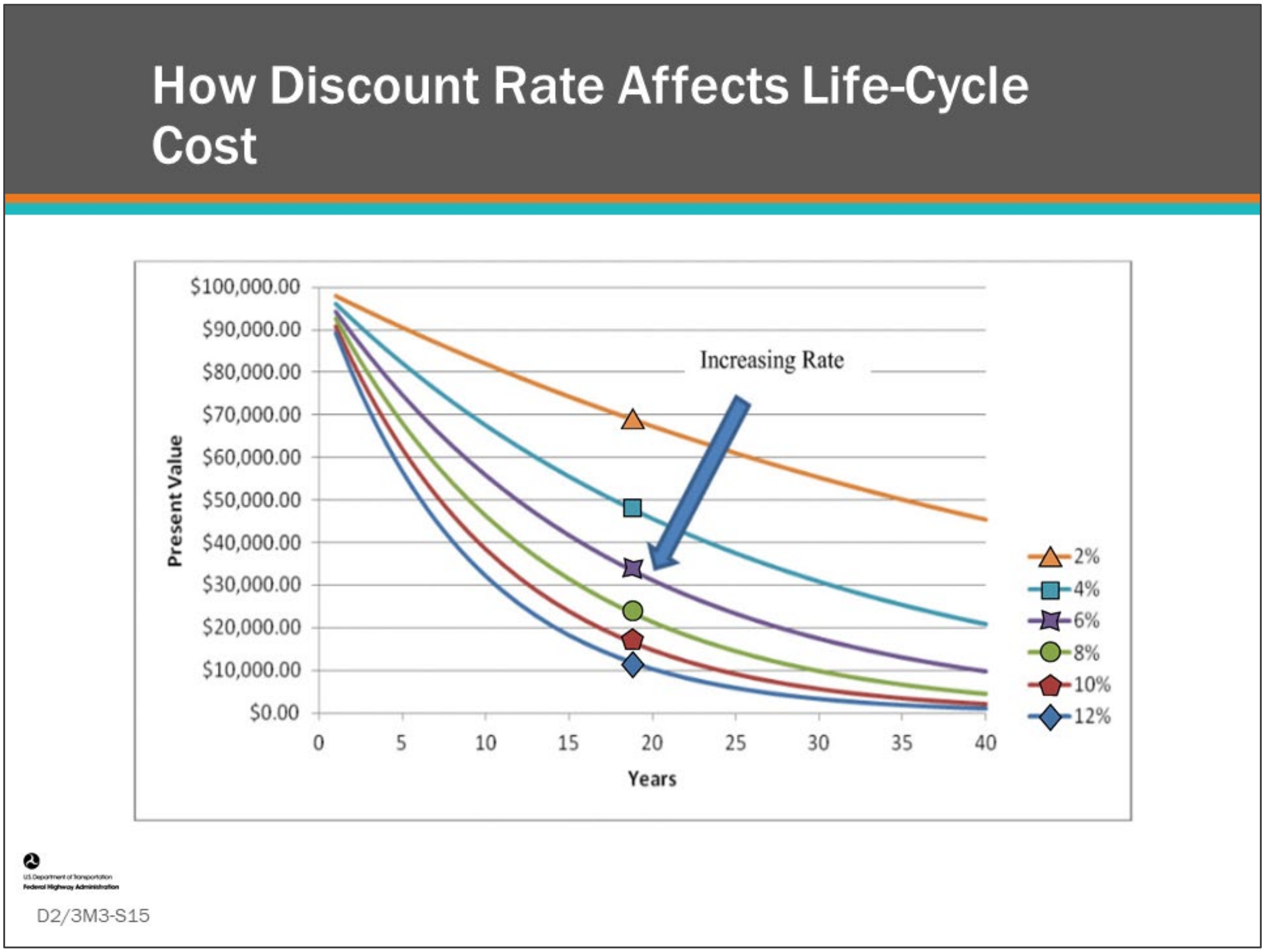


Key Message

We learned on day one of the workshop that discount rate is the way life-cycle cost analysis accounts for the change in value of money over time. BMS software provide input for both discount rate and inflation, but most often engineers will simply input a discount rate. Note: If the same discount rate and inflation factor are input, they will cancel each other.

Shown on the slide is the screen in AgileAssets® Structures Analyst™. In AASHTOWare™ Bridge Management (BrM), the user has the option to enter a cost index for each year of the analysis or to use a flat 4 percent inflation throughout the analysis period.

D2/3M3-Slide 15



Key Message

The SHRP2, *Design Guide For Bridge Service Life*, says "… discount rate can have a significant impact on the analysis. A low discount rate favors projects with long-term benefits and near-term costs."

- In other words, low discount rates favor performing work and incurring costs sooner rather than allow further deterioration that would lead to more expensive work needs later.
- High discount rates favor deferring work although this will result in more expensive work needs later.
- Before deciding upon a discount rate that will be used in a BMS, a sensitivity analysis could be done using a range of discount rates to determine the effect on the analysis.

Shown on this slide is a chart illustrating the effect that different discount rates have on the Present Value calculation for actions taken at different discount rates and time in the future. It shows the present value of a $100,000 expenditure made at different times in the future and at different discount factors.

- At year 0, the present value is $100,000 regardless of discount rate.
- At year 10 and 2 percent discount factor, the present value is $82,000.
- At year 10 and 12 percent discount factor, the present value is $32,000.
- At year 30 and 2 percent discount factor, the present value is $55,000.
- At year 30 and 12 percent discount factor, the present value is $3,300.

D2/3M3-Slide 16

Calculate Net Present Value (NPV)

Source: Adobe Stock

- Compare bridge deck life-cycle plans for three alternatives:
  - Thin Overlay 1
  - Thin Overlay 2
  - Rigid Overlay
- Use scientific calculator
- Use information on following slides

U.S. Department of Transportation
Federal Highway Administration

D2/3M3-S16

Key Message

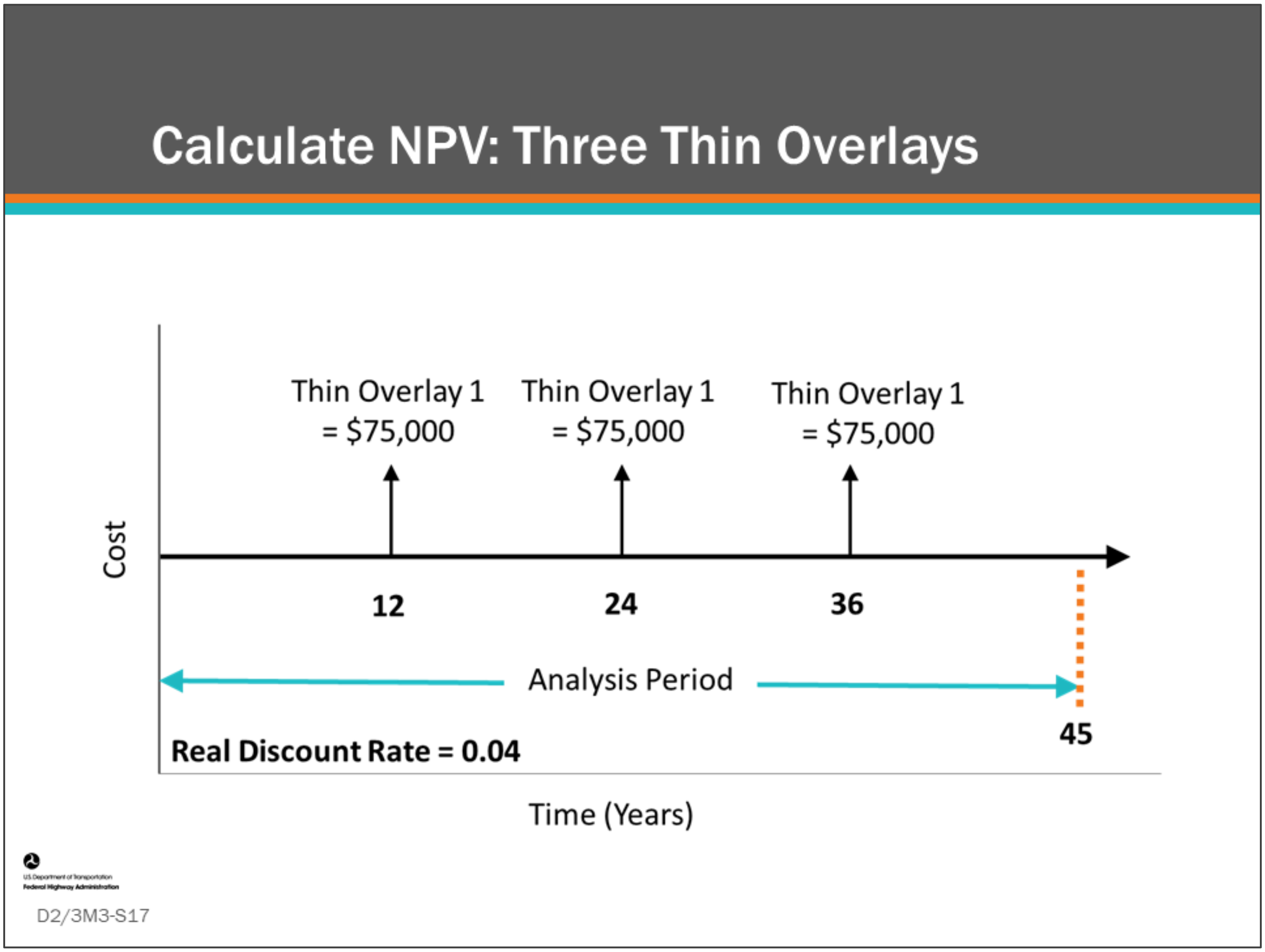
Individually calculate the NPV for three deck preservation options.

Use the following slides to complete the activity for:

- Thin Overlay 1
- Thin Overlay 2
- Rigid Overlay

The resulting values will be compared.

D2/3M3-Slide 17



Key Message

Individually calculate the NPV for the Thin Overlay 1 option.

- Details are shown on the slide.

D2/3M3 - Slide 17: Calculating Net Present Value (NPV) Worksheet (Three Thin Overlays)

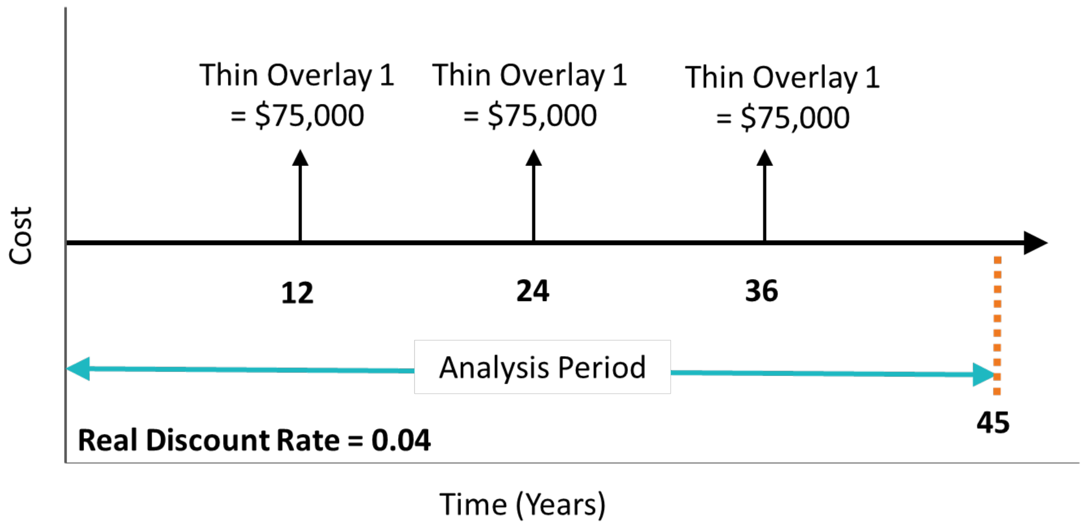
Using the Present Value equation below, calculate NPV for the three thin overlays.

$$\text{Present Value} = \text{Future Value} \times \frac{1}{(1+r)^n}$$

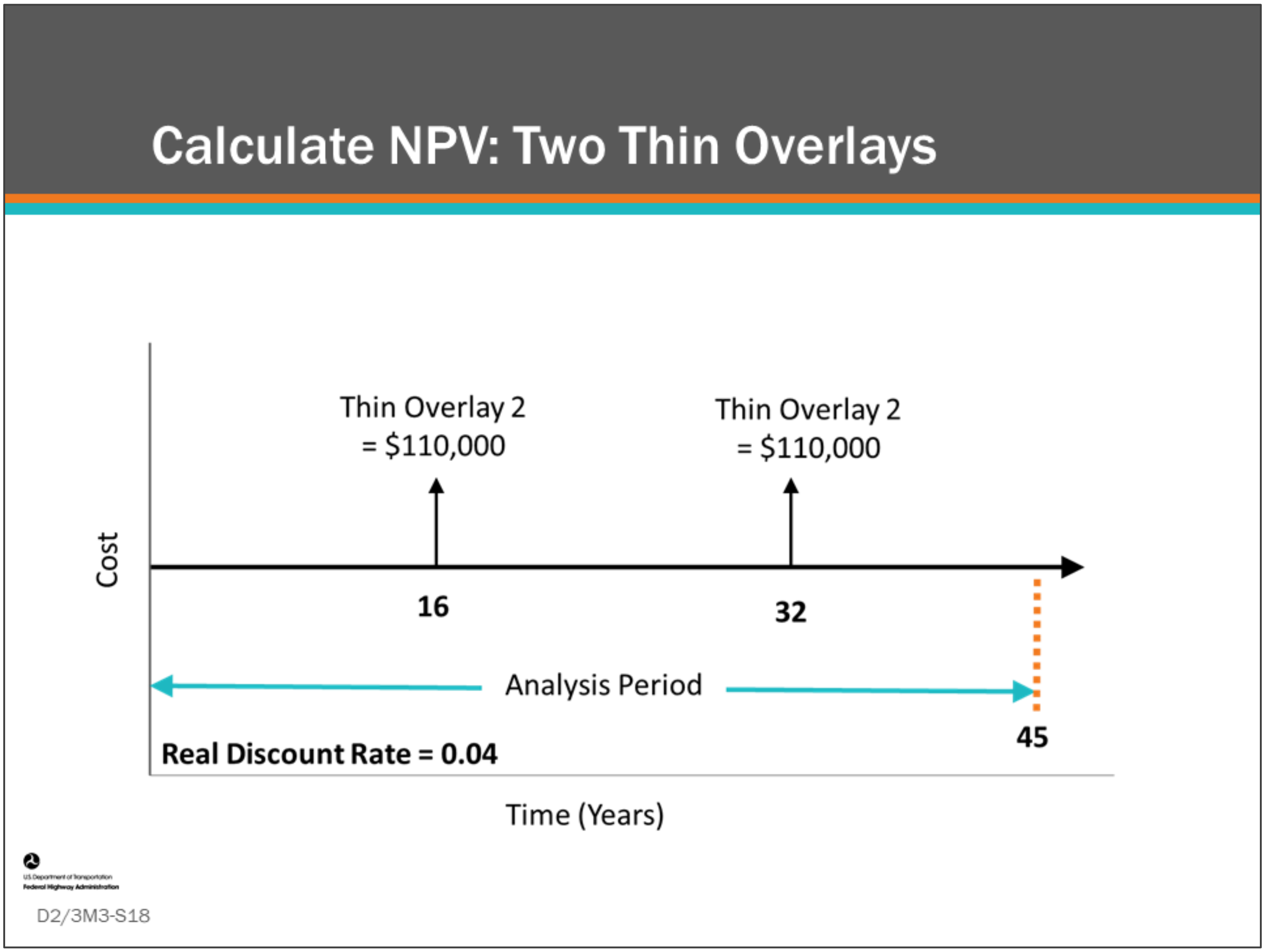
where

r = real discount rate

n = number of years in the future when the cost will be incurred.



D2/3M3-Slide 18



Key Message

Individually calculate the NPV for the Thin Overlay 2 option.

- Details are shown on the slide.

D2/3M3 - Slide 18: Calculating Net Present Value (NPV) Worksheet (Two Thin Overlays)

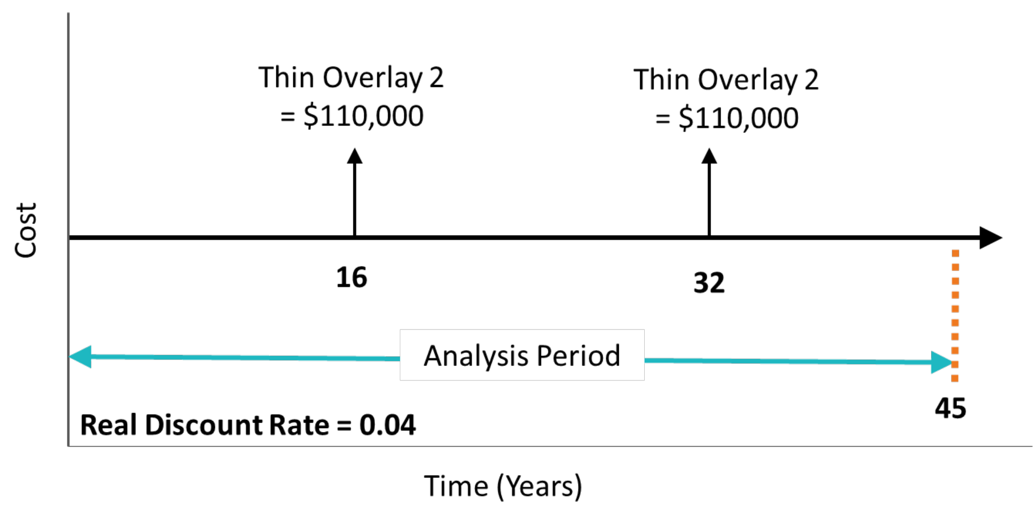
Using the Present Value equation below, calculate NPV for the two thin overlays.

$$\text{Present Value} = \text{Future Value} \times \frac{1}{(1+r)^n}$$

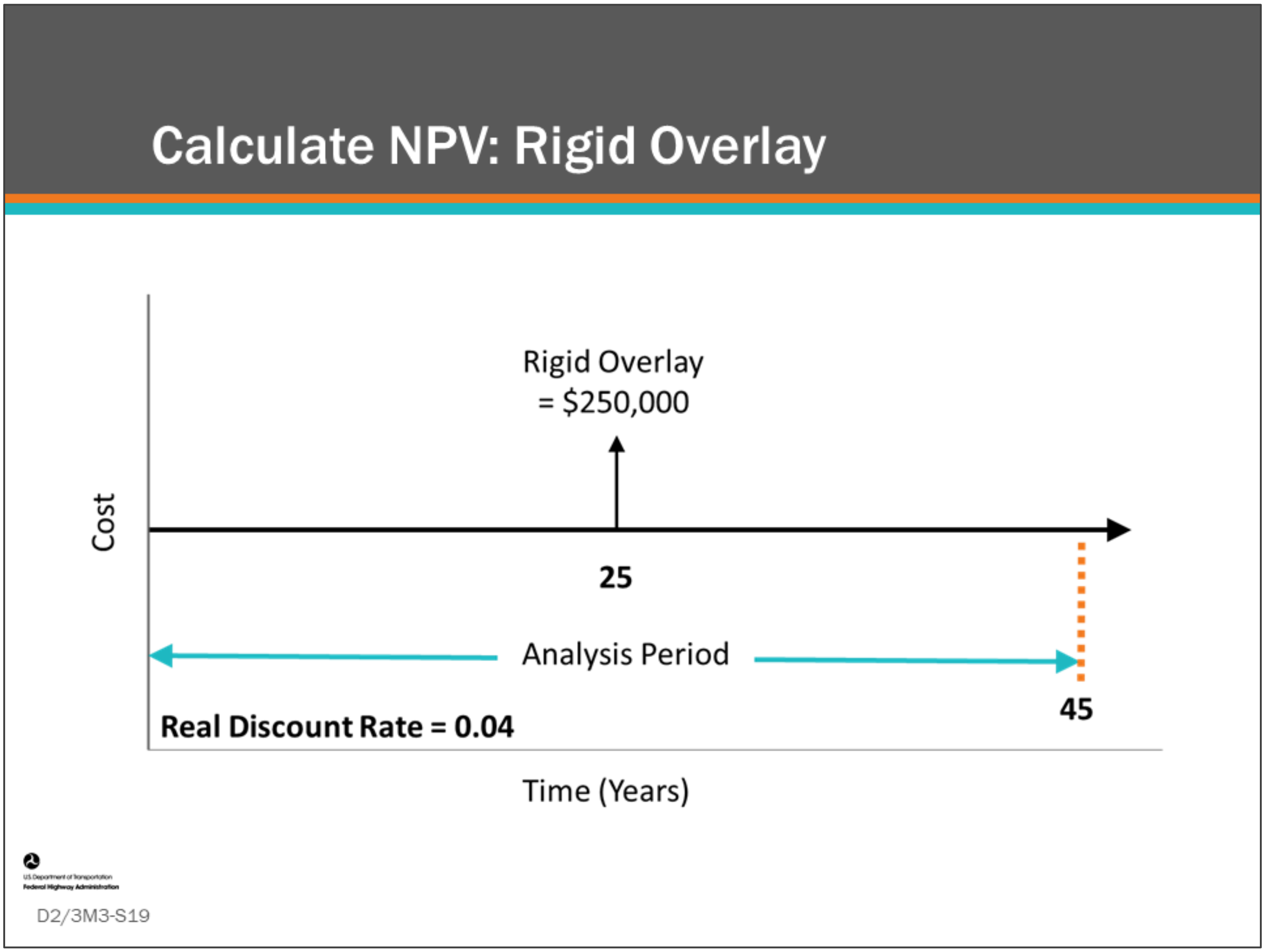
where

r = real discount rate

n = number of years in the future when the cost will be incurred.



D2/3M3-Slide 19



Key Message

Individually calculate the NPV for the Rigid Overlay option.

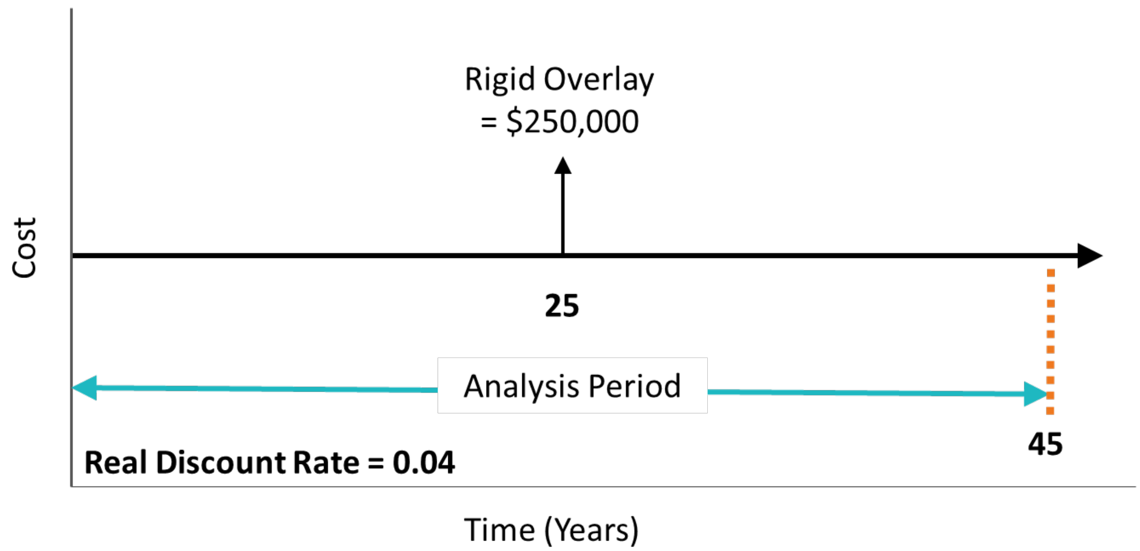
- Details are shown on the slide.

D2/3M3 - Slide 19: Calculating Net Present Value (NPV) Worksheet (Rigid Overlay)

Using the Present Value equation below, calculate NPV for the rigid overlay.

$$\text{Present Value} = \text{Future Value x } \frac{1}{(1+r)^n}$$

where
r = real discount rate
n = number of years in the future when the cost will be incurred.



D2/3M3-Slide 20

Calculate Net Present Value (NPV) – Results

Source: Adobe Stock

$$Net\ Present\ Value\ Thin\ Overlay\ 1 = \$75{,}000 \times \left(\frac{1}{1.04^{12}}\right) + \$75{,}000 \times \left(\frac{1}{1.04^{24}}\right) + \$75{,}000 \times \left(\frac{1}{1.04^{36}}\right) = \$94{,}379$$

$$Net\ Present\ Value\ Thin\ Overlay\ 2 = \$110{,}000 \times \left(\frac{1}{1.04^{16}}\right) + \$110{,}000 \times \left(\frac{1}{1.04^{32}}\right) = \$90{,}086$$

$$Net\ Present\ Value\ Rigid\ Overlay = \$250{,}000 \times \left(\frac{1}{1.04^{25}}\right) = \$93{,}779$$

D2/3M3-S20

Key Message

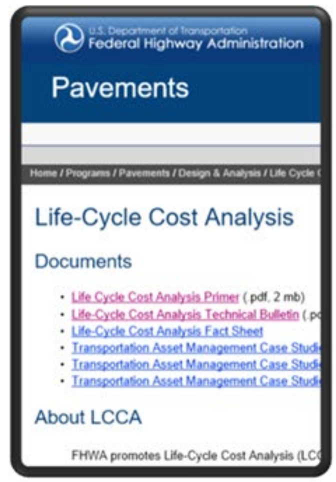
What are the correct answers?

- Thin Overlay 1: ______________________________
- Thin Overlay 2: ______________________________
- Rigid Overlay: _______________________________

D2/3M3-Slide 21

LCCA Resources and Tools: Online

- FHWA website
- BridgeLCC 2.0



Source: FHWA

D2/3M3-S21

Key Message

The FHWA website offers several resources to help agencies with Life Cycle Cost Analysis.

- Shown in the photo is the FHWA web page for LCAA related to “Pavements,” where you will find a listing of documents, user groups, software, training, and web links to other LCCA resources.

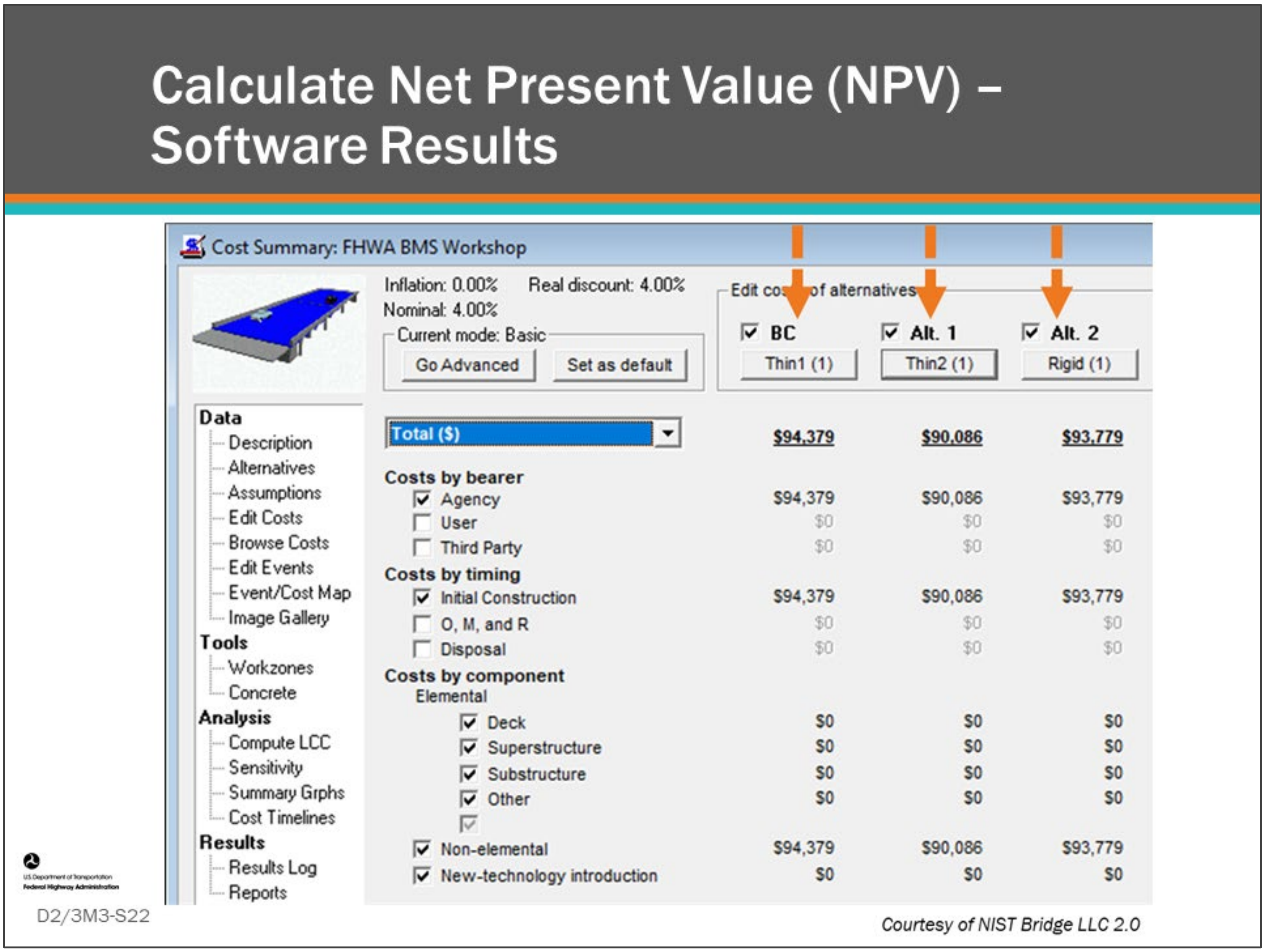
Also offered on the FHWA LCCA website is BridgeLCC 2.0, a bridge LCCA software tool.

- The software can compare up to five alternative project actions.
- Current and future actions can include construction, and operations, maintenance and repair (called OMR in the software), and user cost.
- It can also perform sensitivity analysis for variation in user inputs and probability analysis.

These tools are useful for understanding LCCA but in a BMS, these calculations are performed internally using the included deterioration models, actions, action benefits, and costs. The value of being able to compare life cycle costs between options in a BMS is that these accumulated costs can be used in benefit-cost analysis, and under constrained budget scenarios the projects that yield the least network-level life-cycle cost can be recommended.

AASHTOWare™ Bridge Management (BrM) also has a single bridge life-cycle cost analysis tool that can be used to manually compare and select alternatives based upon net present value of multiple alternative actions. These short-term actions will include subsequent long-term actions that would be taken to the structure determined by network policies.

D2/3M3-Slide 22

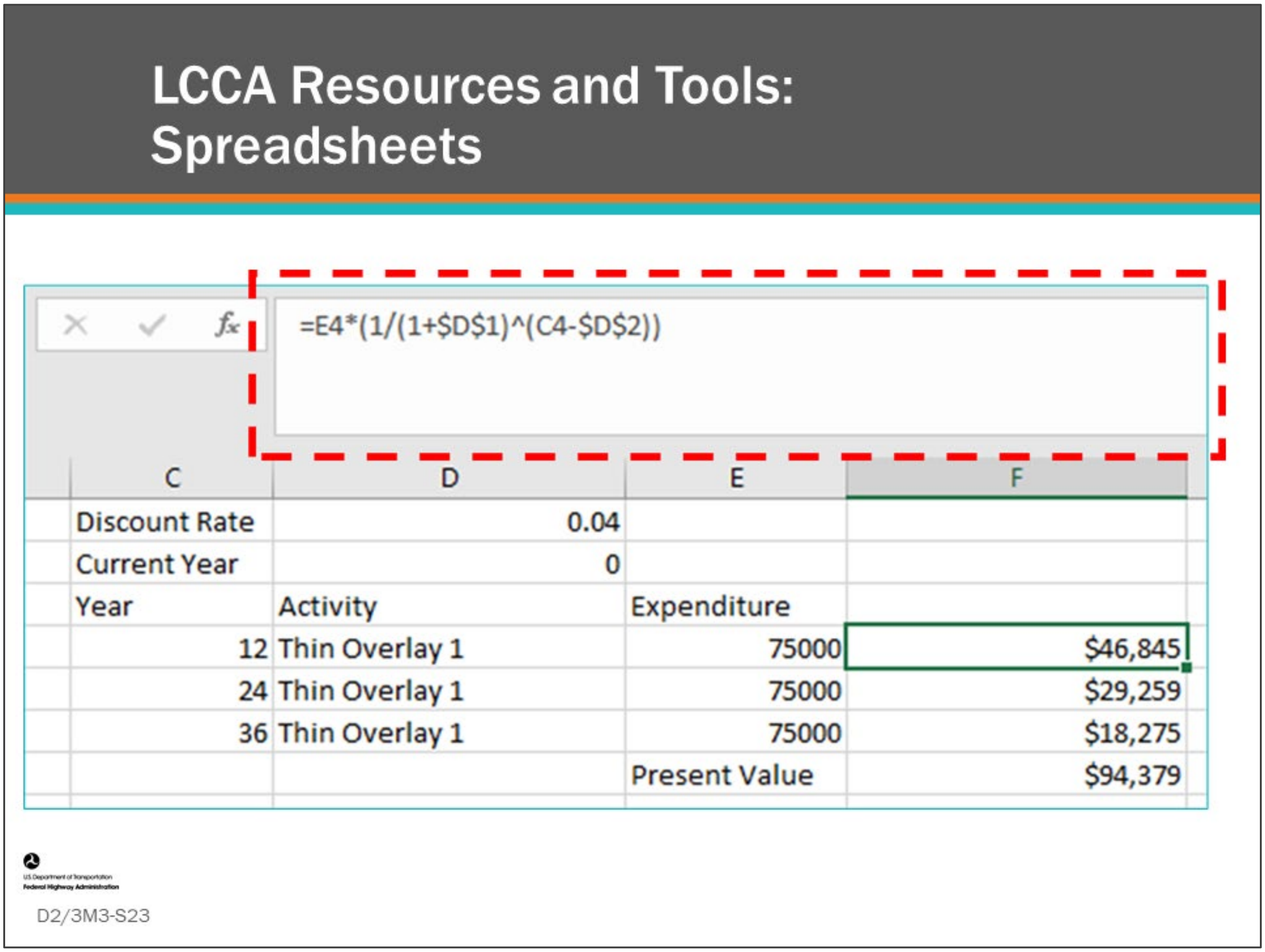


Key Message

Shown on this slide are the results from the previous activity, where we calculated the NPV for three different actions:

- Thin Overlay 1
- Thin Overlay 2
- Rigid Overlay

D2/3M3-Slide 23



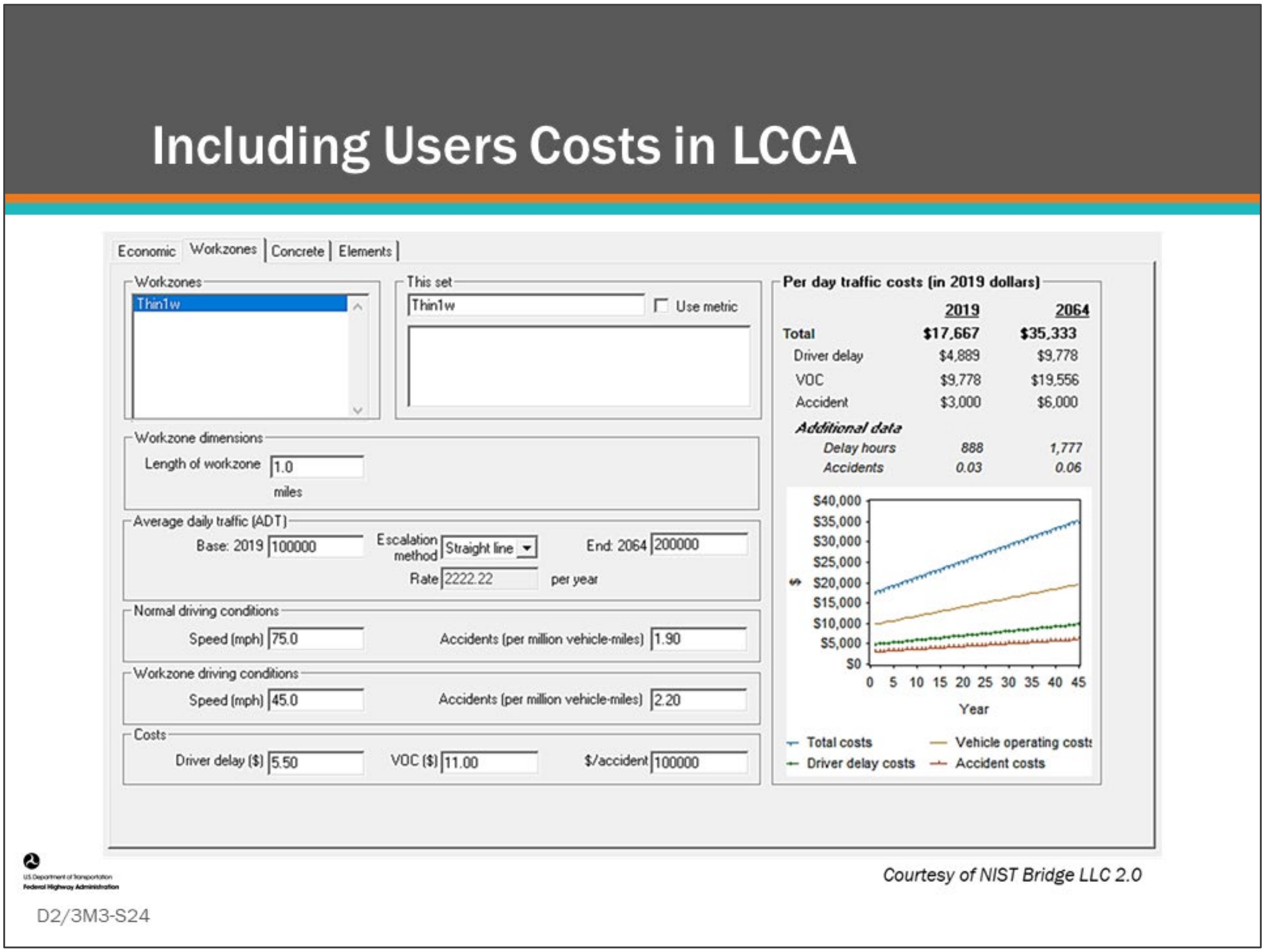
Key Message

The calculations for completing LCCA can also be performed using spreadsheet software.

Shown on this slide is a simple spreadsheet calculation for the Thin Overlay 1 option used in the "Calculating NPV" activity.

- Notice, the NPV calculation being shown in the formula bar.

D2/3M3-Slide 24



Key Message

BridgeLCC 2.0 allows user costs to be included in a the LCCA analysis.

- The software includes a basic tool for calculating user cost from work zones, as shown on this slide.
- Bridge managers can work with traffic engineers to properly estimate user costs for specific routes.

D2/3M3-Slide 25

Calculating NPV with User Cost


Source: Adobe Stock

- Add a user cost of $13,000 for each action:
  - Thin Overlay 1
  - Thin Overlay 2
  - Rigid Overlay
- Use scientific calculator
- Use information on following slides

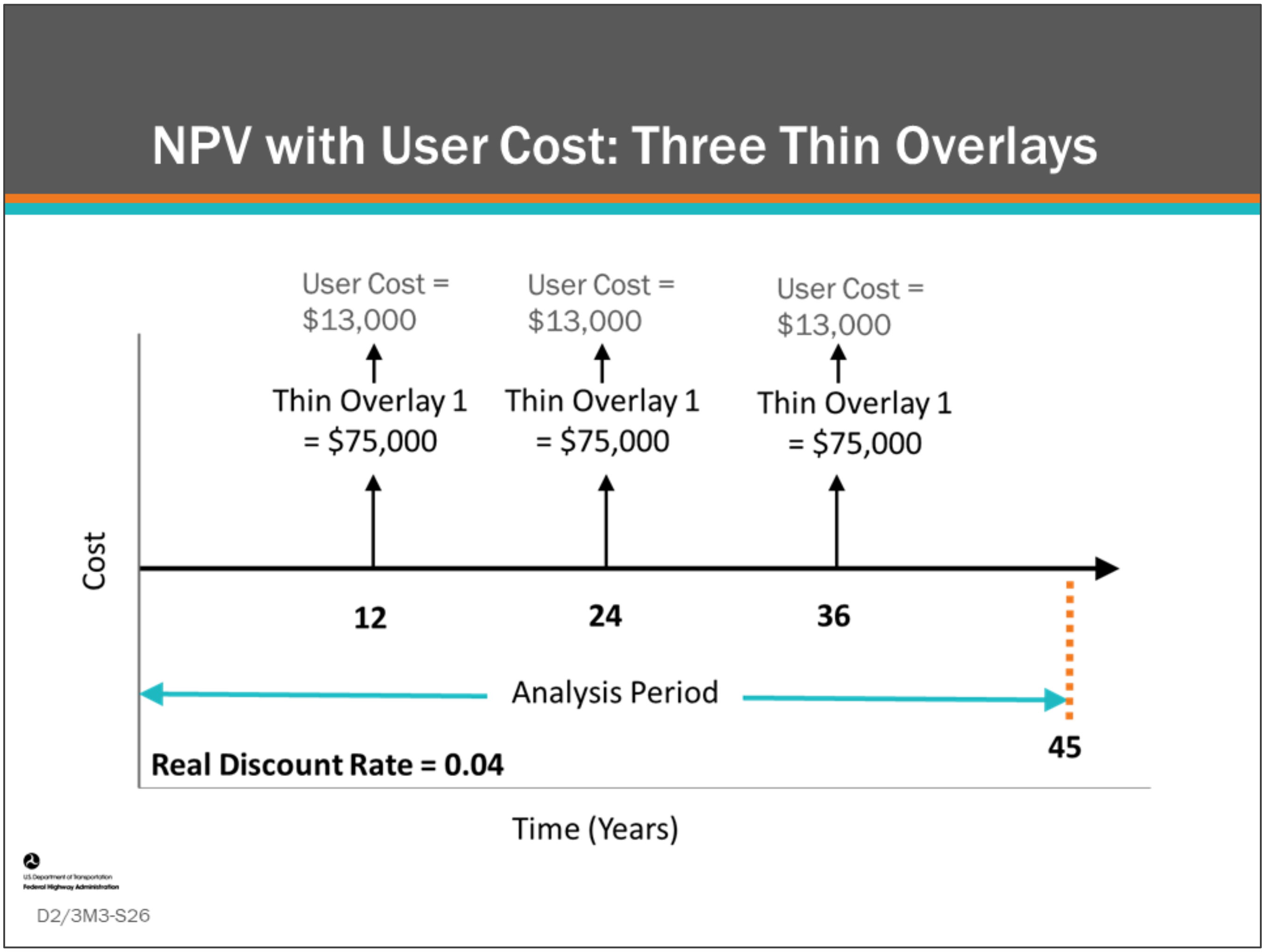
U.S. Department of Transportation Federal Highway Administration

D2/3M3-S25

Key Message

Calculate NPV with user cost for three deck preservation options.
Note, this is User Cost for each work zone application.

D2/3M3-Slide 26



Key Message

Individual calculate NPV with a User Cost of $13,000 for the Thin Overlay 1 option.

- Details are shown on the slide.

D2/3M3 - Slide 26: Calculating NPV With User Cost Worksheet (Three Thin Overlay)

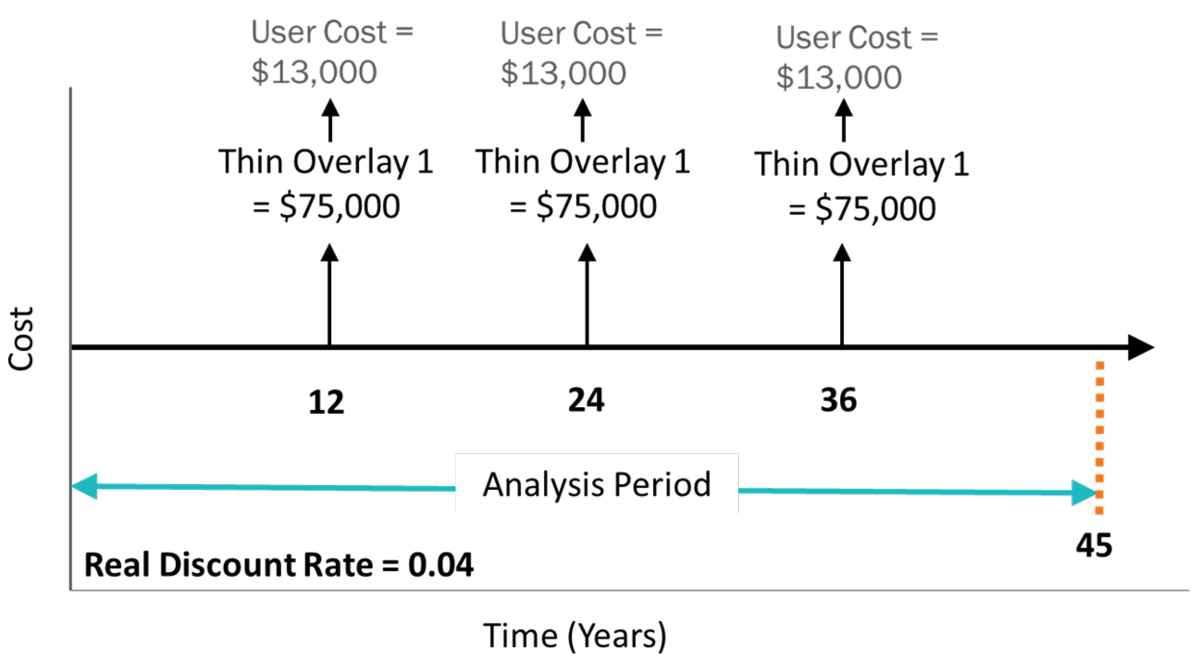
Using the Present Value equation below, calculate NPV for the three thin overlays with User Cost.

$$\text{Present Value} = \text{Future Value} \times \frac{1}{(1+r)^n}$$

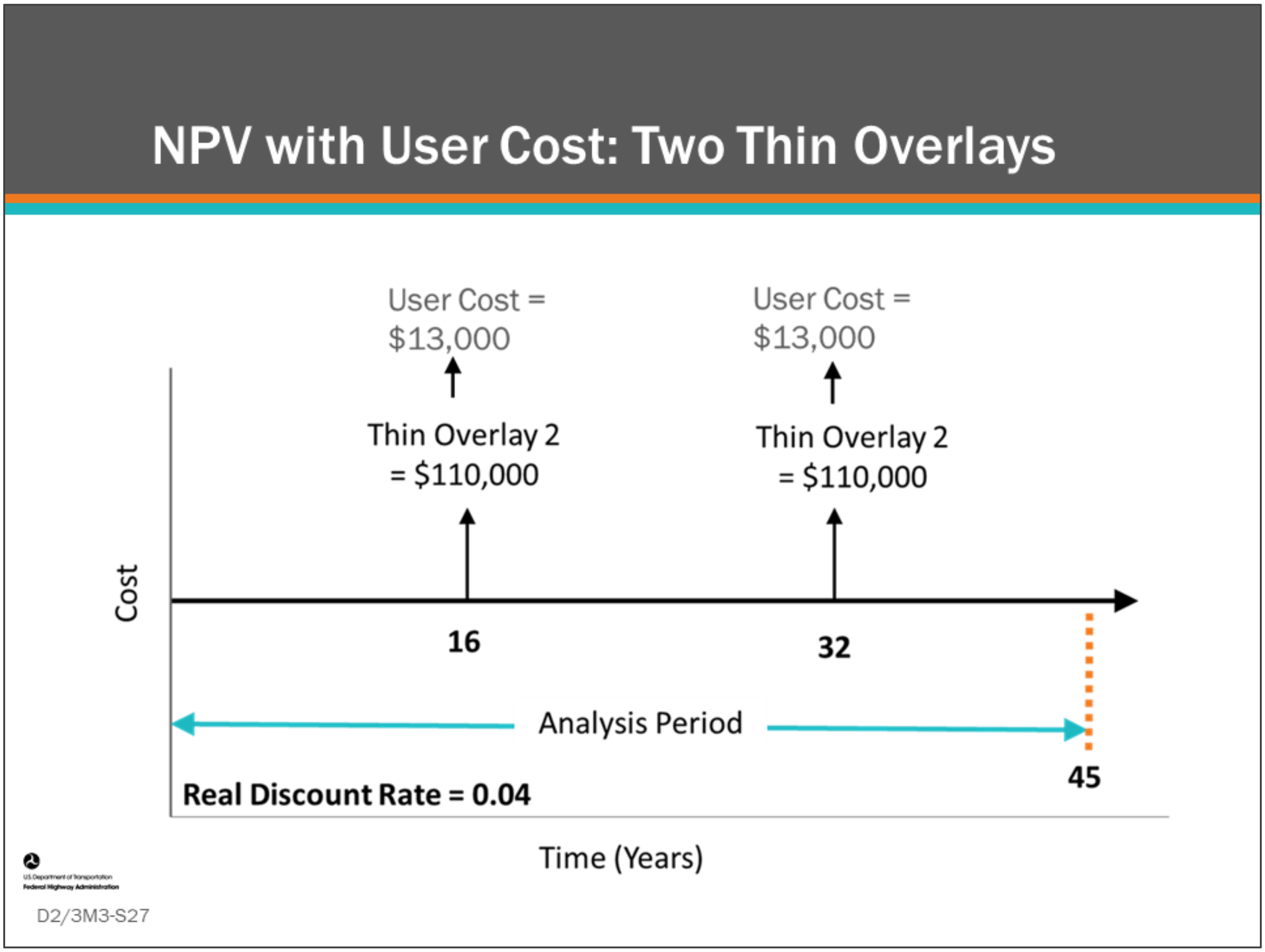
where

r = real discount rate

n = number of years in the future when the cost will be incurred.



D2/3M3-Slide 27



Key Message

Individually calculate NPV with a User Cost of $13,000 for the Thin Overlay 2 option.

- Details are shown on the slide.

D2/3M3 - Slide 27: Calculating NPV With User Cost Worksheet (Two Thin Overlays)

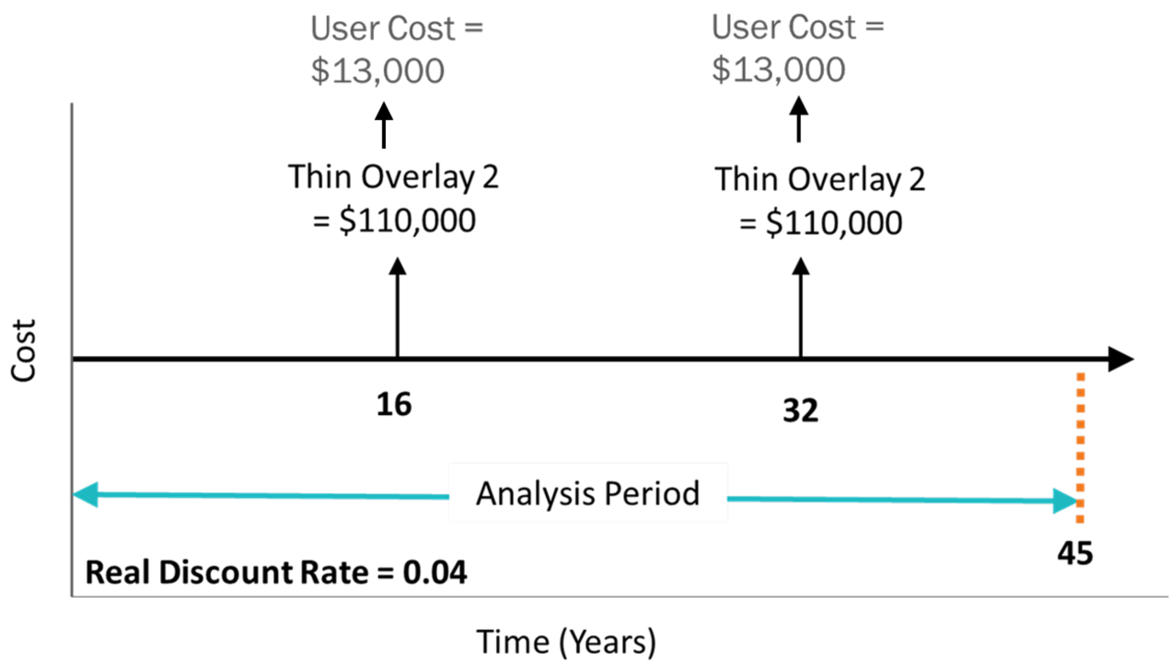
Using the Present Value equation below, calculate NPV for the two thin overlays with User Cost.

$$\text{Present Value} = \text{Future Value} \times \frac{1}{(1+r)^n}$$

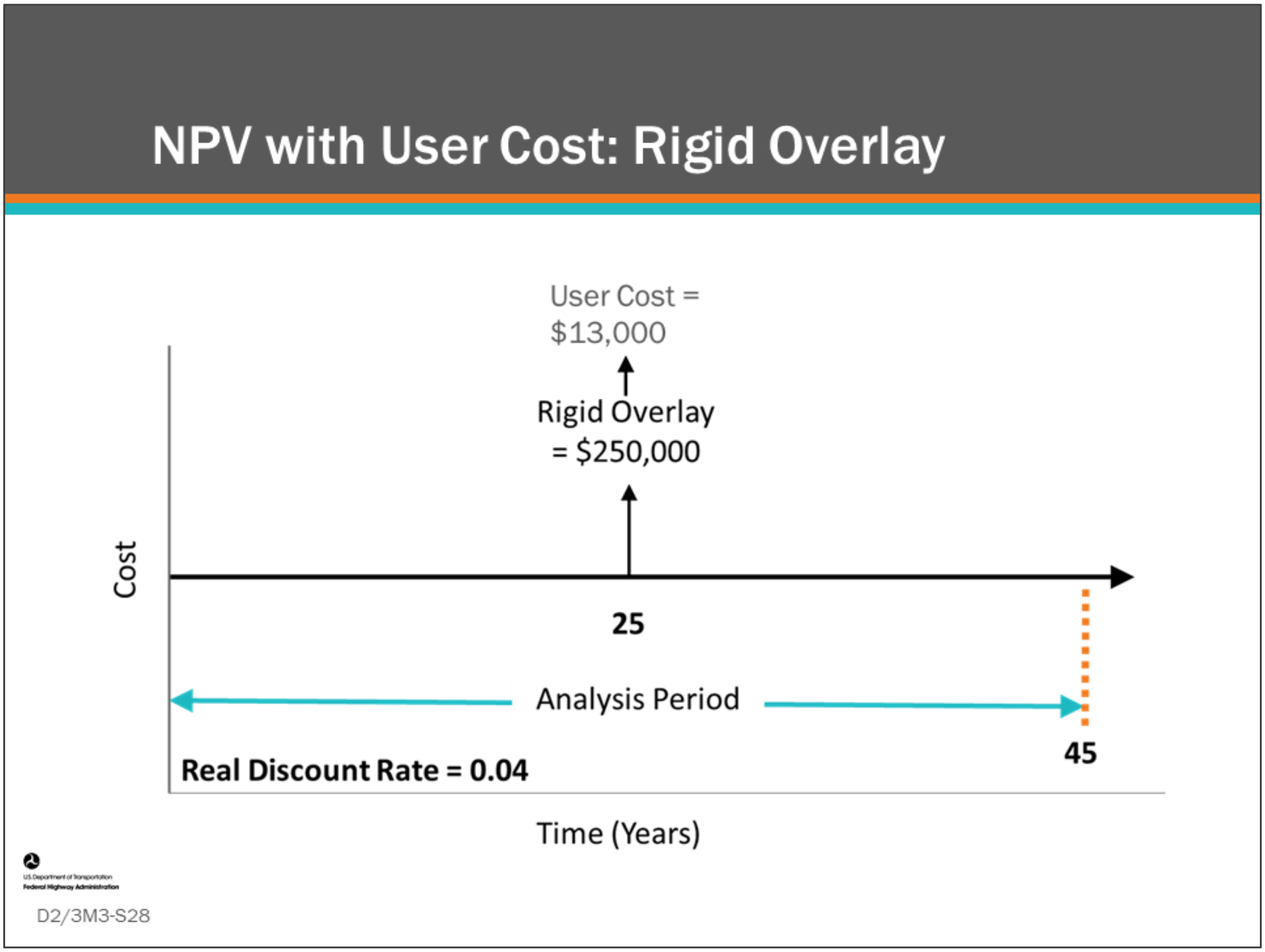
where

r = real discount rate

n = number of years in the future when the cost will be incurred.



D2/3M3-Slide 28



Key Message

Individual calculate NPV with a User Cost $13,000 for the Rigid Overlay option.

- Details are shown on the slide.

D2/3M3 - Slide 28: Calculating NPV With User Cost Worksheet (Rigid Overlay)

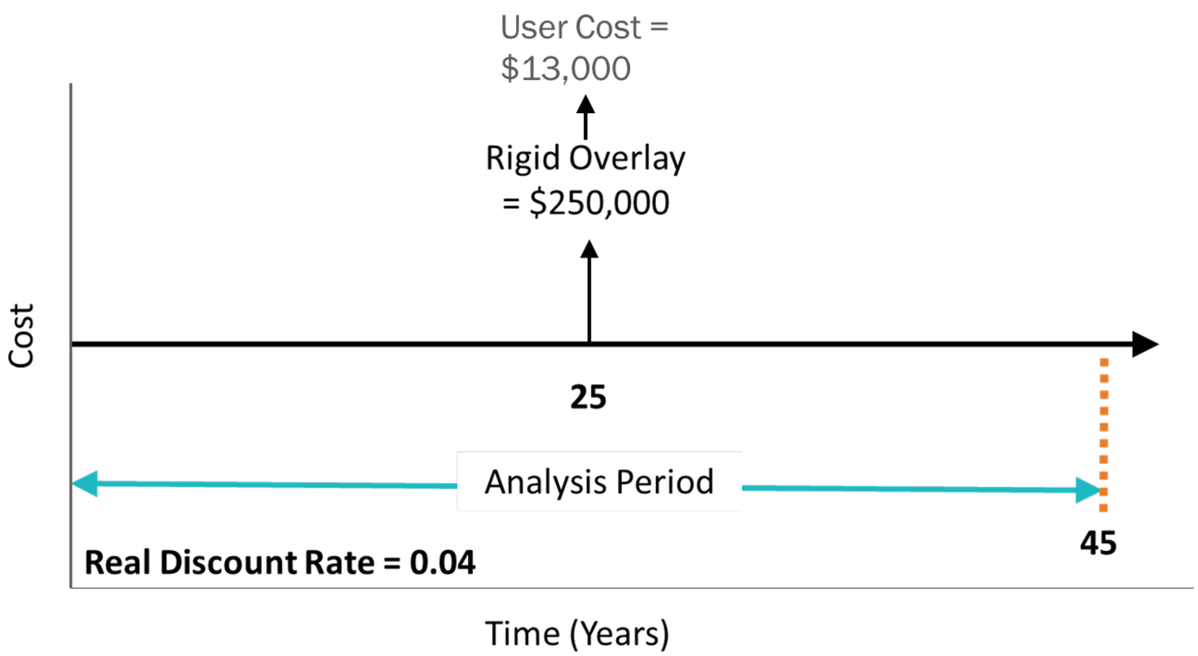
Using the Present Value equation below, calculate NPV for the rigid overlay with User Cost.

$$\text{Present Value} = \text{Future Value x } \frac{1}{(1+r)^n}$$

where

r = real discount rate

n = number of years in the future when the cost will be incurred.



D2/3M3-Slide 29

Calculating NPV with User Cost – Results

Source: Adobe Stock

$$Net\ Present\ Value\ Thin\ Overlay\ 1 = \$94{,}379 + \$13{,}000 \times \left(\frac{1}{1.04^{12}}\right) + \$13{,}000 \times \left(\frac{1}{1.04^{24}}\right) + \$13{,}000 \times \left(\frac{1}{1.04^{36}}\right) = \$110{,}738$$

$$Net\ Present\ Value\ Thin\ Overlay\ 2 = \$90{,}086 + \$13{,}000 \times \left(\frac{1}{1.04^{16}}\right) + \$13{,}000 \times \left(\frac{1}{1.04^{32}}\right) = \$100{,}733$$

$$Net\ Present\ Value\ Rigid\ Overlay = \$93{,}779 + \$13{,}000 \times \left(\frac{1}{1.04^{25}}\right) = 98{,}656$$

U.S. Department of Transportation Federal Highway Administration

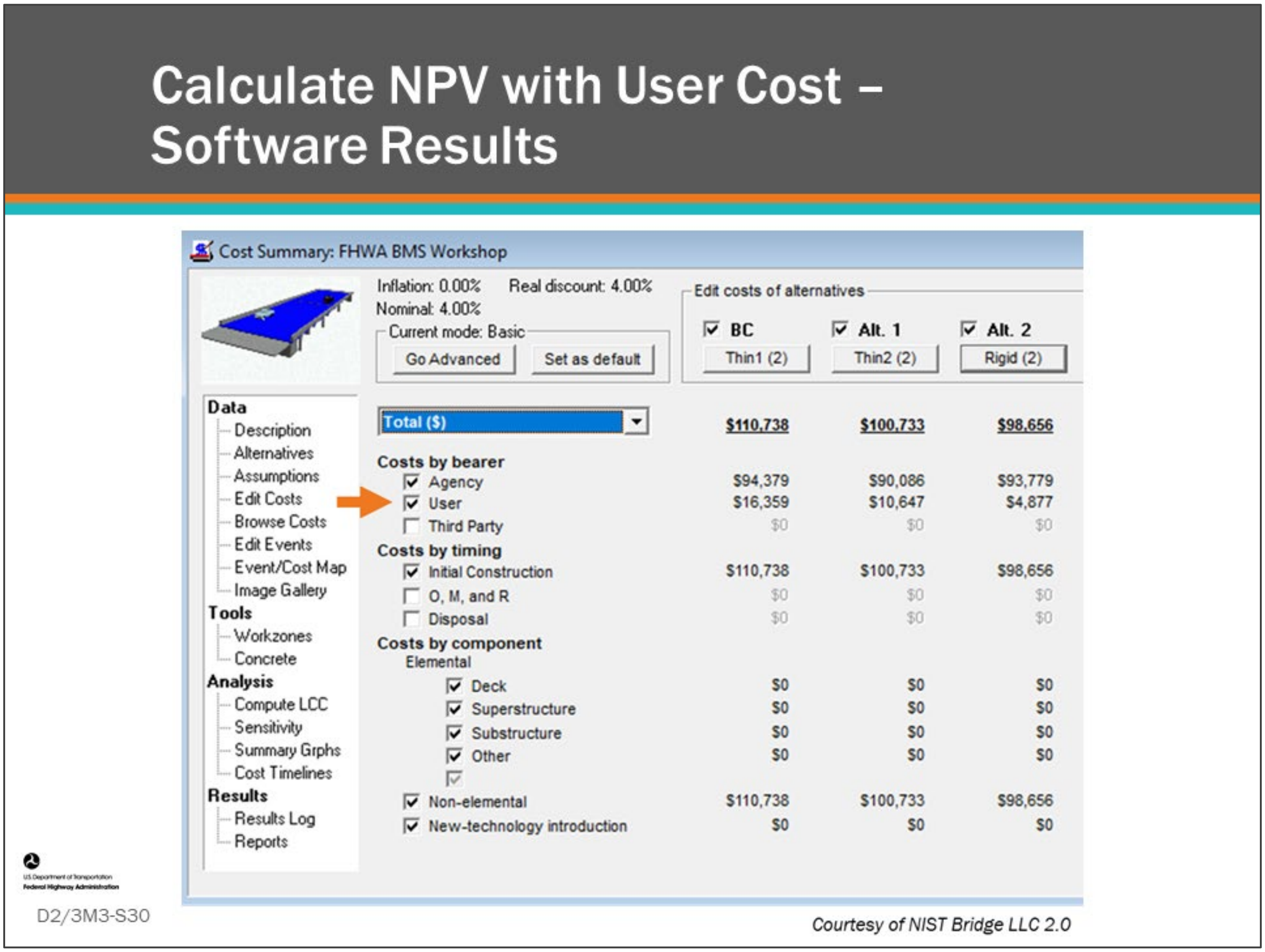
D2/3M3-S29

Key Message

What are the correct answers?

- Thin Overlay 1: ______________________________
- Thin Overlay 2: ______________________________
- Rigid Overlay: _______________________________

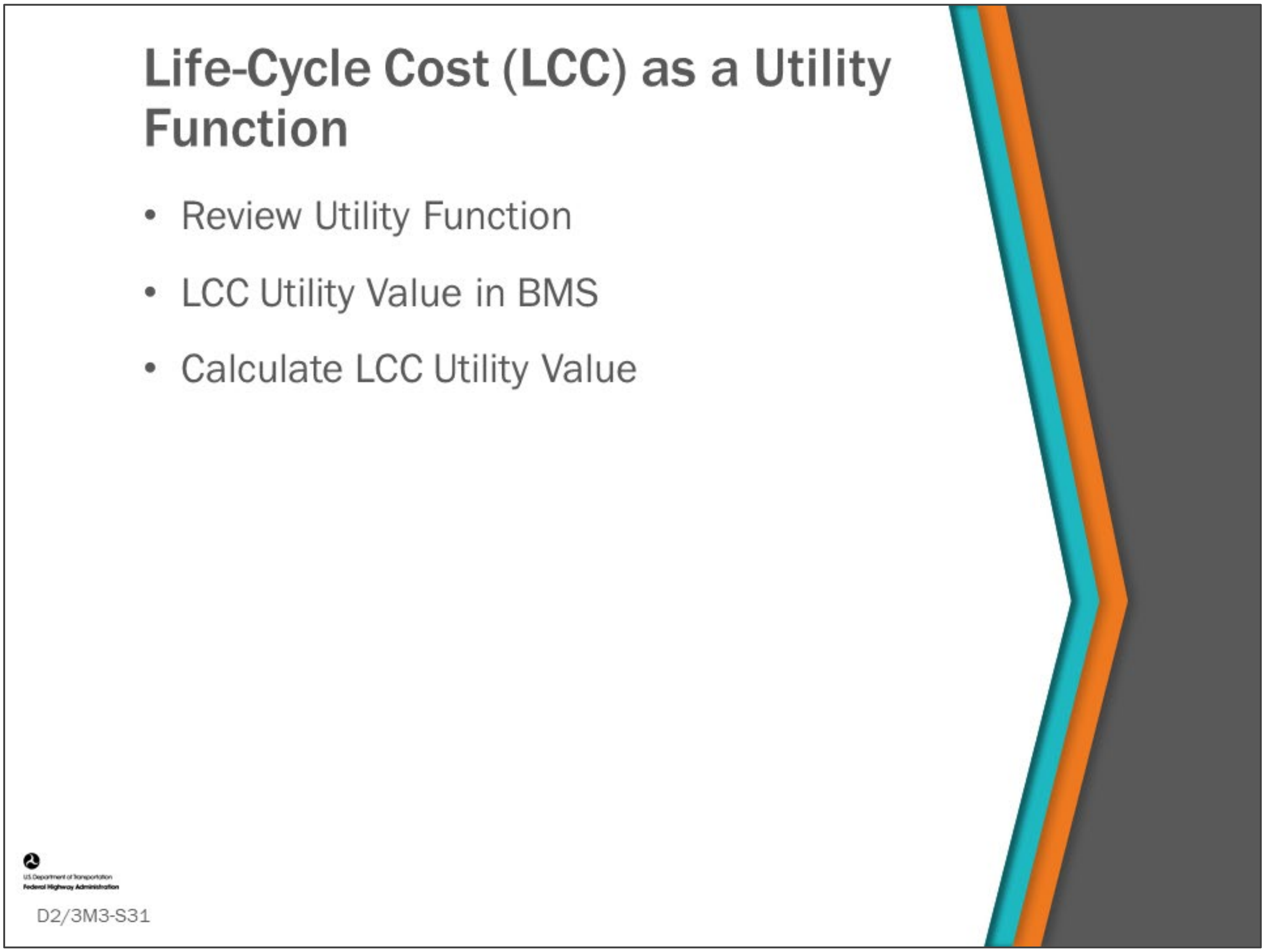
D2/3M3-Slide 30



Key Message

User cost is added to the BridgeLCC 2.0 software, as shown on this slide.

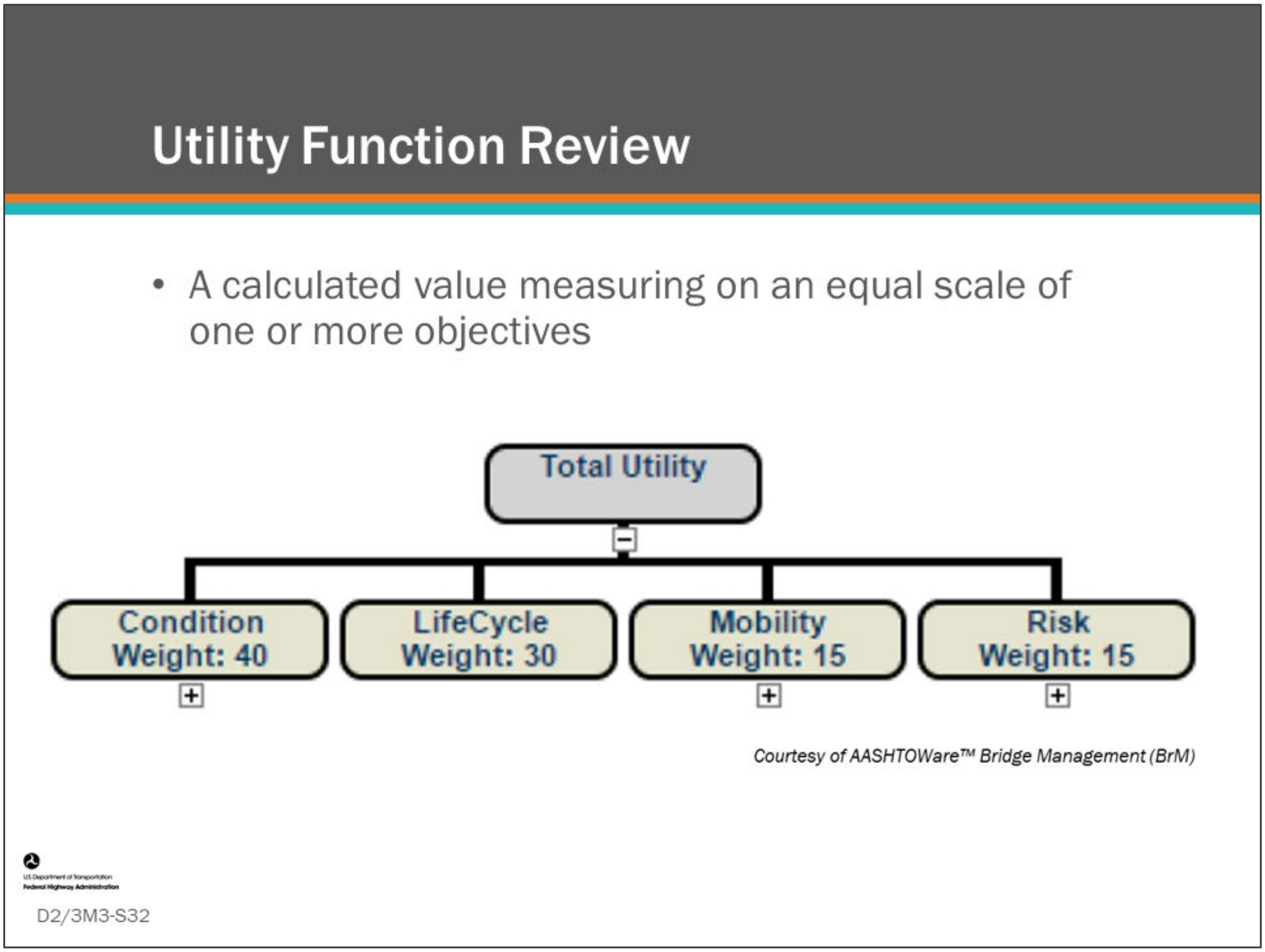
D2/3M3-Slide 31



Key Message

In this section, we will look at life-cycle cost as a utility function. In this way, life-cycle strategies for bridge actions on an individual bridge and life-cycle strategies on a group of bridges can be compared by evaluating LCC differences between alternative bridge actions and alternative network bridge projects.

D2/3M3-Slide 32



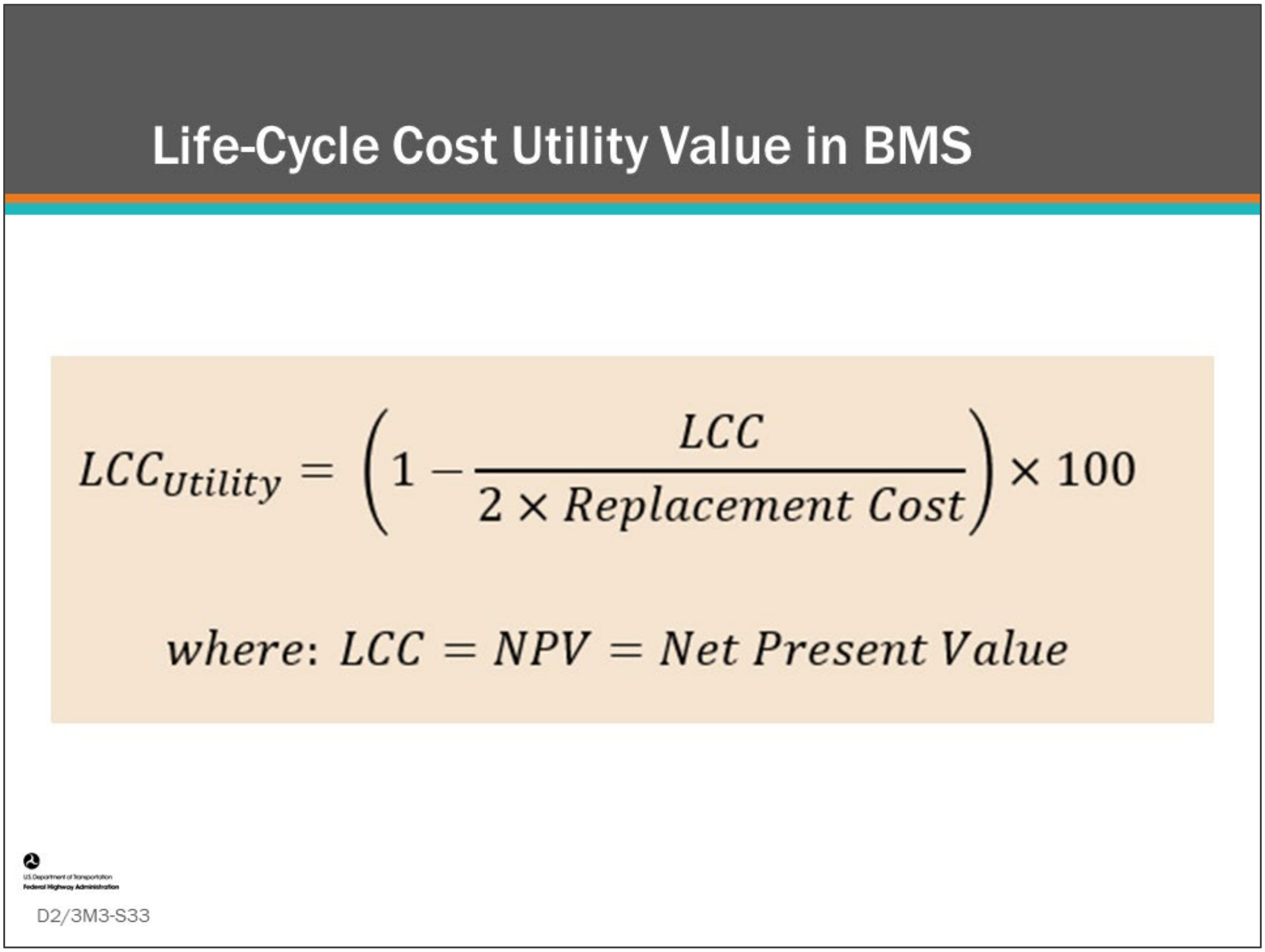
Key Message

This slide defines utility function.

- Some BMS software use utility functions to compare and weigh decisions between multiple objectives. Shown on this slide are four utilities (Condition, Life-Cycle, Mobility, and Risk) with their respective weight values of 40, 30, 15, and 15.
- The Life-Cycle utility is included to provide weight to life-cycle cost benefits of alternative present-day actions and long-term actions over an analysis period which can show the value of preservation actions.
- In AASHTOWare™ Bridge Management (BrM), using Condition Utility alone can yield project recommendations that maximize present-day condition but not select the best life-cycle cycle plan since, unlike in other BMS software, the utility component in AASHTOWare™ Bridge Management (BrM) considers only the immediate improvement in condition. Some may use AASHTOWare Bridge Management (BrM) to compare the long-term network condition benefits of different scenarios with the aim of finding the scenario that yields the best future condition. However, a scenario comparison using condition alone will not always be indicative of life-cycle cost benefits. This can have the unintended consequence of directing funds to bridge types that are lower cost and see the greatest condition improvement from spending. To offset this, the Life-Cycle Utility shows the value of present-day MR&R actions that yield long-term cost savings by delaying future actions.
  - For example, preservation actions typically do not yield significant present-day condition improvements as compared to more major actions such as rehabilitation and replacement. Life-Cycle Utility is applied to show overall benefit over an analysis period.

- Note, that other BMS software use the area under the curve method to calculate long-term condition benefit over an analysis period. Similar to Life-Cycle Cost analysis, this can show the value of preservation actions taken over the analysis period because they are a lower cost way of extending the life of a bridge/component/element over the long term.

D2/3M3-Slide 33



Key Message

As we have learned, present value is a measure of economic effectiveness of a life-cycle plan for a bridge. The lower the present value, the more efficient the plan. The Life-Cycle Cost (LCC) represented by Net Present Value can be converted into a utility value that can be compared to other strategies for a single bridge, for network-level project comparisons, and even for comparison with other agency objectives.

Shown on this slide is the AASHTOWare™ Bridge Management (BrM) formula for converting LCC into a utility value:

- $LCC_{Utility}$ is Life Cycle Cost Utility Value
- LCC is equal to NPV is equal to Net Present Value

D2/3M3-Slide 34

Calculate LCC Utility Value

Source: Adobe Stock

- Calculate the LCC Utility Value for:
  - Thin Overlay 1
    - NPV = $94,379
  - Thin Overlay 2
    - NPV = $90,086
  - Rigid Overlay
    - NPV = $93,779
- Bridge replacement cost = $1.3 million

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D2/3M3-S34

Key Message

Calculate LCC Utility value for the three deck preservation options without user cost considerations, as calculated in the previous activity.

- Details are shown on the slide.
- Notice, user cost is not included in the NPV for this example.

D2/3M3 - Slide 34: Calculating Life Cycle Utility Value Worksheet

$$LCC_{Utility} = \left(1 - \frac{LCC}{2 \times Replacement\ Cost}\right) \times 100$$

$$where: LCC = NPV = Net\ Present\ Value$$

1. Compute the LCC Utility Value for Thin Overlay 1 with NPV = $94,379 and Replacement Cost = $1,300,000 in the space below.

2. Compute the LCC Utility Value for Thin Overlay 2 with NPV = $90,086 and Replacement Cost = $1,300,000 in the space below.

3. Compute the LCC Utility Value for Thin Overlay 1 with NPV = $93,779 and Replacement Cost = $1,300,000 in the space below.

D2/3M3-Slide 35

Calculate LCC Utility Value – Results

Source: Adobe Stock

$$LCC_{Utility\ -Thin\ Overlay\ 1} = \left(1 - \frac{\$94{,}379}{2\times\$1{,}300{,}000}\right) \times 100 = 96.3700$$

$$LCC_{Utility\ -Thin\ Overlay\ 2} = \left(1 - \frac{\$90{,}086}{2\times\$1{,}300{,}000}\right) \times 100 = 96.5352$$

$$LCC_{Utility\ -Rigid\ Overlay} = \left(1 - \frac{\$93{,}779}{2\times\$1{,}300{,}000}\right) \times 100 = 96.3931$$

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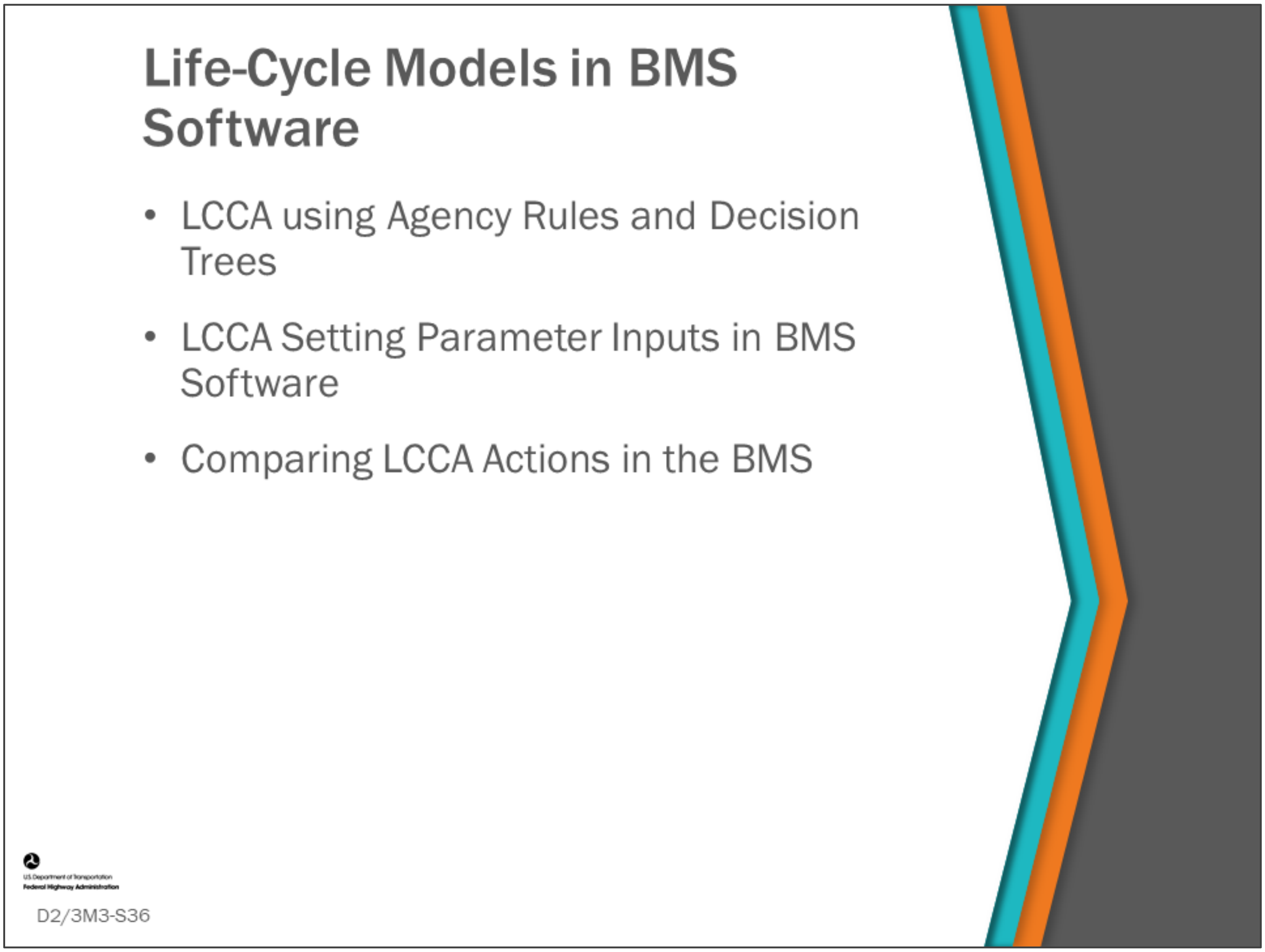
D2/3M3-S35

Key Message

Shown on the slide are answers to the LCC Utility value calculations.

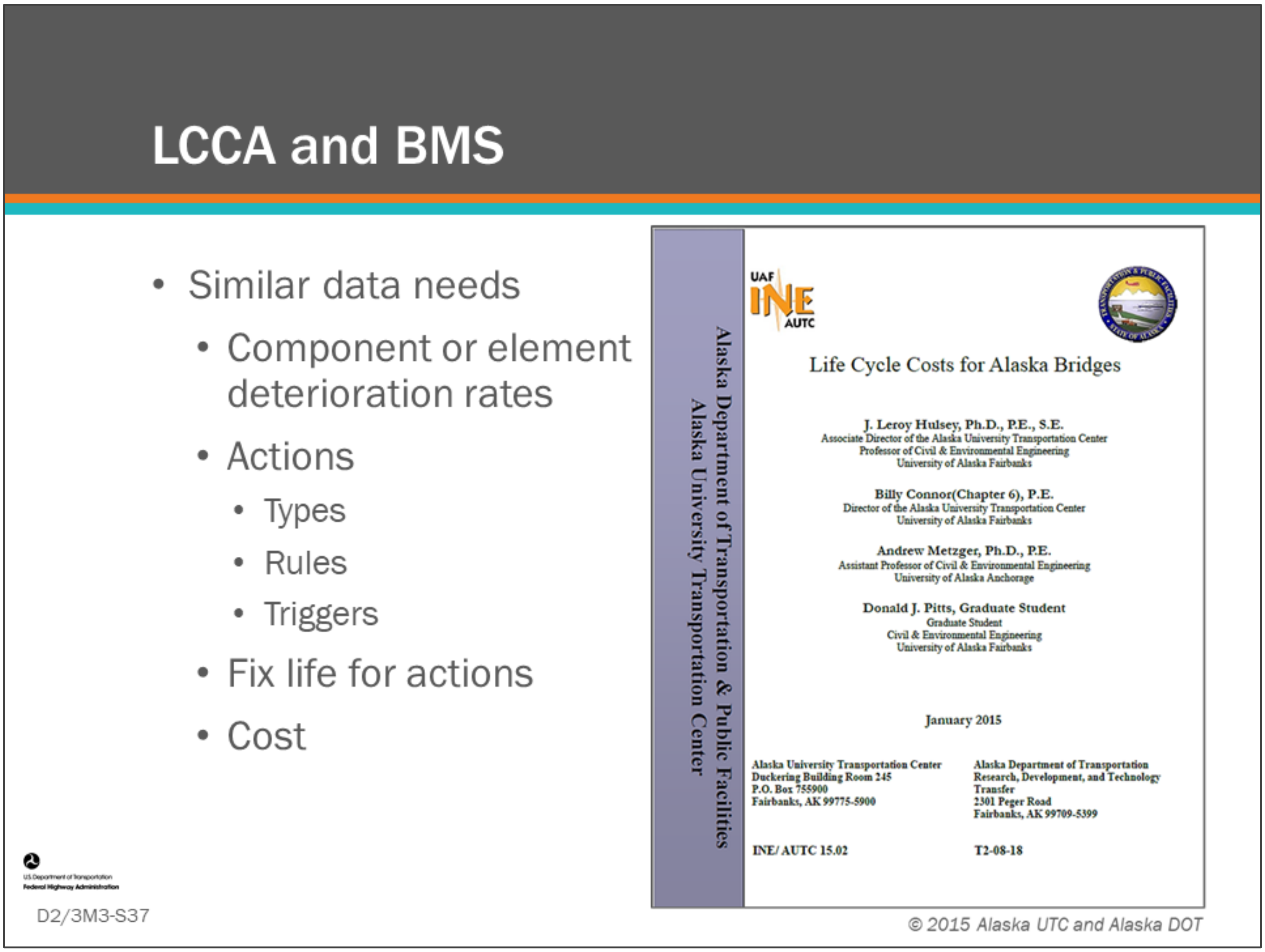
D2/3M3-Slide 36



Key Message

Life-cycle models play an important role in bridge management and in Bridge Management System (BMS) software. In this section, we will look at how life-cycle models are required in State agency policy and discuss how LCCA use agency rules and decision trees to form policies in BMS software, and we will and compare LCCA actions in BMS software.

D2/3M3-Slide 37

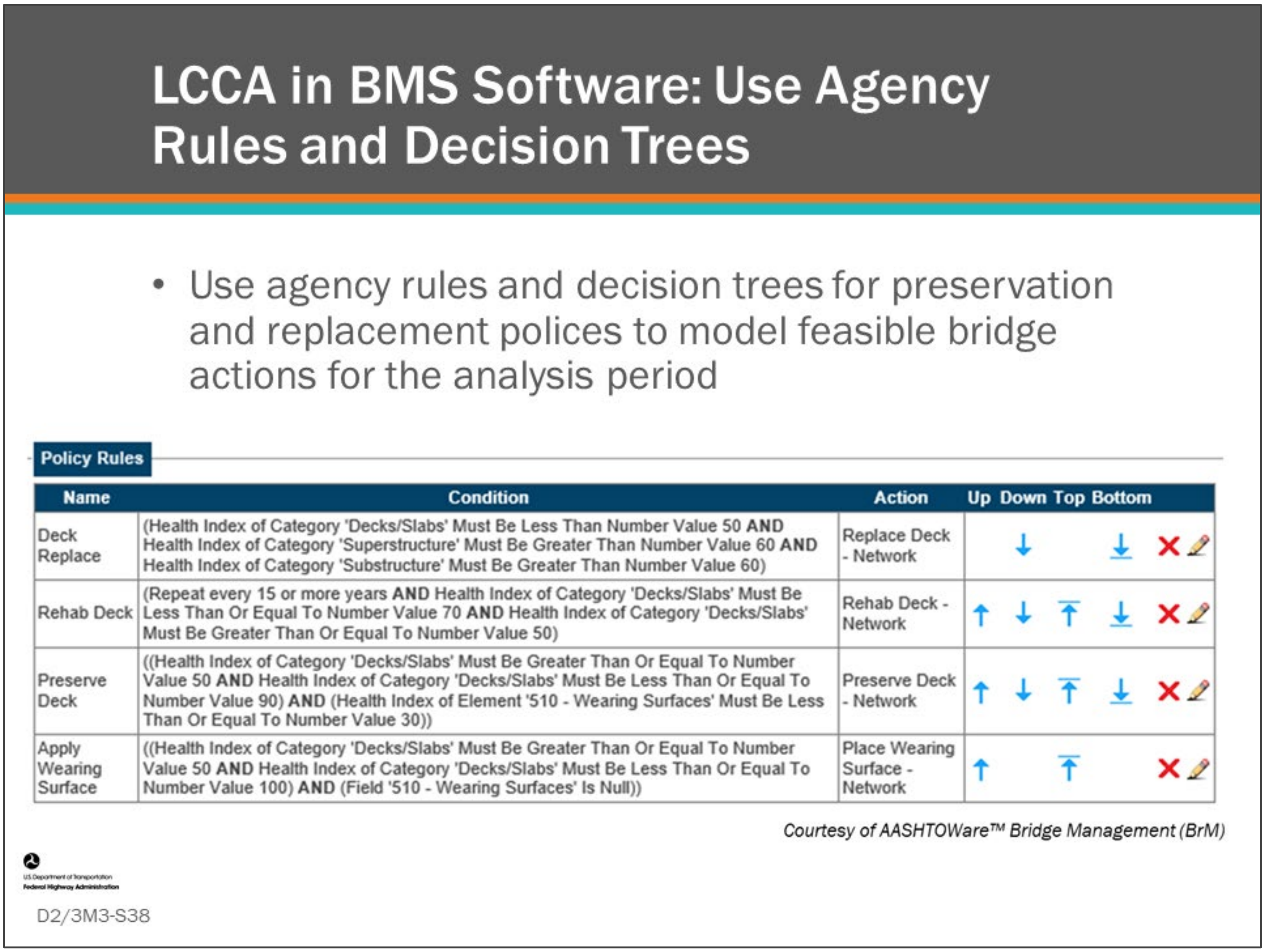


Key Message

LCCA requires much of the same data as a BMS including component or element deterioration rates, actions, fix life for those actions, and cost for actions. Some BMS can perform LCCA with limitations. LCCA studies performed outside of a BMS may also inform some data inputs to BMS that utilize life-cycle models in the form of rules and triggers.

Shown on this slide is a research project, *Life Cycle Costs for Alaska Bridges,* completed for the Alaska DOT.

D2/3M3-Slide 38



Name	Condition	Action	Up	Down	Top	Bottom
Deck Replace	(Health Index of Category 'Decks/Slabs' Must Be Less Than Number Value 50 **AND** Health Index of Category 'Superstructure' Must Be Greater Than Number Value 60 **AND** Health Index of Category 'Substructure' Must Be Greater Than Number Value 60)	Replace Deck - Network		↓		⤓
Rehab Deck	(Repeat every 15 or more years **AND** Health Index of Category 'Decks/Slabs' Must Be Less Than Or Equal To Number Value 70 **AND** Health Index of Category 'Decks/Slabs' Must Be Greater Than Or Equal To Number Value 50)	Rehab Deck - Network	↑	↓	⤒	⤓
Preserve Deck	((Health Index of Category 'Decks/Slabs' Must Be Greater Than Or Equal To Number Value 50 **AND** Health Index of Category 'Decks/Slabs' Must Be Less Than Or Equal To Number Value 90) **AND** (Health Index of Element '510 - Wearing Surfaces' Must Be Less Than Or Equal To Number Value 30))	Preserve Deck - Network	↑	↓	⤒	⤓
Apply Wearing Surface	((Health Index of Category 'Decks/Slabs' Must Be Greater Than Or Equal To Number Value 50 **AND** Health Index of Category 'Decks/Slabs' Must Be Less Than Or Equal To Number Value 100) **AND** (Field '510 - Wearing Surfaces' Is Null))	Place Wearing Surface - Network	↑		⤒	

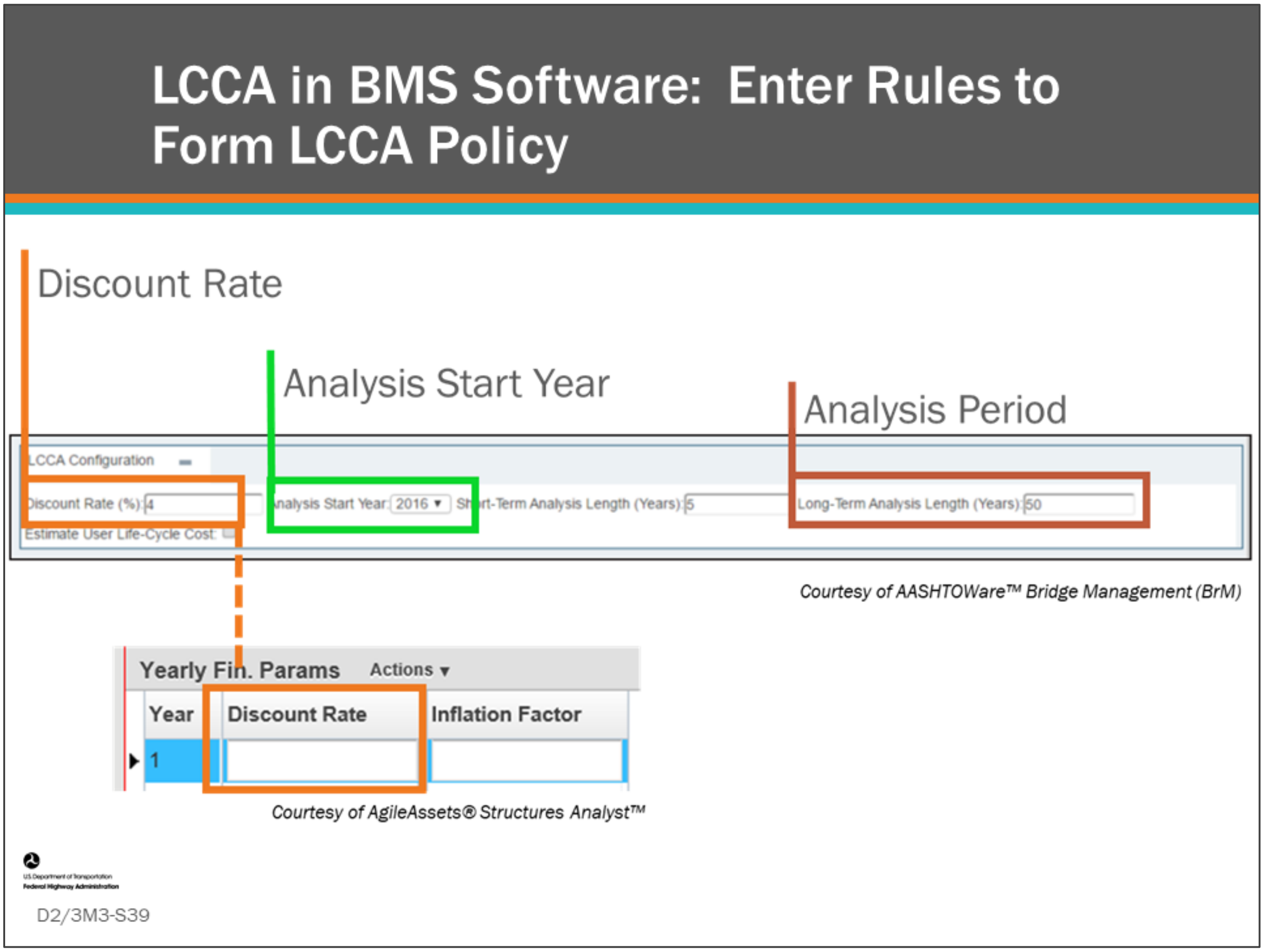
Key Message

BMS software have varying degrees of functionality for performing LCCA, but all of them, in general, are able to use agency rules and decision trees to form preservation and replacement policies that model bridge actions over an analysis period. Some BMS software provide the ability to compute the LCC differences of alternative present-day actions and resulting trailing actions that occur over the life-cycle of a bridge.

These policies are used by the LCCA to determine least life-cycle cost preservation, rehabilitation or replacement actions. Shown on the slide is an example deck life cycle policy.

- Replace deck when the Health Index for the "Deck/Slab" element is less than 50, the Health Index for category "Superstructure" must be greater than 60, and Health Index for category "substructure" must be greater than 60.
- Rehab deck every 15 or more years when and Health Index of category "Deck/Slabs" is less than or equal to 70 and Health Index of category "Deck/Slabs" is greater than or equal to 50.
- Preserve deck when Health Index of category "Deck/Slabs" is greater than or equal to 50, Health Index of category "Decks/Slabs" is less than or equal to 90, and Health Index of "Element 510 – Wearing surfaces" is less than or equal to 30.
- Apply Wearing Surface when Health Index of category "Deck/Slabs" is greater than or equal to 50, Health Index of category "Deck/Slabs" is less than or equal to 100, and element "510 – Wearing Surfaces" is null.

D2/3M3-Slide 39

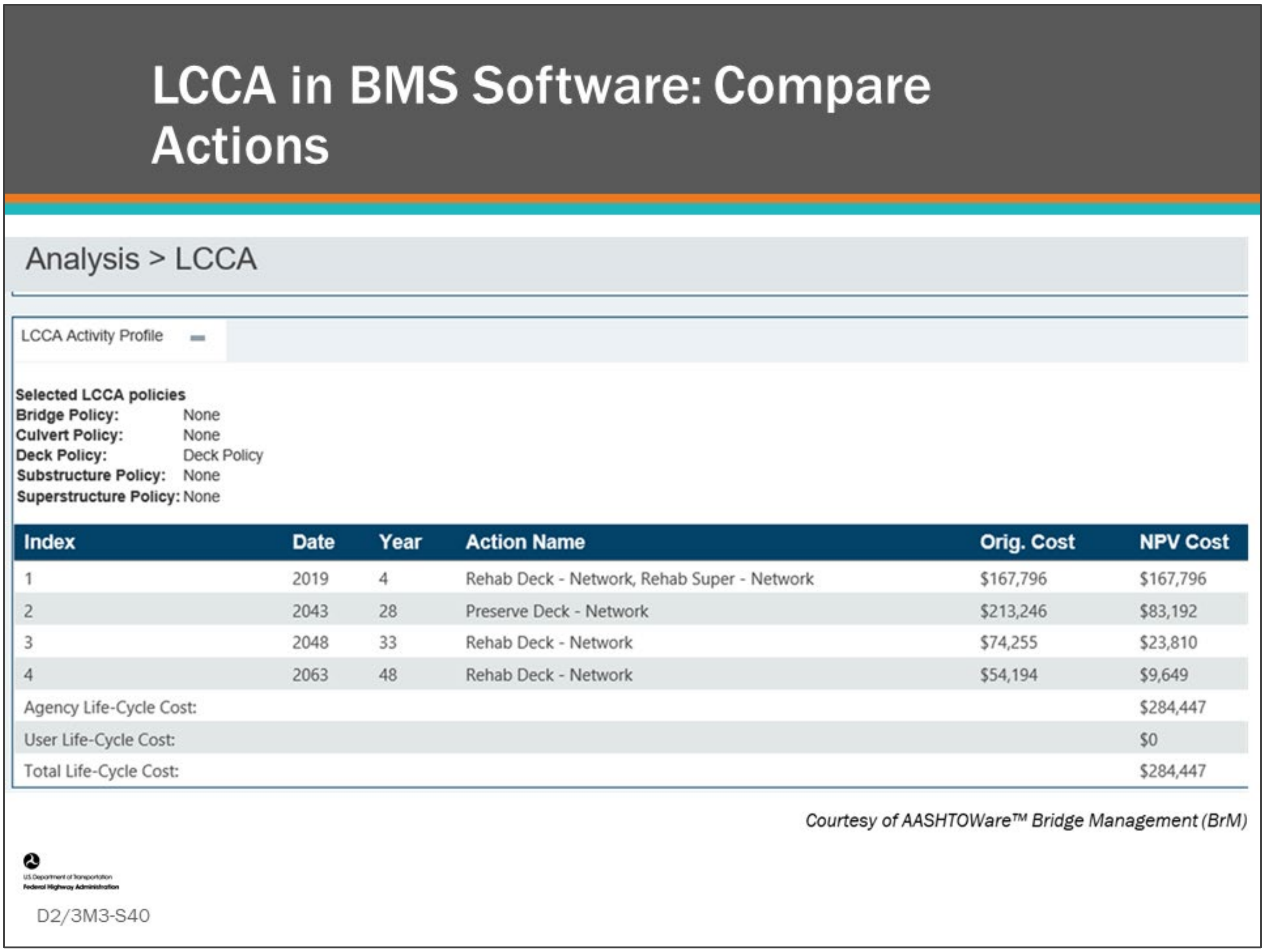


Key Message

The BMS software provide general LCCA input variables that are used in the analysis including the discount rate, analysis start year, and analysis period.

- All BMS software allow the system to be configured to use discount rate or inflation factor.

D2/3M3-Slide 40



LCCA in BMS Software: Compare Actions

Analysis > LCCA

LCCA Activity Profile

Selected LCCA policies
Bridge Policy: None
Culvert Policy: None
Deck Policy: Deck Policy
Substructure Policy: None
Superstructure Policy: None

Index	Date	Year	Action Name	Orig. Cost	NPV Cost
1	2019	4	Rehab Deck - Network, Rehab Super - Network	$167,796	$167,796
2	2043	28	Preserve Deck - Network	$213,246	$83,192
3	2048	33	Rehab Deck - Network	$74,255	$23,810
4	2063	48	Rehab Deck - Network	$54,194	$9,649
Agency Life-Cycle Cost:					$284,447
User Life-Cycle Cost:					$0
Total Life-Cycle Cost:					$284,447

Courtesy of AASHTOWare™ Bridge Management (BrM)

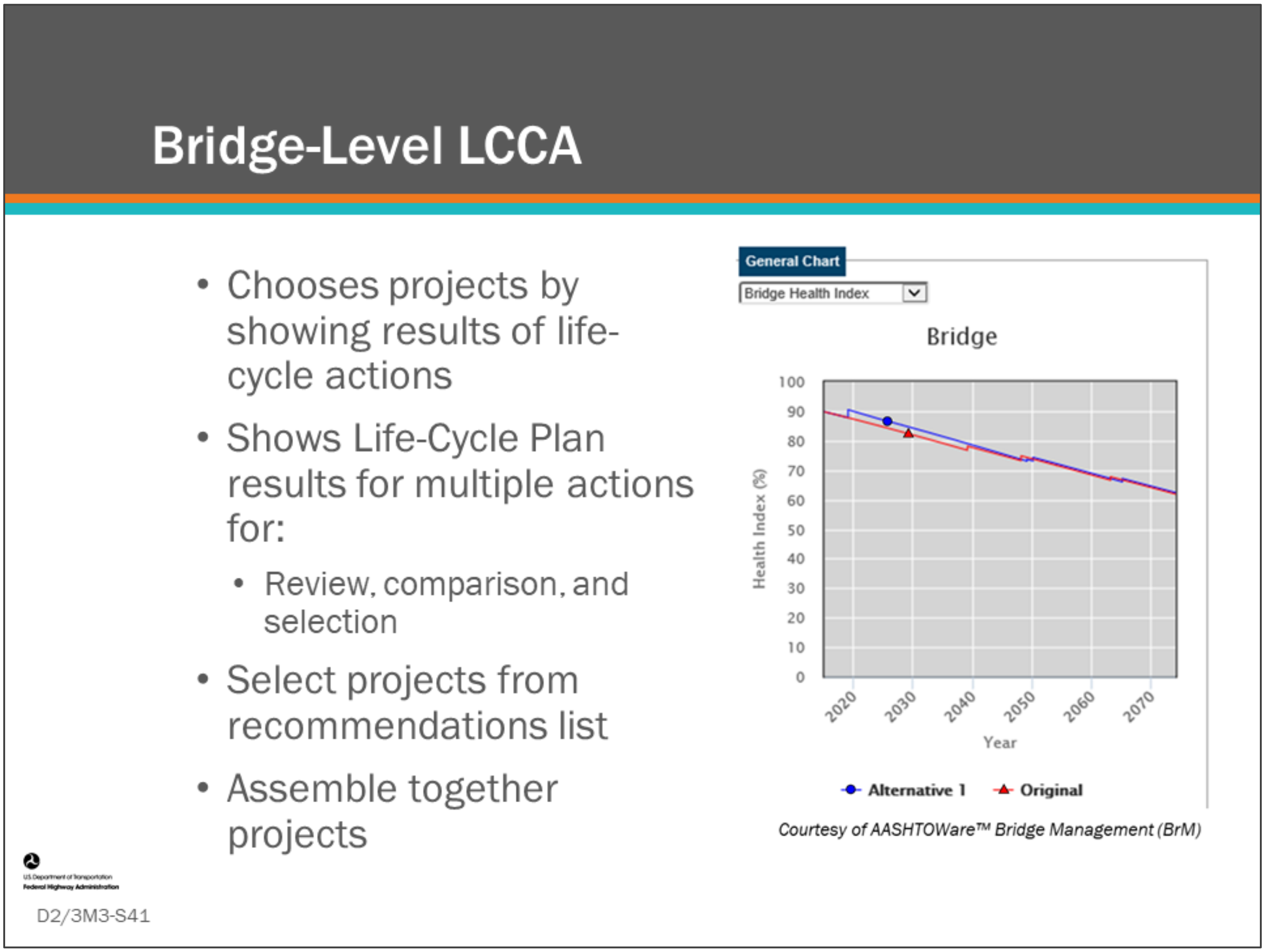
D2/3M3-S40

Key Message

All BMS software provide functionality to compare long term actions, or treatments, for an individual bridge. The specific details of how the LCCA analysis is performed is dependent upon the software.

- AASHTOWare™ Bridge Management (BrM) software completes LCCA for individual bridges comparing “short-term analysis” candidate selections combined with long-term actions selected by the preservation and replacement policy rules. The software provides detailed information for performance measures (health index, utility value, …) and element conditions for each year in the analysis. Note that in BrM, the purpose of the short-term analysis is to compare the life-cycle cost of alternative action(s) that could be performed during the programming period. The Long-Term analysis is a separate computation in BrM and is conducted only to calculate the LCC differences of the short-term actions. It is only used to calculate LCC utility for each year in the analysis period, i.e. it is not used to calculate condition, mobility, risk utility.
    - The screenshot on the slide shows the Analysis>LCCA page showing a LCCA Activity Profile for a bridge
- In the AgileAssets® Structures Analyst™ software, an LCCA for a specific bridge strategy can be conducted by starting with a strategy generated by an optimization scenario analysis, and adding or editing actions and action timing. This software allows you to create and compare multiple strategies.
- Deighton dTIMS© software generates different strategies for each bridge by evaluating all the analysis parameters such as actions, deterioration curves, decision trees, etc. This results in multiple strategies for each bridge which are compared during network optimization on the basis of cost benefit ratios.

D2/3M3-Slide 41



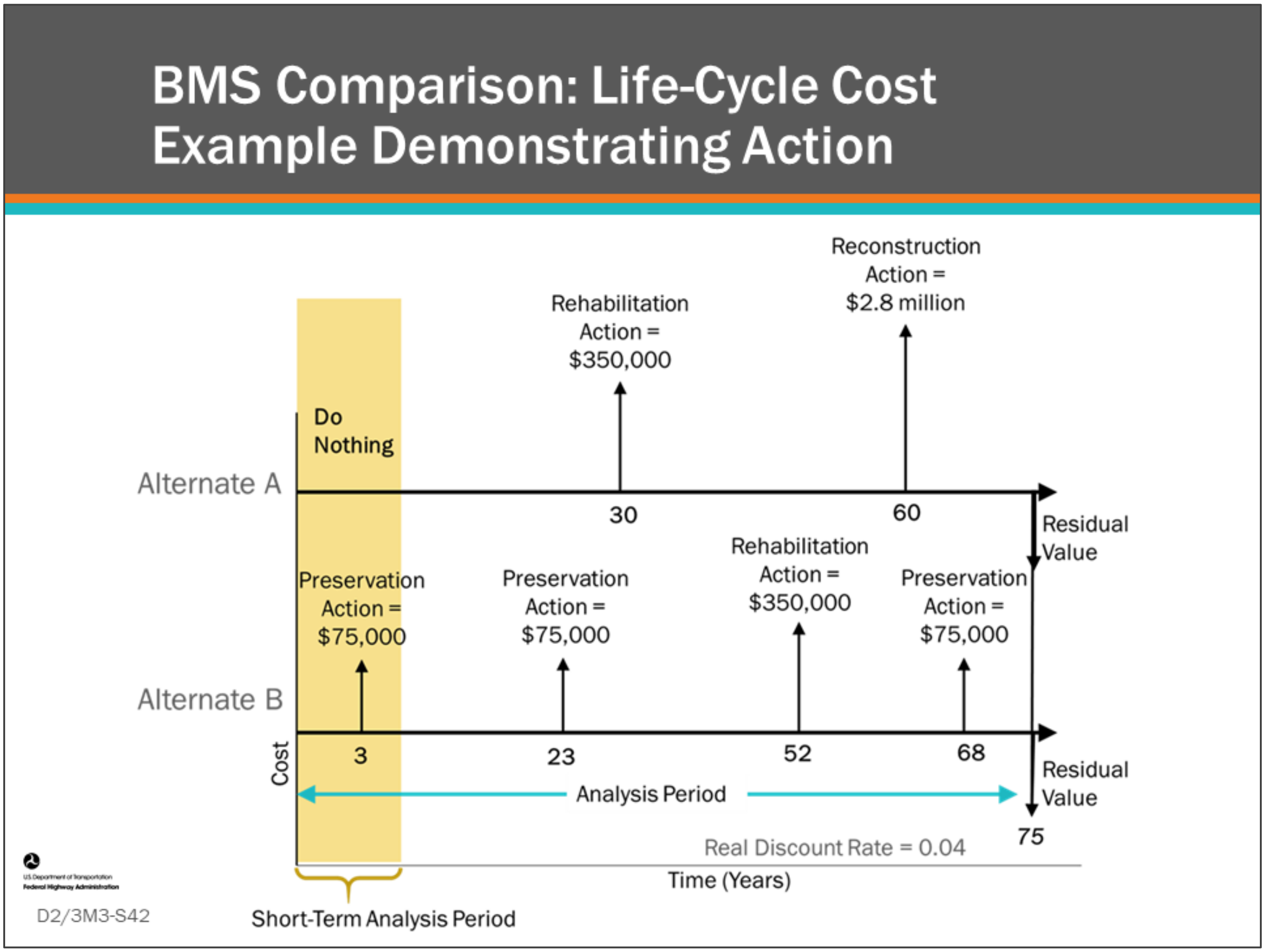
Key Message

Project-level LCCA is a function offered in AASHTOWare™ Bridge Management (BrM) that is separate from optimization modeling.

- It can be used for manual selection of short-term work items.

AgileAssets® Structures Analyst™ and Deighton dTIMS© are specifically optimization modeling tools. However, the life cycle costs can be included as a calculated field for a bridge strategy if desired.

D2/3M3-Slide 42



Key Message

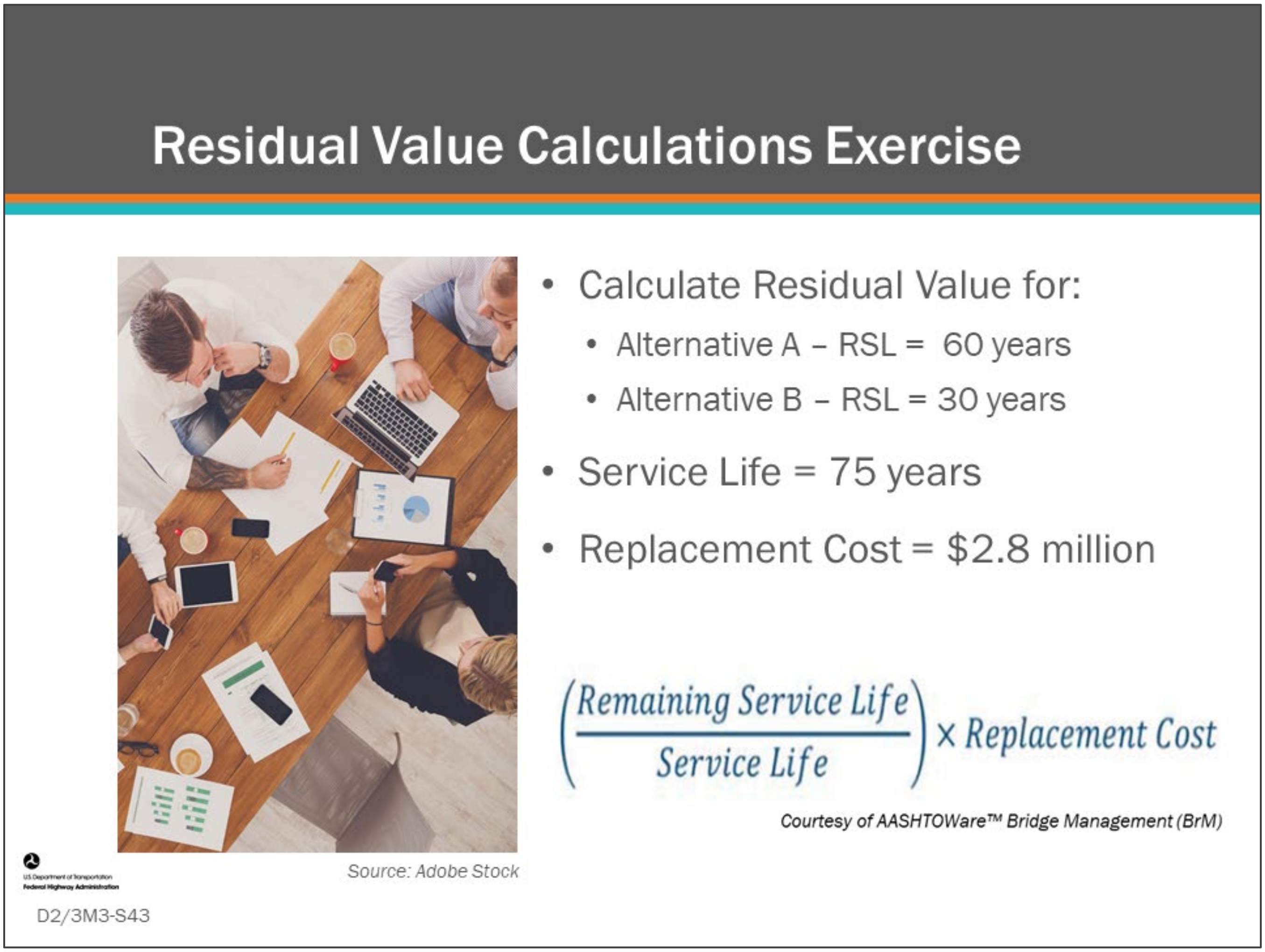
When some BMS include LCCA in the analysis, it is often comparing one or more actions in the short-term analysis period to no action (i.e., Do Nothing) during that time for the purpose of determining if an action should be performed in the current programming period.

The two life-cycle plans shown on the slide illustrate two options:

- The top life-cycle plan (Alternate A) shows no action taken in the short-term analysis period.
- The bottom life-cycle plan (Alternate B) shows a preservation action taken in the short-term analysis period.

In both life-cycle plans, the BMS's long-term preservation and reconstruction policies then model future actions beyond the short-term analysis period. At the end of the analysis period, residual value is applied to the life-cycle plans.

D2/3M3-Slide 43



Key Message

- For the analysis, first we will complete the residual value calculation for the two alternatives from the previous slide:
    - Alternative A: Alternative A will have a Remaining Service Life (RSL) of 60 years.
    - Alternative B: Alternative B will have a Remaining Service Life (RSL) of 30 years.

D2/3M3 - Slide 43: Calculating Residual Value Worksheet

$$\left(\frac{Remaining\ Service\ Life}{Service\ Life}\right) \times Replacement\ Cost$$

1. Compute the Residual Value for Alternate A with Remaining Service Life of 60 years, Service Life of 75 years, and Replacement cost of $2,800,000 in the space below.

2. Compute the Residual Value for Alternate B with Remaining Service Life of 30 years, Service Life of 75 years, and Replacement cost of $2,800,000 in the space below.

D2/3M3-Slide 44

Residual Value Calculations Results

Source: Adobe Stock

Alternative A Residual

$$= \frac{60\ Years}{75\ Years} \times \$2{,}800{,}000$$

$$= \$2{,}240{,}000$$

Alternative B Residual

$$= \frac{30\ Years}{75\ Years} \times \$2{,}800{,}00$$

$$= \$1{,}120{,}000$$

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D2/3M3-S44

Key Message

What are the correct answers?

- Alternative A:______________________________
- Alternative B: ______________________________

D2/3M3-Slide 45

Example NPV Results

Discount Rate	0.04

Alternate A			
Year	Activity	Expenditure	Present Value (PV)
30	Rehab Action	$350,000	$107,912
60	Reconstruct Action	$2,800,000	$266,169
75	Residual Value	-$2,240,000	-$118,235
		Net Present Value	$255,846

Alternate B			
Year	Activity	Expenditure	Present Value (PV)
3	Preservation Action	$75,000	$66,675
23	Preservation Action	$75,000	$30,429
52	Rehab Action	$350,000	$45,534
68	Preservation Action	$75,000	$5,209
75	Residual Value	-$1,120,000	-$59,118
		Net Present Value	$88,729

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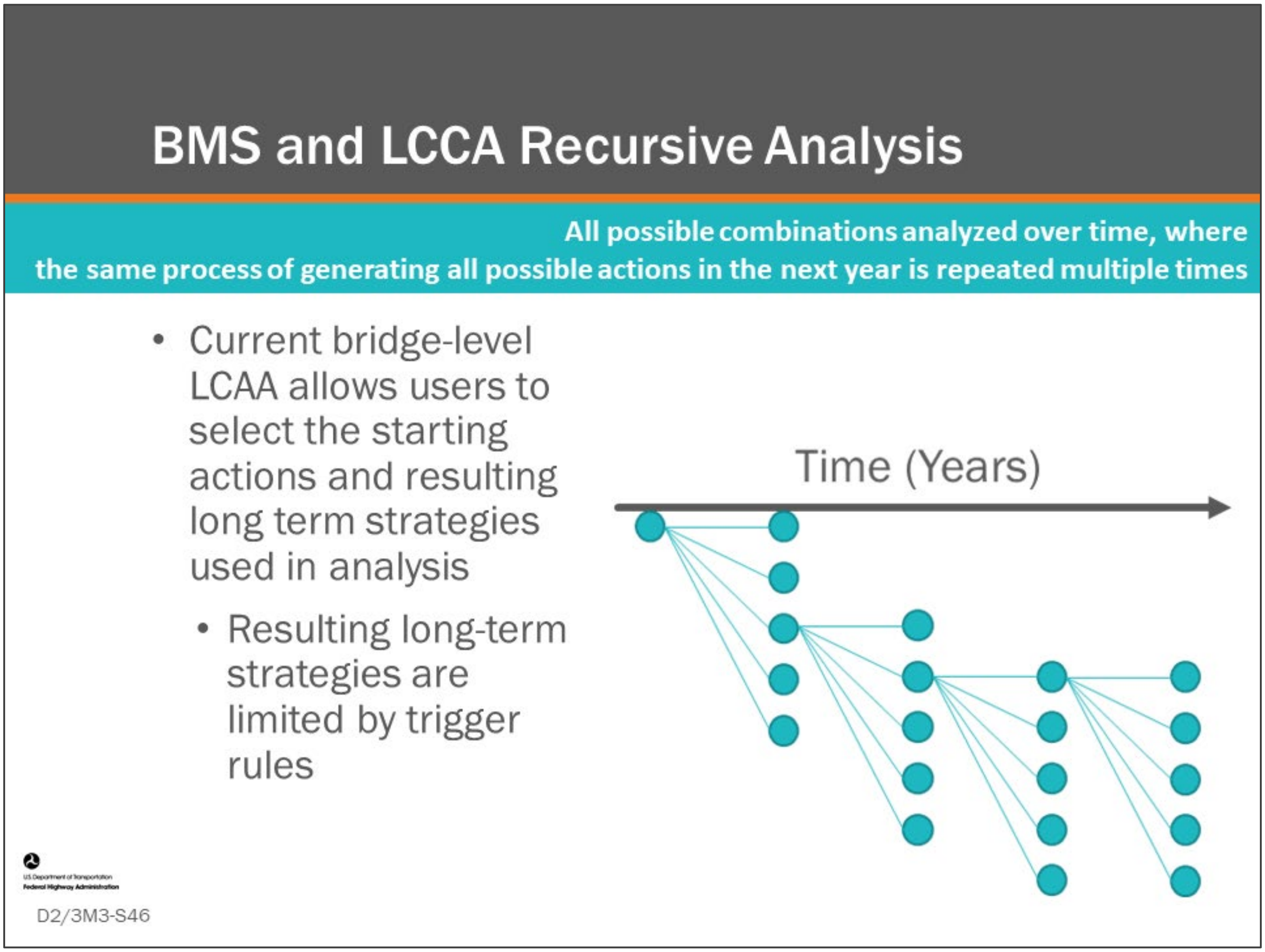
D2/3M3-S45

Key Message

Using the Residual Value calculated in the last slide, the NPV results for Alternate A and Alternate B are shown on this slide.

- Note, Residual Value expenditure is shown as a negative value in the spreadsheet, meaning it is actually a benefit at the end of the analysis period.
- This slide also shows the value of using spreadsheets for calculating LCCA calculations.

D2/3M3-Slide 46

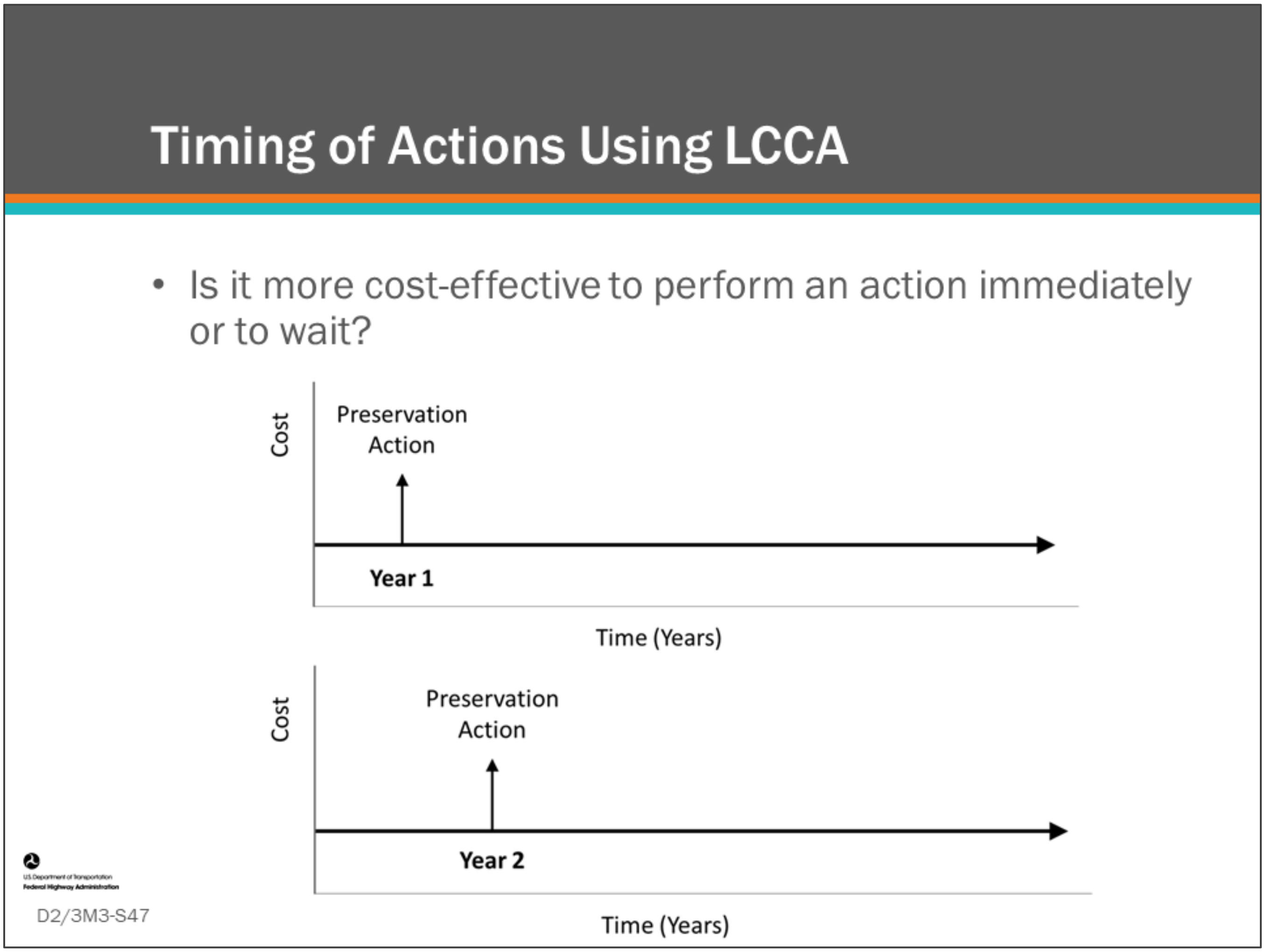


Key Message

As noted previously in Module 11 in Day 1, there are theoretically many possible strategies for each bridge.

- Currently, in both bridge-level LCCA and in network-level optimization, the number of strategies that need to be analyzed is kept to a minimum by reducing the number of possible actions and by imposing rules to define when particular actions would be triggered.
- Ideally, all possible combinations would be analyzed over time in a “recursive” analysis where the same process of generating all possible actions in the next year is repeated over and over. This would result in identification of all possible combination of actions, for which the LCC of each combination can be computed.
- Unfortunately, as noted previously, the size of the problem grows very quickly to be unrealistic for full computation of all options.

D2/3M3-Slide 47



Key Message

Another way to use LCCA is to compare the present value an action taken at different times.

- On this slide, the graphic shows the difference between completing an action in Year 1 versus in Year 2.
- If a positive discount rate is used, the Present Value will be less when the action is done in Year 2.
- This will continue until the component or element in question deteriorates to the point where a more expensive preservation action or rehab action is needed.

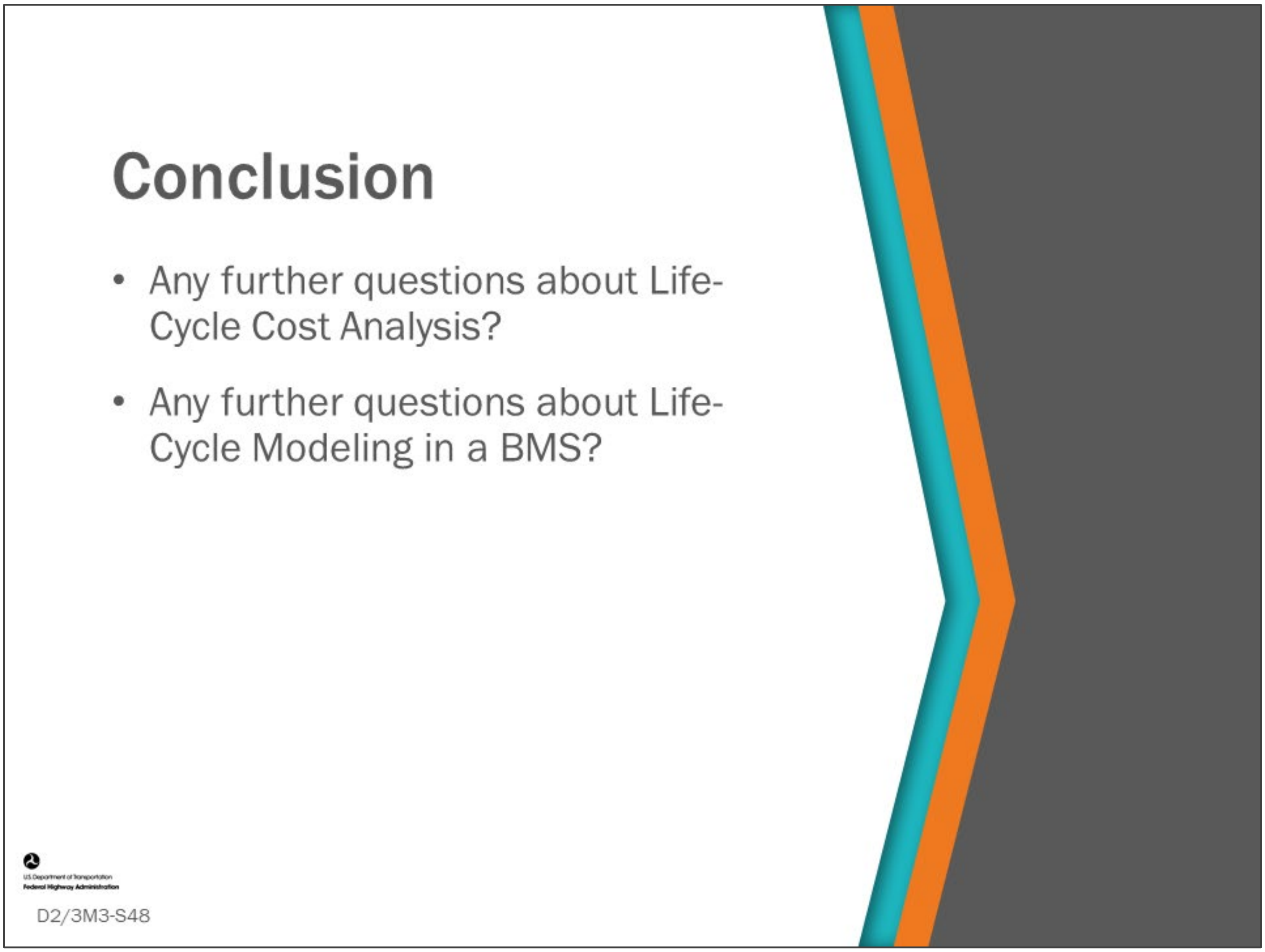
If the BMS has the ability to perform LCAA, it can use deterioration modeling to predict the year in which superstructure replacement will be needed.

The BMS can also use LCCA to determine if it is more cost-effective to:

- Replace the deck now;
- Replace the deck and superstructure now; or,
- Maintain the deck at minimum acceptable level until the superstructure needs replaced.

This type of wholistic analysis is warranted when making a major decision such as a deck, super, or sub rehab or replacement where the return on investment will be dependent on other major components or elements.

D2/3M3-Slide 48



Key Message

This concludes Day 2, Module 3: Life-Cycle Cost Analysis and Life-Cycle Modeling in a BMS.

D2/3M3-Slide 49

Slide #	Image Description	Source Information
2	Chart of bridge management workflow steps.	This Workshop.
6	Schematic charts showing Performance Measure and Expense versus time in years describe the effect of actions.	This Workshop.
7	Equation showing Present Value equals Future Value times 1 over (1 plus r) to the n power. r is real discount rate. n is number of years in the future when the cost will be incurred.	FHWA. *Life-Cycle Cost Analysis Primer*, Page 17. Office of Asset Management USDOT. Washington, DC, 2002.
7	Life-cycle activity profile. A life-cycle activity profile shows from left to right; initial construction with Action 1 and Action 2 present value all at the same location (the present)	This Workshop.
8	A life-cycle activity profile shows from left to right, a tall arrow pointing up representing initial construction, a medium tall arrow pointing up representing action, and a medium tall arrow pointing up representing action. A leader line at the bottom of the chart shows the analysis period.	This Workshop.
8	A life-cycle activity profile with Residual Value circled in red	This Workshop.
9	A life-cycle activity profile shows from left to right; cyclic maintenance (four times) as short arrows pointing up, a medium tall arrow pointing up representing condition-based	This Workshop.
12	Screenshot of Minnesota DOT Expected Repair Service Life for bridge elements.	Minnesota DOT. *Fiscal Year 2016 through 2020 Bridge Preservation and Improvement Guidelines*. Page 14. Bridge Office.
13	The top chart is a line chart having Performance Measure on the y-axis and time in years on the x-axis. The bottom chart shows a life-cycle activity profile which is a horizontal line representing time with vertical arrows representing expenditures.	This Workshop.

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D2/3M3-S49

D2/3M3 Figure Source List

D2/3M3-Slide 50

Slide #	Image Description	Source Information
14	Screenshot from AgileAssets® Structures Analyst™ software showing input text boxes for discount rate and inflation rate.	AgileAssets® Structures Analyst™.
15	A line chart shows Present Value on the y-axis and Years on the x-axis. Discount rate lines are shown for 2, 4, 6, 8, 10, and 12 percent.	National Academies of Sciences, Engineering, and Medicine. *Design Guide For Bridges For Service Life*. Page 507. S2-R19A-RW-2.
17	A life-cycle activity profile shows three thin overlays in years 12, 24, and 36. Each overlay cost is $75,000.	This Workshop.
18	A life-cycle activity profile shows two thin overlays in years 16, and 32. Each overlay cost is $110,000.	This Workshop.
19	A life-cycle activity profile shows Rigid overlay.	This Workshop.
21	Screenshot of FHWA Pavements LCCA webpage.	FHWA. *Life-Cycle Cost Analysis Primer,* Office of Asset Management USDOT. Washington, DC, 2002.
22	Screenshot of the BridgeLCC 2.0 Cost Summary page for the example problem.	National Institute of Standards and Technology (NIST). Bridge LLC 2.0. Software program. US Department of Commerce.
23	Example spreadsheet calculations are shown.	This Workshop.

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D2/3M3-S50

D2/3M3 Figure Source List

D2/3M3-Slide 51

Slide #	Image Description	Source Information
24	Screenshot of the BridgeLCC 2.0 User Cost calculations for work zones.	National Institute of Standards and Technology (NIST). Bridge LLC 2.0. Software program. US Department of Commerce.
26	A life-cycle activity profile shows three thin overlays in years 12, 24, and 36. Each overlay cost is $75,000. The chart also shows user cost for each at $13,000.	This Workshop.
27	A life-cycle activity profile shows three thin overlays in years 12, 24, and 36. Each overlay cost is $75,000. The chart also shows user cost for each at $13,000.	This Workshop.
28	A life-cycle activity profile shows two thin overlays in years 16, and 32. Each overlay cost is $110,000. The chart also shows user cost for each at $13,000.	This Workshop.
30	Screenshot of the BridgeLCC 2.0 User Cost calculations including user costs for each alternative.	FHWA.
32	A utility function tree is shown with total Utility at the top with branches to: condition weight, life-cycle, mobility, and risk. Life cycle is circled to highlight it.	AASHTOWare™ Bridge Management (BrM) software.
33	An equation is shown: LCC sub Utility = (1 - (LCC/(2 x Replacement Cost))) x 100, where: LCC = NPV = Net Present Value.	AASHTOWare™ Bridge Management (BrM) software.

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D2/3M3-S51

D2/3M3 Figure Source List

D2/3M3-Slide 52

Slide #	Image Description	Source Information
37	Title page for research project titled, Life Cycle Costs for Alaska Bridges.	Hulsey, J., et al., *Life Cycle Costs for Alaska Bridges*. Alaska University Transportation Center. Alaska DOT. Fairbanks, AK, 2014.
38	Screenshot of AASHTOWare™ Bridge Management (BrM) software showing example Policy Rules.	AASHTOWare™ Bridge Management (BrM).
39	The top screen shot shows the AASHTOWare BrM software LCCA configuration screen showing input boxes for Discount Rate, Analysis Start Year, Short Term Analysis Length (Years), and Long Term Analysis Length (Years).	AASHTOWare™ Bridge Management (BrM).
39	The bottom screen shot shows the AgileAssets Structure Analyst screen for Yearly Financial Parameters showing Discount Rate.	AgileAssets® Structures Analyst™.
40	Screenshot of AASHTOWare BrM Analysis>LCCA page showing LCCA Activity Profile.	AASHTOWare™ Bridge Management (BrM).
41	Screenshot of AASHTOWare™ Bridge Management (BrM) showing example Health Index over time.	AASHTOWare™ Bridge Management (BrM).
42	The top profile (Alternate A) shows no action taken in the short-term analysis period.	This Workshop.
42	The bottom profile (Alternate B) shows a preservation action taken during the short-term analysis period.	This Workshop.

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D2/3M3-S52

D2/3M3 Figure Source List

D2/3M3-Slide 53

Slide #	Image Description	Source Information
45	Spreadsheet example showing Net Present Value calculations for Alternative A = $255,846 and Alternative B = $88,729.	This Workshop.
46	Figure showing a branching set of actions with an arrow at the top showing Time in years increasing to the right. The figure depicts how quickly the number of possible strategies grows over time.	This Workshop.
47	Schematic plots of cost versus time indicating preservation action at Year 1 (top) and Year 2 (bottom).	This Workshop.

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D2/3M3-S53

D2/3M3 Figure Source List

Module Title: D2/3M4 – Benefit-Cost Analysis and Optimization

Module Time: 120 minutes

Module Summary

Benefit-cost analysis and optimization are described in Day One Modules 10 and 11. This module will delve into greater detail as to how these analysis methods are performed within the BMS.

Expected Outcome(s)

The expected outcome of this module will be an understanding how performance measure indices are used in a BMS and how to perform optimization using Benefit-Cost Analysis (BCA) including the Benefit-Cost Ratio (BCR), Incremental Benefit-Cost Ratio (IBCR), and integer programming.

Resource List

Slide	Reference Information
13,58	NCHRP. *Report 590 Multi-Objective Optimization for Bridge Management Systems.* Washington, DC, 2007.
58	Williams, H.P. *Logic and integer programming. International Series in Operations Research & Management Science*, Springer, New York, 2009.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D2/3M4-Slide 1

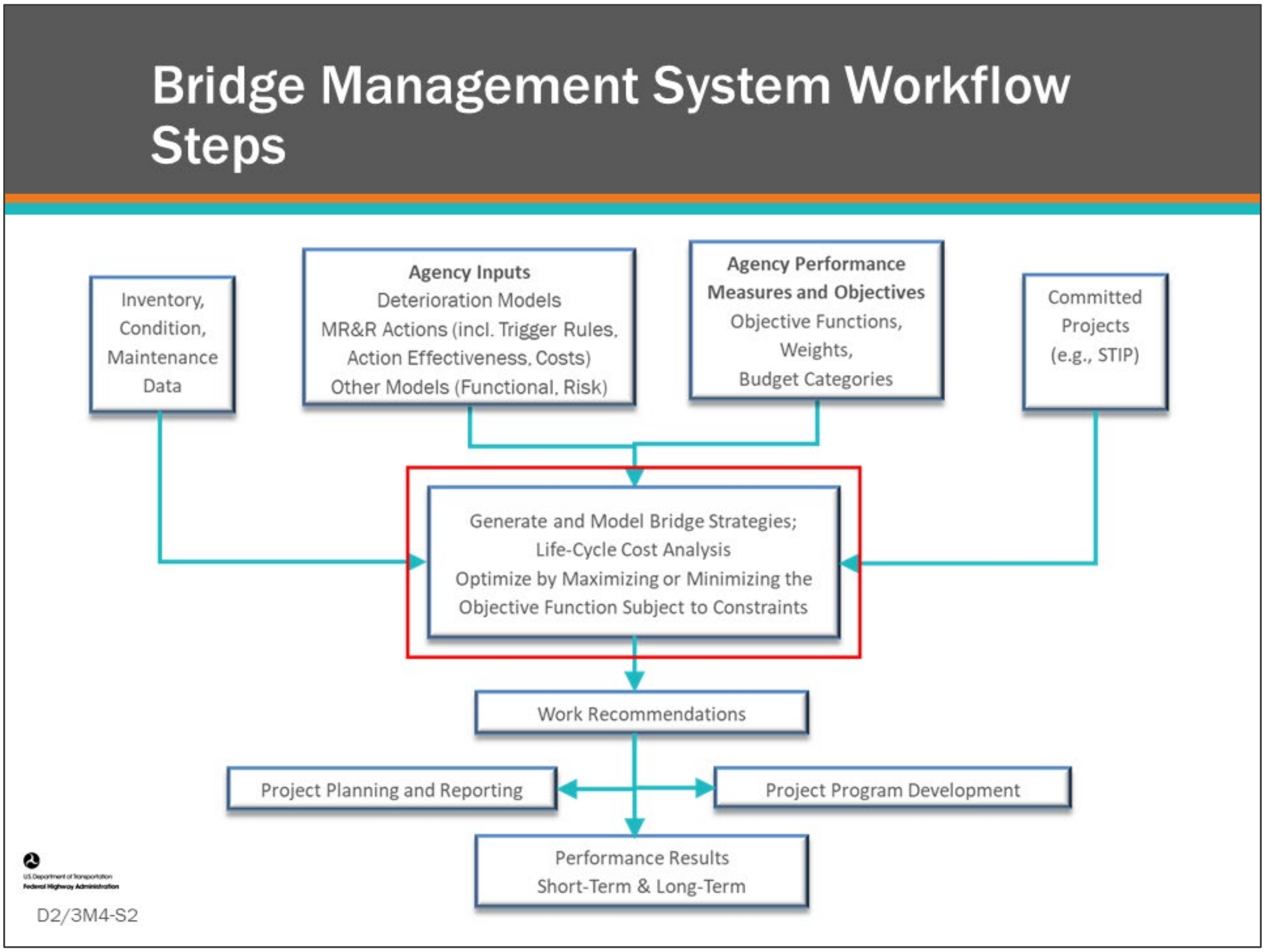
Key Message

Benefit-Cost Analysis (BCA) and Incremental Benefit-Cost (IBC) are two common procedures that BMS use to compare and evaluate multiple options for actions or strategies for individual bridges, and more importantly to compare actions and strategies between a population of bridges. In addition, optimization may also be accomplished by using commercial solver software. This is the highest level of functionality for an advanced BMS.

Disclaimer

FHWA does not promote or endorse patented and proprietary products. Bridge management software is largely proprietary. Workshop content pertaining to proprietary software is included only to illustrate how bridge management system concepts and analyses are applied in practice. The included content shall not be construed as promotion or endorsement of specific software.

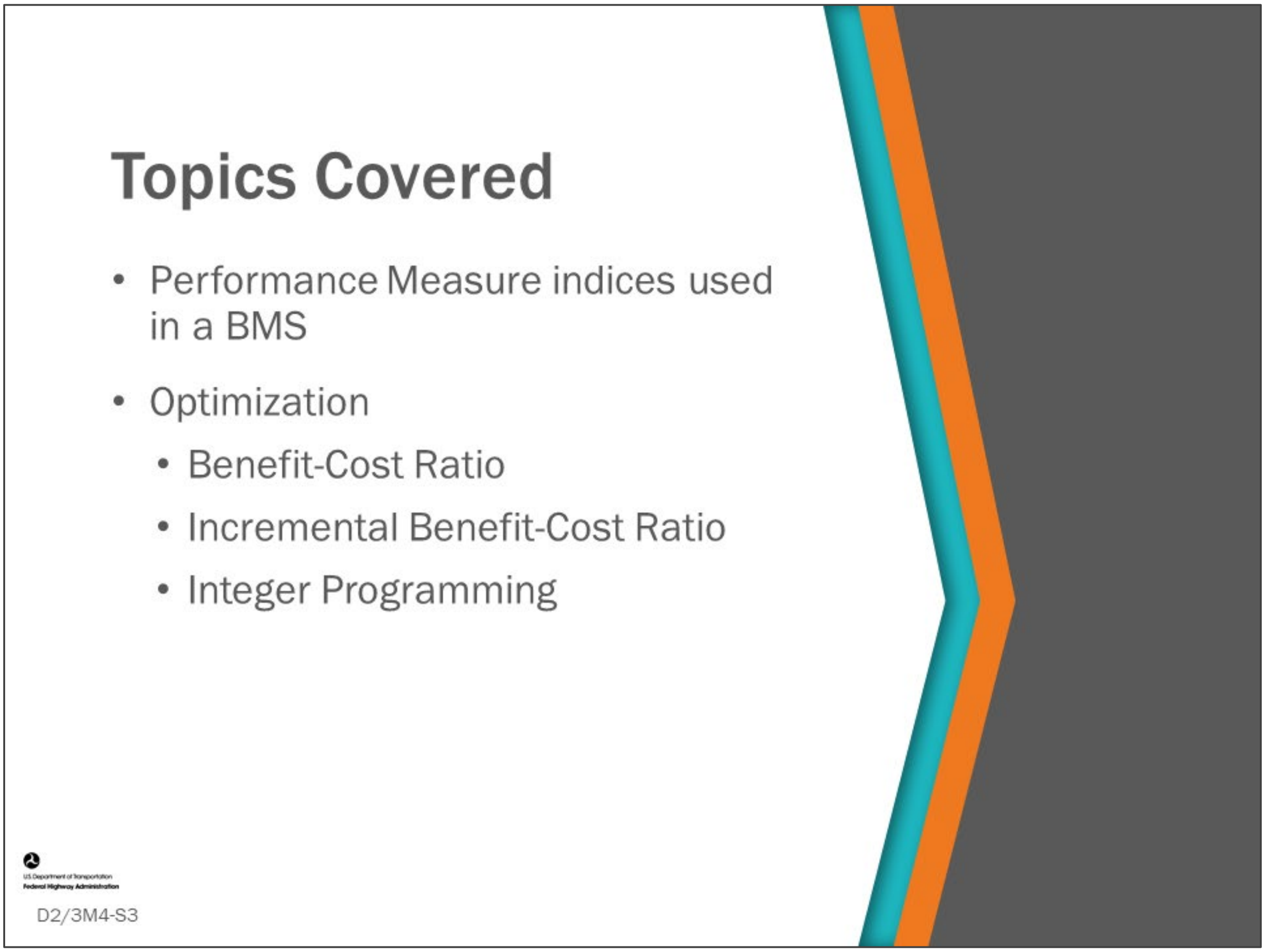
D2/3M4-Slide 2



Key Message

Common workflow steps and features are shown on the slide. In this module, we will continue reviewing how to generate and model bridge strategies.

D2/3M4-Slide 3

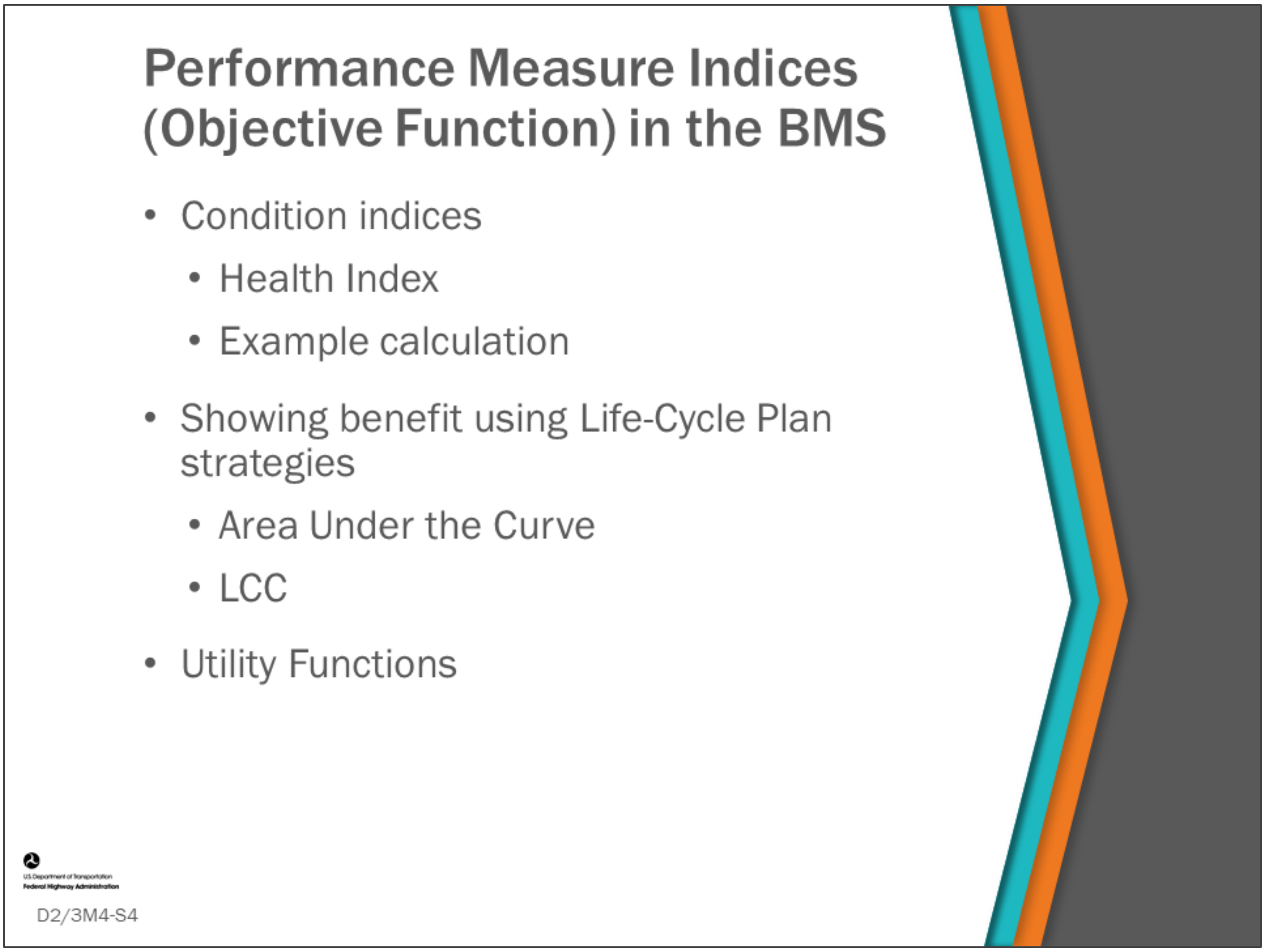


Key Message

In previous modules, we reviewed agency goals, objectives, and performance measures. We also learned how agencies can have multiple objectives. A BMS will use a single index, chosen by the user, to maximize or minimize during optimization. This index may be a simple condition measure or other singular measure, or it can be an amalgamation (combination) of multiple sub-indices as a utility function.

The index is often representative of a point in time. Some indices are a single value representative of a range of time or life-cycle plan strategy (for example, Net Present Value (NPV) and Area Under the Curve intended to account for cumulative benefits over time, i.e., temporal benefits). Optimization solution methods like Benefit-Cost Ratio (BCR), Incremental Benefit-Cost Ratio (IBCR), and integer programming are the engine that drive a BMS to make detailed project and strategy recommendations. In this module, we will learn the basics of how this is performed.

D2/3M4-Slide 4



Key Message

In BMS software, it is important to have a solid understanding of your chosen performance measure index or objective function that the software will use to maximize or minimize during optimization of projects or strategies.

- This objective function (index) should be synced with agency performance measures and objectives.
- In the first day of this workshop, we looked at several different performance measures including condition-based measures, measures that compare life-cycle plan strategies and measures that amalgamate multiple measures into a utility function.

It is important to understand what moves the needle of these indices and how these changes affect project recommendations in BMS software.

In this section, we will take a closer look at three common types of BMS indices: Condition indices, Life-Cycle Plan Strategy indices, and Utility Function indices.

D2/3M4-Slide 5

Condition Indices – Health Index (HI)

$$HI = Bridge\ Health\ Index = \frac{\sum_e q_e \omega_e HI_e}{\Sigma_e q_e \omega_e}, where\ \ HI_e = \frac{CS_1 + WF_{cs2}CS_2 + WF_{cs3}CS_3}{Total\ Element\ Quantity}$$

$HI_e = Element's\ Health\ Index$

q_e = Element's Total Quantity

w_e = Relative Element Weight

$CS_{(CS\#)}$ = Quantity Element in Condition State

$WF_{(CS\#)}$ = Weight Factor for Condition State

WF_{cs1}	WF_{cs2}	WF_{cs3}

Element Number	Element Name	Total Quantity	Units	CS1	CS2	CS3	CS4	ω_e	HI_e	$q_e\omega_e HI_e$	$q_e\omega_e$
12	Concrete Deck	300	SFT	0		300					
107	Steel Girder/Beam	100	LFT	61	34	5					
215	Concrete Abutment	24	LFT	24							
300	Strip Seal Expansion Joint	24	LFT	0			24				
205	Reinforced Concrete Columns	4	Each	4							
									Total		

Bridge Health Index

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Federal Highway Administration

D2/3M4-S5

Key Message

The Health Index (HI) is a numerical value reflecting the condition of the structure. It is often read as "percent of remaining condition value." It is a weighted average of the element conditions. It is highly useful for assessing overall condition, especially structure-to-structure in an asset-management context but may be somewhat blind to localized failures.

All comprehensive BMS software offer the ability to create a HI that uses bridge element condition ratings to provide an overall assessment of bridge condition or remaining condition value.
Shown on this slide is the Health Index formula used in AASHTOWare™ Bridge Management (BrM), with the following:

- HI_e = Element's Health Index
- q_e = Element's Total Quantity
- w_e = Relative Element Weight
- $CS_{(CS\#)}$ = Percent Element in Condition State
- $WF_{(CS\#)}$ = Weight Factor for Condition State

Next, we will complete an example calculation of a bridge HI and discuss the importance of setting the condition state weight factor coefficients and the element relative unit weights so that the HI can predict bridge needs.

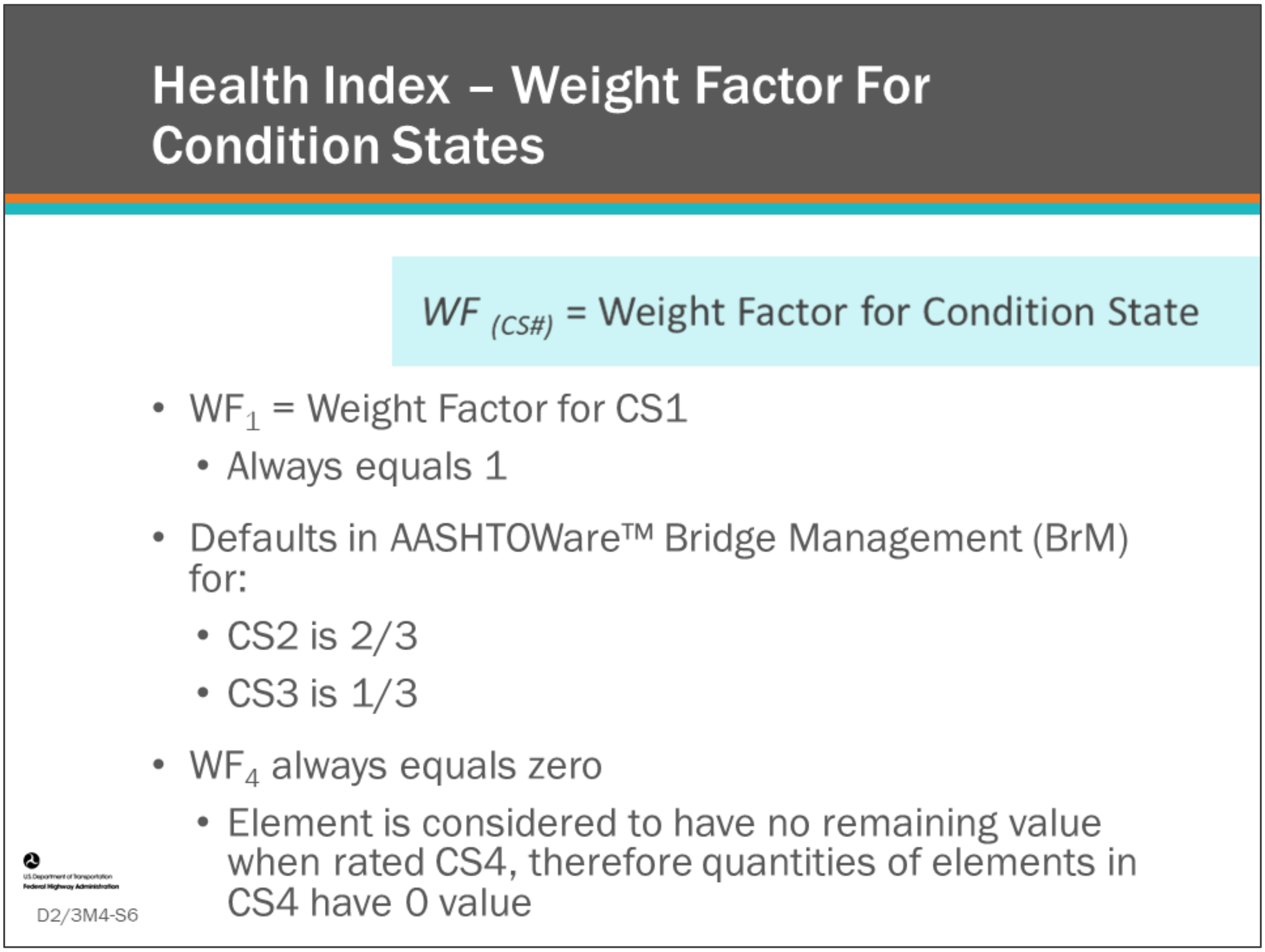
D2/3M4 - Slide 5: Health Index – Weight Factor for Condition States

Choose Weight Factors for Condition State 2 (CS2) and Condition State 3 (CS3) that will be used in the following example calculations.

CS2 ______________

CS3 ______________

D2/3M4-Slide 6



Key Message

The Weight Factors (WF), also called condition state coefficients, reflect the lost value that portion of the element has when it is in certain condition states.

- The portion of the element that is in CS1 has all its value therefore WF_1 is always 1.0 (and WF_1 is often not shown in the equation).
- The portion of the element in CS4 has no remaining condition value, and therefore WF_4 is always zero (and is often not shown in the equation).
- The default in AASHTOWare™ Bridge Management (BrM) for CS2 is 2/3 and CS3 for it is 1/3; however, these can be modified.

D2/3M4 - Slide 6: Health Index – Relative Element Weight

Record what you would use for relative element weights for the elements shown in the table.
Note, relative element weights are simply compared to the unit weights of other elements. They can be on any reasonable scale the user chooses.

$$\omega e = \text{Relative Unit Weight}$$

Element Number	Element Name	ω_e
12	Concrete Deck	
107	Steel Girder/Beam	
215	Concrete Abutment	
300	Strip Seal Expansion Joint	
205	Reinforced Concrete Columns	

1. Record your reasoning for selecting the relative element weights.

D2/3M4-Slide 7

Health Index – Relative Element Weight

$$w_e = \text{Relative Element Weight}$$

Element Number	Element Name	ω_e
12	Concrete Deck	
107	Steel Girder/Beam	
215	Concrete Abutment	
300	Strip Seal Expansion Joint	
205	Reinforced Concrete Columns	

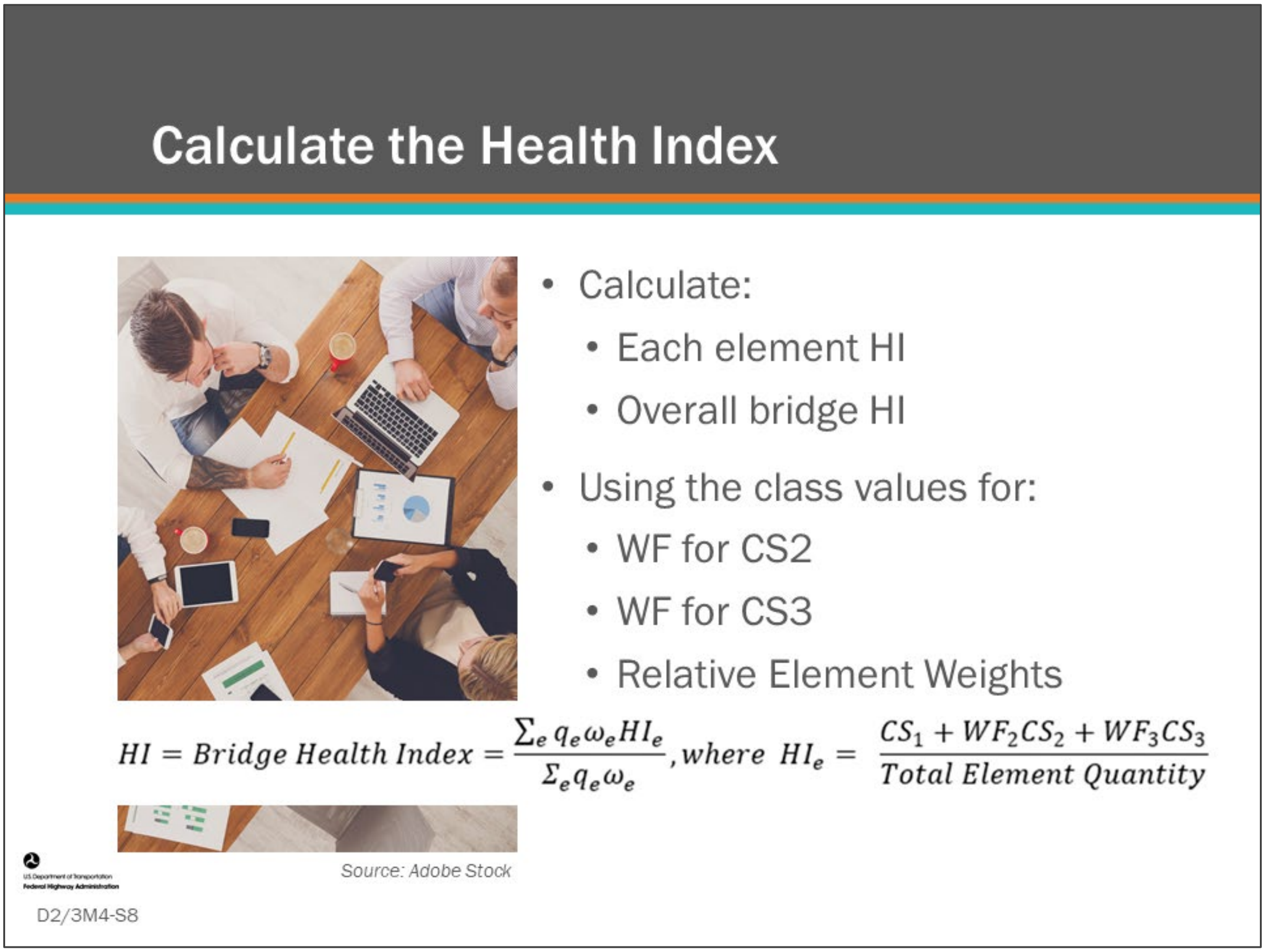
D2/3M4-S7

Key Message

The Relative Element Weight in the bridge HI calculation determines how significant an element is to the bridge, and therefore how it should be weighted.

- The higher the relative element weight, the greater the impact of the element on the bridge health index.
- Relative Unit Weight can be configured based on importance to structural safety, relative cost or other measures of significance.
- When setting Relative Unit Weight, you can consider element construction/replacement unit cost relative to other elements as a first cut and increase or decrease element weights from there.

D2/3M4-Slide 8



Key Message

Calculate the HI for each element and for the overall bridge.

D2/3M4 - Slide 8: Calculating Health Index Worksheet

Compute each element Health Index and the overall bridge Health Index using the group agreed upon values for the Weight Factors for CS2 and CS3 and the relative element weights in the table below.

$$HI = Bridge\ Health\ Index = \frac{\sum_e q_e \omega_e HI_e}{\Sigma_e q_e \omega_e}, where\ \ HI_e = \frac{CS_1 + WF_{cs2}CS_2 + WF_{cs3}CS_3}{Total\ Element\ Quantity}$$

HI_e = Element's Health Index

q_e = Element's Total Quantity

ω_e = Relative Unit Weight

$cs_{(Condition\ State\ \#)}$ = Quantity Element in Condition State

$WF_{(Condition\ State\ \#)}$ = Weight Factor for Condition State

Bridge Health Index

WF_1	WF_2	WF_3

Element Number	Element Name	Total Quantity	Units	CS1	CS2	CS3	CS4	ω_e	HI_e	$q_e\omega_e HI_e$	$q_e\omega_e$
12	Concrete Deck	300	SFT	0		300					
107	Steel Girder/Beam	100	LFT	61	34	5					
215	Concrete Abutment	24	LFT	24							
300	Strip Seal Expansion Joint	24	LFT	0			24				
205	Reinforced Concrete Columns	4	Each	4							
									Total		

D2/3M4-Slide 9

Health Index – Calculation Worksheet

$$HI = Bridge\ Health\ Index = \frac{\Sigma_e\, q_e \omega_e HI_e}{\Sigma_e q_e \omega_e}, where$$

$$HI_e = \frac{CS_1 + WF_2 CS_2 + WF_3 CS_3}{Total\ Element\ Quantity}$$

q_e = Element's Total Quantity $WF_{(Condition\ State\ \#)}$ = Weight Factor for Condition State

w_e = Relative Element Weight $CS_{(Condition\ State\ \#)}$ = Quantity Element in Condition State

				WF_{CS1}	WF_{CS2}	WF_{CS3}					
Element Number	Element Name	Total Quantity	Units	CS1	CS2	CS3	CS4	ω_e	HI_e	$q_e\omega_e HI_e$	$q_e\omega_e$
12	Concrete Deck	300	SFT	0		300					
107	Steel Girder/Beam	100	LFT	61	34	5					
215	Concrete Abutment	24	LFT	24							
300	Strip Seal Expansion Joint	24	LFT	0			24				
205	Reinforced Concrete Columns	4	Each	4							
									Total		

Bridge Health Index

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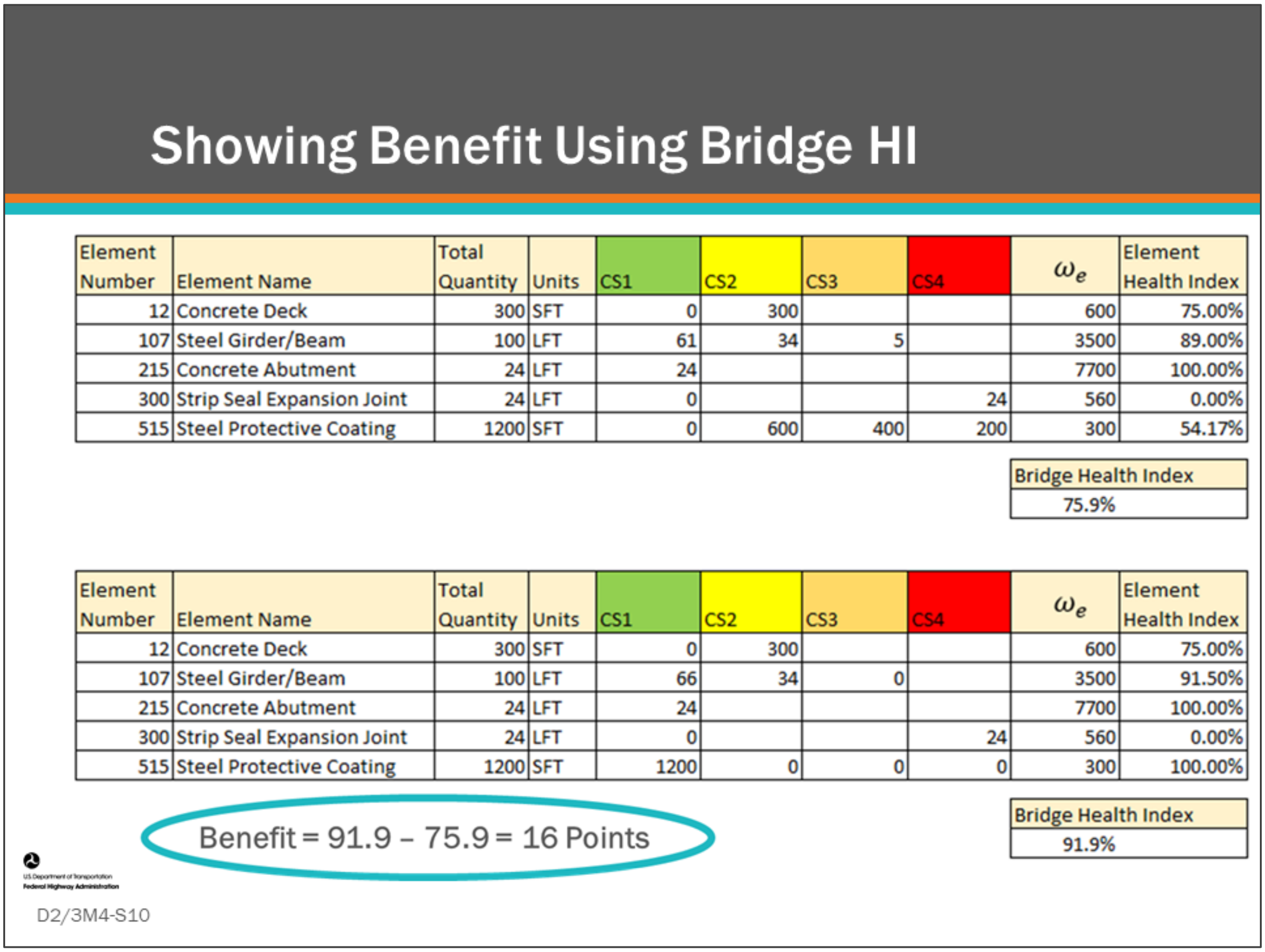
D2/3M4-S9

Key Message

Group exercise: Calculate Health Index

D2/3M4-Slide 10



Showing Benefit Using Bridge HI

Element Number	Element Name	Total Quantity	Units	CS1	CS2	CS3	CS4	ω_e	Element Health Index
12	Concrete Deck	300	SFT	0	300			600	75.00%
107	Steel Girder/Beam	100	LFT	61	34	5		3500	89.00%
215	Concrete Abutment	24	LFT	24				7700	100.00%
300	Strip Seal Expansion Joint	24	LFT	0			24	560	0.00%
515	Steel Protective Coating	1200	SFT	0	600	400	200	300	54.17%

Bridge Health Index
75.9%

Element Number	Element Name	Total Quantity	Units	CS1	CS2	CS3	CS4	ω_e	Element Health Index
12	Concrete Deck	300	SFT	0	300			600	75.00%
107	Steel Girder/Beam	100	LFT	66	34	0		3500	91.50%
215	Concrete Abutment	24	LFT	24				7700	100.00%
300	Strip Seal Expansion Joint	24	LFT	0			24	560	0.00%
515	Steel Protective Coating	1200	SFT	1200	0	0	0	300	100.00%

Bridge Health Index
91.9%

Benefit = 91.9 – 75.9 = 16 Points

D2/3M4-S10

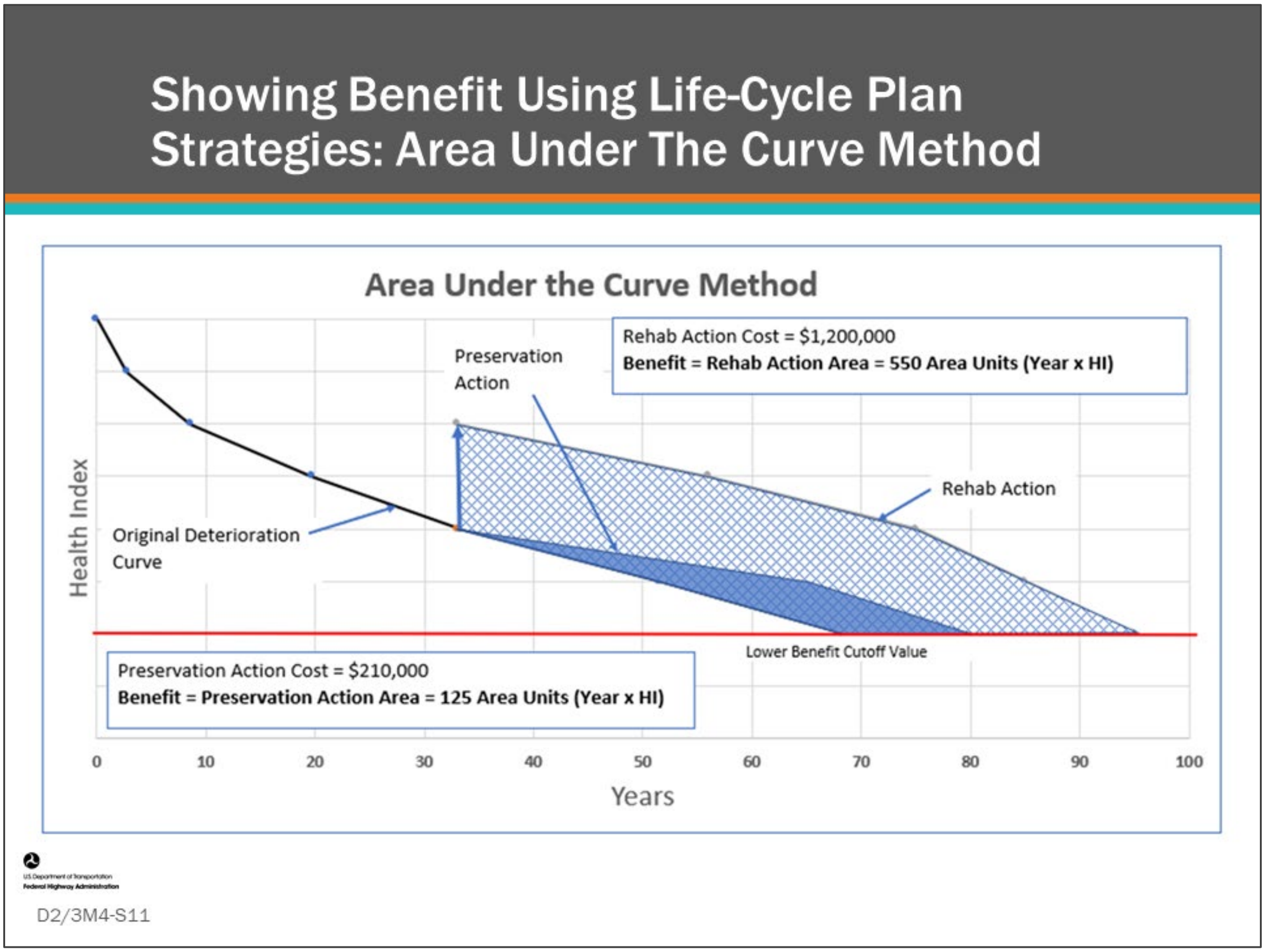
Key Message

Typically, you will model CS improvement in your BMS after an action is performed.

- The example on this slide shows an improvement to Element 107 – Steel Girder/Beam and its protective coating Element 515 after an action was performed that changed the HI for those elements.
- With this information, the BMS can calculate the improvement to the overall bridge HI.
- For the example shown on this slide the "benefit" is the increase in HI from 75.9 to 91.9, for the overall bridge – a 16-point increase.

Note the Weight Factors used for Condition States were WF_1 equal to 0.75 and WF_2 equal to 0.5.

D2/3M4-Slide 11

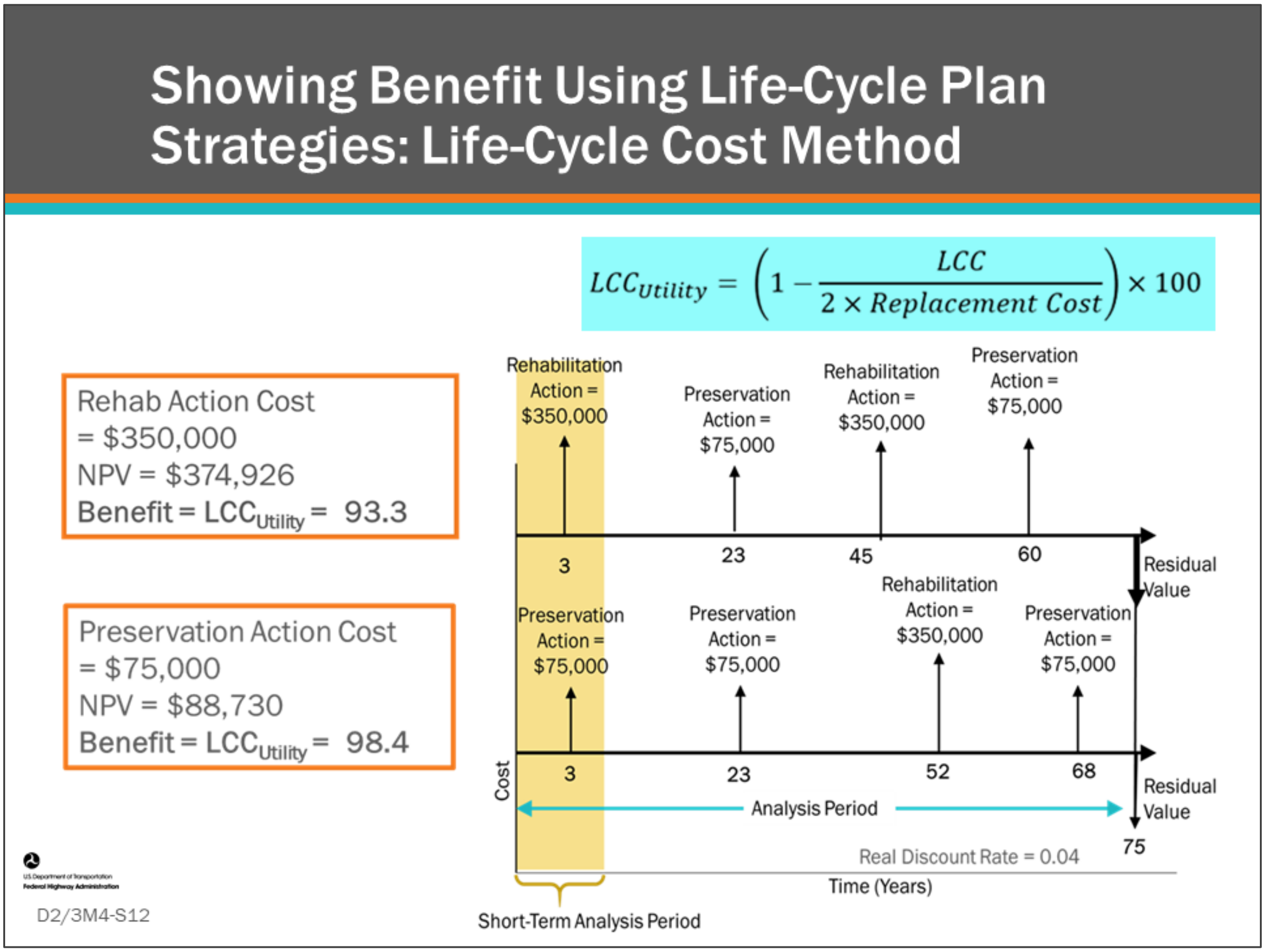


Key Message

For the area under the curve method, the resulting curve after a preservation action and rehabilitation action (shown in the chart) are compared to the original deterioration curve where no action was taken.

- The area between the original curve and the resulting curve from the action is the calculated benefit.
- This is a comparison of the benefit resulting from actions that are taken at the same point in time. For example, an agency is reviewing actions in their BMS for a given year.

D2/3M4-Slide 12



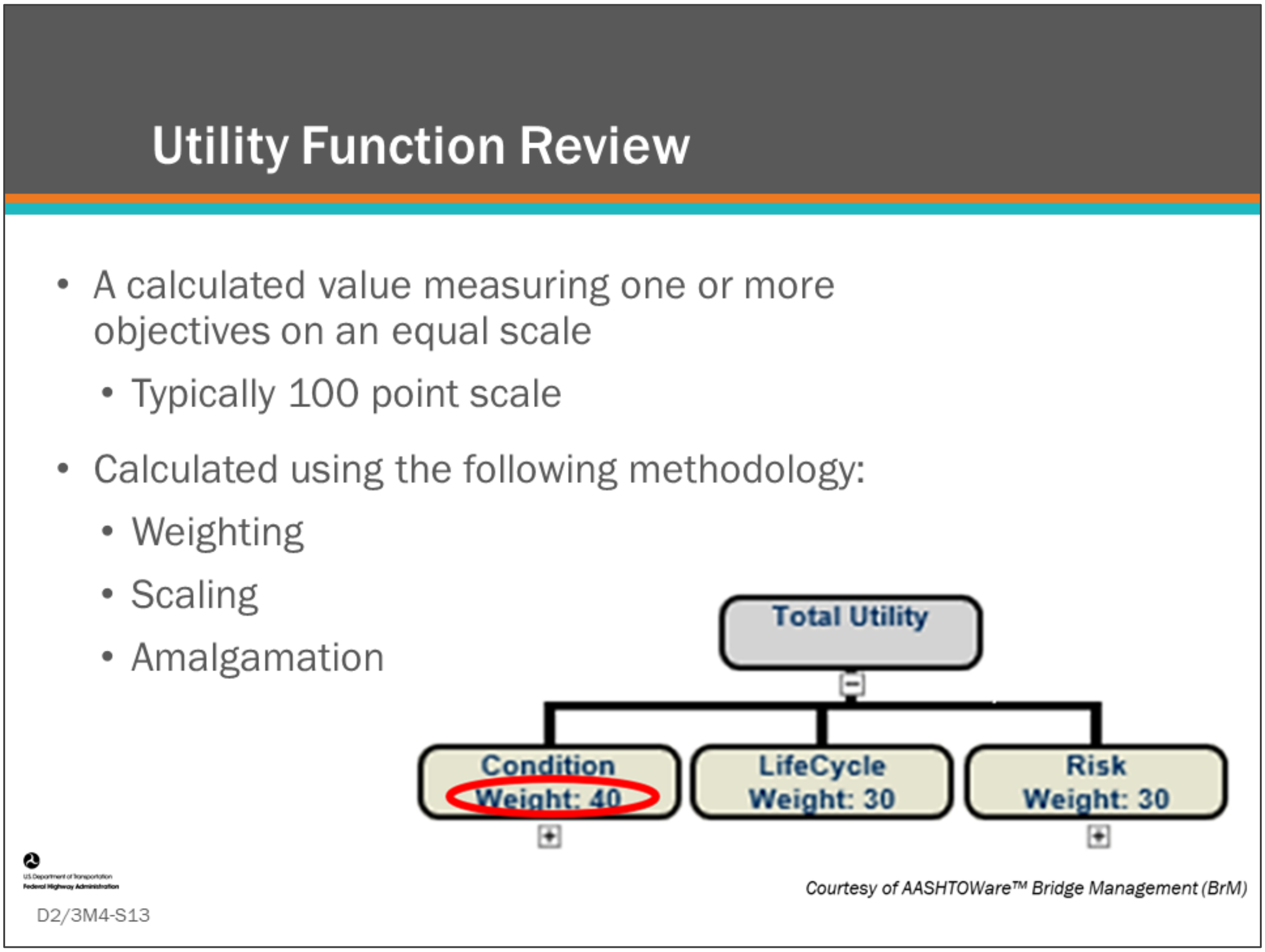
Key Message

When a BMS performs a LCCA, it often is comparing one or more actions in the short-term analysis period to no action (Do Nothing) during that time.

The two life-cycle profiles shown on the slide show two options.

- The top profile shows a rehabilitation action completed in the short-term analysis period.
- The bottom profile shows a preservation action completed during the short-term analysis period.
- In both profiles, the long-term preservation and reconstruction policies in the BMS will determine future actions outside of the short-term analysis period.
    - Then, at the end of the analysis period, residual value is applied to the profiles.
    - The resulting NPV for the rehabilitation option is $374,926 with an LCC utility of 93.3.
    - The resulting NPV for the preservation option $88,730 with an LCC utility of 98.4.

D2/3M4-Slide 13

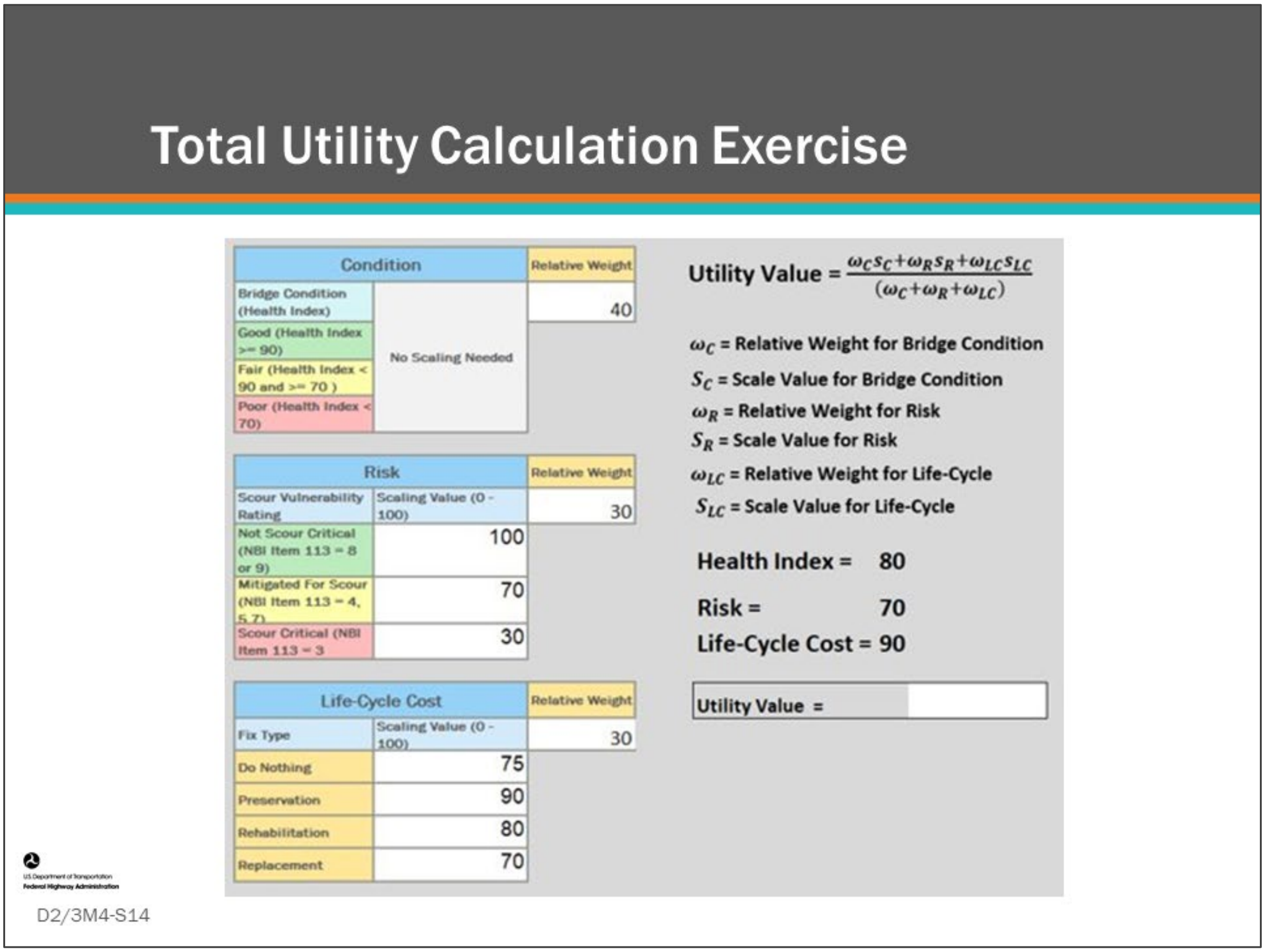


Key Message

On day one of this workshop, we learned about Utility Function. In bridge management, utility functions are useful to compare and weigh decisions between multiple objectives and produce a single utility value that can be used as the optimization index to be maximized.

- In the specific example of the AASHTOWare™ Bridge Management (BrM) utility function, it uses weighting, scaling and amalgamation.

D2/3M4-Slide 14



Key Message

Total utility is calculated using the equation shown on this slide.
Using the equation and information shown on this slide, calculate the total utility value.

Notes:

- The Health Index values corresponding to good, fair, and poor are not based on a standard and are for example only.
- Point out that Health Index does need to be scaled because it is already on a 100-point scale.

D2/3M4 - Slide 14: Calculating Utility Value Worksheet

1. Compute Utility Value after a Preservation action in the space below given the following:
   a. The equation provided below
   b. Bridge condition after the action is fair with a Health Index equal to 80
   c. The bridge is mitigated for scour so the Risk Utility equal to 70
   d. Preservation Action is chosen having a Life-Cycle Cost Utility equal to 90
   e. The relative weight for each objective as shown

$$\text{Utility Value} = \frac{\omega_C s_C + \omega_R s_R + \omega_{LC} s_{LC}}{(\omega_C + \omega_R + \omega_{LC})}$$

ω_C = Relative Weight for Bridge Condition
S_C = Scale Value for Bridge Condition
ω_R = Relative Weight for Risk
S_R = Scale Value for Risk
ω_{LC} = Relative Weight for Life-Cycle
S_{LC} = Scale Value for Life-Cycle

Utility Value =	

Condition		**Relative Weight**
Bridge Condition (Health Index)	No Scaling Needed	40
Good (Health Index ≥ 90)		
Fair (Health Index < 90 and ≥ 70)		
Poor (Health Index < 70)		

Risk		**Relative Weight**
Scour Vulnerability Rating	Scaling Value (0 - 100)	30
Not Scour Critical (NBI Item 113 = 8 or 9)	100	
Mitigated for Scour (NBI Item 113 = 4, 5 7)	70	
Scour Critical (NBI Item 113 = 2 or 3)	30	

Life-Cycle Cost		**Relative Weight**
Fix Type	Scaling Value (0 - 100)	30
Do Nothing	75	
Preservation	90	
Rehabilitation	80	
Replacement	70	

D2/3M4-Slide 15

Key Message

Optimization to find the best combination of actions and strategies for all bridges in the network, is the highest function performed by a BMS.

- This is often done by maximizing a benefit within a constrained budget but can also be done using performance targets as constraints. In this section we will learn the basics how BMS software does this using Benefit-Cost Ratio (BCR) analysis, Incremental Benefit-Cost Ratio (IBCR) analysis, and integer programming.
    - Note: When measure targets are imposed as constraints, it may move the solution away from optimum, therefore there should be a strong basis for imposing targets.

In this section of the lesson, we will go through in-depth examples of each of the three methods for solving a basic network optimization bridge management problem.

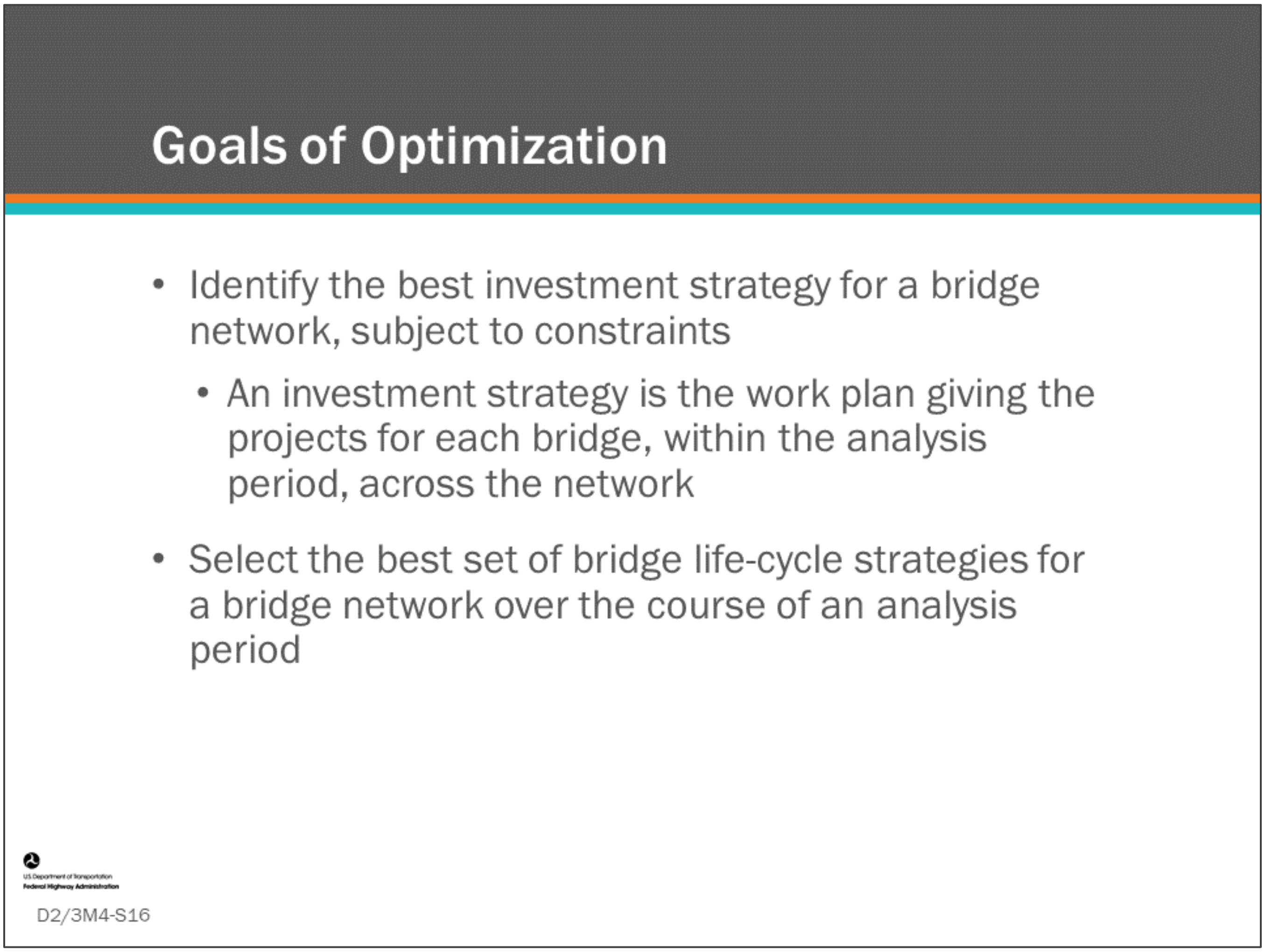
- By reviewing the manual steps behind the three methods, on exactly the same set of data each time, we illustrate the basic methodologies used by bridge management systems to solve the optimization problem.
- We also show and discuss the differences between the three methods.

The three methods discussed are:

- Benefit Cost Ratio (BCR)
- Incremental Benefit Cost (IBCR)

- Integer Programming

D2/3M4-Slide 16



Key Message

The purpose of optimization at the network level is to select a set of bridge projects in such a way that the total benefit derived from the implementation of the selected projects is maximized or costs are minimized.

- This can help to find the best investment strategy for your bridge network over time.
- It can also help identify cost beneficial candidates for preservation, maintenance, rehabilitation and replacement in the near term.

The ability to establish project priorities and optimally allocate limited funds over a predefined planning horizon, both short- and long-term, is a fundamental part of a BMS.

D2/3M4-Slide 17

Individual Exercise: Maximize Benefit with Constrained Budget

Source: Adobe Stock

- Choose actions to maximize benefit with constrained budget
  - Select from the list of “Available Actions” on the following slide
  - Maximize benefit with $2 Million
  - Each bridge can only be worked on once

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D2/3M4-S17

Key Message

Choose from “Available Actions” to maximize benefit with a constrained budget.

D2/3M4-Slide 18

Maximize Benefit with Constrained Budget – List of Available Actions

Annual Budget
$2,000,000

Bridge Number	Action Name	Action Cost	Action Benefit	Benefit-Cost Ratio	Picked Strategy
1001	PR1	$100,000	68	6.80	
1001	PR2	$200,000	71.5	3.58	
1001	PR3	$1,400,000	79.5	0.57	
1002	PR1	$150,000	50	3.33	
1002	PR2	$180,000	51	2.83	
1002	PR3	$1,200,000	65	0.54	
1003	PR1	$6,000	87.5	145.83	
1003	PR2	$10,000	88	88.00	
1003	PR3	$30,000	88.5	29.50	
1004	PR1	$140,000	75	5.36	
1004	PR2	$500,000	79.5	1.59	
1004	PR3	$1,800,000	84.5	0.47	
1005	PR1	$20,000	91	45.50	
1005	PR2	$50,000	94	18.80	
1005	PR3	$80,000	94.5	11.81	
	Total				

D2/3M4-S18

Key Message

Choose from “Available Actions” to maximize benefit with a constrained budget.

- Use the Maximize Benefit with Constrained Budget Worksheet from your PW to complete this activity.
- Select actions (projects).
- Only one action per bridge number is allowed.
- The annual budget of $2,000,000 cannot be exceeded.
- Add up total benefits and cost from the list of “Available Actions” shown on this slide.
- Try different combinations of actions to maximize benefit.

D2/3M4 - Slide 18: Maximize Benefit with Constrained Budget

1. Select actions.
    a. Only one action per bridge number is allowed.
    b. The annual budget of $2,000,000 cannot be exceeded.
2. Add up total benefits and cost from the list of “Available Actions” shown in the table below.
3. Try different combinations of actions to maximize benefit

Note that benefits are weighted by bridge size.

Annual Budget
$2,000,000

Bridge Number	Action Name	Action Cost	Action Benefit	Benefit-Cost Ratio	Picked Strategy
1001	PR1	$100,000	68	6.80	
1001	PR2	$200,000	71.5	3.58	
1001	PR3	$1,400,000	79.5	0.57	
1002	PR1	$150,000	50	3.33	
1002	PR2	$180,000	51	2.83	
1002	PR3	$1,200,000	65	0.54	
1003	PR1	$6,000	87.5	145.83	
1003	PR2	$10,000	88	88.00	
1003	PR3	$30,000	88.5	29.50	
1004	PR1	$140,000	75	5.36	
1004	PR2	$500,000	79.5	1.59	
1004	PR3	$1,800,000	84.5	0.47	
1005	PR1	$20,000	91	45.50	
1005	PR2	$50,000	94	18.80	
1005	PR3	$80,000	94.5	11.81	
	Total				

D2/3M4-Slide 19

Maximize Benefit with Constrained Budget – Results

Source: Adobe Stock

- Review results for Maximize Benefit with Constrained Budget activity
- Who came up with the best combination of actions to create the highest benefit?

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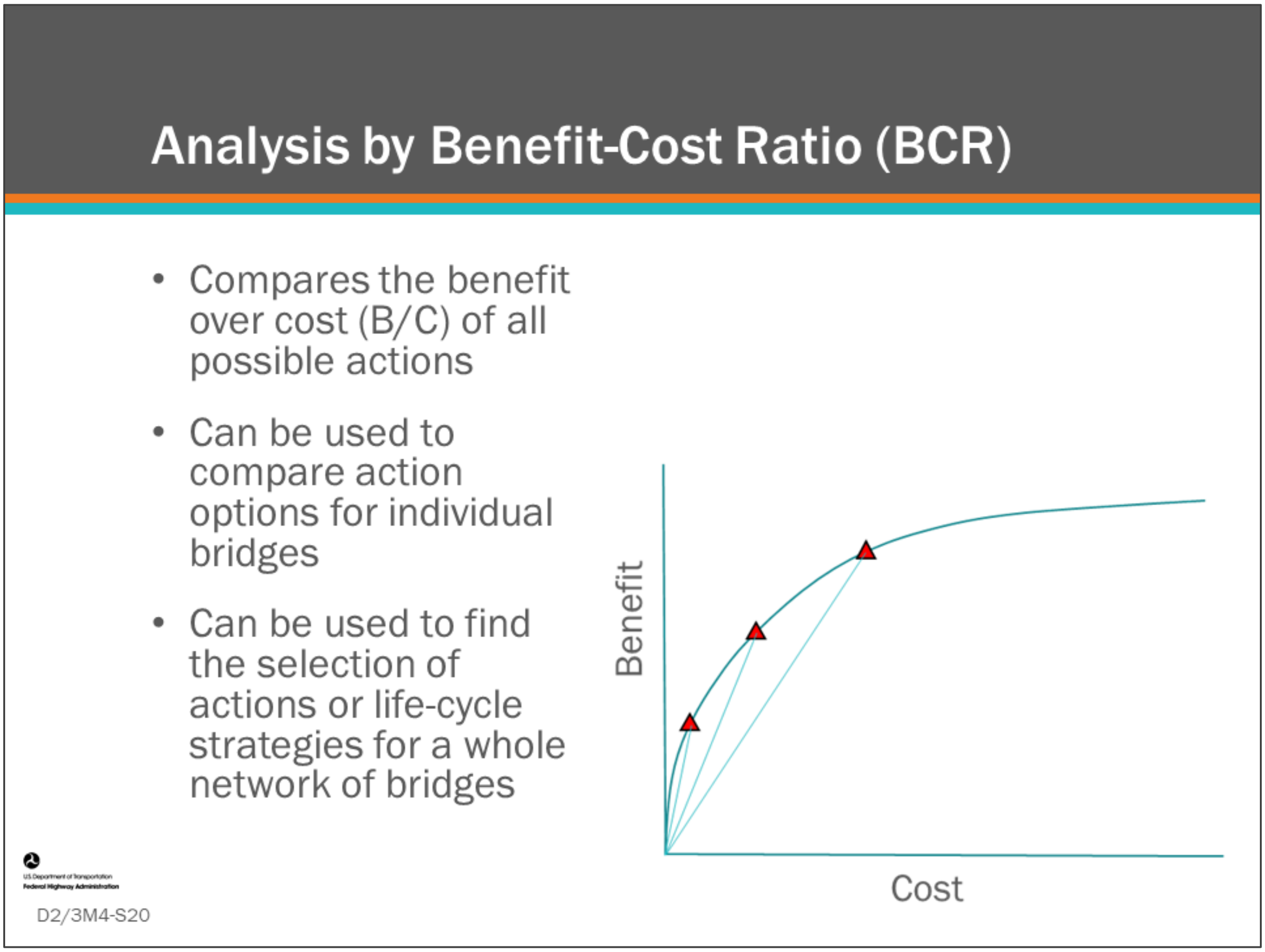
D2/3M4-S19

Key Message

Review result of exercise.

D2/3M4-Slide 20



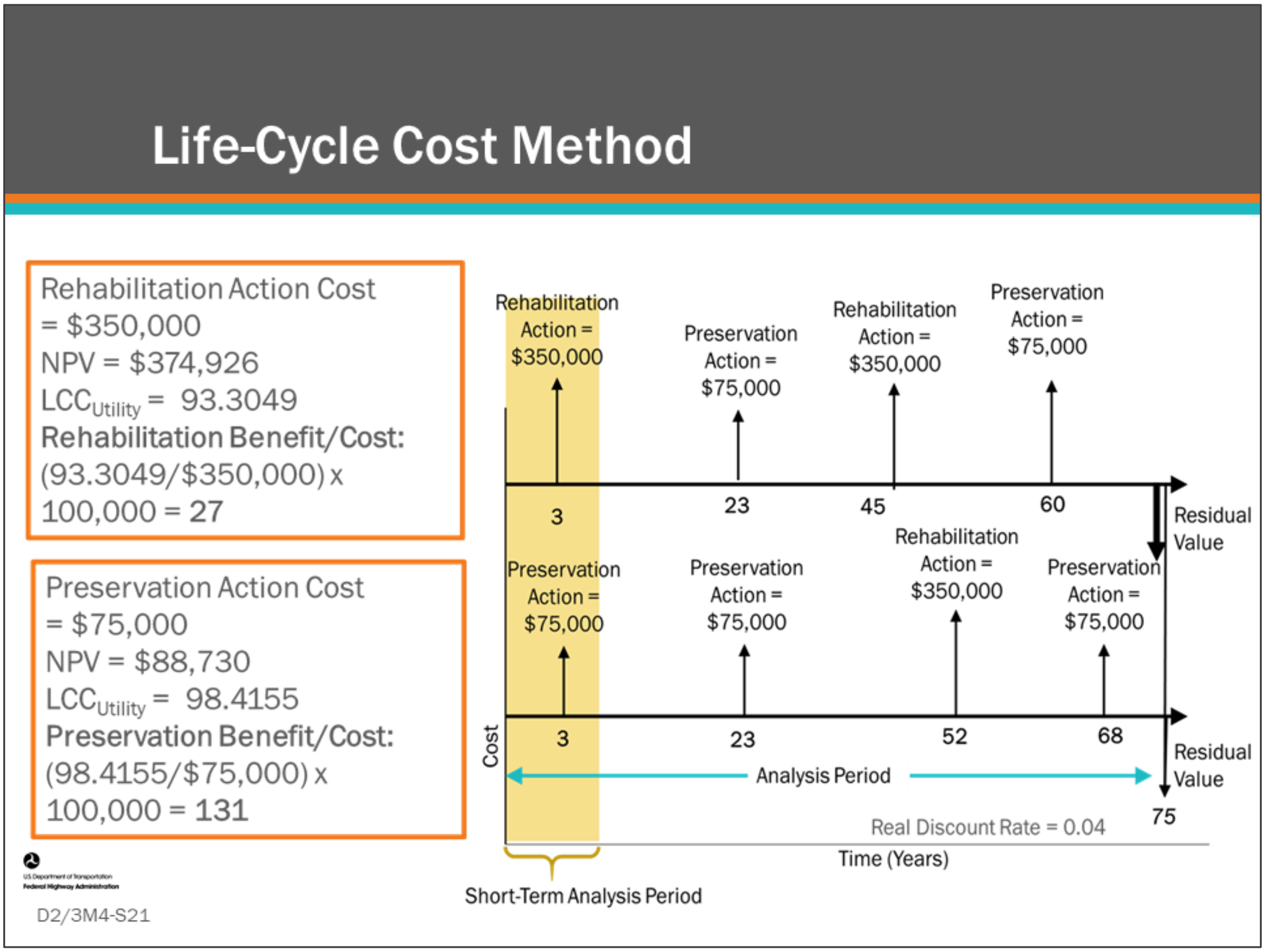
Key Message

Calculating Benefit/Cost is very useful to compare investment options.

- These options can be actions on a single bridge, or actions or life-cycle strategies on a whole network of bridges.

In this section, we will learn how to calculate BCR using several different common indices and how to identify a list of projects having maximum benefit with a constrained budget.

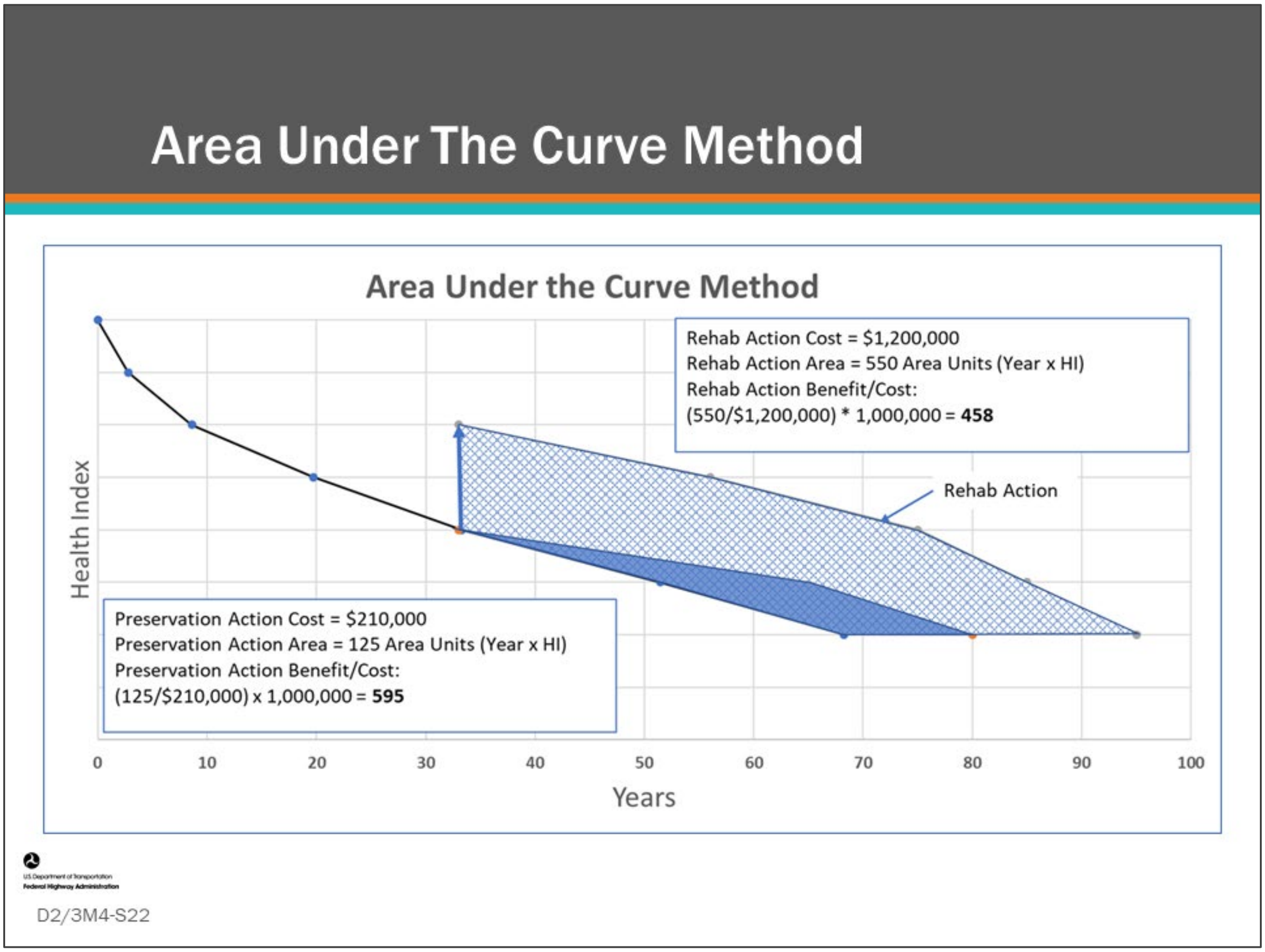
D2/3M4-Slide 21



Key Message

Using the life-cycle cost utility values calculated earlier and the short-term action cost, we can calculate the benefit for the two strategies.

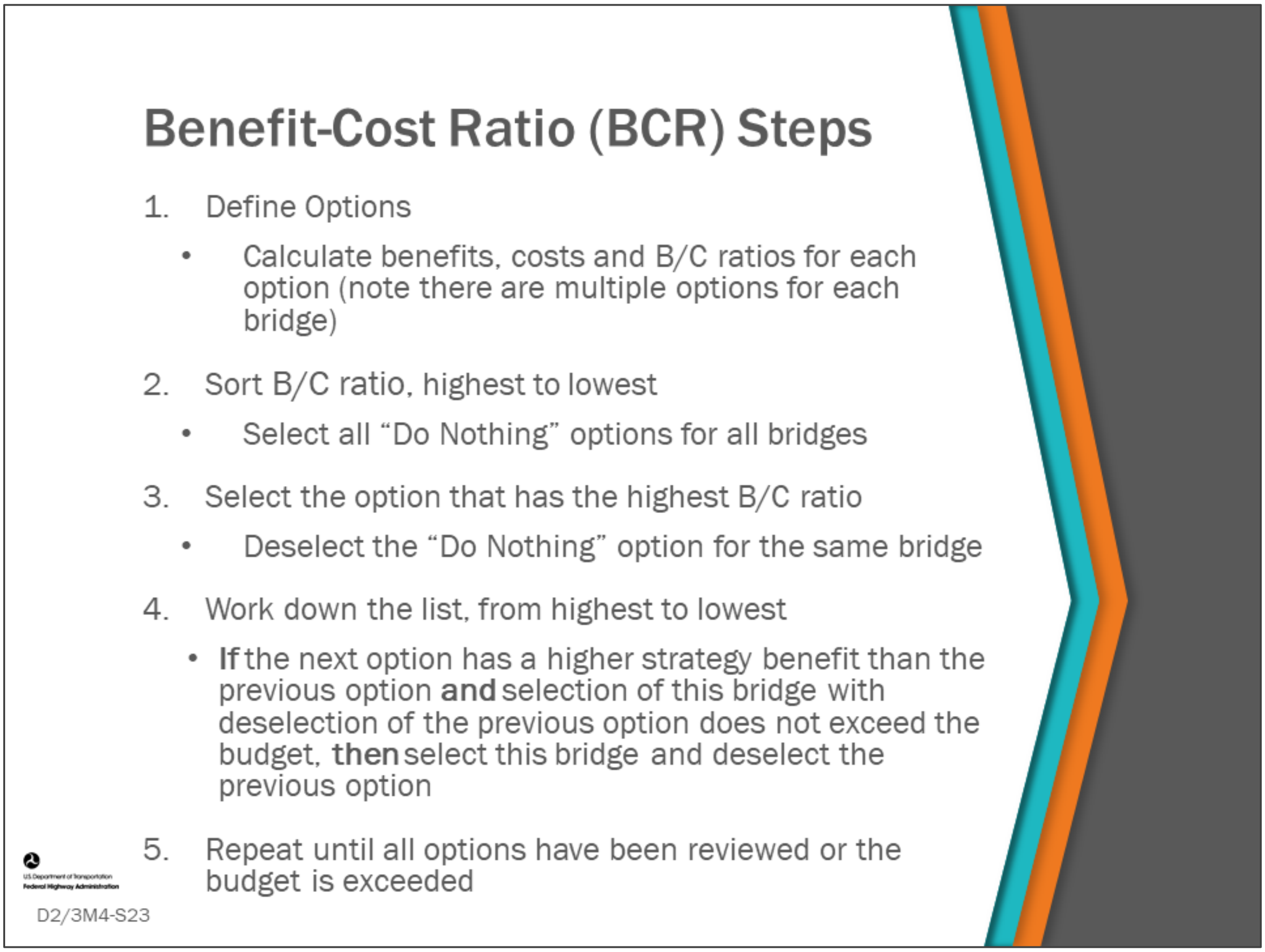
D2/3M4-Slide 22



Key Message

Using the area under the curve method calculations completed earlier, we can calculate the benefit for the two strategies.

D2/3M4-Slide 23



Key Message

Review the steps used for the BCR example in this lesson.

D2/3M4-Slide 24

BCR Example – Step 1

Define Options

- Calculate benefits, costs and B/C ratios for each option

Annual Budget
$2,000,000.00

$$\frac{B}{C} = \frac{68}{\$100{,}000} x10{,}000 = 6.80$$

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Benefit-Cost Ratio
1001	Do Nothing	1	$0	$0	67	67	
1001	PR1		$100,000	$0	68	0	6.80
1001	PR2		$200,000	$0	71.5	0	3.58
1001	PR3		$1,400,000	$0	79.5	0	0.57
1002	Do Nothing	1	$0	$0	44	44	
1002	PR1		$150,000	$0	50	0	3.33
1002	PR2		$180,000	$0	51	0	2.83
1002	PR3		$1,200,000	$0	65	0	0.54
1003	Do Nothing	1	$0	$0	87	87	
1003	PR1		$6,000	$0	87.5	0	145.83
1003	PR2		$10,000	$0	88	0	88.00
1003	PR3		$30,000	$0	88.5	0	29.50
1004	Do Nothing	1	$0	$0	72	72	
1004	PR1		$140,000	$0	75	0	5.36
1004	PR2		$500,000	$0	79.5	0	1.59
1004	PR3		$1,800,000	$0	84.5	0	0.47
1005	Do Nothing	1	$0	$0	90	90	
1005	PR1		$20,000	$0	91	0	45.50
1005	PR2		$50,000	$0	94	0	18.80
1005	PR3		$80,000	$0	94.5	0	11.81

Total Scenario Cost:	$0
Total Scenario Benefit:	360.00
Remaining Budget	$2,000,000.00

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D2/3M4-S24

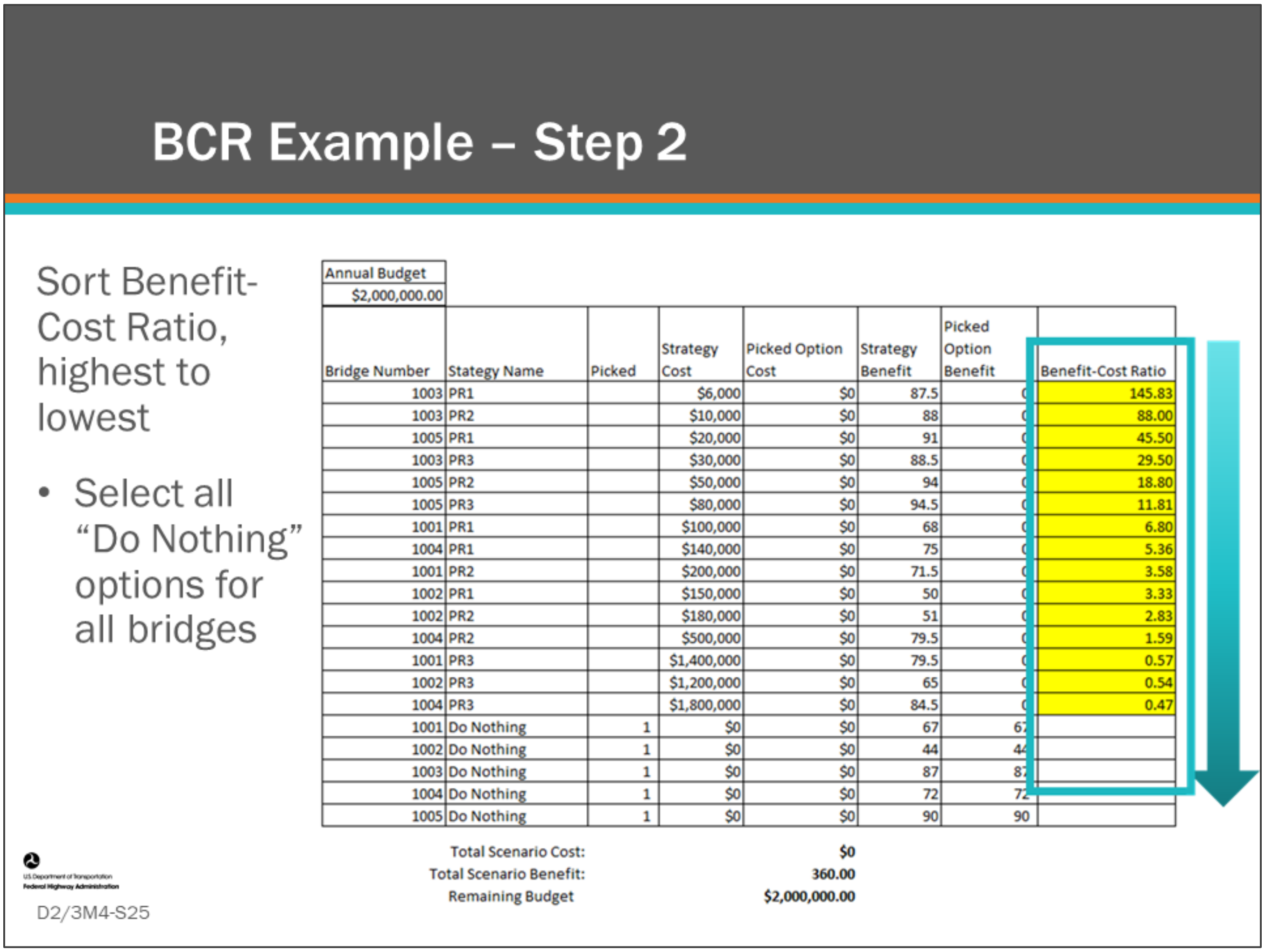
Key Message

Let's complete an example calculation using the BCR method on a bridge from the list that was used previously. Step 1 of the BCR Example is:

- Define strategies and calculate benefits, costs and B/C ratios for each strategy.
    - This list has five bridges with four strategies each totaling 20 strategies.
    - In this example, the benefit is the result of a life-cycle plan strategy, and the "Do Nothing" strategy also has a benefit that is to be compared to the strategies having a short-term action listed generically as PR1, PR2, PR3.

Note that the Do Nothing action can have a benefit. In this example, the Do Nothing benefit could represent the calculated area under the component or element deterioration curves with no actions taken or the bridge LCC with no actions taken.

D2/3M4-Slide 25



Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Benefit-Cost Ratio
1003	PR1		$6,000	$0	87.5	0	145.83
1003	PR2		$10,000	$0	88	0	88.00
1005	PR1		$20,000	$0	91	0	45.50
1003	PR3		$30,000	$0	88.5	0	29.50
1005	PR2		$50,000	$0	94	0	18.80
1005	PR3		$80,000	$0	94.5	0	11.81
1001	PR1		$100,000	$0	68	0	6.80
1004	PR1		$140,000	$0	75	0	5.36
1001	PR2		$200,000	$0	71.5	0	3.58
1002	PR1		$150,000	$0	50	0	3.33
1002	PR2		$180,000	$0	51	0	2.83
1004	PR2		$500,000	$0	79.5	0	1.59
1001	PR3		$1,400,000	$0	79.5	0	0.57
1002	PR3		$1,200,000	$0	65	0	0.54
1004	PR3		$1,800,000	$0	84.5	0	0.47
1001	Do Nothing	1	$0	$0	67	67	
1002	Do Nothing	1	$0	$0	44	44	
1003	Do Nothing	1	$0	$0	87	87	
1004	Do Nothing	1	$0	$0	72	72	
1005	Do Nothing	1	$0	$0	90	90	

Total Scenario Cost:	$0
Total Scenario Benefit:	360.00
Remaining Budget	$2,000,000.00

Key Message

Review step 2 of the BCR example.

Step 2 of the BCR Example is:

- Sort the Benefit-Cost Ratio, highest to lowest.
    - Initially, select all “Do Nothing” options for all bridges.
    - The total scenario cost during this step is $0 because DN strategies are selected.
    - The total scenario benefit is 360 which is the sum of the DN strategies.

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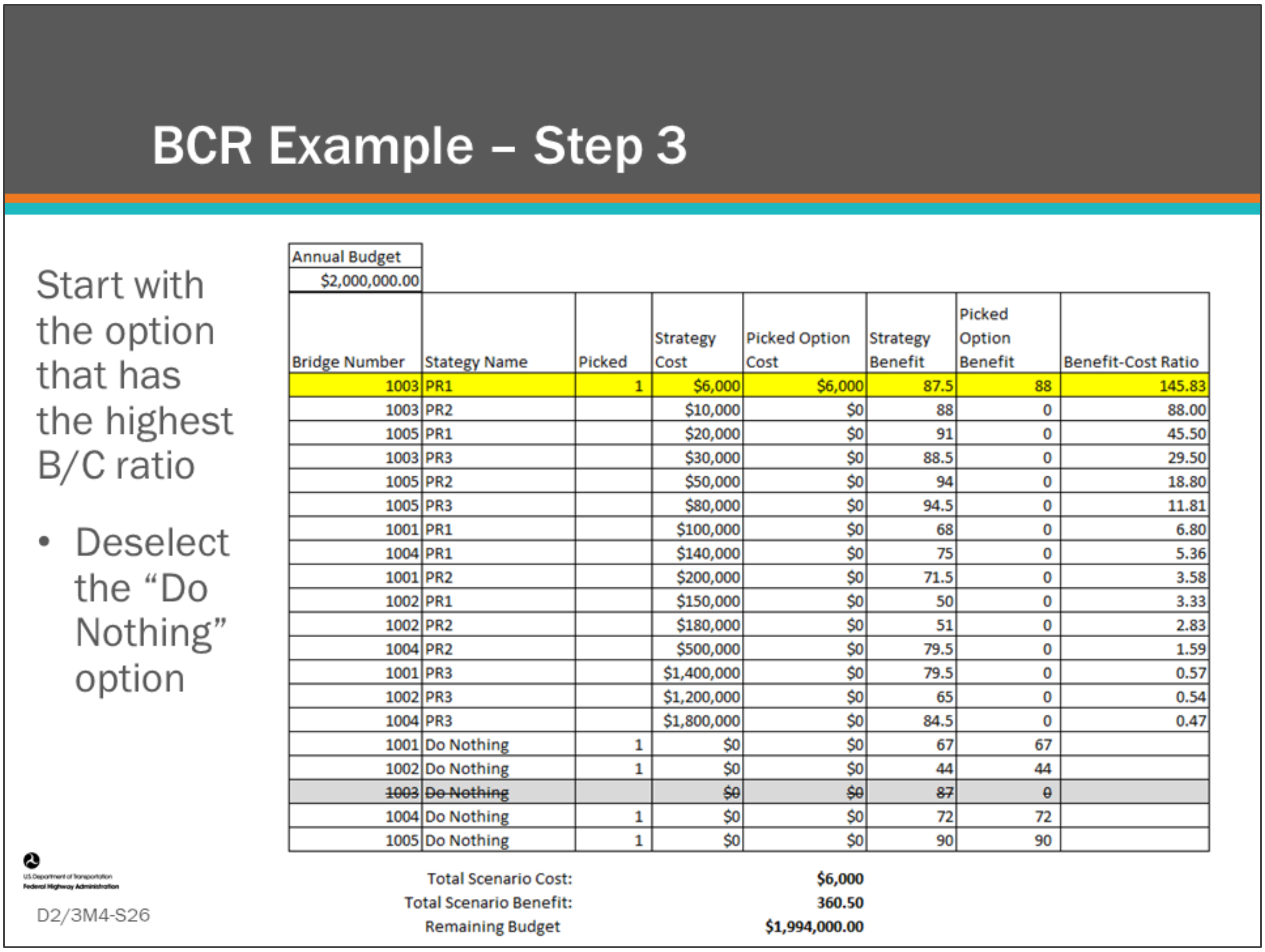


Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Benefit-Cost Ratio
1003	PR1	1	$6,000	$6,000	87.5	88	145.83
1003	PR2		$10,000	$0	88	0	88.00
1005	PR1		$20,000	$0	91	0	45.50
1003	PR3		$30,000	$0	88.5	0	29.50
1005	PR2		$50,000	$0	94	0	18.80
1005	PR3		$80,000	$0	94.5	0	11.81
1001	PR1		$100,000	$0	68	0	6.80
1004	PR1		$140,000	$0	75	0	5.36
1001	PR2		$200,000	$0	71.5	0	3.58
1002	PR1		$150,000	$0	50	0	3.33
1002	PR2		$180,000	$0	51	0	2.83
1004	PR2		$500,000	$0	79.5	0	1.59
1001	PR3		$1,400,000	$0	79.5	0	0.57
1002	PR3		$1,200,000	$0	65	0	0.54
1004	PR3		$1,800,000	$0	84.5	0	0.47
1001	Do Nothing	1	$0	$0	67	67	
1002	Do Nothing	1	$0	$0	44	44	
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
1004	Do Nothing	1	$0	$0	72	72	
1005	Do Nothing	1	$0	$0	90	90	

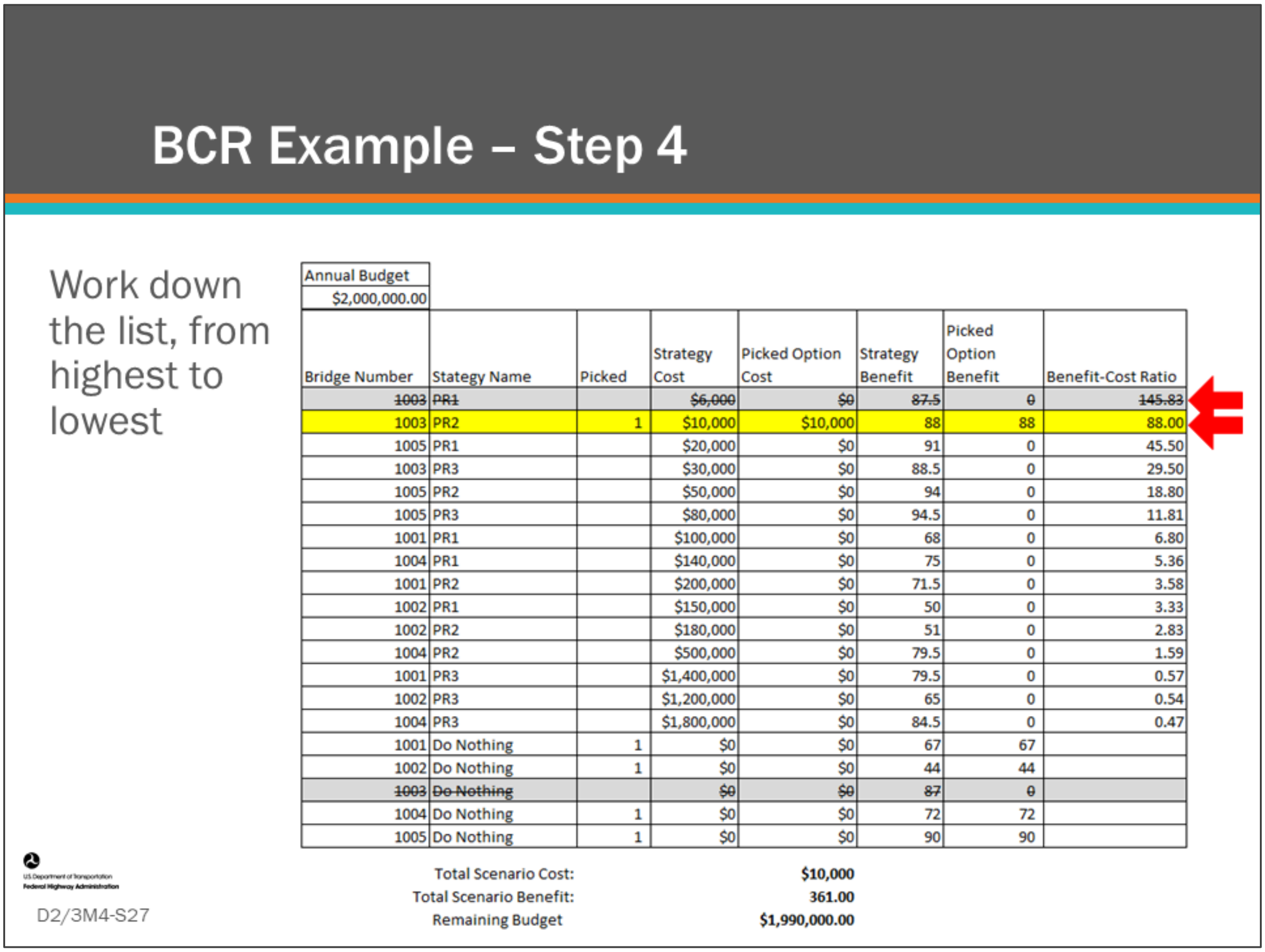
Total Scenario Cost:	$6,000
Total Scenario Benefit:	360.50
Remaining Budget	$1,994,000.00

Key Message

Let's complete an example calculation using the BCR method on a bridge from the list that was used previously. Step 3 of the BCR Example is:

- Start with the option that has the highest B/C ratio
    - Deselect the "Do Nothing" option
    - The total scenario cost is $6,000
    - The total scenario benefit is 360.5

D2/3M4-Slide 27



Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Benefit-Cost Ratio
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	~~145.83~~
1003	PR2	1	$10,000	$10,000	88	88	88.00
1005	PR1		$20,000	$0	91	0	45.50
1003	PR3		$30,000	$0	88.5	0	29.50
1005	PR2		$50,000	$0	94	0	18.80
1005	PR3		$80,000	$0	94.5	0	11.81
1001	PR1		$100,000	$0	68	0	6.80
1004	PR1		$140,000	$0	75	0	5.36
1001	PR2		$200,000	$0	71.5	0	3.58
1002	PR1		$150,000	$0	50	0	3.33
1002	PR2		$180,000	$0	51	0	2.83
1004	PR2		$500,000	$0	79.5	0	1.59
1001	PR3		$1,400,000	$0	79.5	0	0.57
1002	PR3		$1,200,000	$0	65	0	0.54
1004	PR3		$1,800,000	$0	84.5	0	0.47
1001	Do Nothing	1	$0	$0	67	67	
1002	Do Nothing	1	$0	$0	44	44	
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
1004	Do Nothing	1	$0	$0	72	72	
1005	Do Nothing	1	$0	$0	90	90	

Total Scenario Cost:	$10,000
Total Scenario Benefit:	361.00
Remaining Budget	$1,990,000.00

Key Message

Complete Step 4 of the BCR Example.

Step 4 of the BCR Example is:

- Work down the list, from highest to lowest
- If the next option has a higher strategy benefit than the previous option and selection of this option with deselection of the previous option does not exceed the budget, select this option and deselect the previous option

Step 4:

- Step down to the next row, highlighting the next highest Benefit-Cost Ratio, for Bridge Number -1003 and Strategy Name - PR2 (Denoted here as "BN1003-PR2")
  - Since it is the same bridge as the first selection, compare the benefit between the two options.
    - BN1003-PR2 has the greater benefit, and the selection is within budget
      - This can also be observed in the running total "Scenario Cost," shown at the bottom of the slide
    - Therefore, deselect BN1003-PR1 and select BN1003-PR2.
    - The total scenario cost is $10,000
    - The total scenario benefit is 361

D2/3M4-Slide 28

BCR Example – Step 4: If, And, Then

If the next option has a higher benefit than the previous option for the same bridge

And selection of this option with deselection of the previous option does not exceed the budget

Then select this option and deselect the previous option

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Benefit-Cost Ratio
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	~~145.83~~
1003	PR2	1	$10,000	$10,000	88	88	88.00
1005	PR1	1	$20,000	$20,000	91	91	45.50
1003	PR3		$30,000	$0	88.5	0	29.50
1005	PR2		$50,000	$0	94	0	18.80
1005	PR3		$80,000	$0	94.5	0	11.81
1001	PR1		$100,000	$0	68	0	6.80
1004	PR1		$140,000	$0	75	0	5.36
1001	PR2		$200,000	$0	71.5	0	3.58
1002	PR1		$150,000	$0	50	0	3.33
1002	PR2		$180,000	$0	51	0	2.83
1004	PR2		$500,000	$0	79.5	0	1.59
1001	PR3		$1,400,000	$0	79.5	0	0.57
1002	PR3		$1,200,000	$0	65	0	0.54
1004	PR3		$1,800,000	$0	84.5	0	0.47
1001	Do Nothing	1	$0	$0	67	67	
1002	Do Nothing	1	$0	$0	44	44	
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
1004	Do Nothing	1	$0	$0	72	72	
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	

Total Scenario Cost:	$30,000
Total Scenario Benefit:	362.00
Remaining Budget	$1,970,000.00

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Key Message

Continue with step 4 of the BCR Example.

Step 4, continued:

- Step down to the next highest Benefit-Cost Ratio, BN1005-PR1 and select it
- Deselect BN1005-Do Nothing
- In general, you check the previous option of the same bridge to see if selecting it increases benefit
- The total scenario cost is $30,000
- The total scenario benefit is 362

D2/3M4-Slide 29

BCR Example – Step 4: If, And, Then (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Benefit-Cost Ratio
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	~~145.83~~
~~1003~~	~~PR2~~		~~$10,000~~	~~$0~~	~~88~~	~~0~~	~~88.00~~
1005	PR1	1	$20,000	$20,000	91	91	45.50
1003	PR3	1	$30,000	$30,000	88.5	89	29.50
1005	PR2		$50,000	$0	94	0	18.80
1005	PR3		$80,000	$0	94.5	0	11.81
1001	PR1		$100,000	$0	68	0	6.80
1004	PR1		$140,000	$0	75	0	5.36
1001	PR2		$200,000	$0	71.5	0	3.58
1002	PR1		$150,000	$0	50	0	3.33
1002	PR2		$180,000	$0	51	0	2.83
1004	PR2		$500,000	$0	79.5	0	1.59
1001	PR3		$1,400,000	$0	79.5	0	0.57
1002	PR3		$1,200,000	$0	65	0	0.54
1004	PR3		$1,800,000	$0	84.5	0	0.47
1001	Do Nothing	1	$0	$0	67	67	
1002	Do Nothing	1	$0	$0	44	44	
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
1004	Do Nothing	1	$0	$0	72	72	
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	

Total Scenario Cost:	**$50,000**
Total Scenario Benefit:	**362.50**
Remaining Budget	**$1,950,000.00**

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D2/3M4-S29

Key Message

Continue with Step 4 of the BCR Example.

In our example:

Step 4, continued:

- Step down to the next highest Benefit-Cost Ratio, BN1003-PR3
    - Since it is the same bridge that has been previously selected, BN1003-PR2, compare the benefit with the previously selected options
    - BN1003-PR3 has the greater benefit, and the selection is within budget, so deselect BN1003-PR2 and select BN1003-PR3
    - The total scenario cost is $50,000
    - The total scenario benefit is 362.5

D2/3M4-Slide 30

BCR Example – Step 4: If, And, Then (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Benefit-Cost Ratio
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	~~145.83~~
~~1003~~	~~PR2~~		~~$10,000~~	~~$0~~	~~88~~	~~0~~	~~88.00~~
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	~~45.50~~
1003	PR3	1	$30,000	$30,000	88.5	89	29.50
1005	PR2	1	$50,000	$50,000	94	94	18.80
1005	PR3		$80,000	$0	94.5	0	11.81
1001	PR1		$100,000	$0	68	0	6.80
1004	PR1		$140,000	$0	75	0	5.36
1001	PR2		$200,000	$0	71.5	0	3.58
1002	PR1		$150,000	$0	50	0	3.33
1002	PR2		$180,000	$0	51	0	2.83
1004	PR2		$500,000	$0	79.5	0	1.59
1001	PR3		$1,400,000	$0	79.5	0	0.57
1002	PR3		$1,200,000	$0	65	0	0.54
1004	PR3		$1,800,000	$0	84.5	0	0.47
1001	Do Nothing	1	$0	$0	67	67	
1002	Do Nothing	1	$0	$0	44	44	
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
1004	Do Nothing	1	$0	$0	72	72	
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	

Total Scenario Cost:	$80,000
Total Scenario Benefit:	365.50
Remaining Budget	$1,920,000.00

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D2/3M4-S30

Key Message

Continue with step 4 of the BCR Example.

D2/3M4-Slide 31

BCR Example – Step 4: If, And, Then (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Benefit-Cost Ratio
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	~~145.83~~
~~1003~~	~~PR2~~		~~$10,000~~	~~$0~~	~~88~~	~~0~~	~~88.00~~
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	~~45.50~~
1003	PR3	1	$30,000	$30,000	88.5	89	29.50
~~1005~~	~~PR2~~		~~$50,000~~	~~$0~~	~~94~~	~~0~~	~~18.80~~
1005	PR3	1	$80,000	$80,000	94.5	95	11.81
1001	PR1		$100,000	$0	68	0	6.80
1004	PR1		$140,000	$0	75	0	5.36
1001	PR2		$200,000	$0	71.5	0	3.58
1002	PR1		$150,000	$0	50	0	3.33
1002	PR2		$180,000	$0	51	0	2.83
1004	PR2		$500,000	$0	79.5	0	1.59
1001	PR3		$1,400,000	$0	79.5	0	0.57
1002	PR3		$1,200,000	$0	65	0	0.54
1004	PR3		$1,800,000	$0	84.5	0	0.47
1001	Do Nothing	1	$0	$0	67	67	
1002	Do Nothing	1	$0	$0	44	44	
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
1004	Do Nothing	1	$0	$0	72	72	
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	

Total Scenario Cost:	**$110,000**
Total Scenario Benefit:	**366.00**
Remaining Budget	**$1,890,000.00**

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D2/3M4-S31

Key Message

Continue with Step 4 of the BCR Example.

In our example:

Step 4, continued:

- Step down to the next highest Benefit-Cost Ratio, BN1005-PR3.
    - Since it is the same bridge that has been previously selected, BN1005-PR2, compare the benefit between the two options
    - BN1005-PR3 has the greater benefit, and the selection is within budget, so deselect BN1005-PR2 and select BN1005-PR3
    - The total scenario cost is $110,000
    - The total scenario benefit is 366

D2/3M4-Slide 32

BCR Example – Step 4: If, And, Then (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Benefit-Cost Ratio
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	~~145.83~~
~~1003~~	~~PR2~~		~~$10,000~~	~~$0~~	~~88~~	~~0~~	~~88.00~~
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	~~45.50~~
1003	PR3	1	$30,000	$30,000	88.5	89	29.50
~~1005~~	~~PR2~~		~~$50,000~~	~~$0~~	~~94~~	~~0~~	~~18.80~~
1005	PR3	1	$80,000	$80,000	94.5	95	11.81
1001	PR1	1	$100,000	$100,000	68	68	6.80
1004	PR1		$140,000	$0	75	0	5.36
1001	PR2		$200,000	$0	71.5	0	3.58
1002	PR1		$150,000	$0	50	0	3.33
1002	PR2		$180,000	$0	51	0	2.83
1004	PR2		$500,000	$0	79.5	0	1.59
1001	PR3		$1,400,000	$0	79.5	0	0.57
1002	PR3		$1,200,000	$0	65	0	0.54
1004	PR3		$1,800,000	$0	84.5	0	0.47
~~1001~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~67~~	~~0~~	
1002	Do Nothing	1	$0	$0	44	44	
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
1004	Do Nothing	1	$0	$0	72	72	
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	

Total Scenario Cost:	**$210,000**
Total Scenario Benefit:	**367.00**
Remaining Budget	**$1,790,000.00**

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D2/3M4-S32

Key Message

Continue with Step 4 of the BCR Example.

In our example:

Step 4, continued:

- Step down to the next highest Benefit-Cost Ratio, BN1001-PR1
- Select the bridge and deselect BN1001-Do Nothing
- The total scenario cost is $210,000
- The total scenario benefit is 367

D2/3M4-Slide 33

BCR Example – Step 4: If, And, Then (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Benefit-Cost Ratio
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	~~145.83~~
~~1003~~	~~PR2~~		~~$10,000~~	~~$0~~	~~88~~	~~0~~	~~88.00~~
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	~~45.50~~
1003	PR3	1	$30,000	$30,000	88.5	89	29.50
~~1005~~	~~PR2~~		~~$50,000~~	~~$0~~	~~94~~	~~0~~	~~18.80~~
1005	PR3	1	$80,000	$80,000	94.5	95	11.81
1001	PR1	1	$100,000	$100,000	68	68	6.80
1004	PR1	1	$140,000	$140,000	75	75	5.36
1001	PR2		$200,000	$0	71.5	0	3.58
1002	PR1		$150,000	$0	50	0	3.33
1002	PR2		$180,000	$0	51	0	2.83
1004	PR2		$500,000	$0	79.5	0	1.59
1001	PR3		$1,400,000	$0	79.5	0	0.57
1002	PR3		$1,200,000	$0	65	0	0.54
1004	PR3		$1,800,000	$0	84.5	0	0.47
~~1001~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~67~~	~~0~~	
1002	Do Nothing	1	$0	$0	44	44	
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
~~1004~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~72~~	~~0~~	
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	

Total Scenario Cost:	**$350,000**
Total Scenario Benefit:	**370.00**
Remaining Budget	**$1,650,000.00**

D2/3M4-S33

Key Message

Continue with Step 4 of the BCR Example.

In our example:

Step 4, continued:

- Step down to the next highest Benefit-Cost Ratio, BN1004-PR1
- Select the option and deselect BN1004-Do Nothing
- The total scenario cost is $350,000
- The total scenario benefit is 370

D2/3M4-Slide 34

BCR Example – Step 4: If, And, Then (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Benefit-Cost Ratio
1003	PR1		$6,000	$0	87.5	0	145.83
1003	PR2		$10,000	$0	88	0	88.00
1005	PR1		$20,000	$0	91	0	45.50
1003	PR3	1	$30,000	$30,000	88.5	89	29.50
1005	PR2		$50,000	$0	94	0	18.80
1005	PR3	1	$80,000	$80,000	94.5	95	11.81
1001	PR1		$100,000	$0	68	0	6.80
1004	PR1	1	$140,000	$140,000	75	75	5.36
1001	PR2	1	$200,000	$200,000	71.5	72	3.58
1002	PR1		$150,000	$0	50	0	3.33
1002	PR2		$180,000	$0	51	0	2.83
1004	PR2		$500,000	$0	79.5	0	1.59
1001	PR3		$1,400,000	$0	79.5	0	0.57
1002	PR3		$1,200,000	$0	65	0	0.54
1004	PR3		$1,800,000	$0	84.5	0	0.47
1001	Do Nothing		$0	$0	67	0	
1002	Do Nothing	1	$0	$0	44	44	
1003	Do Nothing		$0	$0	87	0	
1004	Do Nothing		$0	$0	72	0	
1005	Do Nothing		$0	$0	90	0	

Total Scenario Cost:	$450,000
Total Scenario Benefit:	373.50
Remaining Budget	$1,550,000.00

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D2/3M4-S34

Key Message

Continue with Step 4 of the BCR Example.

In our example:

Step 4, continued:

- Step down to the next highest Benefit-Cost Ratio, BN1001-PR2
- Because it is the same bridge that has been previously selected, BN1001-PR1, compare the benefit between the two options
- BN1001-PR2 has the greater benefit, and the selection is within budget, so deselect BN1001-PR1 and select BN1001-PR2
- The total scenario cost is $450,000
- The total scenario benefit is 373.50

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BCR Example – Step 4: If, And, Then (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Benefit-Cost Ratio
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	~~145.83~~
~~1003~~	~~PR2~~		~~$10,000~~	~~$0~~	~~88~~	~~0~~	~~88.00~~
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	~~45.50~~
1003	PR3	1	$30,000	$30,000	88.5	89	29.50
~~1005~~	~~PR2~~		~~$50,000~~	~~$0~~	~~94~~	~~0~~	~~18.80~~
1005	PR3	1	$80,000	$80,000	94.5	95	11.81
~~1001~~	~~PR1~~		~~$100,000~~	~~$0~~	~~68~~	~~0~~	~~6.80~~
1004	PR1	1	$140,000	$140,000	75	75	5.36
1001	PR2	1	$200,000	$200,000	71.5	72	3.58
1002	PR1	1	$150,000	$150,000	50	50	3.33
1002	PR2		$180,000	$0	51	0	2.83
1004	PR2		$500,000	$0	79.5	0	1.59
1001	PR3		$1,400,000	$0	79.5	0	0.57
1002	PR3		$1,200,000	$0	65	0	0.54
1004	PR3		$1,800,000	$0	84.5	0	0.47
~~1001~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~67~~	~~0~~	
~~1002~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~44~~	~~0~~	
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
~~1004~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~72~~	~~0~~	
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	

Total Scenario Cost:	**$600,000**
Total Scenario Benefit:	**379.50**
Remaining Budget	**$1,400,000.00**

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D2/3M4-S35

Key Message

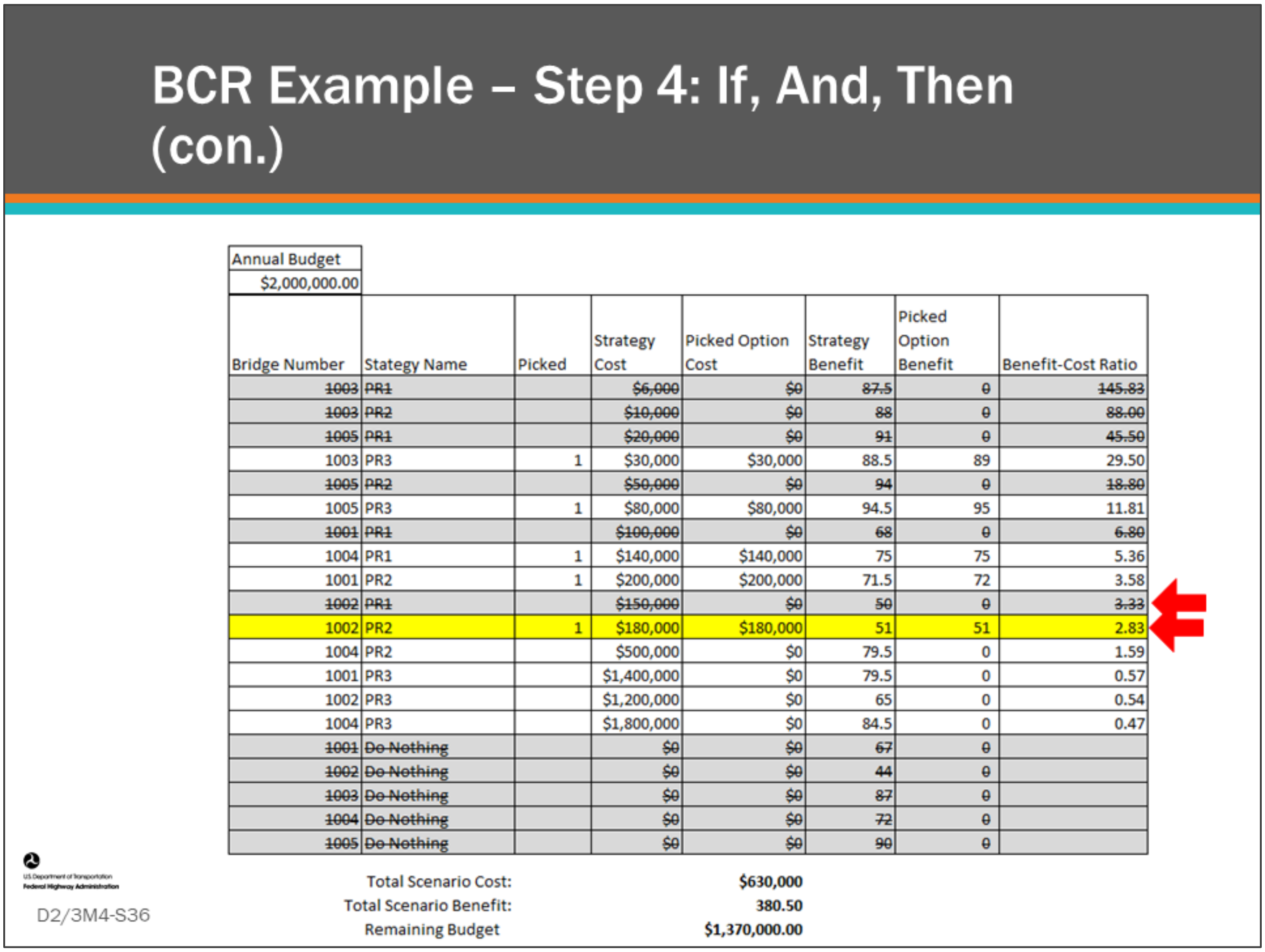
Continue with Step 4 of the BCR Example.

In our example:

Step 4, continued:

- Step down to the next highest Benefit-Cost Ratio, BN1002-PR1
- Select the option and deselect BN1002-Do Nothing
- Note, all of the Do-Nothing options have been deselected.
- The total scenario cost is $600,000
- The total scenario benefit is 379.50

D2/3M4-Slide 36



Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Benefit-Cost Ratio
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	~~145.83~~
~~1003~~	~~PR2~~		~~$10,000~~	~~$0~~	~~88~~	~~0~~	~~88.00~~
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	~~45.50~~
1003	PR3	1	$30,000	$30,000	88.5	89	29.50
~~1005~~	~~PR2~~		~~$50,000~~	~~$0~~	~~94~~	~~0~~	~~18.80~~
1005	PR3	1	$80,000	$80,000	94.5	95	11.81
~~1001~~	~~PR1~~		~~$100,000~~	~~$0~~	~~68~~	~~0~~	~~6.80~~
1004	PR1	1	$140,000	$140,000	75	75	5.36
1001	PR2	1	$200,000	$200,000	71.5	72	3.58
~~1002~~	~~PR1~~		~~$150,000~~	~~$0~~	~~50~~	~~0~~	~~3.33~~
1002	PR2	1	$180,000	$180,000	51	51	2.83
1004	PR2		$500,000	$0	79.5	0	1.59
1001	PR3		$1,400,000	$0	79.5	0	0.57
1002	PR3		$1,200,000	$0	65	0	0.54
1004	PR3		$1,800,000	$0	84.5	0	0.47
~~1001~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~67~~	~~0~~	
~~1002~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~44~~	~~0~~	
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
~~1004~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~72~~	~~0~~	
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	

Total Scenario Cost:	$630,000
Total Scenario Benefit:	380.50
Remaining Budget	$1,370,000.00

Key Message

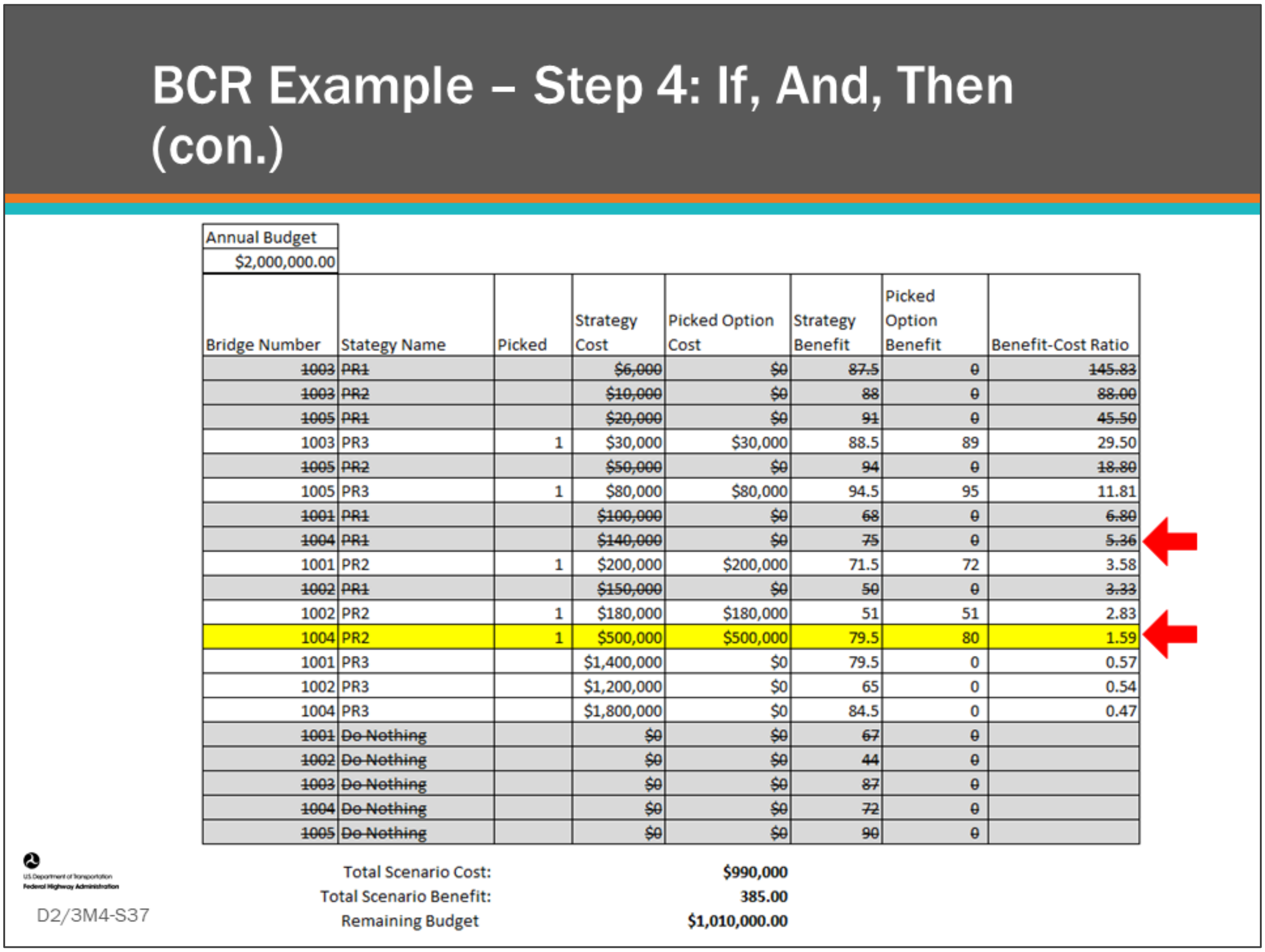
Continue with Step 4 of the BCR Example.

In our example:

Step 4, continued:

- Step down to the next highest B/C ratio, BN1002-PR2
  - Since it is the same bridge that has been previously selected, BN1002-PR1, compare the benefit between the two options
- BN1002-PR2 has a greater benefit than BN1002-PR1, so deselect BN1002-PR1 and select BN1002-PR2
- The total scenario cost is $630,000
- The total scenario benefit is 380.5

D2/3M4-Slide 37



BCR Example – Step 4: If, And, Then (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Benefit-Cost Ratio
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	~~145.83~~
~~1003~~	~~PR2~~		~~$10,000~~	~~$0~~	~~88~~	~~0~~	~~88.00~~
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	~~45.50~~
1003	PR3	1	$30,000	$30,000	88.5	89	29.50
~~1005~~	~~PR2~~		~~$50,000~~	~~$0~~	~~94~~	~~0~~	~~18.80~~
1005	PR3	1	$80,000	$80,000	94.5	95	11.81
~~1001~~	~~PR1~~		~~$100,000~~	~~$0~~	~~68~~	~~0~~	~~6.80~~
~~1004~~	~~PR1~~		~~$140,000~~	~~$0~~	~~75~~	~~0~~	~~5.36~~
1001	PR2	1	$200,000	$200,000	71.5	72	3.58
~~1002~~	~~PR1~~		~~$150,000~~	~~$0~~	~~50~~	~~0~~	~~3.33~~
1002	PR2	1	$180,000	$180,000	51	51	2.83
1004	PR2	1	$500,000	$500,000	79.5	80	1.59
1001	PR3		$1,400,000	$0	79.5	0	0.57
1002	PR3		$1,200,000	$0	65	0	0.54
1004	PR3		$1,800,000	$0	84.5	0	0.47
~~1001~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~67~~	~~0~~	
~~1002~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~44~~	~~0~~	
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
~~1004~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~72~~	~~0~~	
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	

Total Scenario Cost:	$990,000
Total Scenario Benefit:	385.00
Remaining Budget	$1,010,000.00

D2/3M4-S37

Key Message

Continue with Step 4 of the BCR Example.

In our example:

Step 4, continued:

- Step down to the next highest B/C ratio, BN1004-PR2
    - Since it is the same bridge that has been previously selected, BN1004-PR1, compare the benefit between the two options
- BN1004-PR2 has the greater benefit, and the selection is within budget, so deselect BN1004-PR1 and select BN1004-PR2
- The total scenario cost is $990,000
- The total scenario benefit is 385

D2/3M4-Slide 38

BCR Example – Steps 4 and 5

Repeat until all options have been reviewed or the budget is exceeded

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Benefit-Cost Ratio
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	~~145.83~~
~~1003~~	~~PR2~~		~~$10,000~~	~~$0~~	~~88~~	~~0~~	~~88.00~~
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	~~45.50~~
1003	PR3	1	$30,000	$30,000	88.5	89	29.50
~~1005~~	~~PR2~~		~~$50,000~~	~~$0~~	~~94~~	~~0~~	~~18.80~~
1005	PR3	1	$80,000	$80,000	94.5	95	11.81
~~1001~~	~~PR1~~		~~$100,000~~	~~$0~~	~~68~~	~~0~~	~~6.80~~
~~1004~~	~~PR1~~		~~$140,000~~	~~$0~~	~~75~~	~~0~~	~~5.36~~
1001	PR2	1	$200,000	$200,000	71.5	72	3.58
~~1002~~	~~PR1~~		~~$150,000~~	~~$0~~	~~50~~	~~0~~	~~3.33~~
1002	PR2	1	$180,000	$180,000	51	51	2.83
1004	PR2	1	$500,000	$500,000	79.5	80	1.59
~~1001~~	~~PR3~~		~~$1,400,000~~	~~$0~~	~~79.5~~	~~0~~	~~0.57~~
~~1002~~	~~PR3~~		~~$1,200,000~~	~~$0~~	~~65~~	~~0~~	~~0.54~~
~~1004~~	~~PR3~~		~~$1,800,000~~	~~$0~~	~~84.5~~	~~0~~	~~0.47~~
~~1001~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~67~~	~~0~~	
~~1002~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~44~~	~~0~~	
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
~~1004~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~72~~	~~0~~	
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	

Total Scenario Cost:	$990,000
Total Scenario Benefit:	385.00
Remaining Budget	$1,010,000.00

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D2/3M4-S38

Key Message

Complete Steps 4 and 5 of the BCR Example.

In our example:

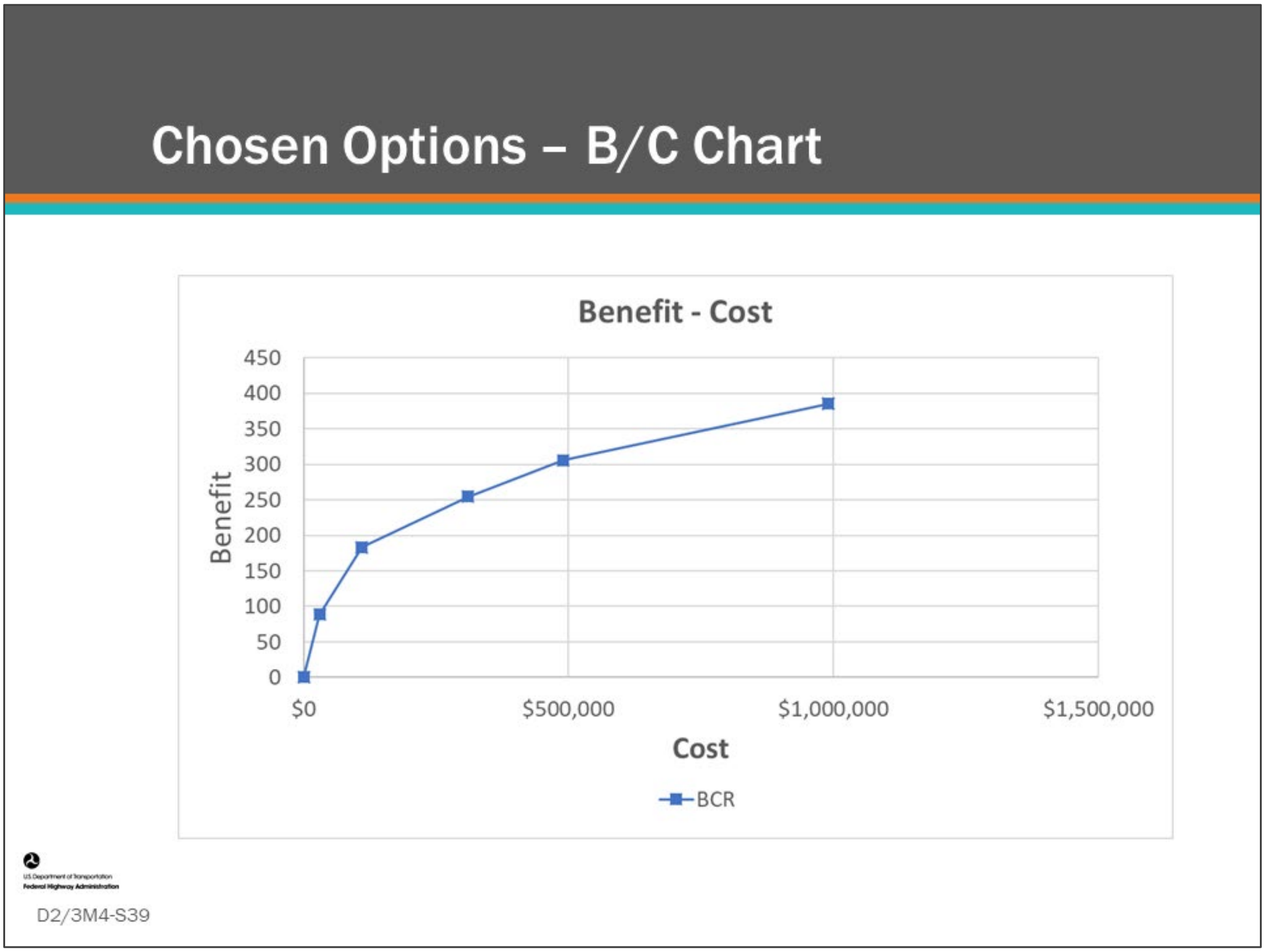
Step 4, continued:

- Step down to the next highest Benefit-Cost Ratio, BN1001-PR3
- Since it is the same bridge that has been previously selected, BN1001-PR2, compare the benefit between the two options
- BN1001-PR3 has the greater benefit, but the selection is not within budget. (Remaining budget is $1,010,000. BN1001-PR3 cost is $1,400,000. BN1001-PR2 cost is $200,000. $1,400,000 - $200,000 = $1,200,000, which exceeds the remaining budget)
- A check of BN1002-PR3 and BN1004-PR3 also show they exceed the remaining budget

Step 5:

- Repeat until all options have been reviewed or the budget is exceeded
  - All options have been checked so the analysis is complete.
  - **The result of the BCR analysis is a benefit of 385.0 having a cost of $990,000**
- Note, because we have such a small population of bridges in this example and some high cost options, the remaining budget is rather large ($1,010,000). When you have a large population of bridges with many different cost options for projects, this does not typically occur.

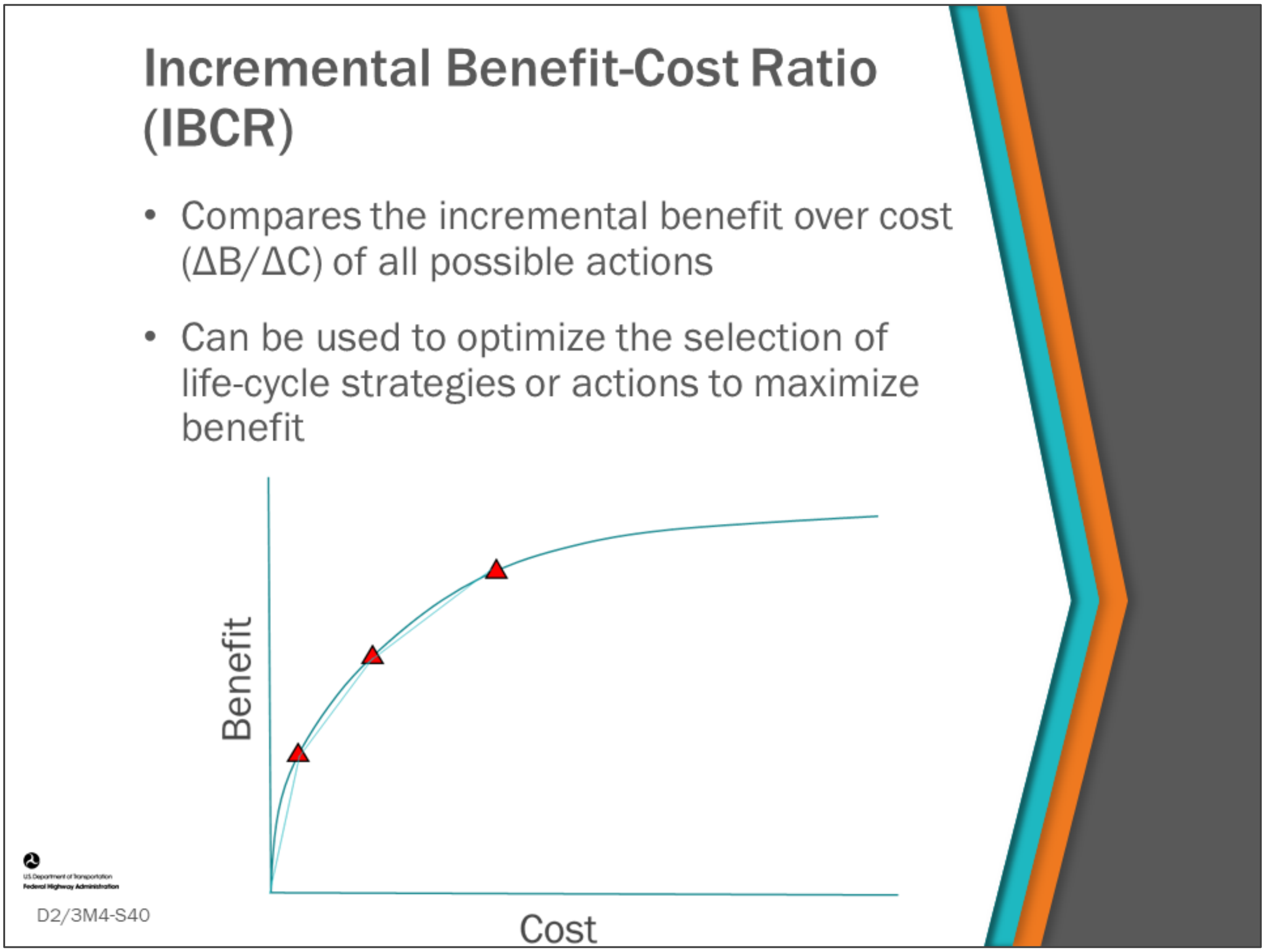
D2/3M4-Slide 39



Key Message

- The chosen strategies can be illustrated on a B/C scatter chart showing the accumulation of benefit when the bridges are plotted in order of benefit-cost ratios.
- This chart will be used for comparison to the alternate methods.

D2/3M4-Slide 40



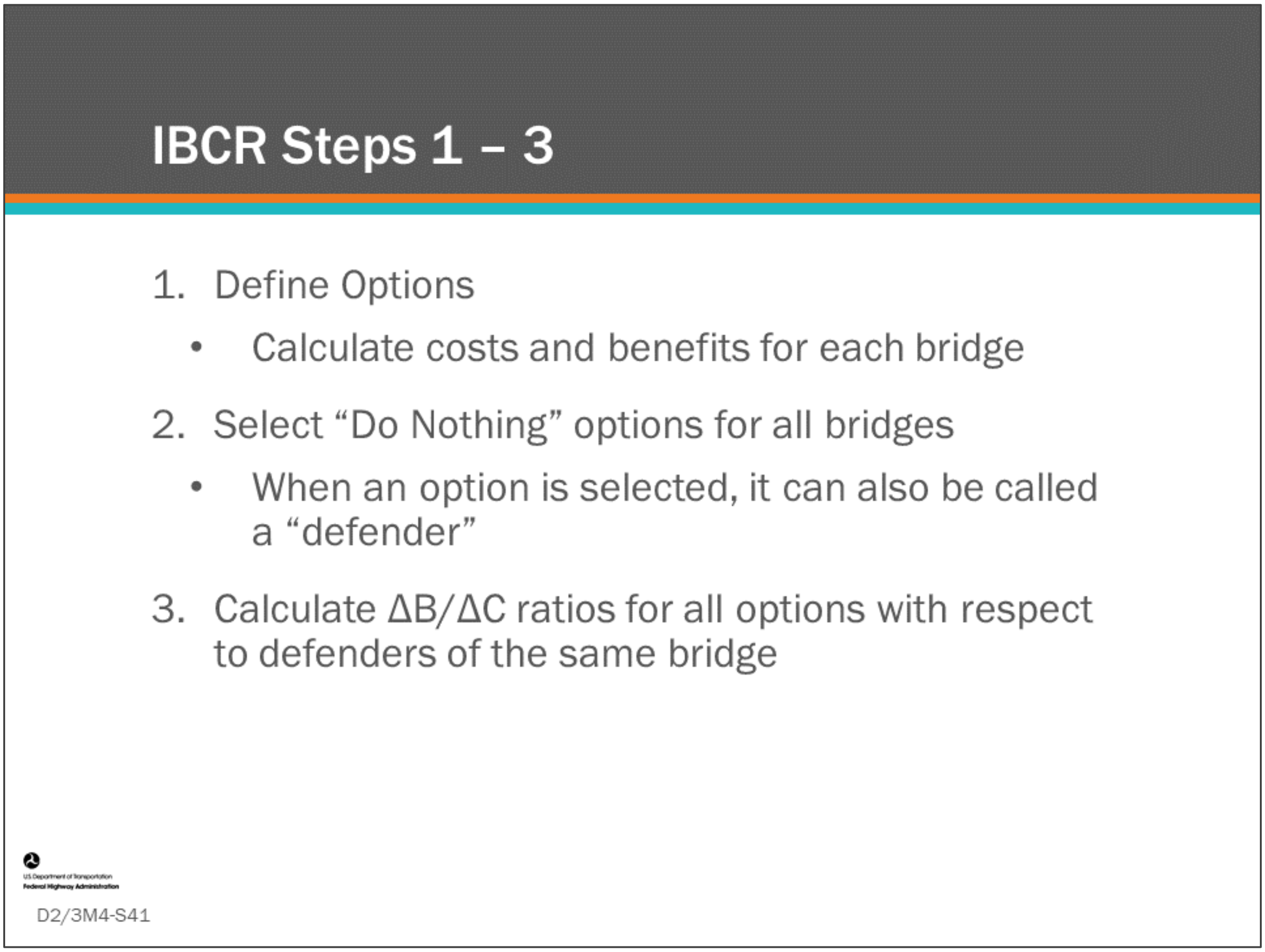
Key Message

Incremental Benefit-Cost Ratio (IBCR) is one of several advanced methods used to optimize actions or life-cycle strategy benefits having one or more constraints.

- IBCR is the "additional" utility or benefit gained from doing an action (treatment) over a less costly action (treatment).
- We will use our example bridge list to do an IBCR calculation.

The graph on this slide is illustrating IBC as the slope of the lines between consecutive options taken in the order of reducing benefit/cost ratio.

D2/3M4-Slide 41



Key Message

Review the first three steps used for the IBCR example in this lesson.

D2/3M4-Slide 42

IBCR Steps 4 - 5

4. Review entire list and select the option with the highest $\Delta B/\Delta C$
   - If the selection of this option does not violate constraints, deselect (and rule out for further consideration) the previous defender for the same bridge
     - $\Delta B/\Delta C$ for the newly selected defender is set to null
     - Eliminate for consideration all options for the same bridge with less benefit than the new defender
       - Recalculate $\Delta B/\Delta C$ for remaining options of the same bridge with respect to the new defender
5. Repeat Step 4 until a selection would violate constraints and or you run out of bridges and options

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D2/3M4-S42

Key Message

Review the steps 4 and 5 used for the IBCR example in this lesson.

D2/3M4-Slide 43

IBCR Example

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Incremental Benefit-Cost Ratio
1001	Do Nothing	1	$0	$0	67	67	
1001	PR1		$100,000	$0	68	0	10.00
1001	PR2		$200,000	$0	71.5	0	22.50
1001	PR3		$1,400,000	$0	79.5	0	8.93
1002	Do Nothing	1	$0	$0	44	44	
1002	PR1		$150,000	$0	50	0	40.00
1002	PR2		$180,000	$0	51	0	38.89
1002	PR3		$1,200,000	$0	65	0	17.50
1003	Do Nothing	1	$0	$0	87	87	
1003	PR1		$6,000	$0	87.5	0	83.33
1003	PR2		$10,000	$0	88	0	100.00
1003	PR3		$30,000	$0	88.5	0	50.00
1004	Do Nothing	1	$0	$0	72	72	
1004	PR1		$140,000	$0	75	0	21.43
1004	PR2		$500,000	$0	79.5	0	15.00
1004	PR3		$1,800,000	$0	84.5	0	6.94
1005	Do Nothing	1	$0	$0	90	90	
1005	PR1		$20,000	$0	91	0	50.00
1005	PR2		$50,000	$0	94	0	80.00
1005	PR3		$80,000	$0	94.5	0	56.25

Total Scenario Cost:	$0
Total Scenario Benefit:	360.00
Remaining Budget	$2,000,000.00

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D2/3M4-S43

Key Message

In this example, we will use IBCR to identify a list of strategies that will produce the maximum benefit, with a budget constraint of $2.0 million.

- Note, the strategy cost and benefits are shown on the slide.
- The same list of bridges and strategies are used here which were used for the BCR example.

D2/3M4-Slide 44

IBCR Example: Steps 1 – 2

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Incremental Benefit-Cost Ratio
1001	Do Nothing	1	$0	$0	67	67	
1001	PR1		$100,000	$0	68	0	10.00
1001	PR2		$200,000	$0	71.5	0	22.50
1001	PR3		$1,400,000	$0	79.5	0	8.93
1002	Do Nothing	1	$0	$0	44	44	
1002	PR1		$150,000	$0	50	0	40.00
1002	PR2		$180,000	$0	51	0	38.89
1002	PR3		$1,200,000	$0	65	0	17.50
1003	Do Nothing	1	$0	$0	87	87	
1003	PR1		$6,000	$0	87.5	0	83.33
1003	PR2		$10,000	$0	88	0	100.00
1003	PR3		$30,000	$0	88.5	0	50.00
1004	Do Nothing	1	$0	$0	72	72	
1004	PR1		$140,000	$0	75	0	21.43
1004	PR2		$500,000	$0	79.5	0	15.00
1004	PR3		$1,800,000	$0	84.5	0	6.94
1005	Do Nothing	1	$0	$0	90	90	
1005	PR1		$20,000	$0	91	0	50.00
1005	PR2		$50,000	$0	94	0	80.00
1005	PR3		$80,000	$0	94.5	0	56.25

Total Scenario Cost:	**$0**
Total Scenario Benefit:	**360.00**
Remaining Budget	**$2,000,000.00**

D2/3M4-S44

Key Message

Review Step 1 and 2 of the IBCR Example.

Steps 1 and 2 of the IBCR Example are:

1. Define Options
    - Calculate costs and benefits for each strategy
2. Select “Do Nothing” options for all bridges
    - When an option is selected, it can also be called a “defender”
        - Note, for this example the “Do Nothing” option is shown as having a benefit or value because the index used here is a life-cycle plan strategy where the “Do Nothing” option also has a benefit

D2/3M4-Slide 45

IBCR Example: Step 3

$$\frac{\Delta B}{\Delta C} = \frac{(71.5 - 67)}{(\$0.2M - \$0)} = 22.50$$

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Incremental Benefit-Cost Ratio
1001	Do Nothing	1	$0	$0	67	67	
1001	PR1		$100,000	$0	68	0	10.00
1001	PR2		$200,000	$0	71.5	0	22.50
1001	PR3		$1,400,000	$0	79.5	0	8.93
1002	Do Nothing	1	$0	$0	44	44	
1002	PR1		$150,000	$0	50	0	40.00
1002	PR2		$180,000	$0	51	0	38.89
1002	PR3		$1,200,000	$0	65	0	17.50
1003	Do Nothing	1	$0	$0	87	87	
1003	PR1		$6,000	$0	87.5	0	83.33
1003	PR2		$10,000	$0	88	0	100.00
1003	PR3		$30,000	$0	88.5	0	50.00
1004	Do Nothing	1	$0	$0	72	72	
1004	PR1		$140,000	$0	75	0	21.43
1004	PR2		$500,000	$0	79.5	0	15.00
1004	PR3		$1,800,000	$0	84.5	0	6.94
1005	Do Nothing	1	$0	$0	90	90	
1005	PR1		$20,000	$0	91	0	50.00
1005	PR2		$50,000	$0	94	0	80.00
1005	PR3		$80,000	$0	94.5	0	56.25

Total Scenario Cost:	$0
Total Scenario Benefit:	360.00
Remaining Budget	$2,000,000.00

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D2/3M4-S45

Key Message

Review Step 3 of the IBCR Example.

Step 3: Calculate ΔB/ΔC for all options with respect to defenders of the same bridge

- In this case the defenders are the Do Nothing "Picked" options.
- An example calculation is shown on the slide
- These calculations are bridge specific
    - Example: challengers for BN1001 are always compared to the defender for BN1001 in the ΔB/ΔC calculations

D2/3M4-Slide 46

IBCR Example: Step 4

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Incremental Benefit-Cost Ratio
1001	Do Nothing	1	$0	$0	67	67	
1001	PR1		$100,000	$0	68	0	10.00
1001	PR2		$200,000	$0	71.5	0	22.50
1001	PR3		$1,400,000	$0	79.5	0	8.93
1002	Do Nothing	1	$0	$0	44	44	
1002	PR1		$150,000	$0	50	0	40.00
1002	PR2		$180,000	$0	51	0	38.89
1002	PR3		$1,200,000	$0	65	0	17.50
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	
1003	PR2	1	$10,000	$10,000	88	88	100.00
1003	PR3		$30,000	$0	88.5	0	25.00
1004	Do Nothing	1	$0	$0	72	72	
1004	PR1		$140,000	$0	75	0	21.43
1004	PR2		$500,000	$0	79.5	0	15.00
1004	PR3		$1,800,000	$0	84.5	0	6.94
1005	Do Nothing	1	$0	$0	90	90	
1005	PR1		$20,000	$0	91	0	50.00
1005	PR2		$50,000	$0	94	0	80.00
1005	PR3		$80,000	$0	94.5	0	56.25

Total Scenario Cost:	$10,000
Total Scenario Benefit:	361.00
Remaining Budget	$1,990,000.00

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D2/3M4-S46

Key Message

Review Step 4 of the IBCR Example.

Step 4: Review entire list and select the option with the highest ΔB/ΔC

- If the selection of this option does not violate constraints, deselect (and rule out for further consideration) the previous defender for the same bridge.
- ΔB/ΔC for the newly selected defender is set to null.
- Eliminate for consideration all options for the same bridge as the new defender with less benefit than the new defender.
- Recalculate ΔB/ΔC for remaining options (these will be options with greater benefit than the new defender) of the same with respect to the new defender.

In our example:

- Select the bridge strategy with the maximum IBC ratio (BN1003 – PR2 with an IBC ratio = 100) as the selected option or “defender” replacing BN1003 – Do Nothing.
    - BR1003 – Do Nothing is deselected and ruled out for further consideration.
    - The IBC ratio for the new defender will be set to null as shown in the next slide.
- Review the other BN1003 bridges (called challengers).
    - BN1003-PR1 is disqualified for further consideration because it has lower benefit than BN1003-PR2.
    - Set its IBC ratio to null.

- BN1003-PR3 has a greater benefit than BN1003-PR2, therefore, re-calculate the IBC ratio for BN1003-PR3 with respect to BN1003-PR2.
- The new ΔB/ΔC is 25 for BN1003-PR3 as shown on the slide. The calculation is (88.5 – 88) divided by ($0.03M - $0.01M) equals 25.
- The total scenario cost is $10,000.
- The total scenario benefit is 361.

D2/3M4-Slide 47

IBCR Example: Step 4 (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Incremental Benefit-Cost Ratio
1001	Do Nothing	1	$0	$0	67	67	
1001	PR1		$100,000	$0	68	0	10.00
1001	PR2		$200,000	$0	71.5	0	22.50
1001	PR3		$1,400,000	$0	79.5	0	8.93
1002	Do Nothing	1	$0	$0	44	44	
1002	PR1		$150,000	$0	50	0	40.00
1002	PR2		$180,000	$0	51	0	38.89
1002	PR3		$1,200,000	$0	65	0	17.50
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	
1003	PR2	1	$10,000	$10,000	88	88	
1003	PR3		$30,000	$0	88.5	0	25.00
1004	Do Nothing	1	$0	$0	72	72	
1004	PR1		$140,000	$0	75	0	21.43
1004	PR2		$500,000	$0	79.5	0	15.00
1004	PR3		$1,800,000	$0	84.5	0	6.94
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	
1005	PR2	1	$50,000	$50,000	94	94	80.00
1005	PR3		$80,000	$0	94.5	0	16.67

Total Scenario Cost:	$60,000
Total Scenario Benefit:	365.00
Remaining Budget	$1,940,000.00

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D2/3M4-S47

Key Message

Continue with Step 4 of the IBCR Example.

In our example:

- Review remaining IBC ratios for the next highest ΔB/ΔC.
- The Highest IBC ratio is BN1005 – PR2 with a value of 80.00, which is selected, and it becomes the new defender.
    - Its IBC ratio will be set to null in the next slide.
- BN1005 – Do Nothing is disqualified.
- BN1005 – PR1 is disqualified because it has a lower benefit than BN1005-PR2 (the defender).
    - Its IBC ratio is set to null.
- Re-calculate IBC ratio for BN1005 – PR3, again, which has a higher benefit than BN1005 – PR2 (the defender). As shown on the slide, the new value is 16.67.
- The total scenario cost is $60,000.
- The total scenario benefit is 365.

D2/3M4-Slide 48

IBCR Example: Step 4 (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Incremental Benefit-Cost Ratio
1001	Do Nothing	1	$0	$0	67	67	
1001	PR1		$100,000	$0	68	0	10.00
1001	PR2		$200,000	$0	71.5	0	22.50
1001	PR3		$1,400,000	$0	79.5	0	8.93
~~1002~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~44~~	~~0~~	
1002	PR1	1	$150,000	$150,000	50	50	40.00
1002	PR2		$180,000	$0	51	0	33.33
1002	PR3		$1,200,000	$0	65	0	14.29
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	
1003	PR2	1	$10,000	$10,000	88	88	
1003	PR3		$30,000	$0	88.5	0	25.00
1004	Do Nothing	1	$0	$0	72	72	
1004	PR1		$140,000	$0	75	0	21.43
1004	PR2		$500,000	$0	79.5	0	15.00
1004	PR3		$1,800,000	$0	84.5	0	6.94
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	
1005	PR2	1	$50,000	$50,000	94	94	
1005	PR3		$80,000	$0	94.5	0	16.67

Total Scenario Cost: **$210,000**
Total Scenario Benefit: **371.00**
Remaining Budget **$1,790,000.00**

D2/3M4-S48

Key Message

Continue with Step 4 of the IBCR Example.

In our example:

- Review remaining IBC ratios for the next highest ΔB/ΔC.
- Highest IBC ratio is BN1002-PR1 with a value of 40.00. It becomes the new defender.
- BN1002 – Do Nothing is deselected and disqualified.
- Re-calculate IBC ratio for BN1002-PR2 and BN1002-PR3 with respect to BN1002-PR1 (the defender).
- The recalculated IBC ratio for BN1002-PR2 is 33.33.
- The recalculated IBC ratio for BN1002-PR3 is 14.29.
- The total scenario cost is $210,000.
- The total scenario benefit is 371.

D2/3M4-Slide 49

IBCR Example: Step 4 (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Incremental Benefit-Cost Ratio
1001	Do Nothing	1	$0	$0	67	67	
1001	PR1		$100,000	$0	68	0	10.00
1001	PR2		$200,000	$0	71.5	0	22.50
1001	PR3		$1,400,000	$0	79.5	0	8.93
~~1002~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~44~~	~~0~~	
~~1002~~	~~PR1~~		~~$150,000~~	~~$0~~	~~50~~	~~0~~	
1002	PR2	1	$180,000	$180,000	51	51	33.33
1002	PR3		$1,200,000	$0	65	0	13.73
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	
1003	PR2	1	$10,000	$10,000	88	88	
1003	PR3		$30,000	$0	88.5	0	25.00
1004	Do Nothing	1	$0	$0	72	72	
1004	PR1		$140,000	$0	75	0	21.43
1004	PR2		$500,000	$0	79.5	0	15.00
1004	PR3		$1,800,000	$0	84.5	0	6.94
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	
1005	PR2	1	$50,000	$50,000	94	94	
1005	PR3		$80,000	$0	94.5	0	16.67

Total Scenario Cost:	**$240,000**
Total Scenario Benefit:	**372.00**
Remaining Budget	**$1,760,000.00**

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D2/3M4-S49

Key Message

Continue with Step 4 of the IBCR Example.

In our example:

- Review remaining IBC ratios for the next highest ΔB/ΔC.
- Highest IBC ratio is BN1002-PR2, with a value of 33.33. It becomes the new defender.
- This disqualifies the previous pick which has a lower benefit BN1002–PR1.
- The IBC ratio for BN1002-PR3 is recalculated with respect to BN1002-PR2 to get 13.73.
- The total scenario cost is $240,000.
- The total scenario benefit is 372.

D2/3M4-Slide 50

IBCR Example: Step 4 (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Incremental Benefit-Cost Ratio
1001	Do Nothing	1	$0	$0	67	67	
1001	PR1		$100,000	$0	68	0	10.00
1001	PR2		$200,000	$0	71.5	0	22.50
1001	PR3		$1,400,000	$0	79.5	0	8.93
~~1002~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~44~~	~~0~~	
~~1002~~	~~PR1~~		~~$150,000~~	~~$0~~	~~50~~	~~0~~	
1002	PR2	1	$180,000	$180,000	51	51	
1002	PR3		$1,200,000	$0	65	0	13.73
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	
~~1003~~	~~PR2~~		~~$10,000~~	~~$0~~	~~88~~	~~0~~	
1003	PR3	1	$30,000	$30,000	88.5	89	25.00
1004	Do Nothing	1	$0	$0	72	72	
1004	PR1		$140,000	$0	75	0	21.43
1004	PR2		$500,000	$0	79.5	0	15.00
1004	PR3		$1,800,000	$0	84.5	0	6.94
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	
1005	PR2	1	$50,000	$50,000	94	94	
1005	PR3		$80,000	$0	94.5	0	16.67

Total Scenario Cost:	**$260,000**
Total Scenario Benefit:	**372.50**
Remaining Budget	**$1,740,000.00**

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D2/3M4-S50

Key Message

Continue with Step 4 of the IBCR Example, and check Step 5.

In our example:

- Review remaining IBC ratios for the next highest ΔB/ΔC.
- Highest IBC ratio is BN1003 – PR3 with a value of 25.0, which is selected and becomes the new defender.
  - This disqualifies BN1003-PR2.
- The total scenario cost is $260,000.
- The total scenario benefit is 372.5.

D2/3M4-Slide 51

IBCR Example: Steps 5 and 6 (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Incremental Benefit-Cost Ratio
~~1001~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~67~~	~~0~~	
~~1001~~	~~PR1~~		~~$100,000~~	~~$0~~	~~68~~	~~0~~	
1001	PR2	1	$200,000	$200,000	71.5	72	22.50
1001	PR3		$1,400,000	$0	79.5	0	6.67
~~1002~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~44~~	~~0~~	
~~1002~~	~~PR1~~		~~$150,000~~	~~$0~~	~~50~~	~~0~~	
1002	PR2	1	$180,000	$180,000	51	51	
1002	PR3		$1,200,000	$0	65	0	13.73
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	
~~1003~~	~~PR2~~		~~$10,000~~	~~$0~~	~~88~~	~~0~~	
1003	PR3	1	$30,000	$30,000	88.5	89	
1004	Do Nothing	1	$0	$0	72	72	
1004	PR1		$140,000	$0	75	0	21.43
1004	PR2		$500,000	$0	79.5	0	15.00
1004	PR3		$1,800,000	$0	84.5	0	6.94
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	
1005	PR2	1	$50,000	$50,000	94	94	
1005	PR3		$80,000	$0	94.5	0	16.67

Total Scenario Cost:	**$460,000**
Total Scenario Benefit:	**377.00**
Remaining Budget	**$1,540,000.00**

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Key Message

Continue with Step 4 and check Step 5 of the IBCR Example.

In our example:

- Review remaining IBC ratios for the next highest ΔB/ΔC.
- Highest IBC ratio is BN1001-PR2, with a value of 22.50. It becomes the new defender.
- This disqualifies the BN1001 – Do Nothing and BN1001 – PR1 which has a lower benefit.
- Re-calculate IBC ratio for BN1001 – PR3, with respect to BN1001 – PR2 (the defender).
    - As shown on the slide, the new IBC ratio for BN1001 – PR3 is 6.67.
- The total scenario cost is $460,000.
- The total scenario benefit is 377.

D2/3M4-Slide 52

IBCR Example: Step 4 (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Incremental Benefit-Cost Ratio
~~1001~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~67~~	~~0~~	
~~1001~~	~~PR1~~		~~$100,000~~	~~$0~~	~~68~~	~~0~~	
1001	PR2	1	$200,000	$200,000	71.5	72	
1001	PR3		$1,400,000	$0	79.5	0	6.67
~~1002~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~44~~	~~0~~	
~~1002~~	~~PR1~~		~~$150,000~~	~~$0~~	~~50~~	~~0~~	
1002	PR2	1	$180,000	$180,000	51	51	
1002	PR3		$1,200,000	$0	65	0	13.73
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	
~~1003~~	~~PR2~~		~~$10,000~~	~~$0~~	~~88~~	~~0~~	
1003	PR3	1	$30,000	$30,000	88.5	89	
~~1004~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~72~~	~~0~~	
1004	PR1	1	$140,000	$140,000	75	75	21.43
1004	PR2		$500,000	$0	79.5	0	12.50
1004	PR3		$1,800,000	$0	84.5	0	5.72
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	
1005	PR2	1	$50,000	$50,000	94	94	
1005	PR3		$80,000	$0	94.5	0	16.67

Total Scenario Cost:	**$600,000**
Total Scenario Benefit:	**380.00**
Remaining Budget	**$1,400,000.00**

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Key Message

Continue with Step 4 and check Step 5 of the IBCR Example.

In our example:

- Review remaining IBC ratios for the next highest ΔB/ΔC.
- Highest IBC ratio is BN1004-PR1 with a value of 21.43. It becomes the new defender.
- This disqualifies the BN1004-Do Nothing.
- IBC ratios for BN1004-PR2 and BN1004-PR3 are recalculated with respect to BN1004-PR1.
    - BN1004-PR2 new IBC ratio is 12.50.
    - BN1004-PR3 new IBC ratio is 5.72.
- The total scenario cost is $600,000.
- The total scenario benefit is 380.

D2/3M4-Slide 53

IBCR Example: Steps 4, 5 and 6 (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Incremental Benefit-Cost Ratio
~~1001~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~67~~	~~0~~	
~~1001~~	~~PR1~~		~~$100,000~~	~~$0~~	~~68~~	~~0~~	
1001	PR2	1	$200,000	$200,000	71.5	72	
1001	PR3		$1,400,000	$0	79.5	0	6.67
~~1002~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~44~~	~~0~~	
~~1002~~	~~PR1~~		~~$150,000~~	~~$0~~	~~50~~	~~0~~	
1002	PR2	1	$180,000	$180,000	51	51	
1002	PR3		$1,200,000	$0	65	0	13.73
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	
~~1003~~	~~PR2~~		~~$10,000~~	~~$0~~	~~88~~	~~0~~	
1003	PR3	1	$30,000	$30,000	88.5	89	
~~1004~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~72~~	~~0~~	
1004	PR1	1	$140,000	$140,000	75	75	
1004	PR2		$500,000	$0	79.5	0	12.50
1004	PR3		$1,800,000	$0	84.5	0	5.72
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	
~~1005~~	~~PR2~~		~~$50,000~~	~~$0~~	~~94~~	~~0~~	
1005	PR3	1	$80,000	$80,000	94.5	95	16.67

Total Scenario Cost:	**$630,000**
Total Scenario Benefit:	**380.50**
Remaining Budget	**$1,370,000.00**

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D2/3M4-S53

Key Message

Continue with Step 4 and check Step 5 of the IBCR Example.

In our example:

- Review remaining IBC ratios for the next highest ΔB/ΔC.
- Highest IBC ratio is BN1005– PR3, with a value of 16.67. It becomes the new defender.
- This disqualifies the BN1005-PR2, which has a lower benefit.
- The total scenario cost is $630,000.
- The total scenario benefit is 380.5.

D2/3M4-Slide 54

IBCR Example: Step 4 (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Incremental Benefit-Cost Ratio
~~1001~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~67~~	~~0~~	
~~1001~~	~~PR1~~		~~$100,000~~	~~$0~~	~~68~~	~~0~~	
1001	PR2	1	$200,000	$200,000	71.5	72	
1001	PR3		$1,400,000	$0	79.5	0	6.67
~~1002~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~44~~	~~0~~	
~~1002~~	~~PR1~~		~~$150,000~~	~~$0~~	~~50~~	~~0~~	
~~1002~~	~~PR2~~		~~$180,000~~	~~$0~~	~~51~~	~~0~~	
1002	PR3	1	$1,200,000	$1,200,000	65	65	13.73
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	
~~1003~~	~~PR2~~		~~$10,000~~	~~$0~~	~~88~~	~~0~~	
1003	PR3	1	$30,000	$30,000	88.5	89	
~~1004~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~72~~	~~0~~	
1004	PR1	1	$140,000	$140,000	75	75	
1004	PR2		$500,000	$0	79.5	0	12.50
1004	PR3		$1,800,000	$0	84.5	0	5.72
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	
~~1005~~	~~PR2~~		~~$50,000~~	~~$0~~	~~94~~	~~0~~	
1005	PR3	1	$80,000	$80,000	94.5	95	

Total Scenario Cost:	**$1,650,000**
Total Scenario Benefit:	**394.50**
Remaining Budget	**$350,000.00**

D2/3M4-S54

Key Message

Continue with Step 4 and check Step 5 of the IBCR Example.

In our example:

- Review remaining IBC ratios for the next highest ΔB/ΔC.
- Highest IBC ratio is BN1002-PR3 with a value of 13.73 and it becomes the new defender.
- This disqualifies the BN1002-PR2, which has a lower benefit.
- The total scenario cost is $1,650,000 and the remaining budget is $350,000.
- The total scenario benefit is 394.5.

D2/3M4-Slide 55

IBCR Example: Step 4 (con.)

Annual Budget
$2,000,000.00

Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Incremental Benefit-Cost Ratio
~~1001~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~67~~	~~0~~	
~~1001~~	~~PR1~~		~~$100,000~~	~~$0~~	~~68~~	~~0~~	
1001	PR2	1	$200,000	$200,000	71.5	72	
~~1001~~	~~PR3~~		~~$1,400,000~~	~~$0~~	~~79.5~~	~~0~~	~~6.67~~
~~1002~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~44~~	~~0~~	
~~1002~~	~~PR1~~		~~$150,000~~	~~$0~~	~~50~~	~~0~~	
~~1002~~	~~PR2~~		~~$180,000~~	~~$0~~	~~51~~	~~0~~	
1002	PR3	1	$1,200,000	$1,200,000	65	65	
~~1003~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~87~~	~~0~~	
~~1003~~	~~PR1~~		~~$6,000~~	~~$0~~	~~87.5~~	~~0~~	
~~1003~~	~~PR2~~		~~$10,000~~	~~$0~~	~~88~~	~~0~~	
1003	PR3	1	$30,000	$30,000	88.5	89	
~~1004~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~72~~	~~0~~	
1004	PR1	1	$140,000	$140,000	75	75	
~~1004~~	~~PR2~~		~~$500,000~~	~~$0~~	~~79.5~~	~~0~~	~~12.50~~
~~1004~~	~~PR3~~		~~$1,800,000~~	~~$0~~	~~84.5~~	~~0~~	~~5.72~~
~~1005~~	~~Do Nothing~~		~~$0~~	~~$0~~	~~90~~	~~0~~	
~~1005~~	~~PR1~~		~~$20,000~~	~~$0~~	~~91~~	~~0~~	
~~1005~~	~~PR2~~		~~$50,000~~	~~$0~~	~~94~~	~~0~~	
1005	PR3	1	$80,000	$80,000	94.5	95	

Total Scenario Cost:	**$1,650,000**
Total Scenario Benefit:	**394.50**
Remaining Budget	**$350,000.00**

D2/3M4-S55

Key Message

Continue with Step 4 and check Step 5 of the IBCR Example.

In our example:

- A review of all remaining options shows the combination of picking them and disqualifying the current picked option will result in exceeding the available budget.
    - Example: If BN1001-PR3 is selected disqualifying BN1001-PR2: $1,650,000 - $200,000 + $1,400,000 = $2,850,000 which is greater than $2,000,000.
- Therefore, the process is complete.
- Total scenario cost is $1,650,000 and the remaining budget is $350,000.
- Total scenario benefit is 394.50.

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BCR versus IBCR

Method	Cost Result	Benefit Result
BCR	$990,000	385.00
IBCR	$1,650,000	394.50

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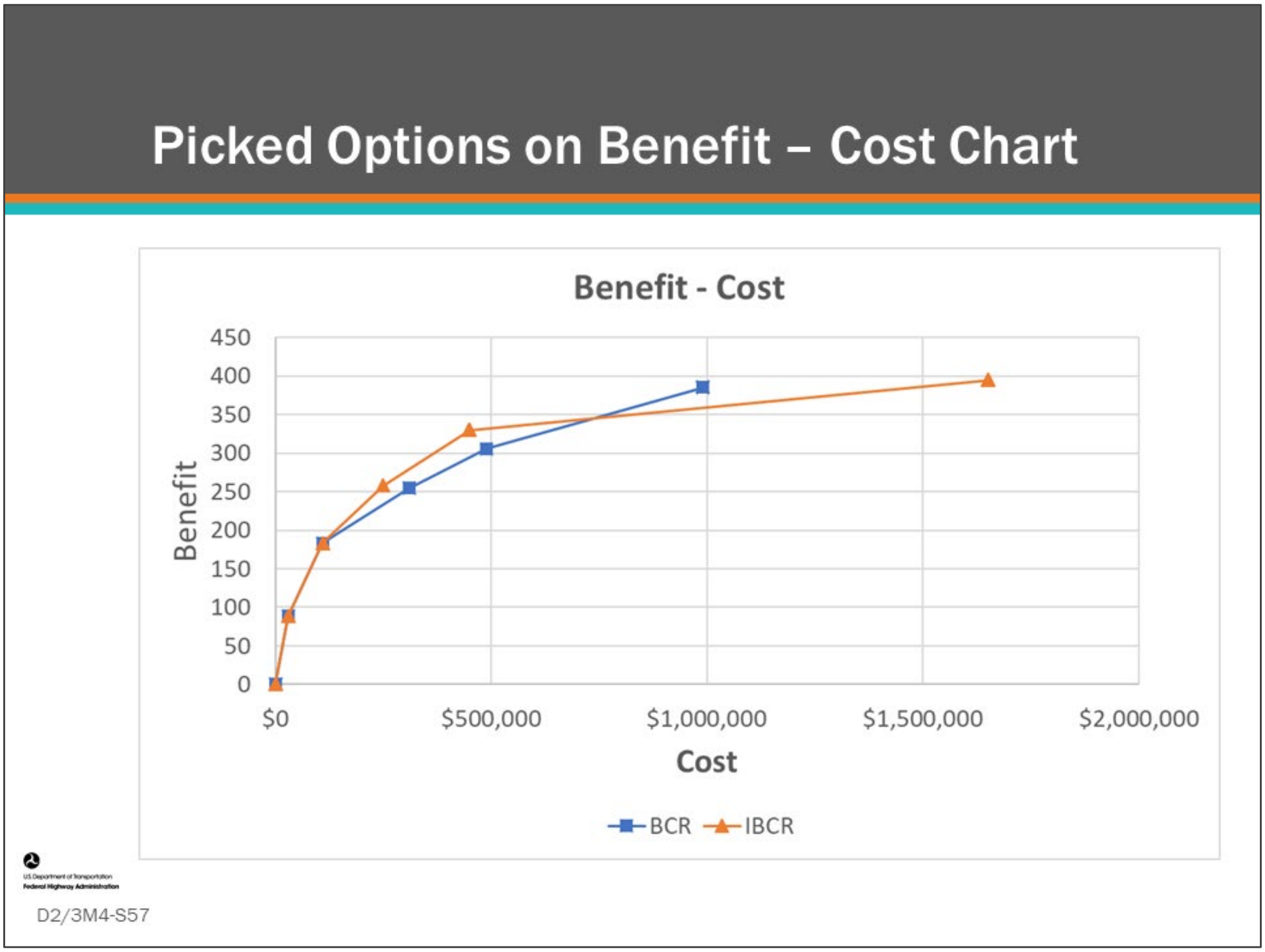
Key Message

A comparison of the BCR versus IBCR methods.

- In this case, the IBCR method found the greater benefit within the constrained budget of $2 Million.
  - This is because IBCR made slightly different order of choices.
- Note, that there are various enhancements which could be made to either of the processes that would permit us to spend more of the budget.
- These two methods illustrate how using a commercial solver for optimization can provide different choices to further maximize benefit, while still staying within constraints, such as a budget.

D2/3M4-Slide 57

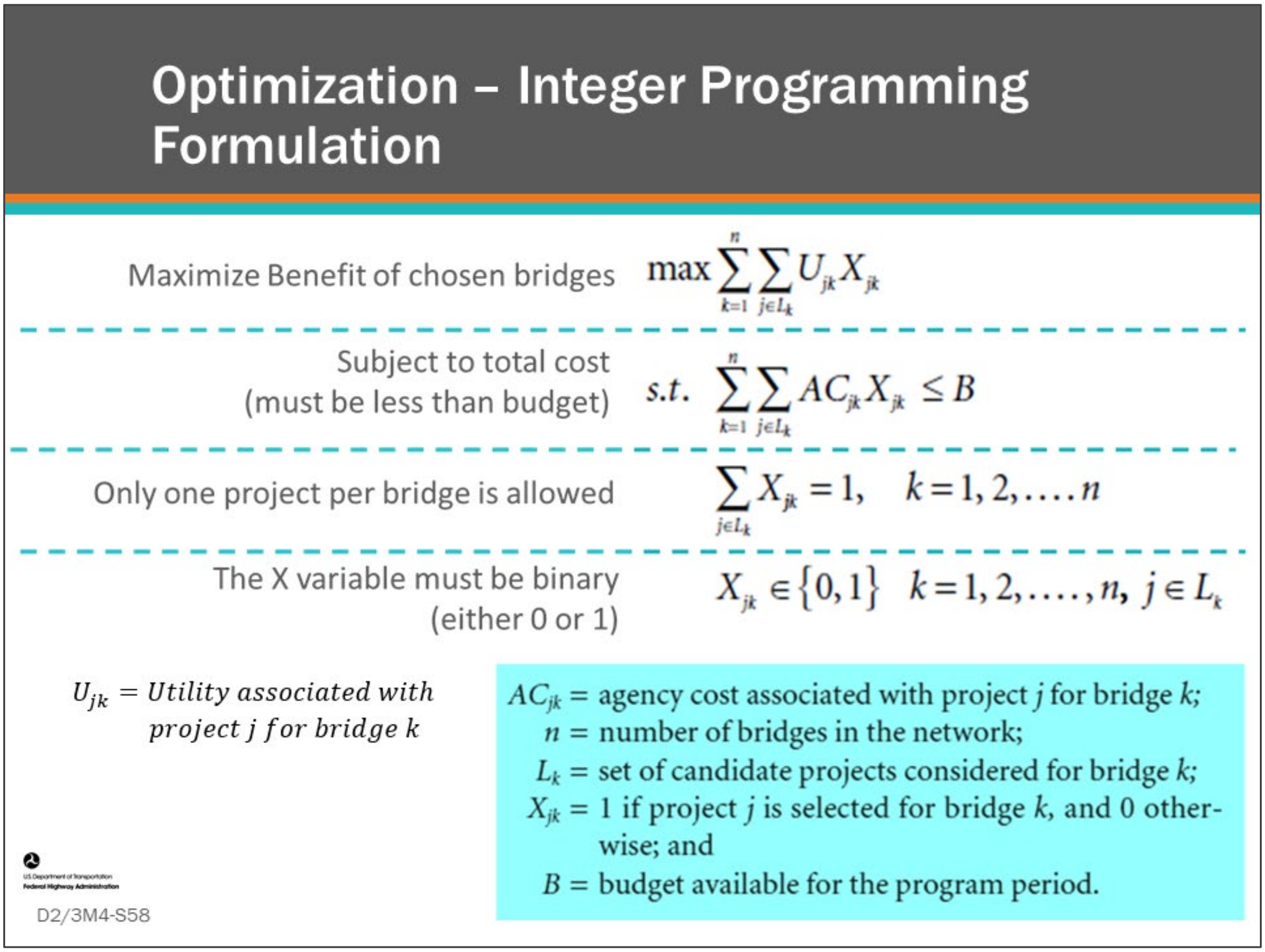


Key Message

Benefit – Cost are plotted for BCR and IBCR for comparison.

- This demonstrates the different methods produce different results.
- IBCR is known to produce more optimum results than BCR.
- The chosen strategies for IBCR are shown along with the chosen strategies for BCR completed earlier.
- The chosen options are shown on a B/C scatter chart illustrating the accumulation of benefit when the bridges are plotted in order of B/C ratios.
- It is difficult to see why the methods produce different results with the small data set that was used. If the number of bridges in the example were larger it would be more apparent that IBCR produces more optimum results.

D2/3M4-Slide 58



Key Message

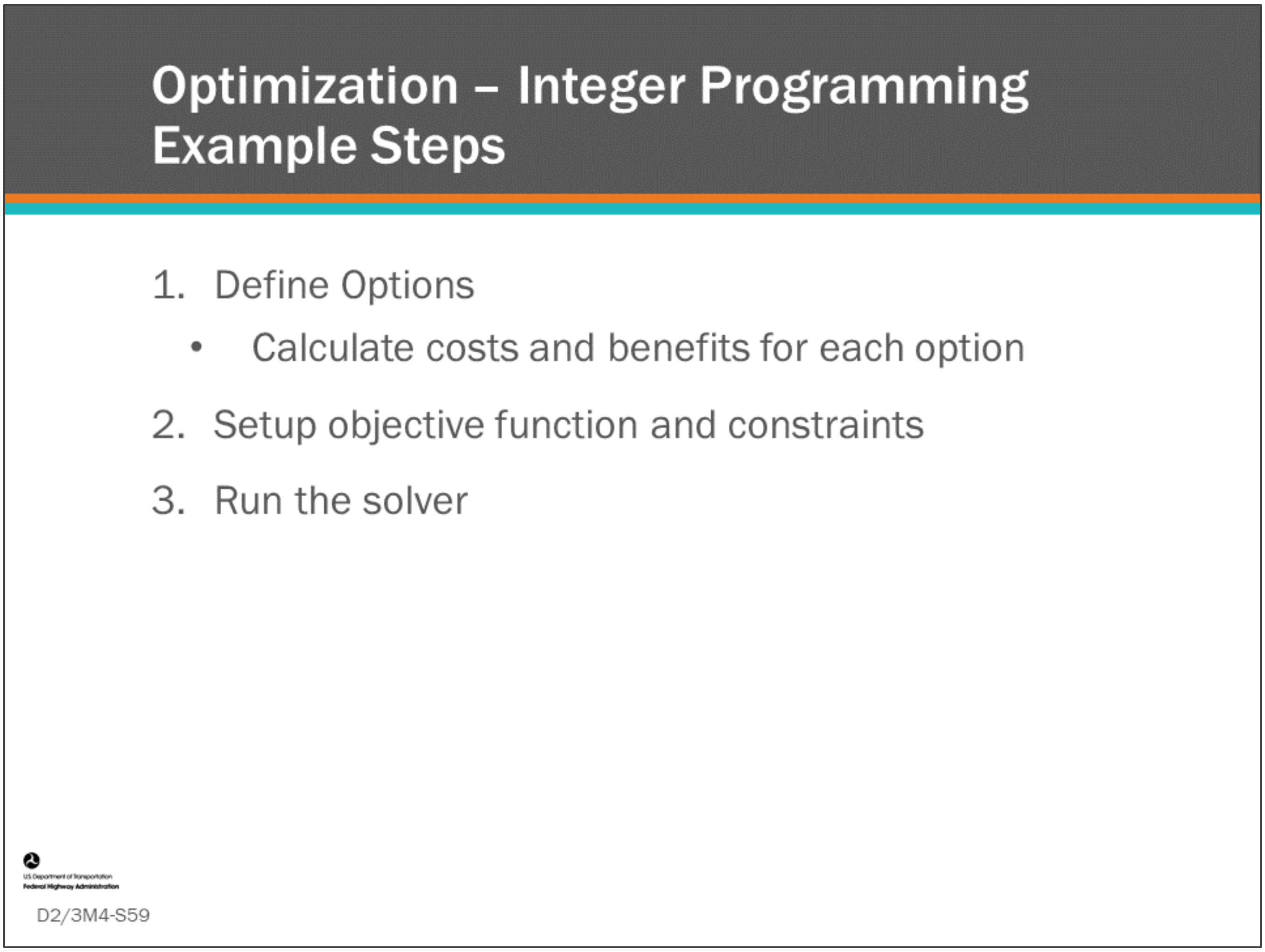
Integer programming uses binary numbers (1 = chosen, 0 = not chosen) to find the best combinations of bridge and project selections to solve an optimization problem.

- Commercial solvers have various methods to do this efficiently and accurately with the most common being “branch-and-bound” or “branch-and-cut”.
- Some BMS software uses commercial solvers for optimization.

In this section of the lesson, we will review how optimization can be performed using integer programming functions.

- For demonstration, we will use the “Solver” add-in for Microsoft Excel to solve for the maximum benefit for the data set that was used for the previous examples.

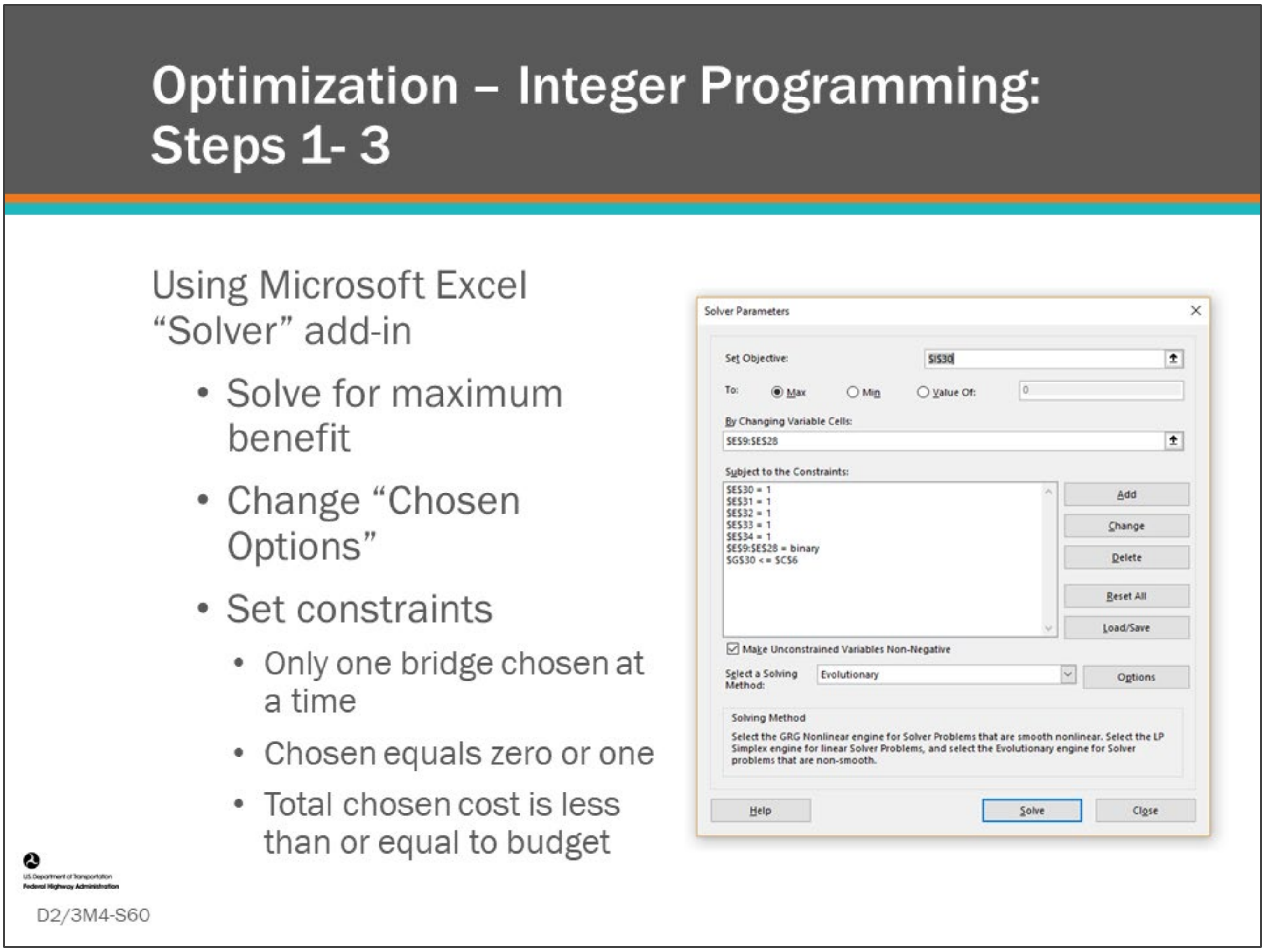
D2/3M4-Slide 59



Key Message

Review the steps used to set up the problem for a solver to complete.

D2/3M4-Slide 60



Key Message

Review steps one through three of the Optimization – Integer Programming Example.

Steps one through three of the Optimization – Integer Programming Example are:

- Using Microsoft Excel "Solver" add-in
    - Solve for maximum benefit
    - Change "Chosen Options"
    - Set constraints
        - Only one bridge chosen at a time
        - Chosen equals zero or one
        - Total chosen cost is less than or equal to budget

D2/3M4-Slide 61

Optimization – Integer Programming Example Results

- Sum Chosen Benefit = 398.5
- Sum Chosen Cost = $1,990,000

	C	D	E	F	G	H	I	J
4								
5	Annual Budget							
6	$2,000,000.00							
8	Bridge Number	Stategy Name	Picked	Strategy Cost	Picked Option Cost	Strategy Benefit	Picked Option Benefit	Benefit-Cost Ratio
9	1001	Do Nothing	-	$0	$0	67	0	
10	1001	PR1	-	$100,000	$0	68	0	6.80
11	1001	PR2	1	$200,000	$200,000	71.5	72	3.58
12	1001	PR3	-	$1,400,000	$0	79.5	0	0.57
13	1002	Do Nothing	-	$0	$0	44	0	
14	1002	PR1	-	$150,000	$0	50	0	3.33
15	1002	PR2	-	$180,000	$0	51	0	2.83
16	1002	PR3	1	$1,200,000	$1,200,000	65	65	0.54
17	1003	Do Nothing	-	$0	$0	87	0	
18	1003	PR1	-	$6,000	$0	87.5	0	145.83
19	1003	PR2	1	$10,000	$10,000	88	88	88.00
20	1003	PR3	-	$30,000	$0	88.5	0	29.50
21	1004	Do Nothing	-	$0	$0	72	0	
22	1004	PR1	-	$140,000	$0	75	0	5.36
23	1004	PR2	1	$500,000	$500,000	79.5	80	1.59
24	1004	PR3	-	$1,800,000	$0	84.5	0	0.47
25	1005	Do Nothing	-	$0	$0	90	0	
26	1005	PR1	-	$20,000	$0	91	0	45.50
27	1005	PR2	-	$50,000	$0	94	0	18.80
28	1005	PR3	1	$80,000	$80,000	94.5	95	11.81
29					Sum Pick Cost		Sum Picked Benefit	
30	Total options chosen for Bridge 1001:		1		$1,990,000		398.5	
31	Total options chosen for Bridge 1002:		1					
32	Total options chosen for Bridge 1003:		1					
33	Total options chosen for Bridge 1004:		1					
34	Total options chosen for Bridge 1005:		1					

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D2/3M4-S61

Key Message

Shown here are the results from the Excel “Solver” add-in, with the highlighted column showing the options for each bridge that were chosen by the solver.

- If you compare the cell values to the “Solver Parameters” in the previous slide, you can relate the setup for the solver including the objective (I30), the chosen cells (the only ones to vary, with everything else being calculated) and constraints back to the cell addresses in this slide.
- The data used for this example is the same that was used for the BCR and IBCR examples.

D2/3M4-Slide 62

Comparing All Three Optimization Methods

- Differences between BCR, IBCR, and MS Excel Solver

Method	Cost Result	Benefit Result
BCR	$990,000	385.0
IBCR	$1,650,000	394.5
MS Excel Solver	$1,990,000	398.5 ⬅ Highest Benefit

- Note, Integer Programming used more of the budget

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D2/3M4-S62

Key Message

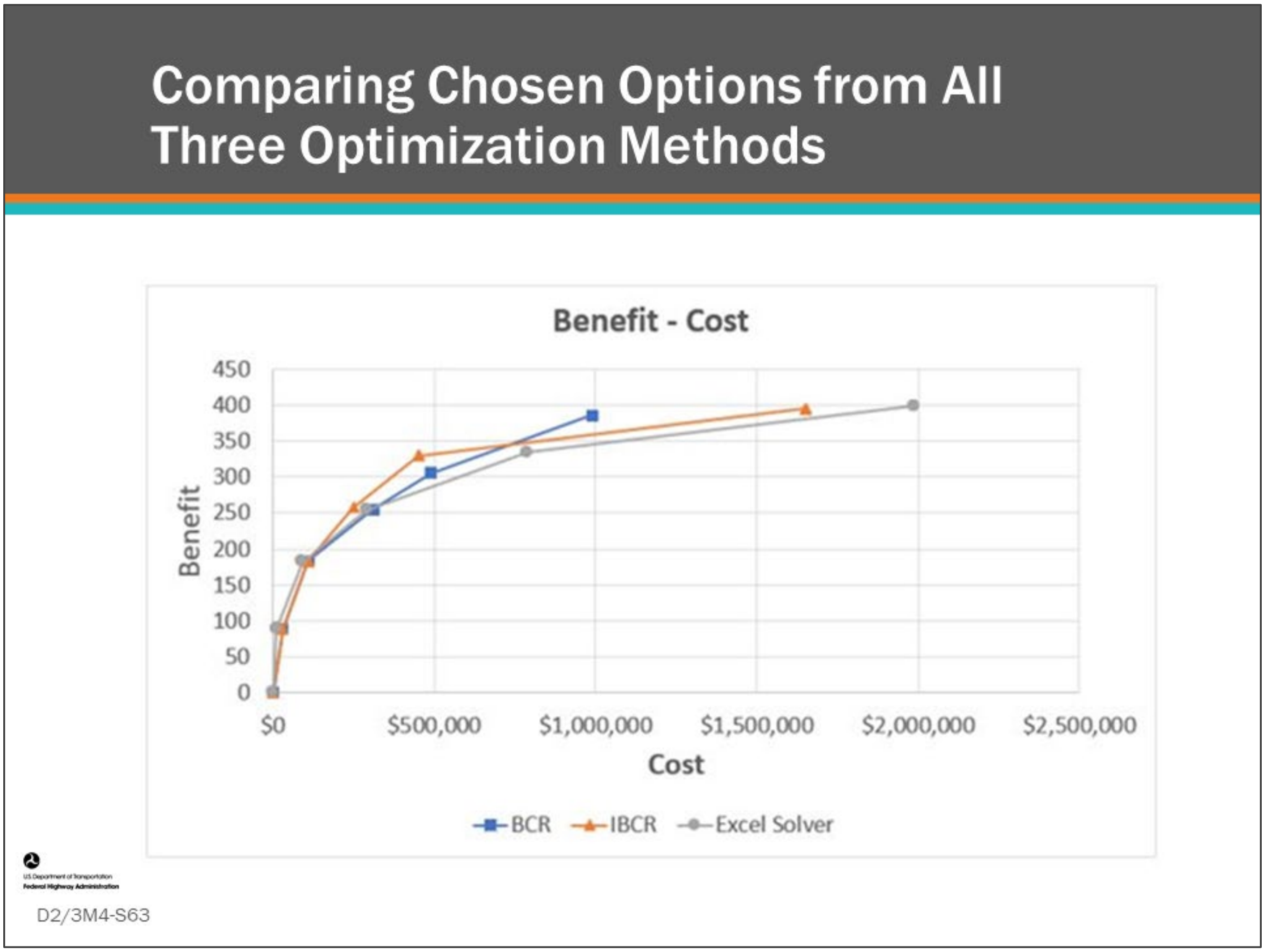
The cost and benefit results are shown for all three methods of maximizing cost with the constrained budget of $2.0 million.

Note that the Integer Programming Example resulted in a higher overall benefit and spent more of the budget.

This comparison points out a couple of differences between the methods. Although BCR and IBCR give true optimum answers some of the time, for budgets in between these points, an optimization solver may be able to find a better solution. It can also be seen that an integer program solver can handle a large number of constraints relatively easily. Finally, a solver solution does not inherently give a “priority” for each option, it simply finds the best set of options within the constraints. Nonetheless, a B/C ratio can often be calculated later to give an idea of the value of each solution option that was picked.

Note that if the budget was reduced to $1,000,000 instead of being set at $2,000,000, the optimization solver would have given the same result as the IBCR method. This shows that the IBCR method does give the true optimum at specific points as the budget is increased. The effect is not very pronounced for problems involving many bridges and large budgets, and the IBCR and BCR methods can give good solutions in a relatively short time.

D2/3M4-Slide 63

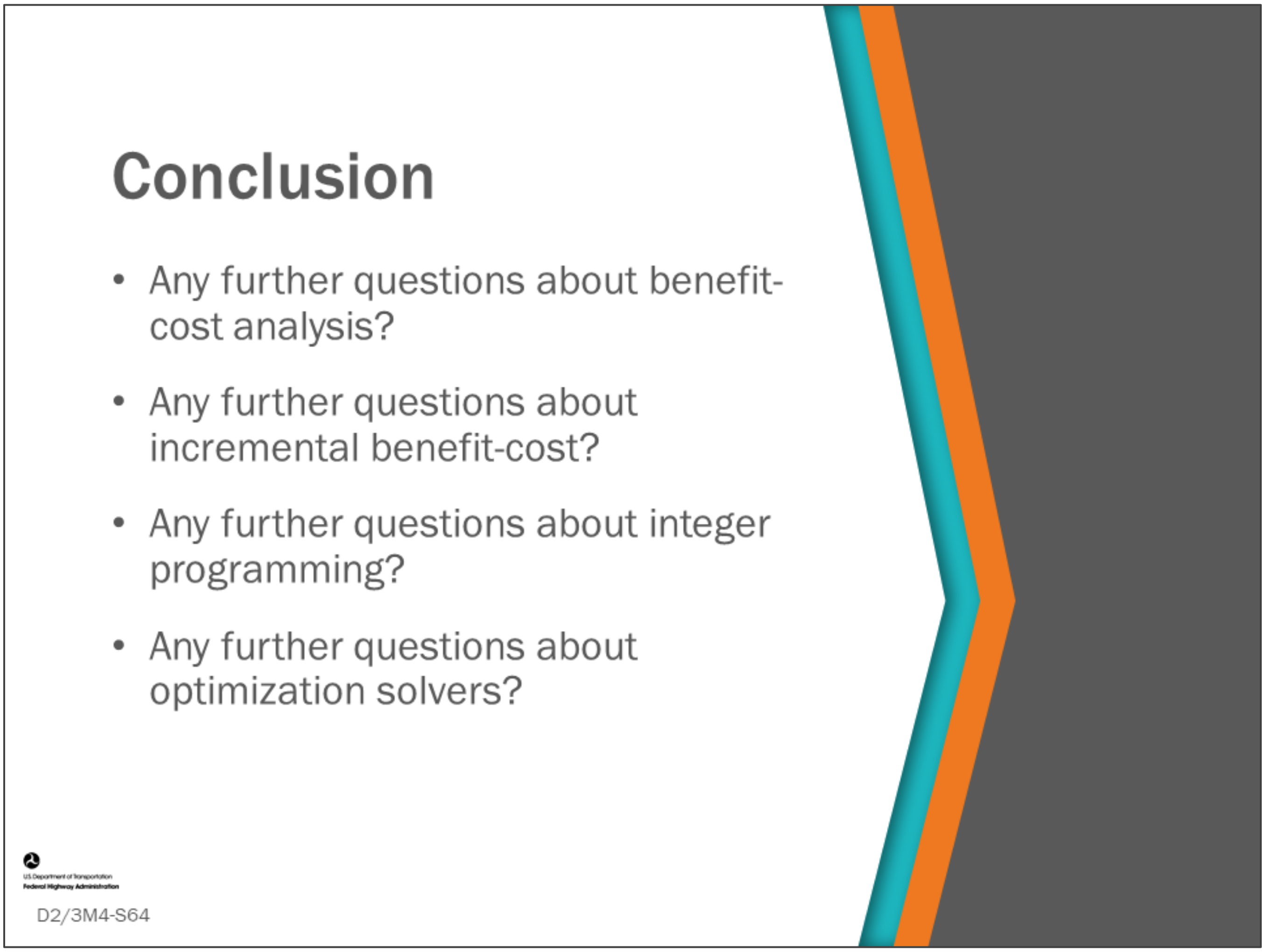


Key Message

The chosen options generated by the Excel "Solver" add-in are shown on this slide, along with the chosen options from the BCA and IBC examples completed earlier.

- Notice, that all the lines are similar in shape. The larger differences in total money spent is the result of the very small data set.
    - This is the result of the small data set used in the example and the results found here should not be considered typical when larger data sets are used.
- The purpose of this demonstration is to show there are several methods for solving the optimization problem, but this demonstration does not promote one method over another. BMS software use methods far more advanced that are demonstrated here.

D2/3M4-Slide 64



Key Message

This concludes Module 4: Benefit-Cost Ratio, Analysis by Incremental Benefit-Cost Ratio, and Analysis by Integer Programming.

- Any final questions or discussion? Lessons learned?

D2/3M4-Slide 65

Slide #	Image Description	Source Information
11	Line chart with health index on the y-axis and years on the x-axis. A curve represents a typical deterioration curve. The area under the curve method is demonstrated.	This Workshop.
12	The top profile has rehab action at 3 years with a cost of $350,000, a preservation action at 23 years with a cost of $75,000, a rehab action at 45 years with a cost of $350,000, and a preservation action at 60 years with a cost of $75,000, and a residual value at 75 years. The second profile shows preservation action at 3 years for a cost of $75,000, a preservation action at 23 years for $75,000, a rehab action at 52 years for a cost of $350,000, and a preservation action at 68 years for a cost of $75,000, and a residual value at 75 years. A short-term analysis period is shown of approximately 5 years.	This Workshop.
13	A family tree chart shows Total Utility at the top and Condition Weight (40), Lifecycle Weight (30), Mobility (15), and Risk (15) on the second level down. A red circle indicates the weight assigned to "Condition," equaling 40.	AASHTOWare™ Bridge Management (BrM).
20	Benefit/Cost ratio plotted on graph.	This Workshop.
21	The top profile has rehab action at 3 years with a cost of $350,000, a preservation action at 23 years with a cost of $75,000, a rehab action at 45 years with a cost of $350,000, and a preservation action at 60 years with a cost of $75,000, and a residual value at 75 years. The second profile shows preservation action at 3 years for a cost of $75,000, a preservation action at 23 years for $75,000, a rehab action at 52 years for a cost of $350,000, and a preservation action at 68 years for a cost of $75,000, and a residual value at 75 years. A short-term analysis period is shown of approximately 5 years.	This Workshop.

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D2/3M4-S65

D2/3M4 Figure Source List

D2/3M4-Slide 66

Slide #	Image Description	Source Information
22	Line chart with Health index on the y-axis and years on the x-axis. A curve represents a typical deterioration curve. Area under the curve method is demonstrated.	This Workshop.
39	A line chart shows benefit on the y-axis and cost on the x-axis. A curved line represents the benefit-cost.	This Workshop.
40	An example line chart with benefit on the y-axis and cost on the x-axis. A curved line with markers also has a lines extending from each successive marker which represents incremental benefit cost.	This Workshop.
57	A line chart titled Benefit - Cost has Benefit on y-axis and cost on the x-axis. Two curved lines are shown. One for BCR and one for IBCR. The two lines are identical, so the IBCR line covers the BCR line but both line markers can be seen.	This Workshop.
60	Screenshot of MS Excel Solver function pop-out screen.	MS Excel Solver.
60	Screenshot of MS Excel Solver function pop-out screen.	MS Excel Solver.
63	A line chart titled Benefit - Cost has Benefit on y-axis and cost on the x-axis. Three curved lines are shown. One for BCR, one for IBCR, and one for Excel Solver. The excel Solver line extends to the right (higher cost) than the other two.	This Workshop.

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D2/3M4-S66

D2/3M4 Figure Source List

Module Title: D2/3M5 – Using BMS for Performance Measure Validation and Selection, Investment Strategy Development, Target Setting, and Program Planning

Module Time: 120 minutes

Module Summary

On the first day of this workshop, Module 12 provided an introduction into scenario modeling and participants were introduced to using these models to develop investment strategies. In this module, we will take a deeper look at setting up scenario models, and we will see how BMS scenario modeling can be used for performance measure validation and selection, investment strategy development, target testing, and program planning. Before we proceed, we will first review how to perform scenario modeling and reasonableness testing of initial models.

Expected Outcome(s)

The expected outcome of this topic will be development of an understanding for the use of BMS scenario modeling for performance measure validation and selection, investment strategy development, target setting, and program planning.

Resource List

Slide	Reference Information
8,17, 21	AASHTO. *AASHTOWare™ Bridge Management (BrM) User's Manual*, version 5.2.3, Washington, DC, 2016.
30,31	FHWA. *Using a LCP (Life Cycle Planning) Process to Support Asset Management: A Handbook on Putting the Federal Guidance into Practice*. Washington, DC, January 2019.
33	U.S. Code of Federal Regulations. *Title 23 Highways.* Volume 1. Chapter 1. Part 515-Asset Management Plans. Office of the Federal Registrar (OFR).
40	FHWA. *Using a Life Cycle Planning Process to Support Asset Management*. Washington, DC, November, 2017.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D2/3M5-Slide 1

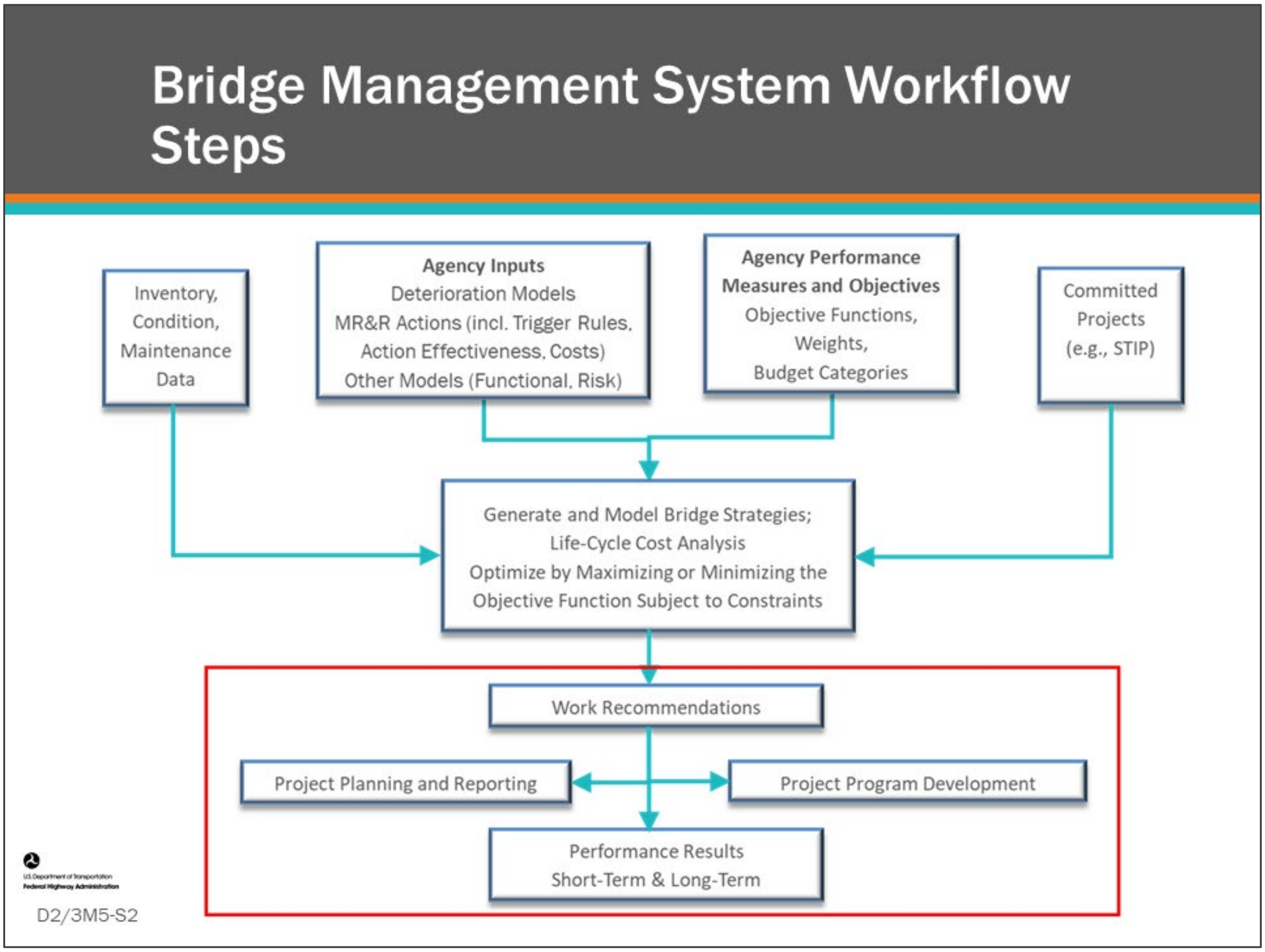
Key Message

On the first day of this workshop, Module 12 provided an introduction to scenario modeling, and participants were introduced to using these models to develop investment strategies. In this module, we will take a deeper look at setting up scenario models, and we will see how BMS scenario modeling can be used for performance measure validation and selection, investment strategy development, target setting, and program planning. Before we proceed, we will first review how to perform scenario modeling and reasonableness testing of initial models.

Disclaimer

FHWA does not promote or endorse patented and proprietary products. Bridge management software is largely proprietary. Workshop content pertaining to proprietary software is included only to illustrate how bridge management system concepts and analyses are applied in practice. The included content shall not be construed as promotion or endorsement of specific software.

D2/3M5-Slide 2



Key Message

Common workflow steps and features are shown on the slide. In this module, we will review work recommendations, project planning and reporting, project program development, and performance results.

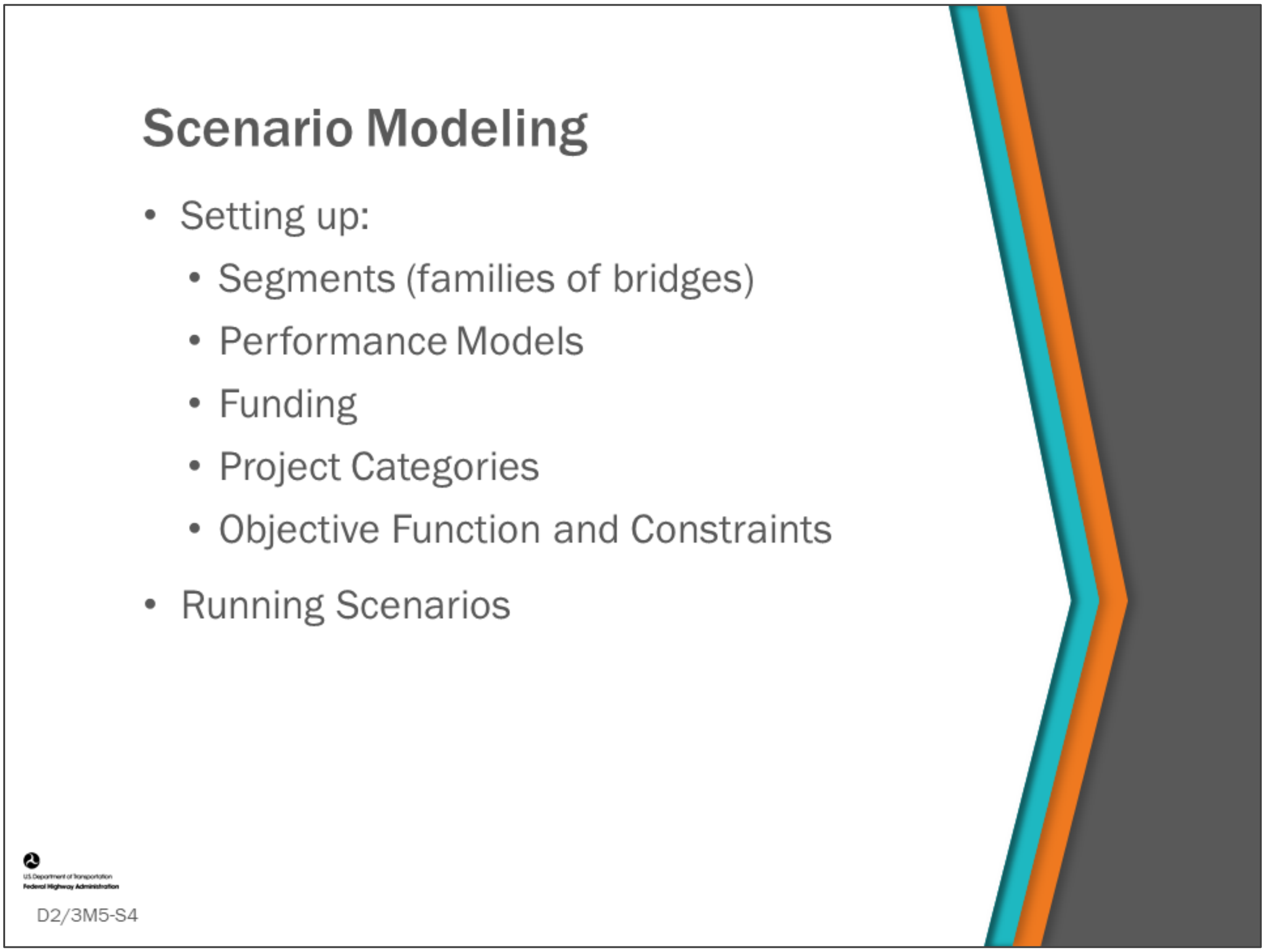
D2/3M5-Slide 3

Key Message

The topics to be discussed in this module include:

- How to use a BMS to perform scenario modeling including reasonableness testing of initial results
- Common examples where scenario modeling can be useful including:
  - Performance measure validation and selection
  - BMS utilization for investment strategy development
  - Target setting
  - Program planning

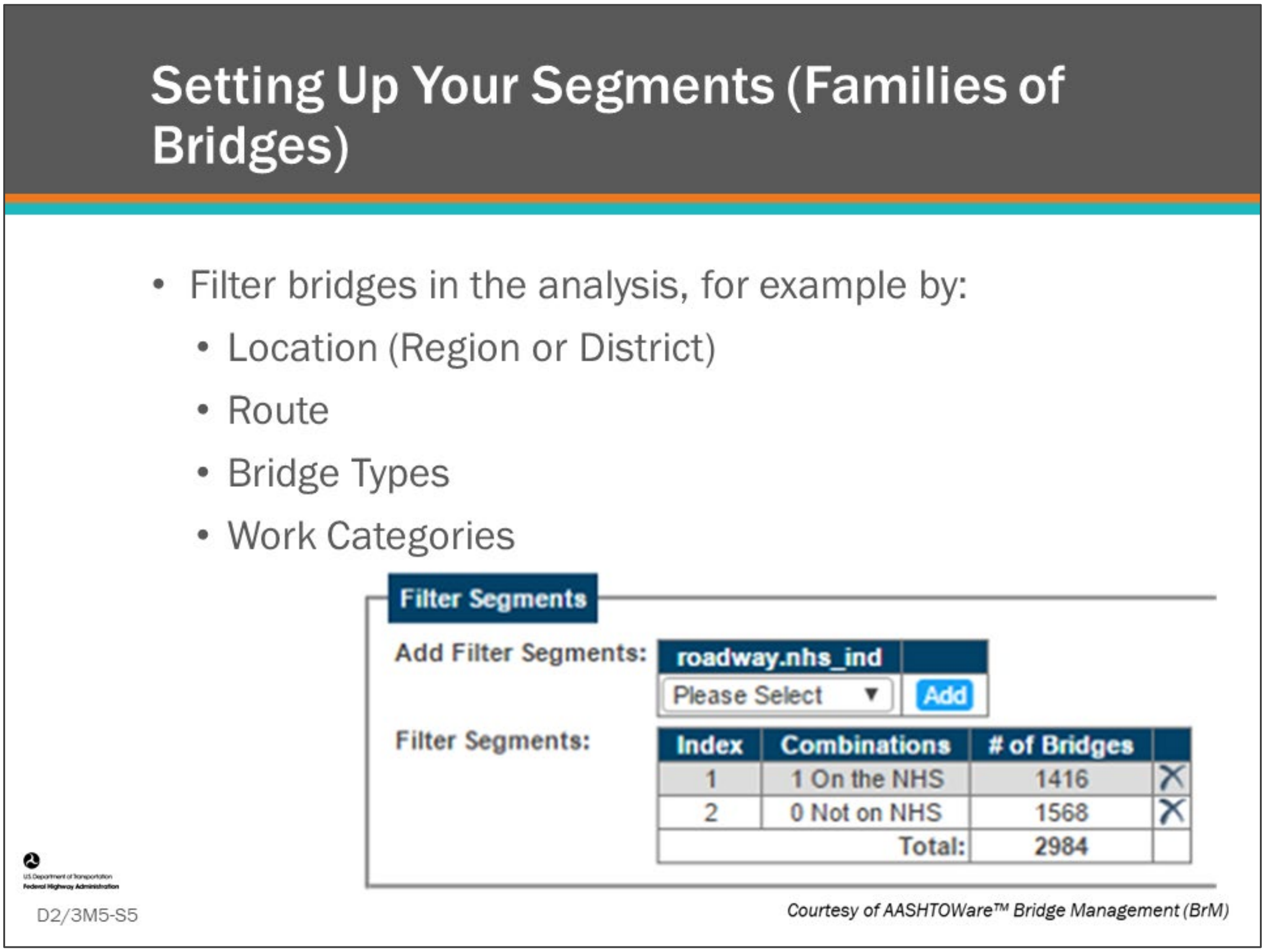
D2/3M5-Slide 4



Key Message

In this section, we will review the steps to creating scenario models which will be run through the optimization routine in a BMS. This includes setting up segments or families of bridges that are to be included in the analysis. It also includes setting up the performance models, setting funding and project categories, setting objective function and constraints, and finally running scenarios.

D2/3M5-Slide 5

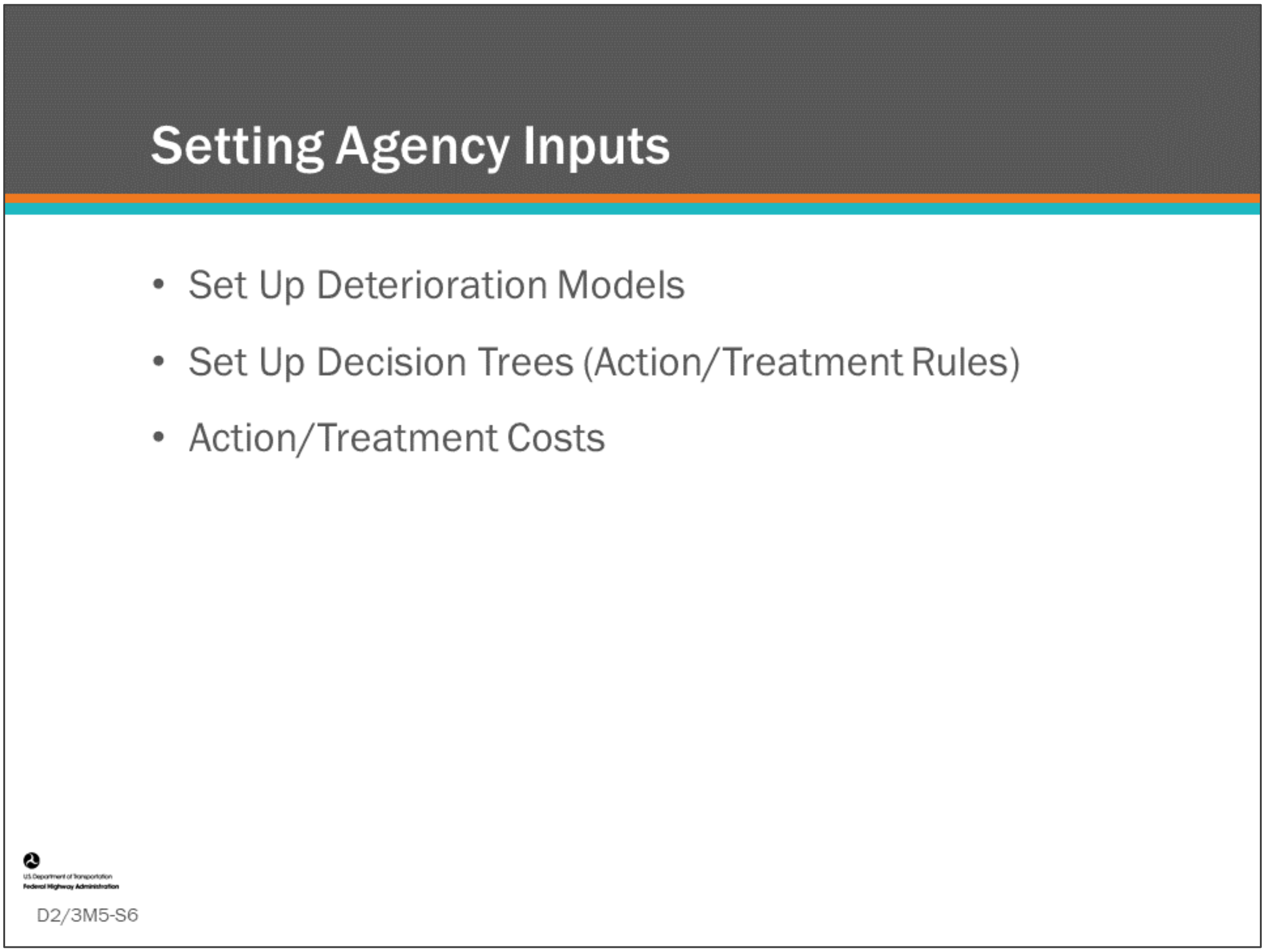


Key Message

One of the first steps you will do when setting up a scenario model is to set up your family of bridges to be included in the analysis. BMS software facilitate setting up families of bridges for analysis and management. Bridge segments or families are set up in relation to how you will manage your bridges. This can be by location (Region or District), route, bridge type, work category, or any other way your agency feels they need to manage their bridges.

Note: if you are running a scenario model for the first time, you may want to select a small segment of your bridge population for testing purposes, as results will run faster with less chance of error.

D2/3M5-Slide 6

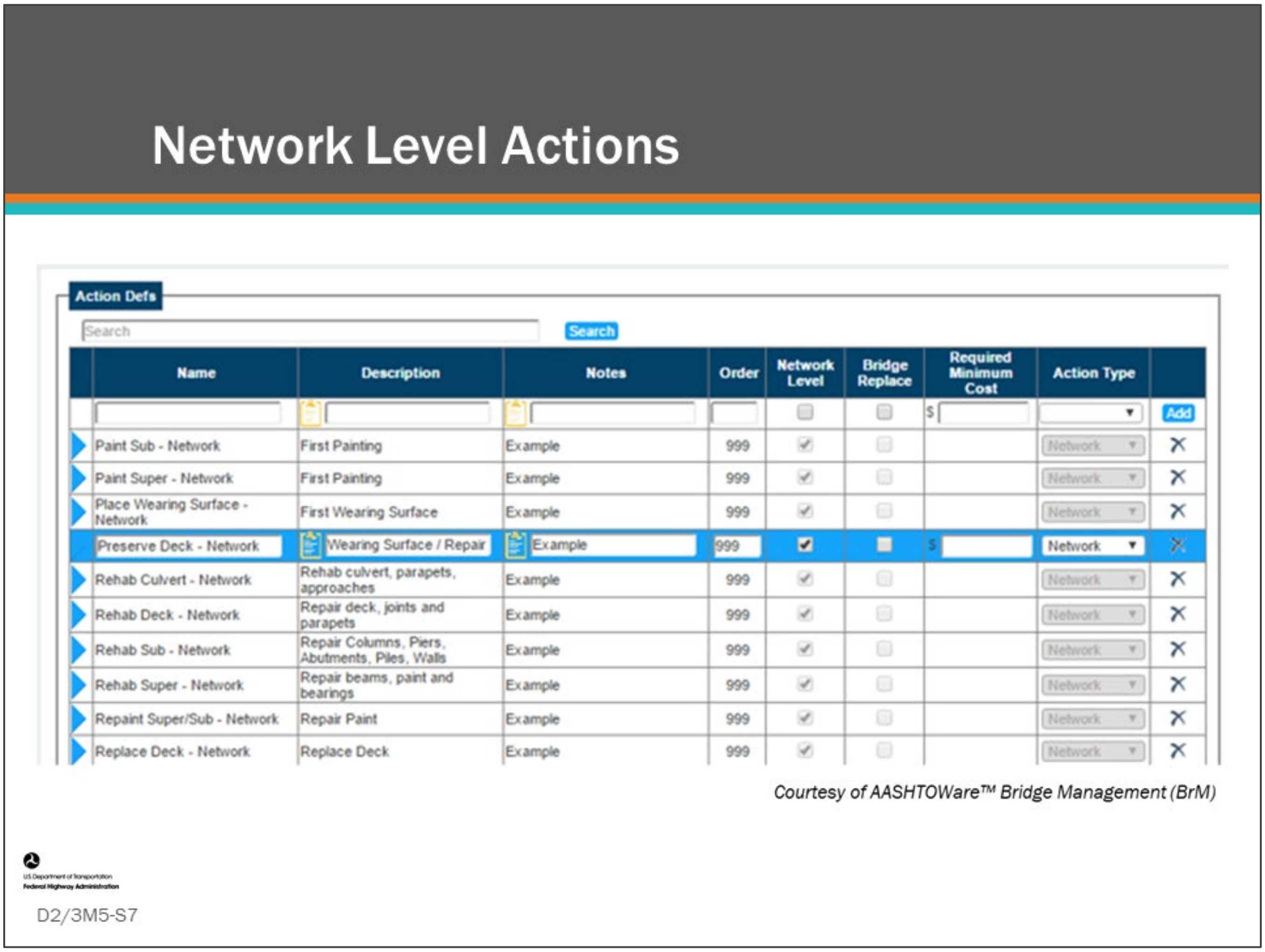


Key Message

The next step is to set up your agency inputs. The items shown on the slide are covered in other Day One and Day Two models, however, these implementation steps are included here to point out that some of these can be modified for scenario comparisons. Examples of parameters that can be modified and compared include the following:

- A scenario model can be run that only does rehabilitation and replacement projects, and another scenario model may include and emphasize preservation projects. This can be accomplished by altering the decision trees, project categories, and budget in each category.
- Exploring the effect of experimental materials or treatments. This can be accomplished by altering decision trees and action/treatment costs.

D2/3M5-Slide 7



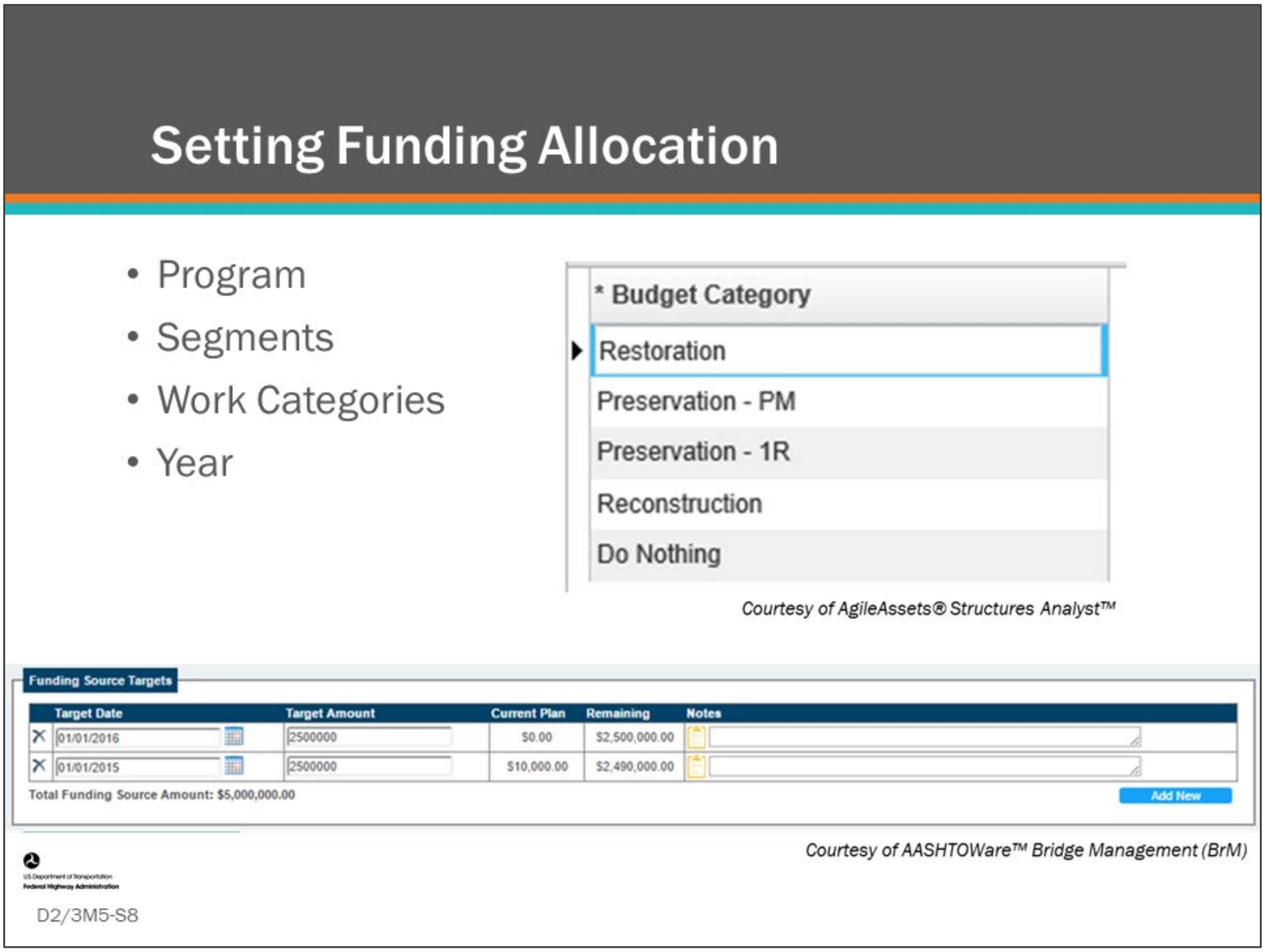
Name	Description	Notes	Order	Network Level	Bridge Replace	Required Minimum Cost	Action Type
Paint Sub - Network	First Painting	Example	999	✓			Network
Paint Super - Network	First Painting	Example	999	✓			Network
Place Wearing Surface - Network	First Wearing Surface	Example	999	✓			Network
Preserve Deck - Network	Wearing Surface / Repair	Example	999	✓		$	Network
Rehab Culvert - Network	Rehab culvert, parapets, approaches	Example	999	✓			Network
Rehab Deck - Network	Repair deck, joints and parapets	Example	999	✓			Network
Rehab Sub - Network	Repair Columns, Piers, Abutments, Piles, Walls	Example	999	✓			Network
Rehab Super - Network	Repair beams, paint and bearings	Example	999	✓			Network
Repaint Super/Sub - Network	Repair Paint	Example	999	✓			Network
Replace Deck - Network	Replace Deck	Example	999	✓			Network

Key Message

Network Level actions in AASHTOWare™ Bridge Management (BrM) are the set of actions used for network-level analysis. Regardless of the BMS used, the output simulated work program of general projects will typically be in terms of Network Level actions.

Remember that more general actions are typically used since the size of the problem (and hence the run-time for work program simulation and optimization) grows exponentially as you increase the number of action types which occurs when using many detailed actions.

D2/3M5-Slide 8

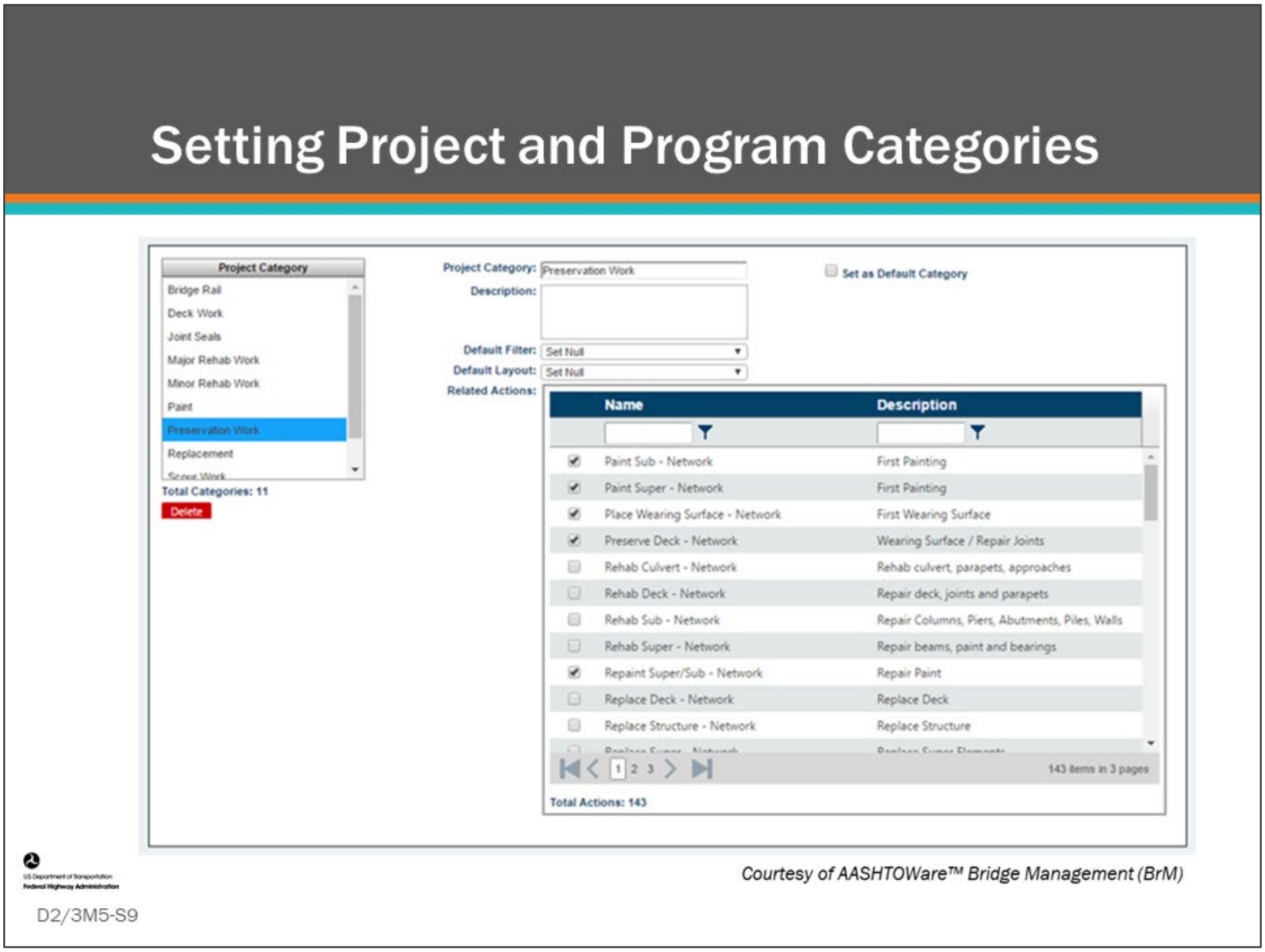


Key Message

Management of funding in a BMS provides the ability to increase or decrease overall funding and to define funding sources. Funding sources can then be attached to project categories, which can be included in scenario models.

BMS software offer various tools to manage funding as part of programs, segments (families), work categories, and by year in the program. In some BMS software, funding can be managed at the project level, where a bridge project may use a percentage of several different funding sources. Since funding is often a constraint during the program simulation and optimization routine, it is important to understand how your BMS funding management tools work.

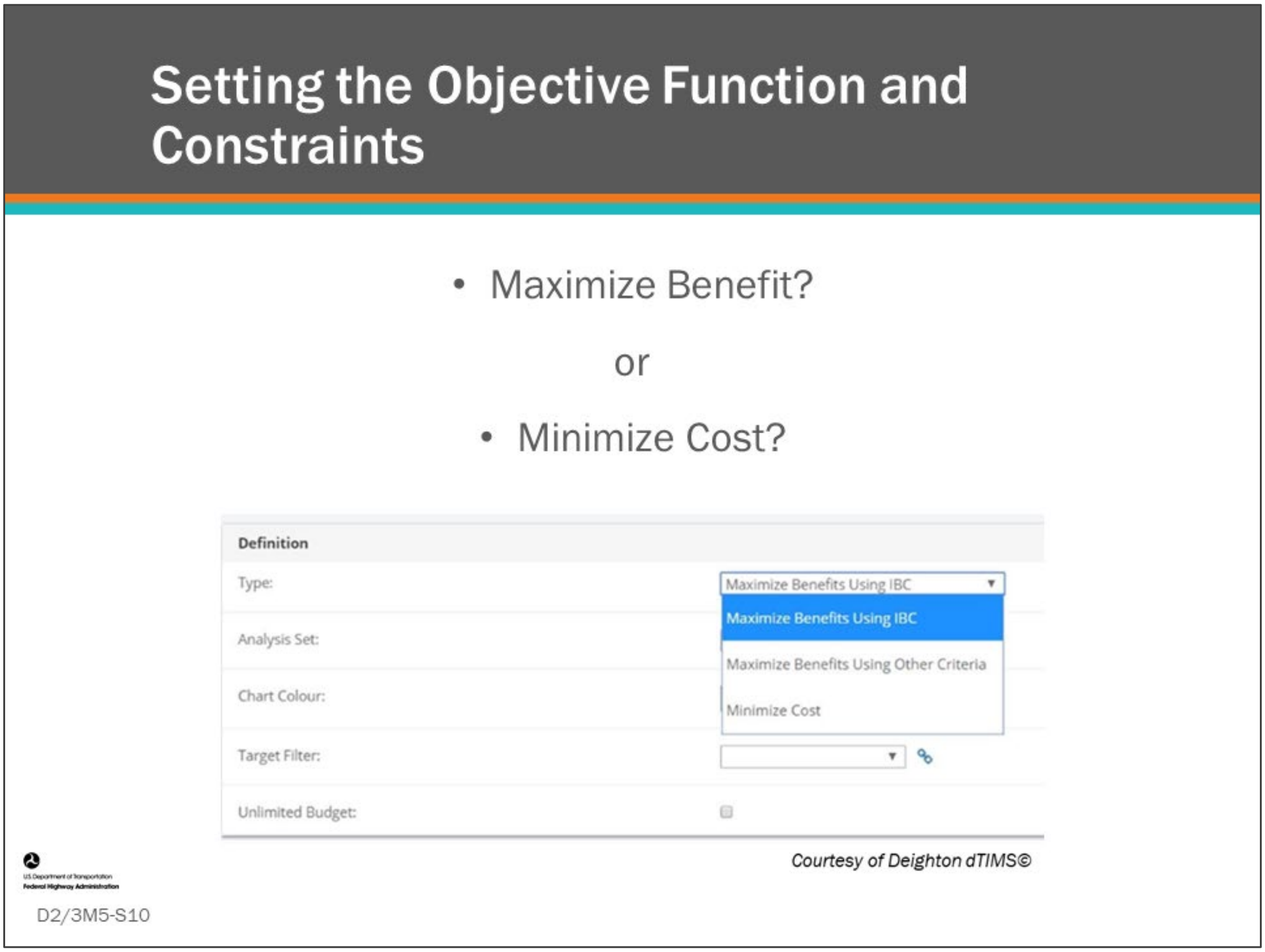
D2/3M5-Slide 9



Key Message

Actions/treatments, which are typically created for bridge elements or components in decision trees, are grouped into project categories. Project categories can be grouped into program categories such as preservation, rehabilitation, and reconstruction. BMS software allow you to set up project categories defined by work types which can be included in scenario models.

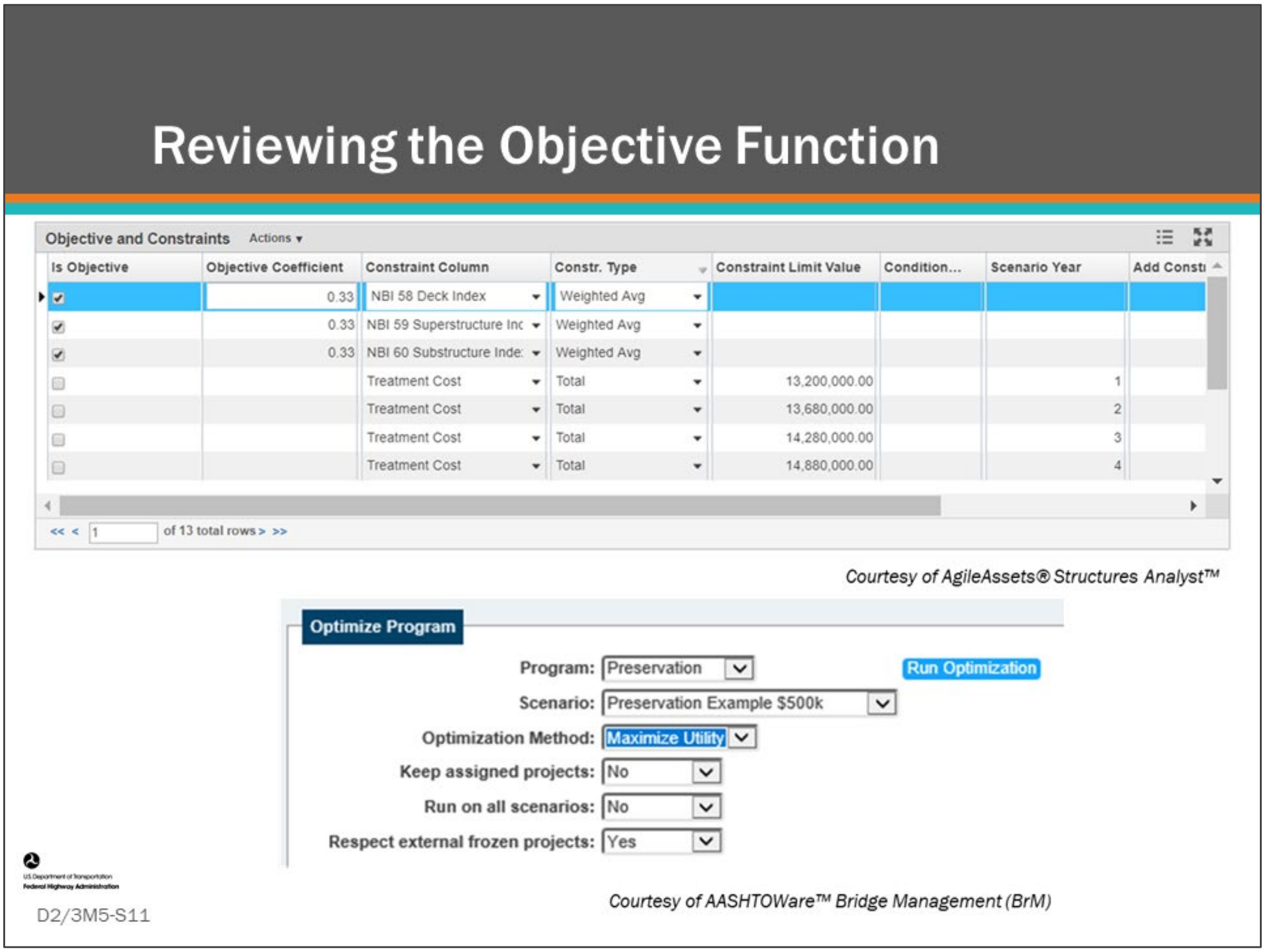
D2/3M5-Slide 10



Key Message

The most important feature of a BMS is the optimization functionality. When creating a scenario simulation, the objective function (also known as optimization index or utility function) must be selected, and whether you are going to maximize or minimize it. Often you will maximize benefit or minimize cost. The project selections chosen by the BMS optimizer will vary depending on the objective function and constraints. These are frequently modified when running scenarios.

D2/3M5-Slide 11

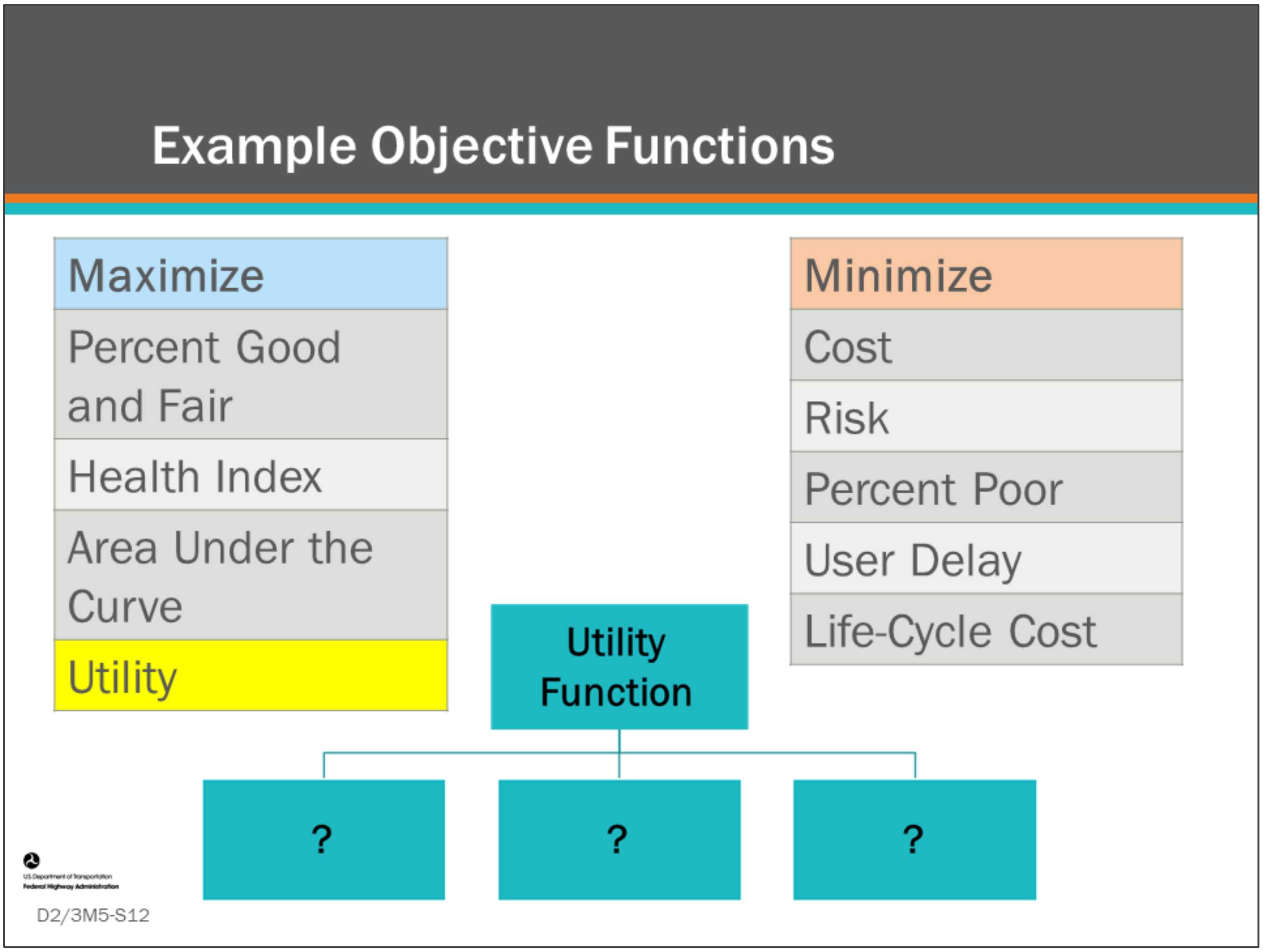


Key Message

Review BMS optimization example set-up screens.

The common functionality of all BMS software is the ability to run an optimization routine, with the ability to maximize or minimize an objective function. Note that the objective function is created by the bridge manager and can be changed to run different scenarios. In the case of BrM, the bridge manager may set the weightings within the Utility function to emphasize different goals. For Deighton and AgileAssets, the bridge manager may choose the exact formula for their specific objectives and goals.

D2/3M5-Slide 12



Key Message

When running an optimization routine in an advanced BMS, the objective function is the most important user input to be determined. The objective function can maximize "Benefit" which can be percent good and fair bridges by deck area or count, health index, area under the curve, or a combination of weighted objectives defined by a utility function. The objective function can also minimize cost, risk, percent poor, or average life-cycle cost for long-term investment strategy.

D2/3M5-Slide 13

Group Formation for Module Discussions

Source: Adobe Stock

- Divide into equal groups
- Gather group materials
- Assign a group representative for note keeping and reporting

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D2/3M5-S13

Key Message

Throughout the remainder of this module, participants will utilize group discussions regarding BMS optimization scenario modeling results to develop investment strategy.

The discussions will be used to give the participants experience with:

- Scenario modeling
- Performance measure validation and selection
- BMS for investment strategy development
- Target setting
- Program planning

D2/3M5-Slide 14

Group Discussion – Select or Create an Objective Function

Source: Adobe Stock

- Identify or create an objective function that your BMS will maximize or minimize
  - If you have multiple objectives:
    - Describe them and provide a formula to combine the different objectives into a single objective function
  - Which inputs would need to be modeled over time, and which would be static?

D2/3M5-S14

Key Message

As a group, consider your goals, objectives and performance measures to select or create an agency objective function that your BMS will maximize or minimize.

D2/3M5 - Slide 14: Select or Create an Objective Function

1. Discuss and choose the objective function that your BMS will optimize. It must be more detailed than just saying the Total Utility. If you have multiple objectives, you need to describe these objectives and give a formula to combine the different objectives into a single objective function.

2. Which inputs would need to be modeled over time, and which would be static?

D2/3M5-Slide 15

Group Discussion – Maximize or Minimize?

Source: Adobe Stock

- Describe your approach for using the optimization solver to develop your investment strategy
  - Are you going to maximize benefit or minimize cost?
  - Describe your bridge management investment plan
- Describe the different scenarios you would run
  - Explain how you would use the results

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D2/3M5-S15

Key Message

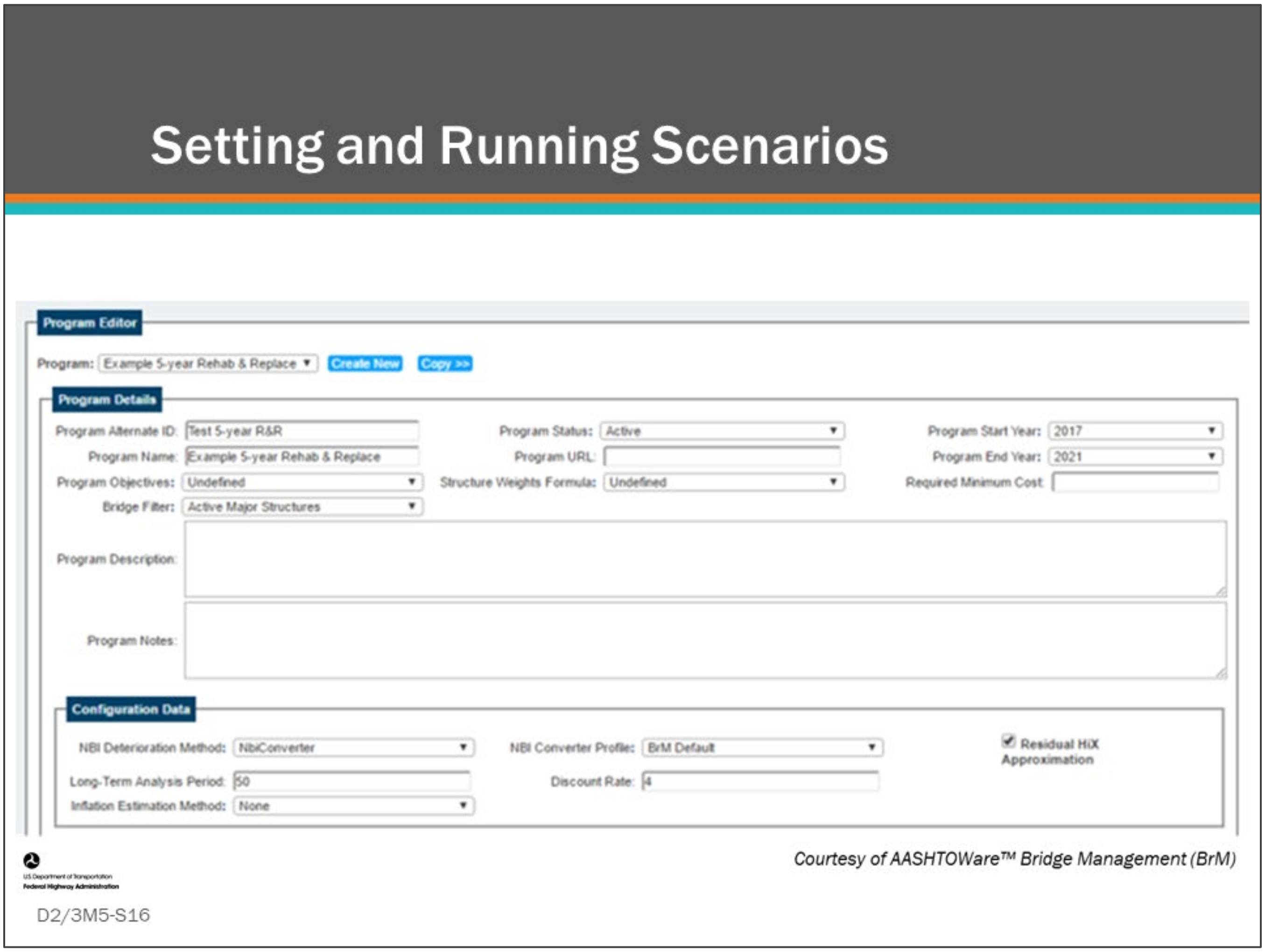
Given the objective function selected by each group, discuss and describe your strategy for using the optimization modeler to develop your investment plan.

D2/3M5 - Slide 15: Maximize or Minimize?

1. Describe your approach for using the optimizer solver to develop your investment strategy.
    a. Are you going to maximize benefit or minimize costs? Describe your process.
    b. Describe your bridge management investment plan. (Note: example investment plans may include subprograms and budgets.)

2. Describe the different scenarios you would run.
    a. Explain how you would use the results.

D2/3M5-Slide 16

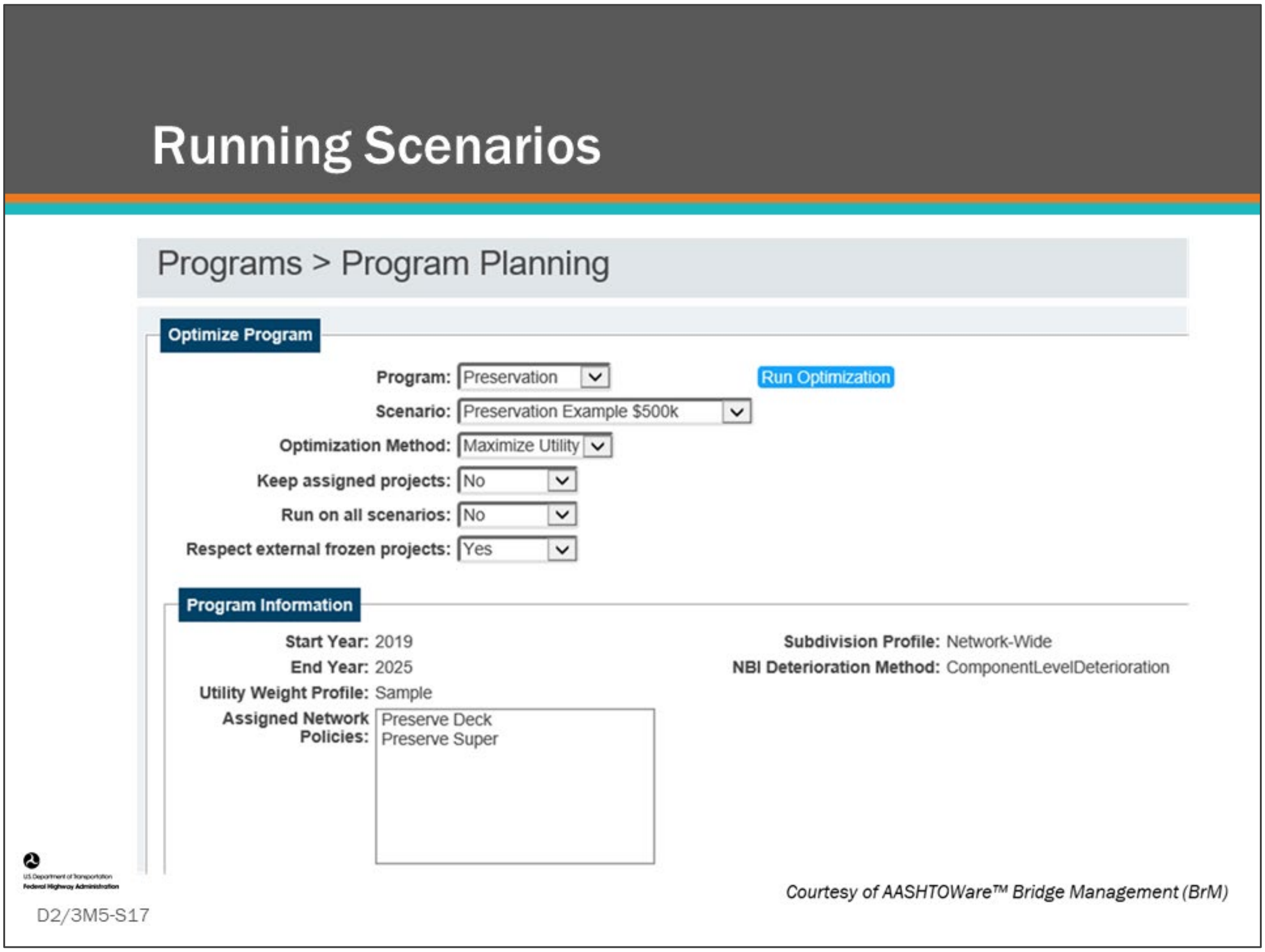


Key Message

Setting up and running a scenario or a group of scenarios for comparison is a core function of an advanced BMS. Terminology and set up varies among the BMS software.

In AASHTOWare™ Bridge Management (BrM), a "program" is a collection of scenarios with specific constraints (budget, performance, etc.) that operates for a predetermined period of time. In AgileAssets® Structures Analyst™ and Deighton dTIMS©, a collection of scenarios is called a set of scenarios. Parameters are defined such as analysis period, the objective function, budget, the pool of bridges to be included in the analysis, deterioration methods, and discount rate.

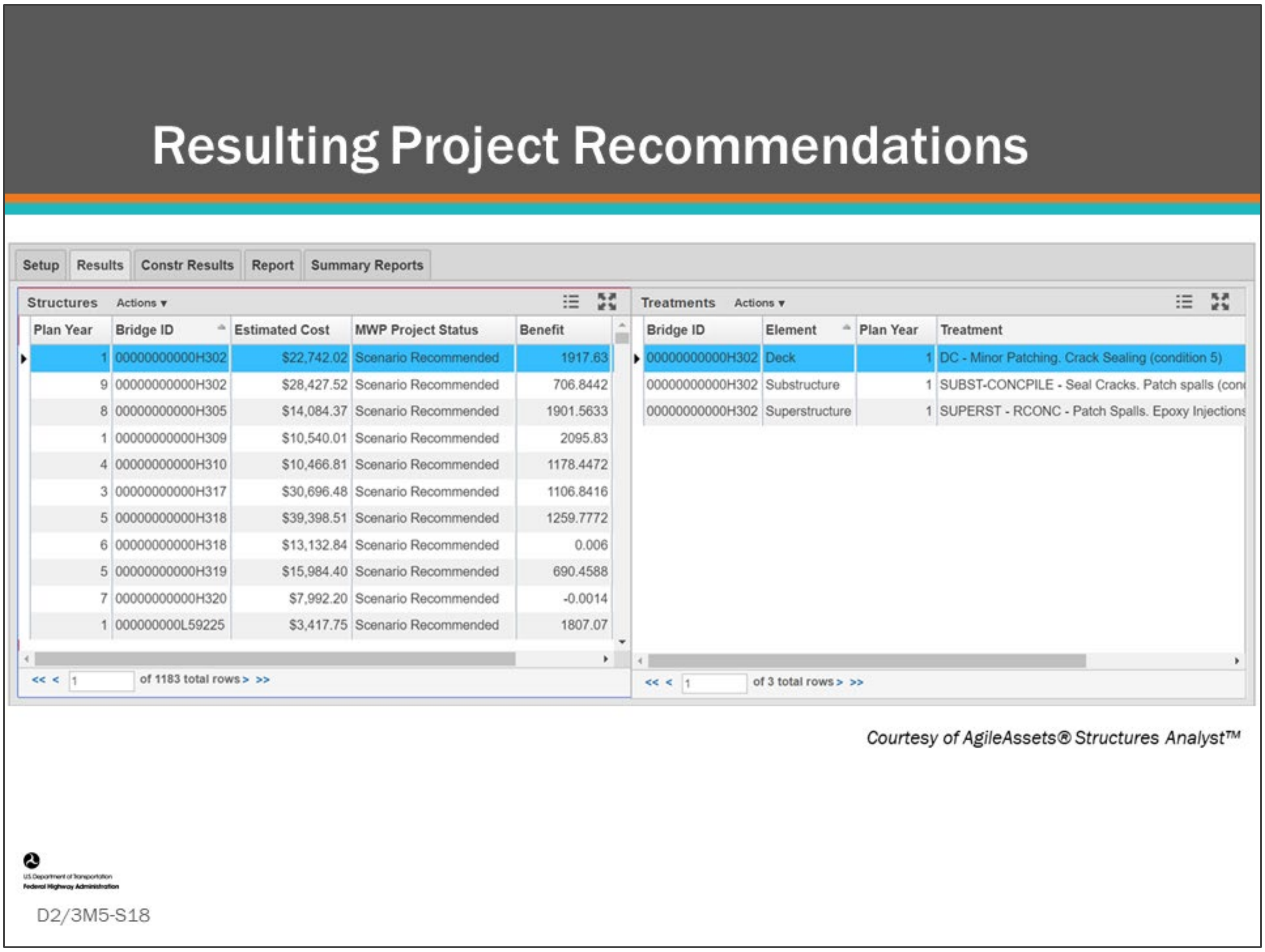
D2/3M5-Slide 17



Key Message

In all advanced BMS software, running the optimization is the defining point of the software purpose. When you hit the “Run Optimization” button, the scenario is run based upon all the agency inputs and rules and definitions for that scenario. Shown on this slide is a scenario for “Preservation Example $500k.” The assigned network polices are; Preserve Deck and Preserve Super(structure).

D2/3M5-Slide 18



Key Message

The BMS optimizer produces a list of projects generated by the analysis.

Shown on this slide is an example project list showing the project on the left, with the details of the highlighted bridge project on the right (specifically, what actions are recommended on each component).

D2/3M5-Slide 19

Resulting Project Recommendations (con.)

Structure Name	Bridge Description	Present Value Cost	Present Value Benefit	Benefit Cost	First Major Treatment Year	First Major Treatment Name	First Major Treatment Cost
200189002E04142	Rolled beam	$395,723	67,626	0.17089	2018	Str_Bridge_Minor_Rehab	428,014
200189002W04142	Rolled beam	$362,766	50,698	0.13975	2027	Str_Bridge_Minor_Rehab	558,462
200189003W04142	3 span rolled beam	$1,201,374	60,726	0.05055	2027	Str_Bridge_Major_Rehab	1,849,460
200089067E04142	3 span rolled beam	$486,479	24,580	0.05053	2029	Str_Bridge_Minor_Rehab	810,023
200089006N14082	3 span rolled beam	$1,897,844	57,485	0.03029	2021	Str_Bridge_Major_Rehab	2,309,017
200189002W04142	Rolled beam	$2,602,190	78,103	0.03001	2024	Str_Bridge_Replacement	3,561,277
200089063N04172	Rolled beam	$305,647	7,359	0.02408	2026	Str_Bridge_Preservation	452,433
200089032N09032	Rolled beam	$336,650	7,997	0.02375	2025	Str_Bridge_Preservation	479,158
200089063N04172	Rolled beam	$323,890	7,359	0.02272	2020	Str_Bridge_Preservation	378,905
200089063S04172	Rolled beam	$323,890	7,359	0.02272	2020	Str_Bridge_Preservation	378,905
200091048S14112	3 span continuous plate girder	$1,176,532	26,703	0.0227	2028	Str_Bridge_Minor_Rehab	1,883,665
200089098N06152	3 span rolled beam	$1,321,800	30,000	0.0227	2021	Str_Bridge_Major_Rehab	1,608,172
200089052S04112	3 span rolled beam	$537,883	12,204	0.02269	2035	Str_Bridge_Minor_Rehab	1,133,238
200091011S13022	3 span rolled beam	$1,426,277	32,340	0.02267	2030	Str_Bridge_Major_Rehab	2,469,850
200089045N12102	3 span steel beam	$521,593	11,817	0.02265	2035	Str_Bridge_Minor_Rehab	1,098,917

Courtesy of Deighton dTIMS©

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D2/3M5-S19

Key Message

Shown on this slide is an example of scenario results from Deighton dTIMS©. The data can be further analyzed in spreadsheets.

It is important to understand all BMS software that use an optimization routine produce a list of bridge projects for each year of the analysis period, and post processing analysis is done using the list of projects to develop investment strategies, create forecasts, categorize work activities, and set targets.

D2/3M5-Slide 20

Group Exercise – How to Model Scenarios

Source: Adobe Stock

- Describe your experience with using BMS to set up and run scenarios
  - Which tools do you find most helpful for creating or editing a work plan or program?
- If you have not used BMS features, what kinds of features would you like to see?
  - What would help you assemble your bridge program?

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D2/3M5-S20

Key Message

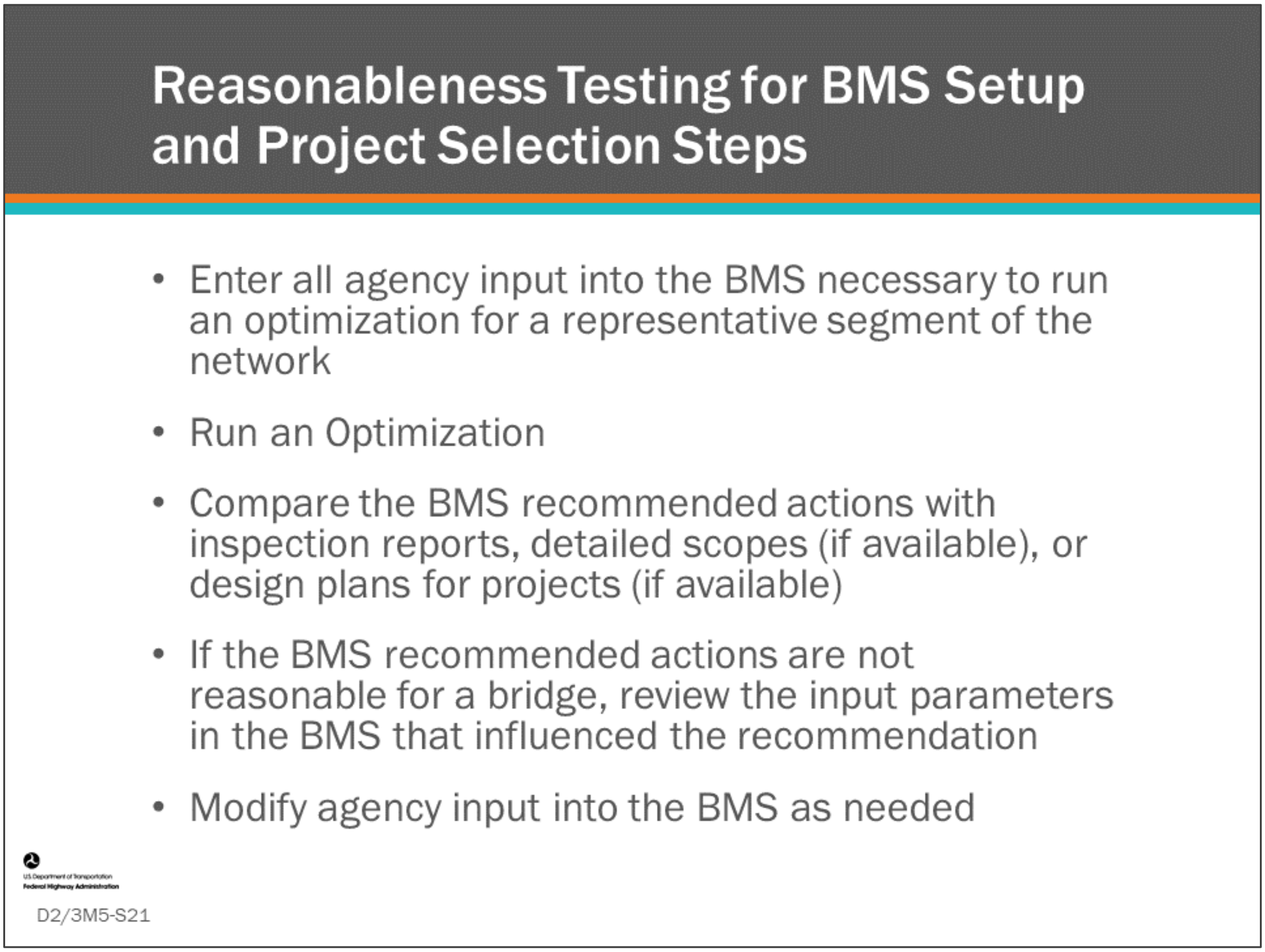
Individual group discussion.

D2/3M5 - Slide 20: How to Model Scenarios

1. Describe your experience with using BMS to set up and run scenarios.
    a. Which tools do you find most helpful for creating or editing a work plan or program?

2. If you have not used BMS features, what kinds of features would you like to see?
    a. What would help you assemble your bridge program?

D2/3M5-Slide 21

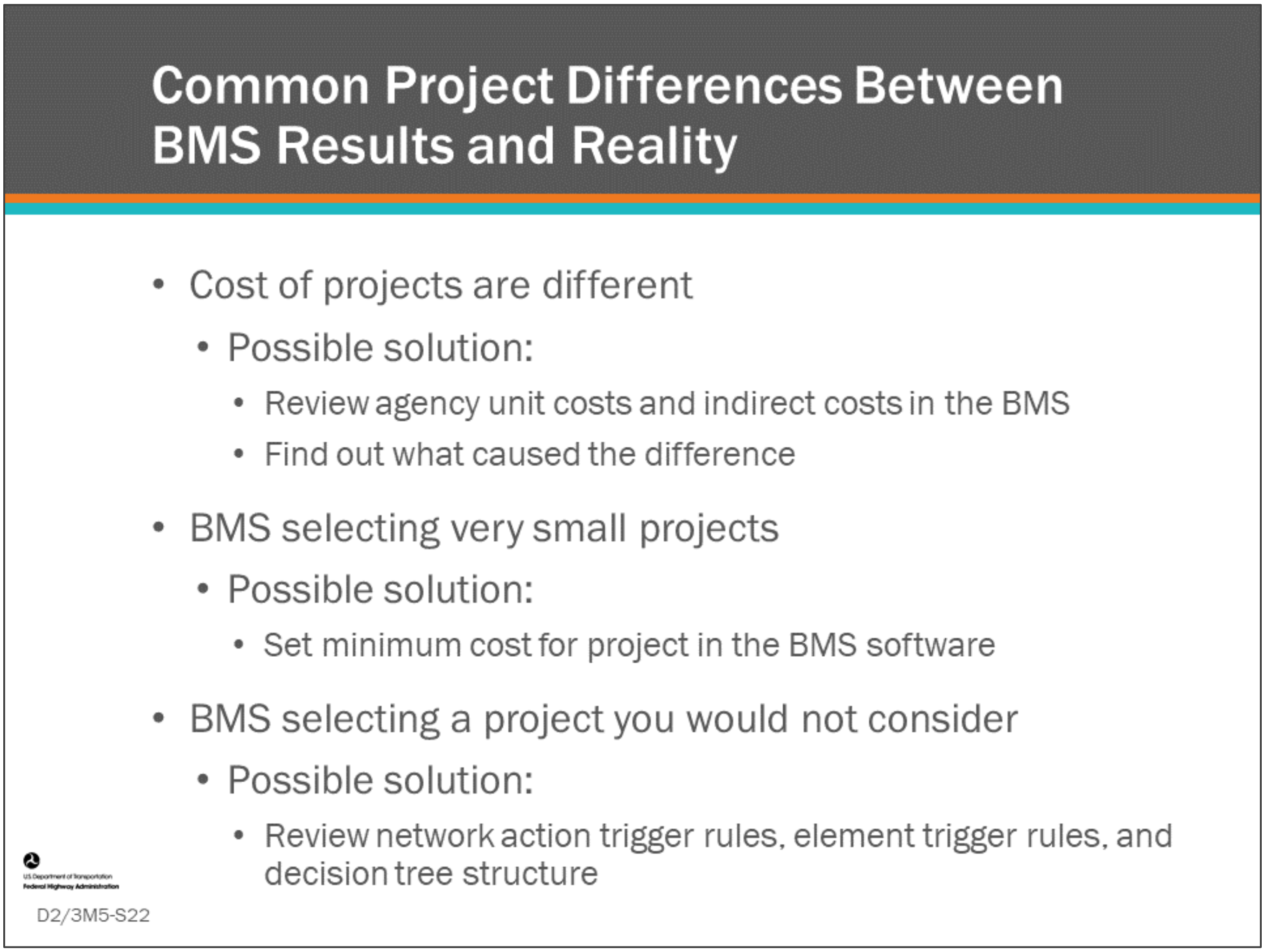


Key Message

How variables interact in a configured bridge management system is only known after setup and initial testing and analyses are run and reviewed. It is essential that the system is tested for reasonableness prior to utilizing it to make real world decisions and final reporting. Reasonableness testing can involve the following steps:

- Enter all agency input into the BMS necessary to run an optimization for a representative segment of the network.
- Run an Optimization.
- Compare the BMS recommended actions with inspection reports, detailed scopes (if available), or design plans for projects (if available).
- If the BMS recommended actions are not reasonable for a bridge, review the input parameters in the BMS that influenced the recommendation.
- Modify agency input into the BMS as needed.
- Multiple iterations of reasonableness tests should be done with your BMS before it is used for program and project analysis. This is simply running scenarios and reviewing the results using detailed scopes or knowledge of experienced bridge managers and inspectors.
- When testing, it is best to start with a small segment of bridges to reduce runtime and then as results look more reasonable, increase the number of bridges you are analyzing.
- If testing network policies or decision trees, it is not necessary to run a multi-year program. Start by running a one year program.

D2/3M5-Slide 22



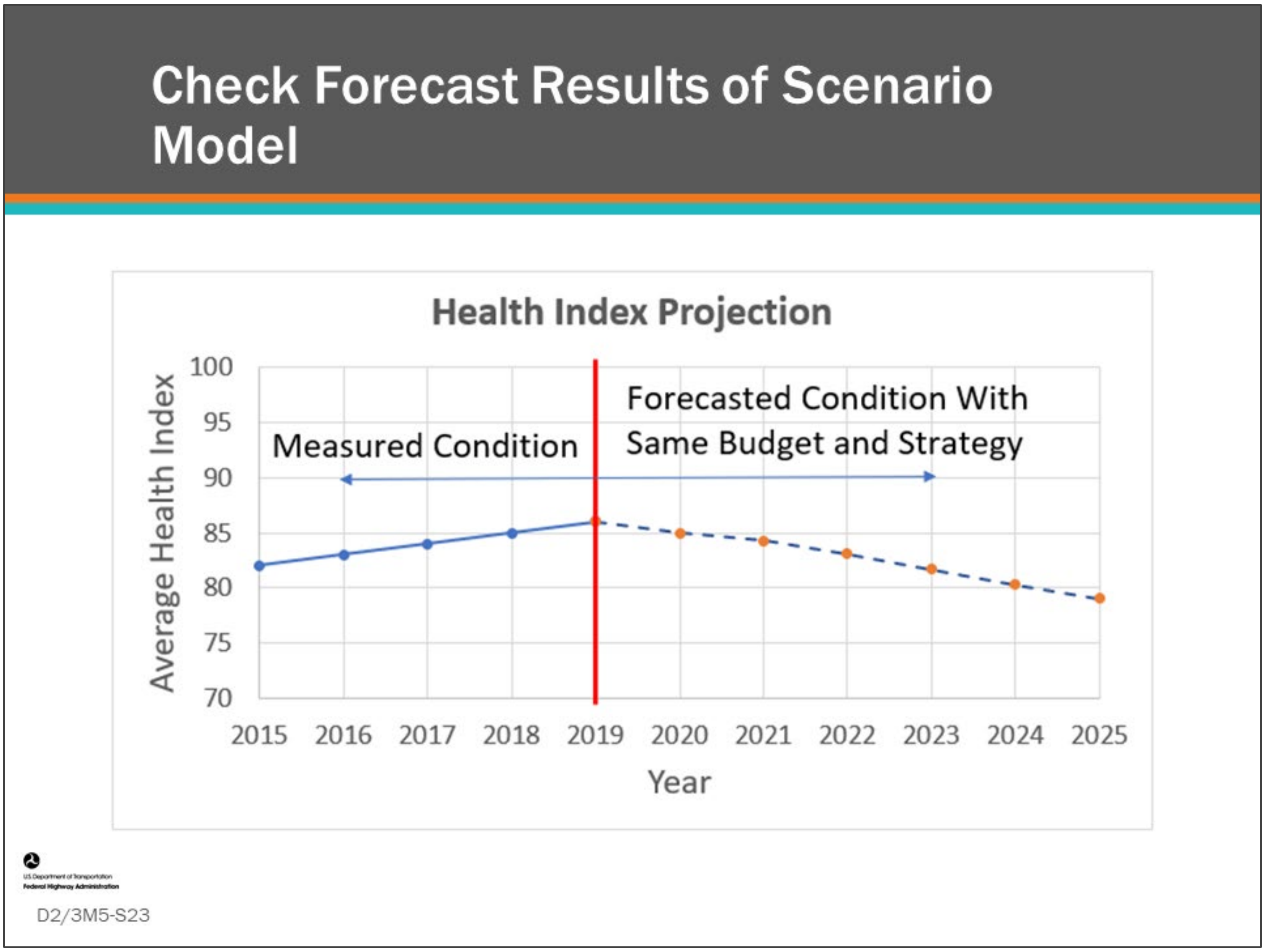
Key Message

When you begin running scenario models, most likely the project selections and cost are not going to match real life very well. The results of the analysis should be used to track down the reasons why results are not realistic and make changes to input parameters as needed. As the BMS software is repeatedly used, results will get better.

You should also keep in mind that deterioration and cost models are often created for the typical or average bridge, however, few bridges are actually average. Parameters that can affect results include:

- Unique bridge types
- Bridge location
    - Urban or rural
    - High average daily traffic
    - Complex construction and extended duration construction
    - Accelerated construction
- Keep in mind that BMS project recommendations will never be perfect because of data and model limitations and the inability to account for all factors that enter into project selection. Manual review and revision of projects will always be necessary.

D2/3M5-Slide 23



Key Message

Another way to check results of a scenario model is to review the forecast results for your performance measure. If you have been monitoring performance measure trends, you can review the forecast result of a scenario model with the same budget you have had. If there is an unexpected change in performance measure trends, as demonstrated on the slide, something is likely wrong with your model.

D2/3M5-Slide 24

Group Exercise - BMS Work Program Simulation, and Optimization Validation

Source: Adobe Stock

- Describe your experience with performing BMS work program simulation and optimization and reasonableness testing
- If you have no experience with BMS model validation, what would you want to verify before using BMS models?

U.S. Department of Transportation Federal Highway Administration

D2/3M5-S24

Key Message

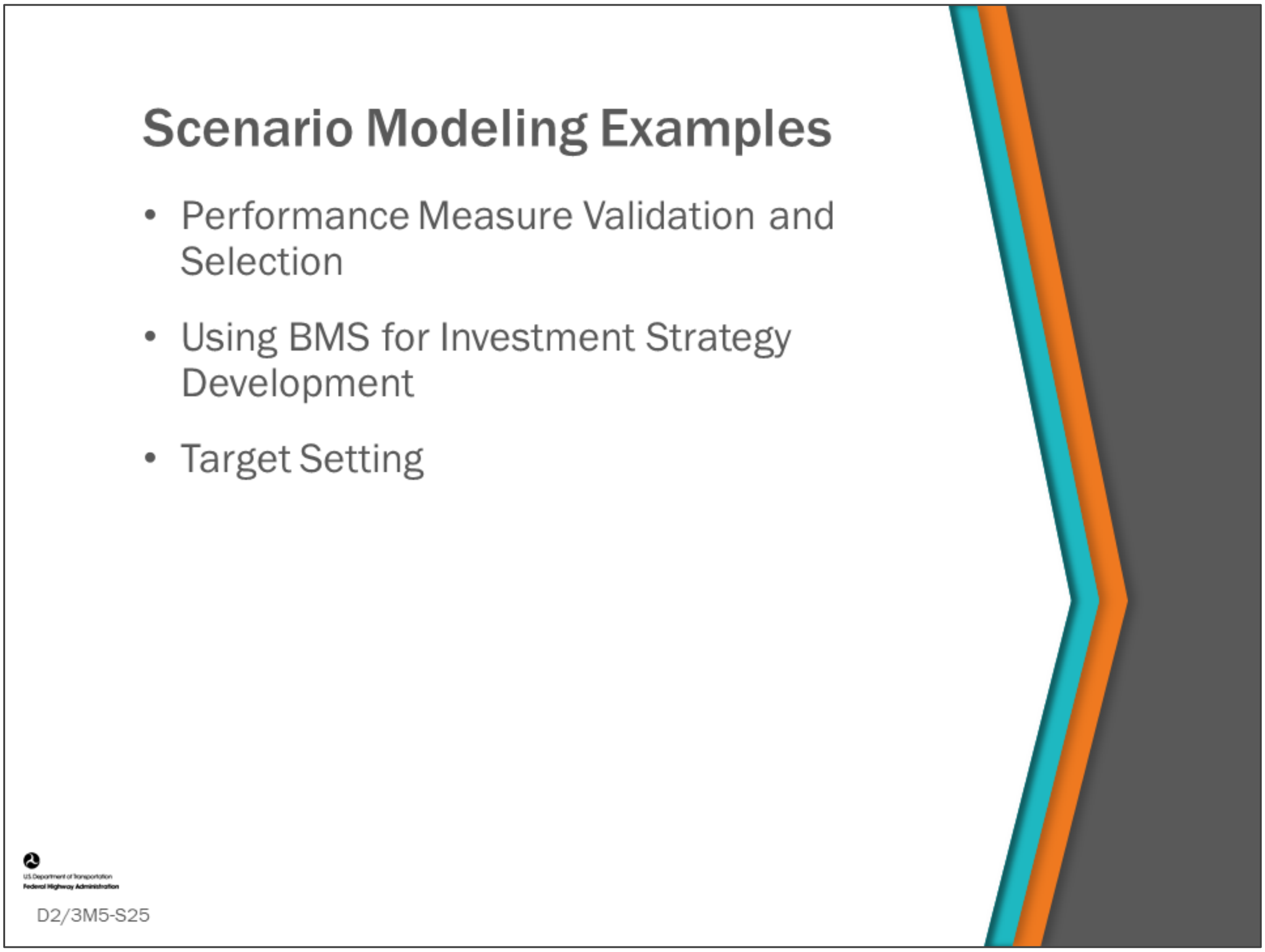
Group discussion.

D2/3M5 - Slide 24: BMS Work Program Simulation and Optimization Validation

1. Describe your experience with performing BMS model simulation and optimization and reasonableness testing.

2. If you have no experience with BMS model validation, what would you want to verify before using BMS models?

D2/3M5-Slide 25



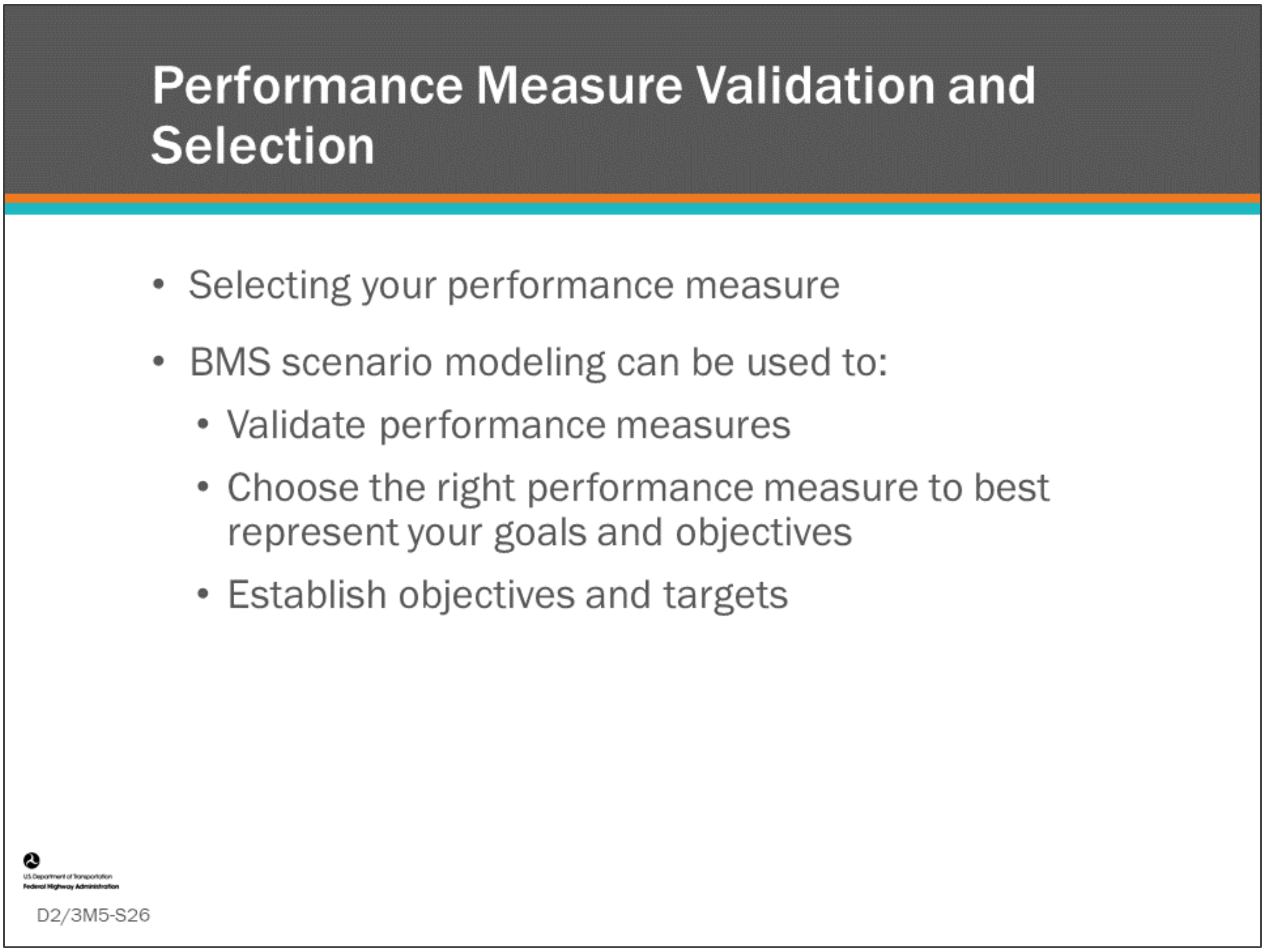
Key Message

In the following sections we will look at three ways to use scenario modeling, including:

- Performance measure validation and selection
- Utilization of BMS for investment strategy development
- Target setting

These are only a few examples of the many ways you will eventually use scenario modeling.

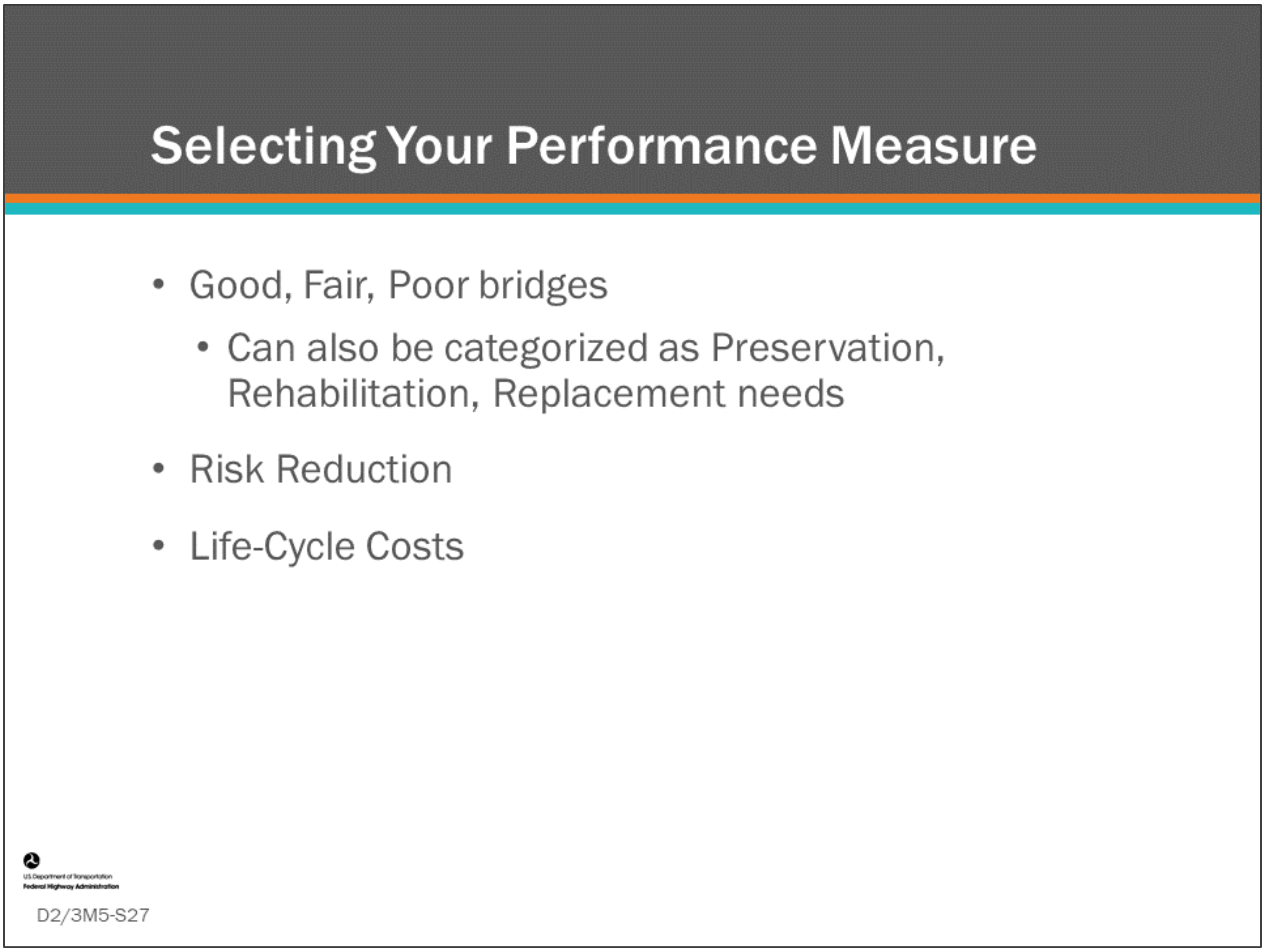
D2/3M5-Slide 26



Key Message

You may have a performance measure that was predetermined, or you may have high level goals and objectives and you want to choose the right performance measure. Scenario modeling can be used to help select the right performance measure and then establish your objectives and targets.

D2/3M5-Slide 27

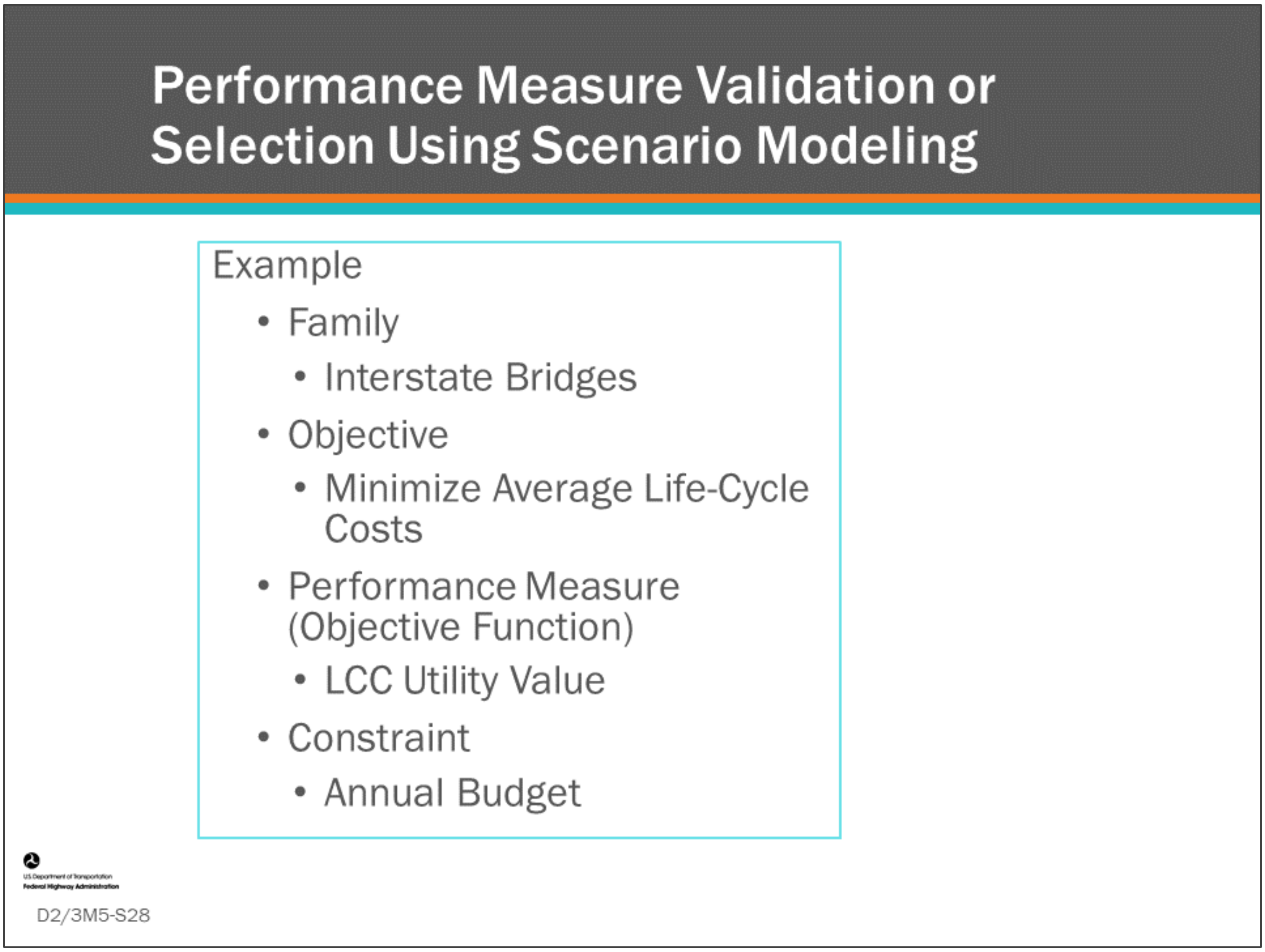


Key Message

Data used for network level work program simulation and optimization is typically more general and should relate to agency goals and objectives. The data could utilize General Condition Ratings (GCRs) or a base set of bridge elements with agency trigger rules for preservation, rehabilitation, and replacement activity, or it may be health index or utility function. Using inventory items, you also may identify bridges for safety, functional improvement, and risk mitigation actions.

The first thing to check when validating the use of a potential performance measure is that the recommended projects including the bridges selected, the recommended actions, and the mix of work types across the network make sense and are what is desired from using the measure.

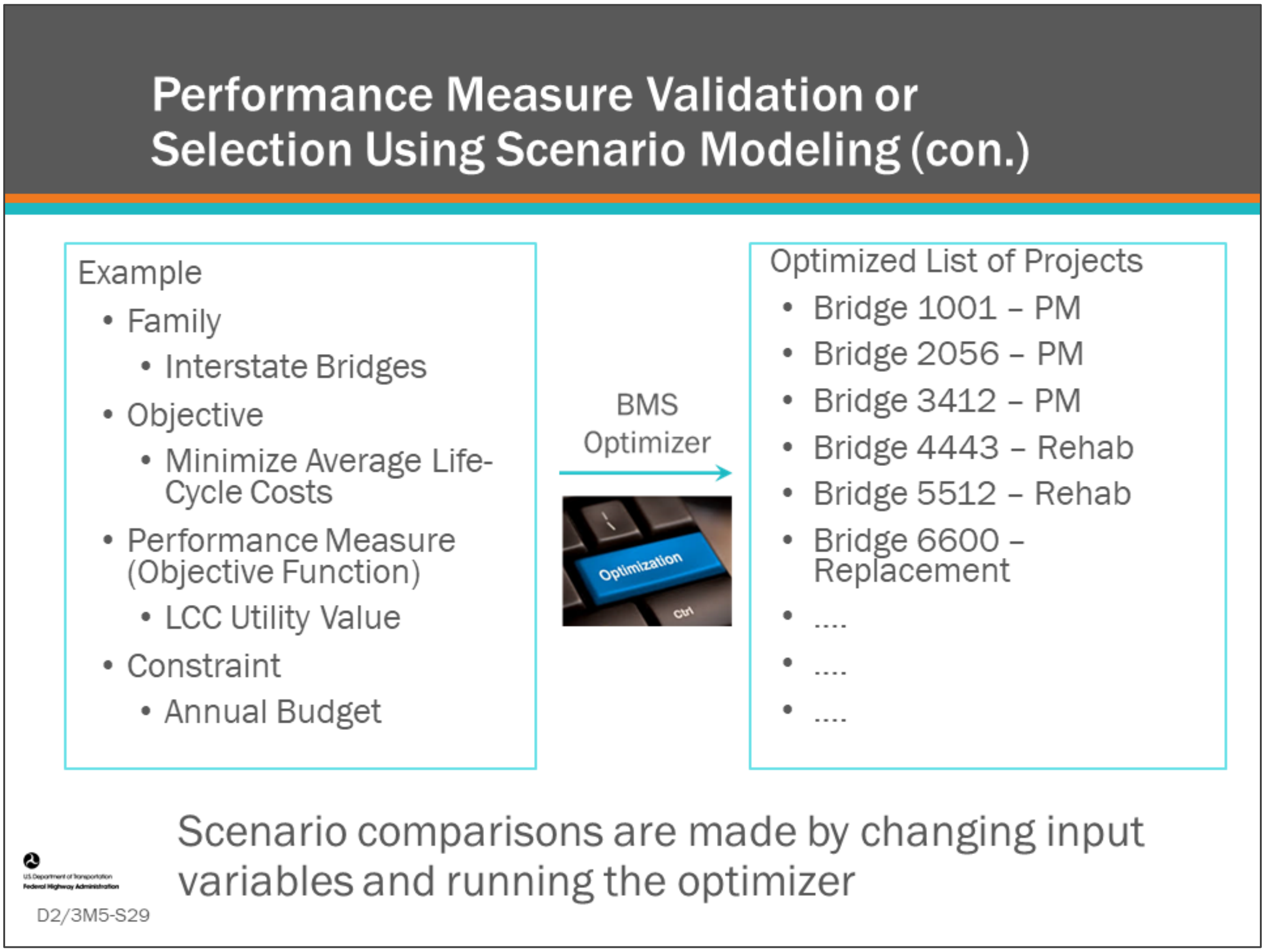
D2/3M5-Slide 28



Key Message

Select a performance measure that is representative of your objective. The objective shown on this slide is, “Minimize Average Life-Cycle Costs.” Life-Cycle Cost (LCC) Utility is selected for the performance measure, which also serves as the objective function. Scenario models will be run for a family of interstate bridges with various budget constraints.

D2/3M5-Slide 29

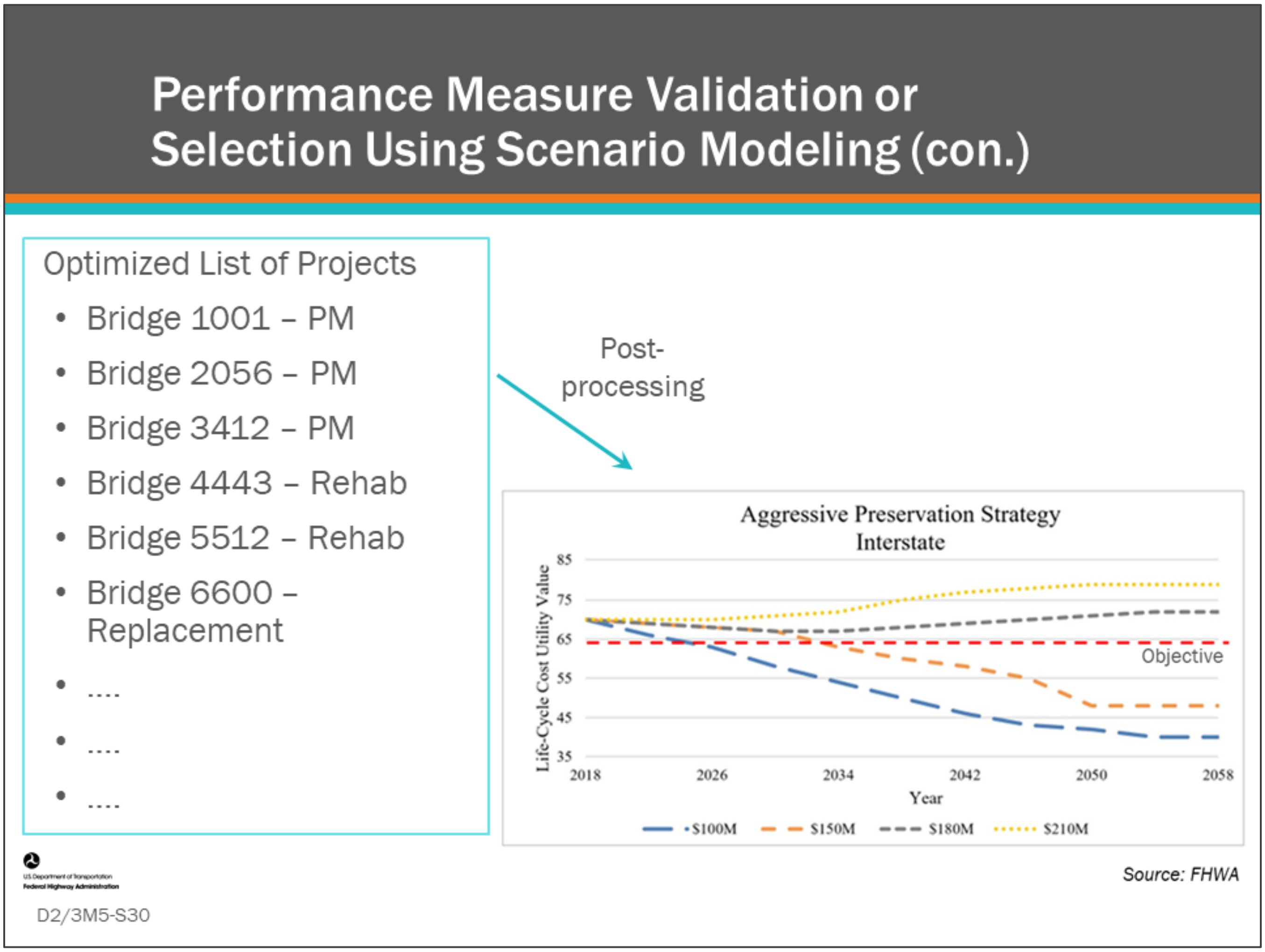


Key Message

The results of the BMS optimizer is a list of bridges that minimized average life-cycle cost while staying within budget constraints. Multiple scenarios can be run with different budgets to compare results and provide data points to help set a reasonable objective.

The first things to check when validating the use of a potential performance measure is that the recommended projects including the bridges selected, the recommended actions, and the mix of work types across the network make sense and are what is desired from using the measure.

D2/3M5-Slide 30



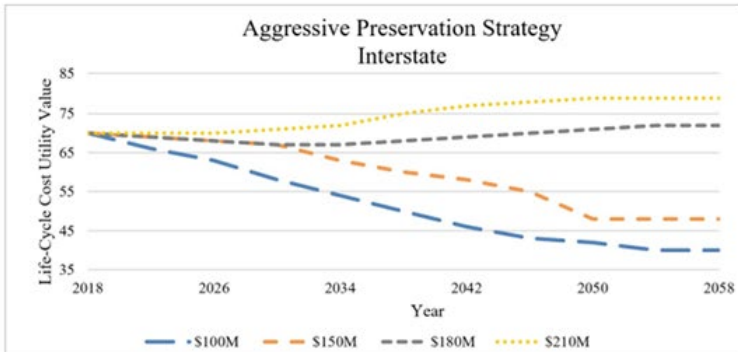
Key Message

If your performance is LCC Utility Value and your objective is to maintain an average LCC Utility Value greater than 65 (as shown on the chart) over the next 20 years, you would need to be able to provide an annual budget of $180 Million. If that budget is not achievable, then you can reduce your objective. For example, given an objective of average LCC Utility Value set at 55, you can achieve the objective with a budget of $150 Million.

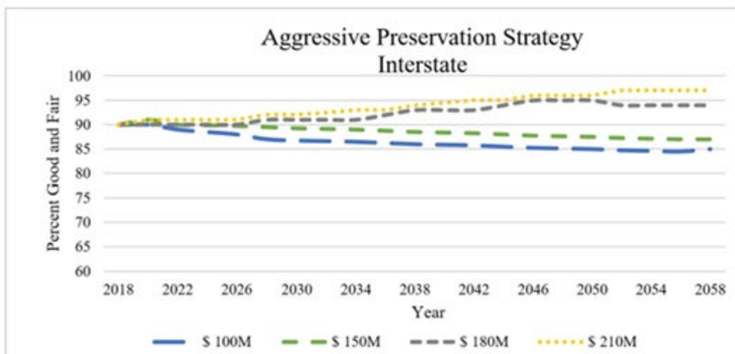
This is only one example how a BMS scenario model can be used to validate or select a performance measure.

D2/3M5-Slide 31

Validating Your Performance Measure



Source: FHWA



Source: FHWA

D2/3M5-S31

Key Message

When validating your performance measure, you may want to determine if the measure and its weighting within the objective function yield projects and outcomes that are expected. If not, and issues with the inputs including models are not at fault, then a different measure or weighting may be required.

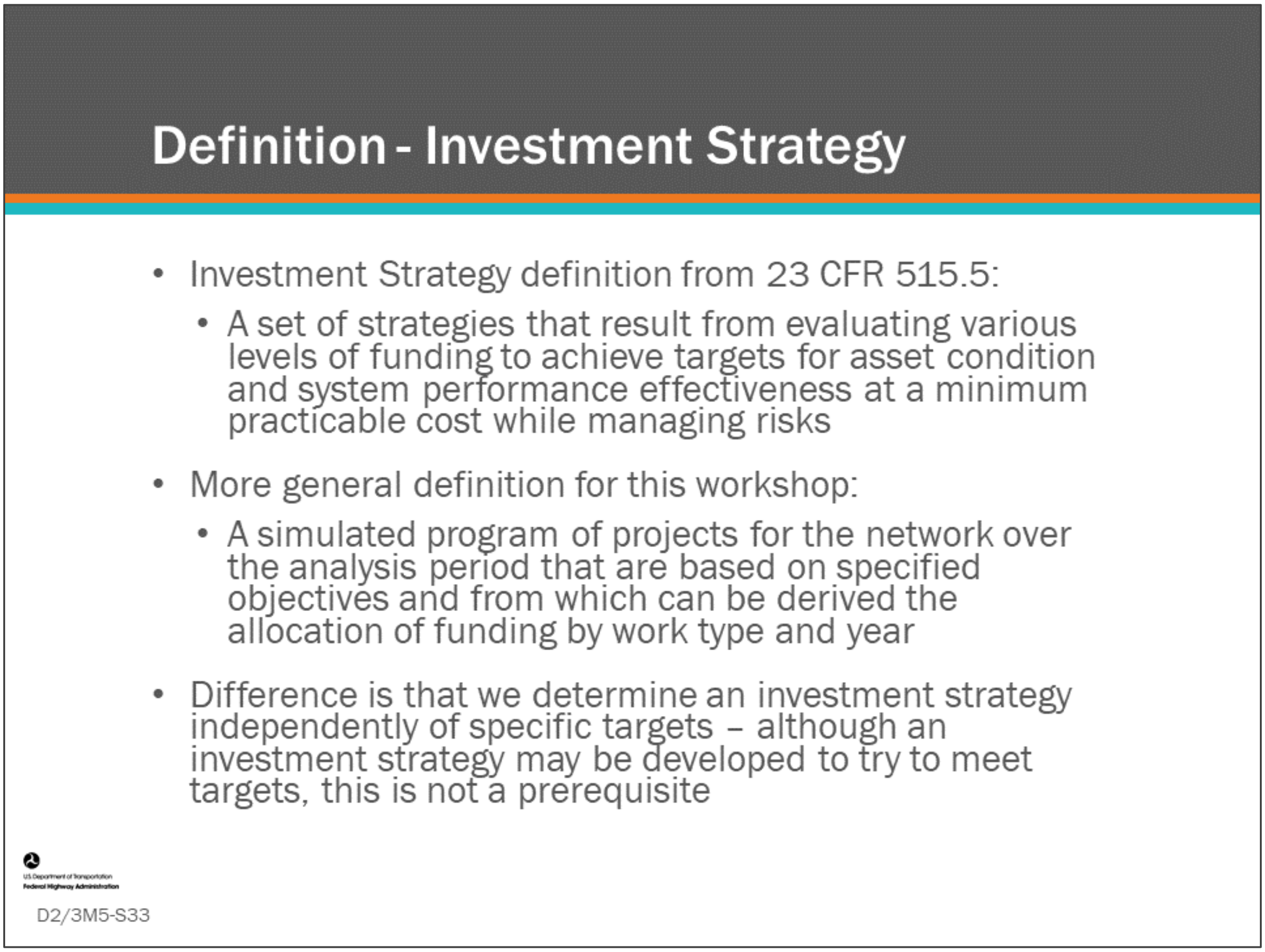
The first graph shows the outcomes of using life-cycle cost as the measure that is maximized in the project and program optimization. The second graph shows the outcome of the least life-cycle cost strategy, but relative to condition. The user can then decide if using solely a life-cycle cost-based measure, or the weighting of the life-cycle cost-based measure yields acceptable condition values over the long-term. The hypothetical results differ.

D2/3M5-Slide 32

Key Message

Once your BMS has the necessary input parameters and has been tested, and you have established performance measures and objectives, you can then begin using your BMS to develop an investment strategy and to set performance targets. This can be done in many different ways.

D2/3M5-Slide 33



Key Message

The investment Strategy definition from CFR 515.5 is:

- A set of strategies that result from evaluating various levels of funding to achieve targets for asset condition and system performance effectiveness at a minimum practicable cost while managing risks

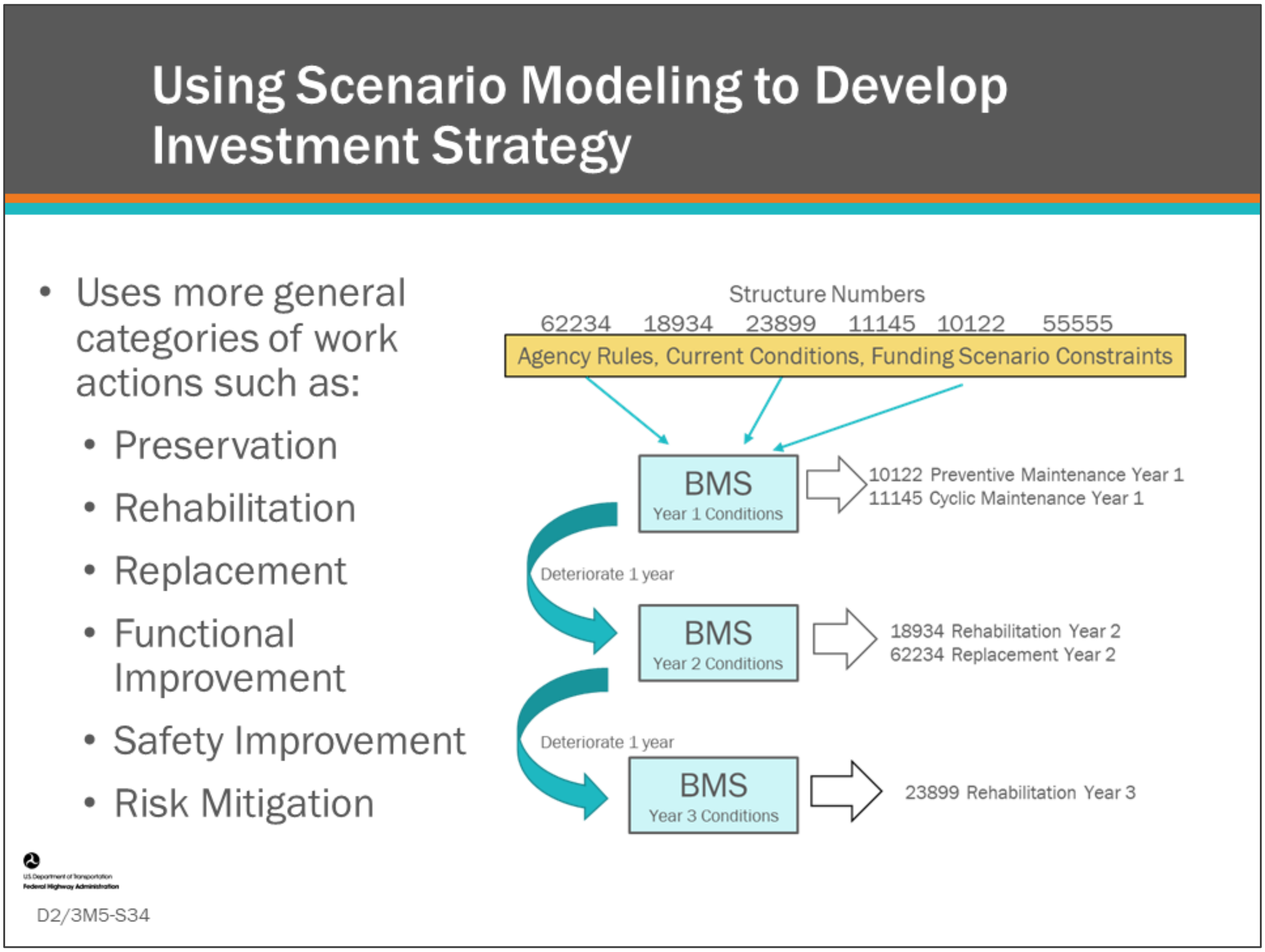
A more general definition for this workshop is:

- A simulated program of projects for the network over the analysis period from which can be derived the allocation of funding by work type and year.

The difference is that we determine an investment strategy independently of specific targets; although an investment strategy may be developed to try to meet targets, this is not a prerequisite. This allows the optimization to be conducted with minimal constraints allowing it to find the best solution.

The following discussion on investment strategy investigation is relative to how BMS have traditionally supported analysis of investment strategies and is not intended to address the requirements of 23 CFR 515 Asset Management Plans process for investment strategy development.

D2/3M5-Slide 34



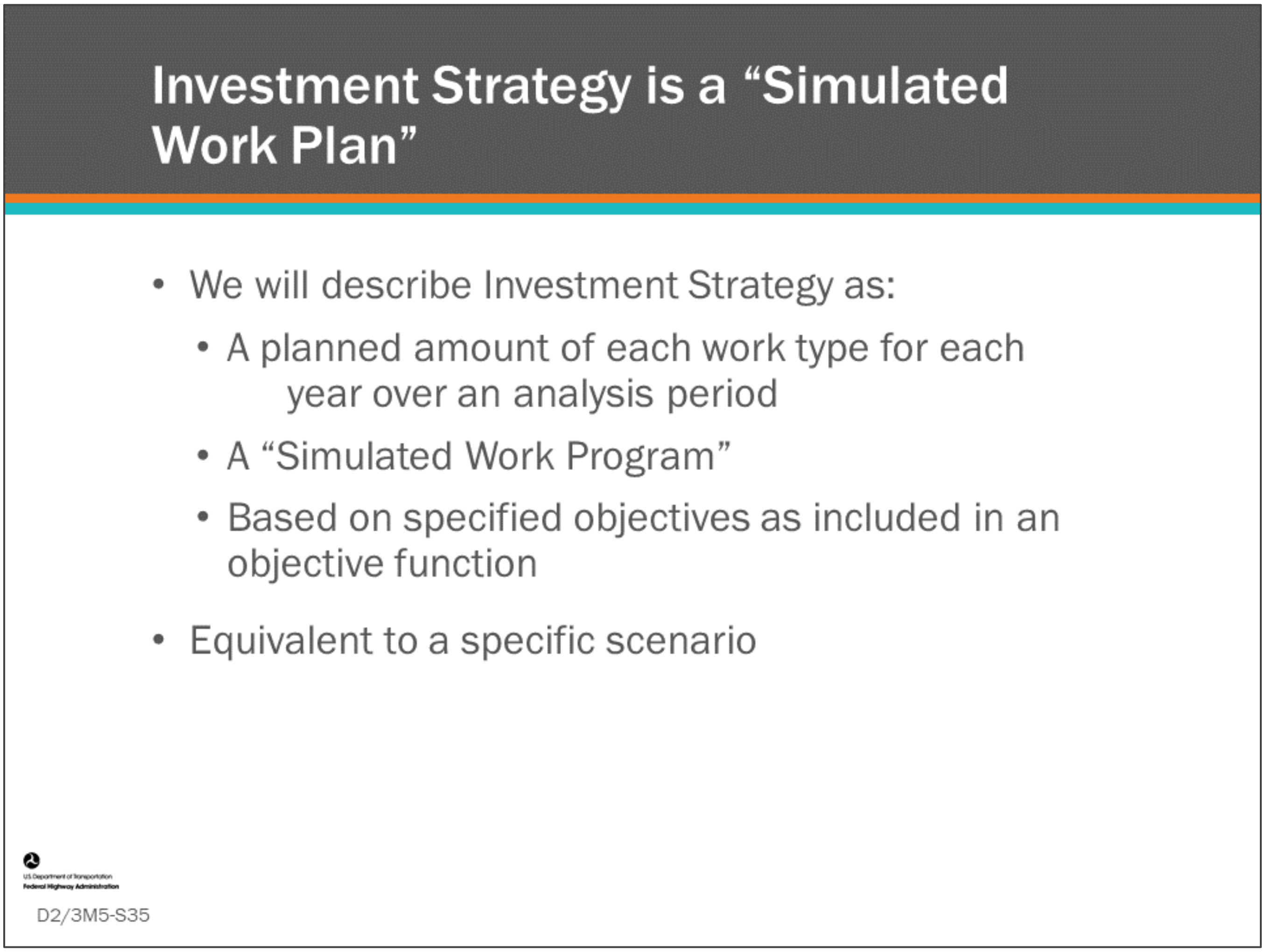
Key Message

In network level work program and optimization, the bridge manager is trying to identify the best overall network strategy by evaluating different work program scenarios and the resulting bridge projects for each year of the analysis period.

These projects are generated in general action categories such as preservation, rehabilitation, replacement, functional improvement, safety improvement or risk mitigation.

This output simulated work program of general projects can be used to set program and sub-program budgets, to identify work type allocations from total budget, and to do long-range forecasting and set targets for transportation asset management plans.

D2/3M5-Slide 35



Key Message

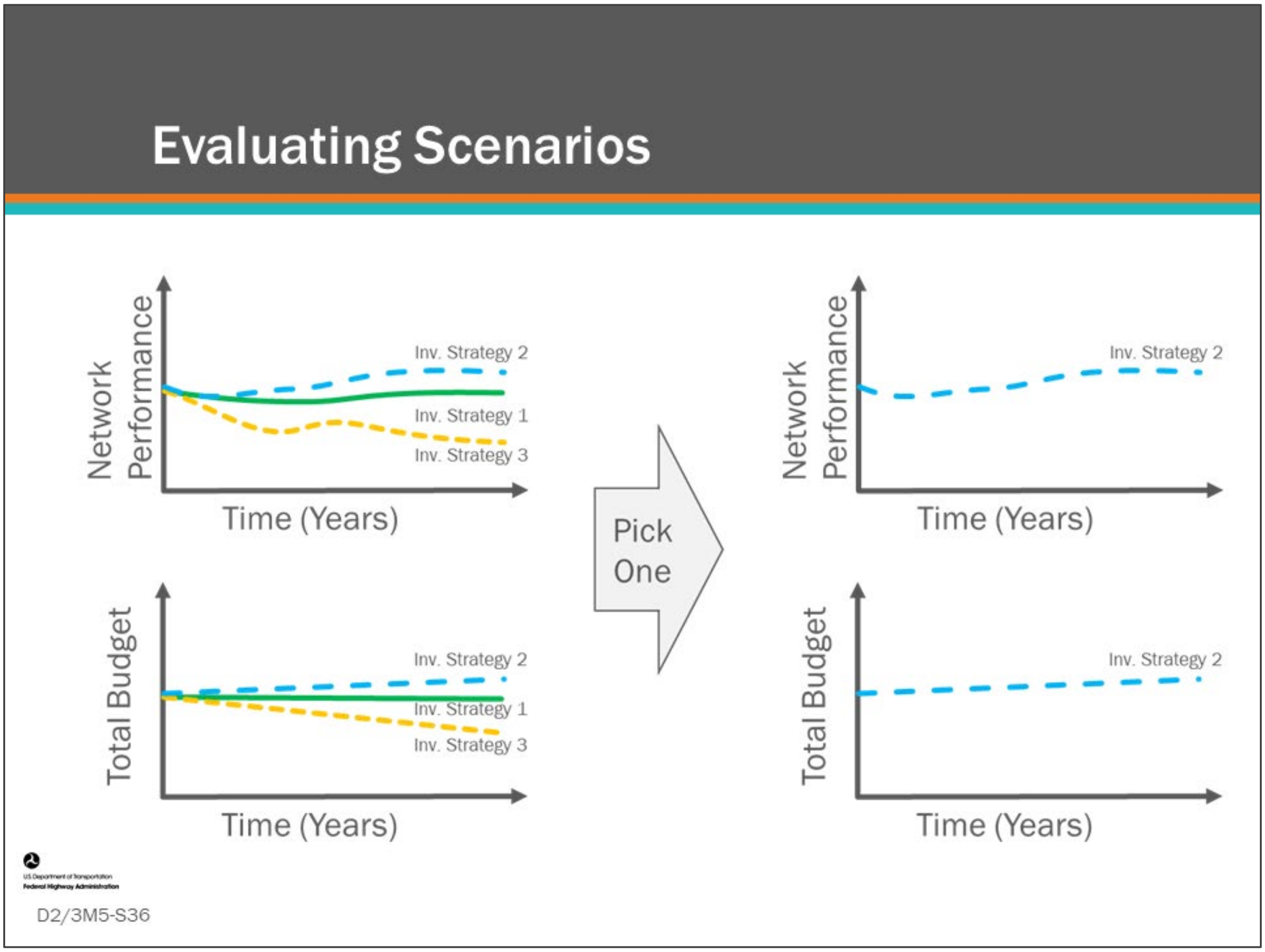
In the context of a BMS, we call an investment strategy, "a planned amount of each work type for each year over an analysis period."

Even more simply, we can call it a simulated work program, which is equivalent to the set of projects chosen for a specific scenario or program. Each project will reflect one or more actions that can be assigned to more general work types.

The simulated work program or scenario can be set up and run to maximize performance subject to a certain budget or minimize cost subject to certain performance or condition targets. The work program may further attempt to maximize mobility-based or risk-based objectives depending on the indices being used, or the weightings of components within a general index such as an overall utility index. Lastly the simulated work program may utilize different sets of decision trees or trigger rules that perhaps promote more or less preservation.

Whatever the simulated work program in question, this is deemed "simulated", because it is understood that the actual projects that are chosen in each year will likely not match exactly the projects that were projected; and the simulation should be rerun every year based on the actual projects selected in the prior years (and that are actually selected in the near term future for that matter).

D2/3M5-Slide 36



Key Message

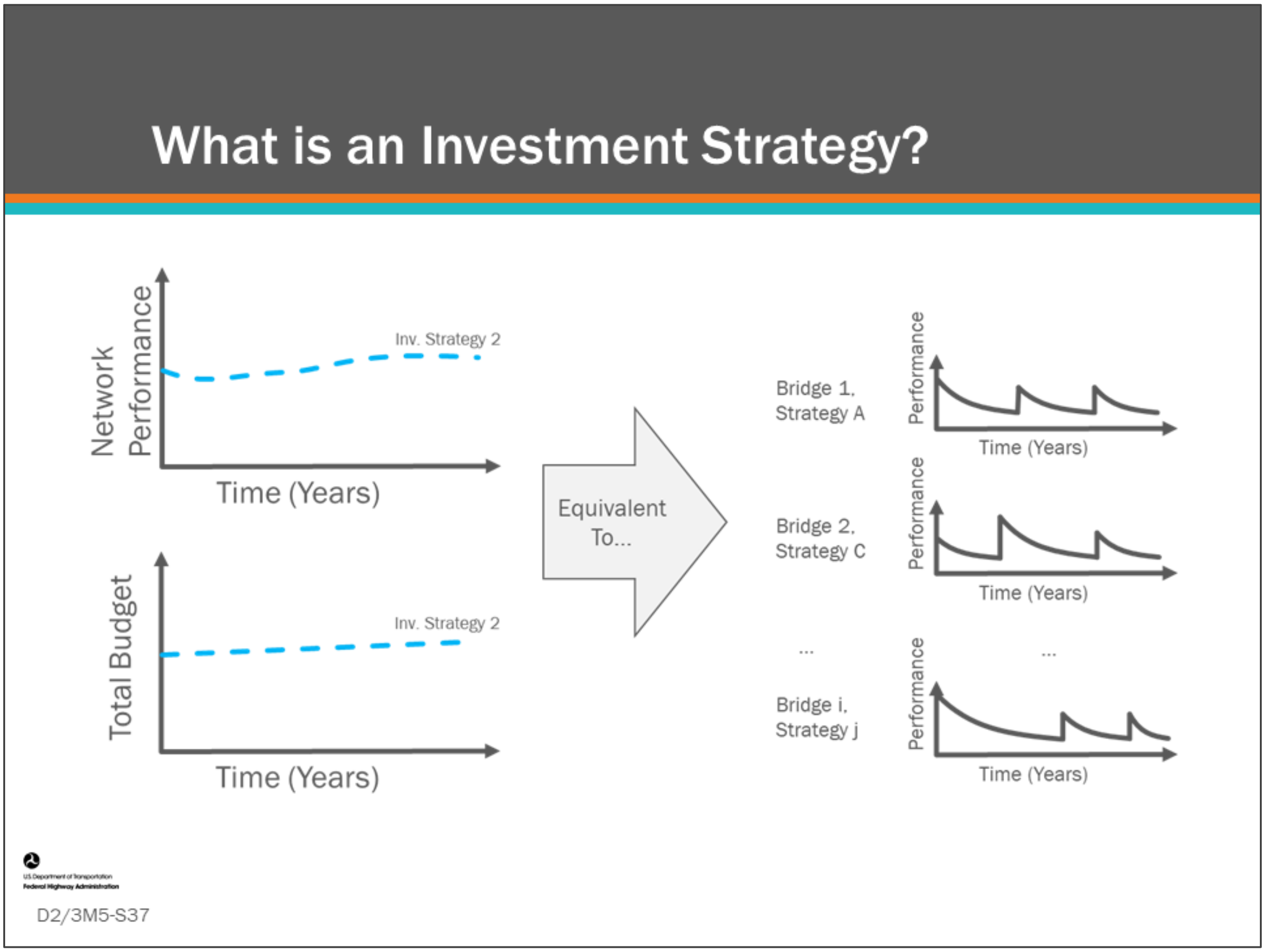
The ability to set up and run different scenarios in the BMS generates multiple possible investment strategies. Example scenarios or investment strategies may be:

- Baseline funding scenario
- Increased funding scenario
- Decreased funding scenario
- Maintain current performance levels scenario

Only three strategies are shown on the slide for the sake of presentation, but a more complete set of funding levels (e.g., in 5% increments) could be used for investigating a more complete set of funding levels. Plotting a single measure (such as average performance, or condition at the end of analysis period) could then be plotted against budget to give an efficient frontier.

By analyzing multiple "what-if" scenarios, the bridge manager can work with agency leadership to choose a specific investment strategy that balances project performance and budget requirements with agency goals and available funding.

D2/3M5-Slide 37

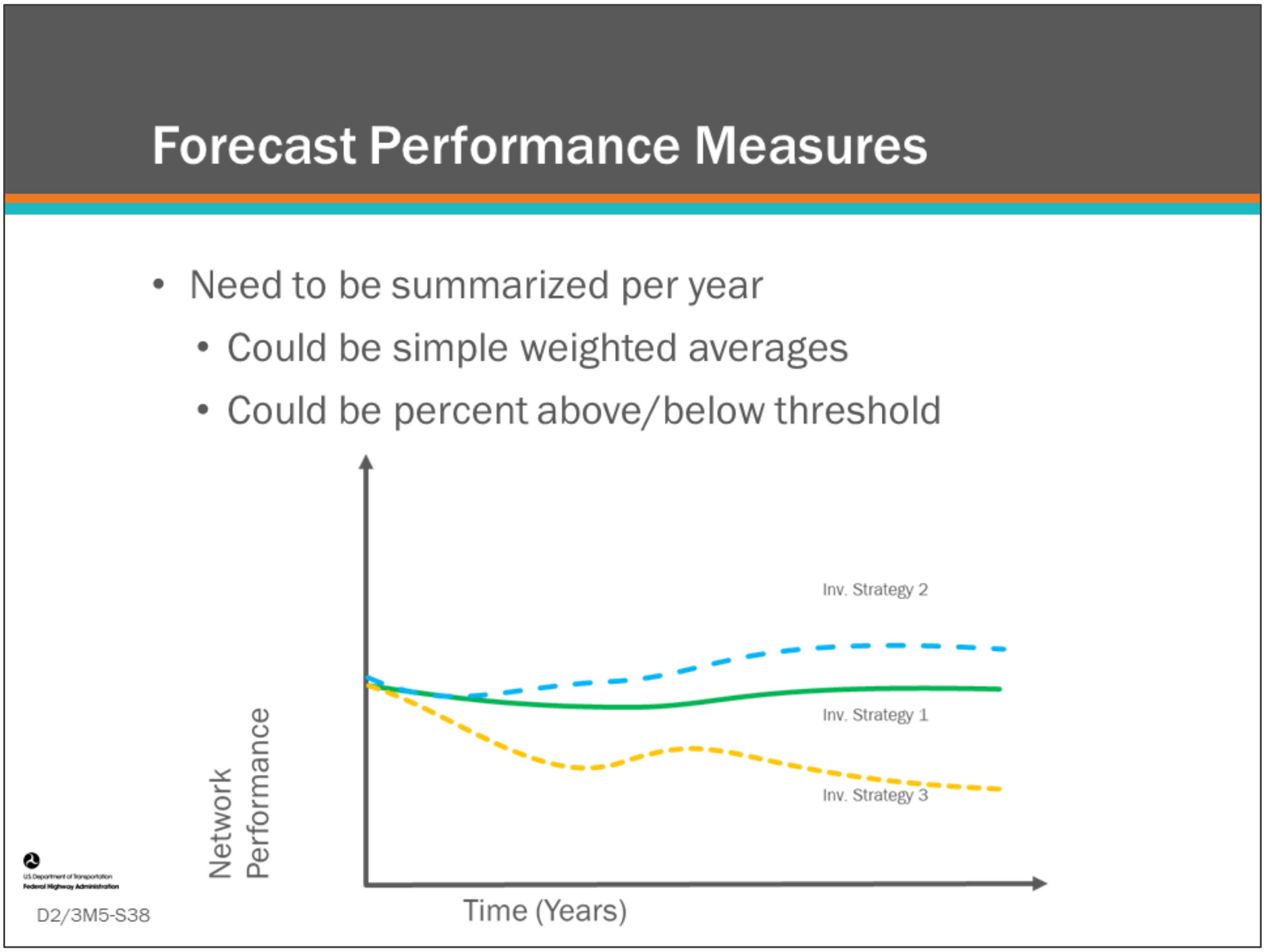


Key Message

Remember from the first day of the workshop that each scenario yields an investment strategy which in turn is a series of actions (bridge life cycle strategies) taken for each bridge over an analysis period. Each investment strategy is therefore a full work plan for each bridge in the bridge network or a sub-set of the network.

In other words, each individual scenario equates to choosing a life-cycle plan (sequence of actions, or bridge strategy) over the analysis period for each bridge. When the scenario modeling and optimization is run, the results for the agency's performance measures and the required budgets per work type can be predicted and shown over time.

D2/3M5-Slide 38

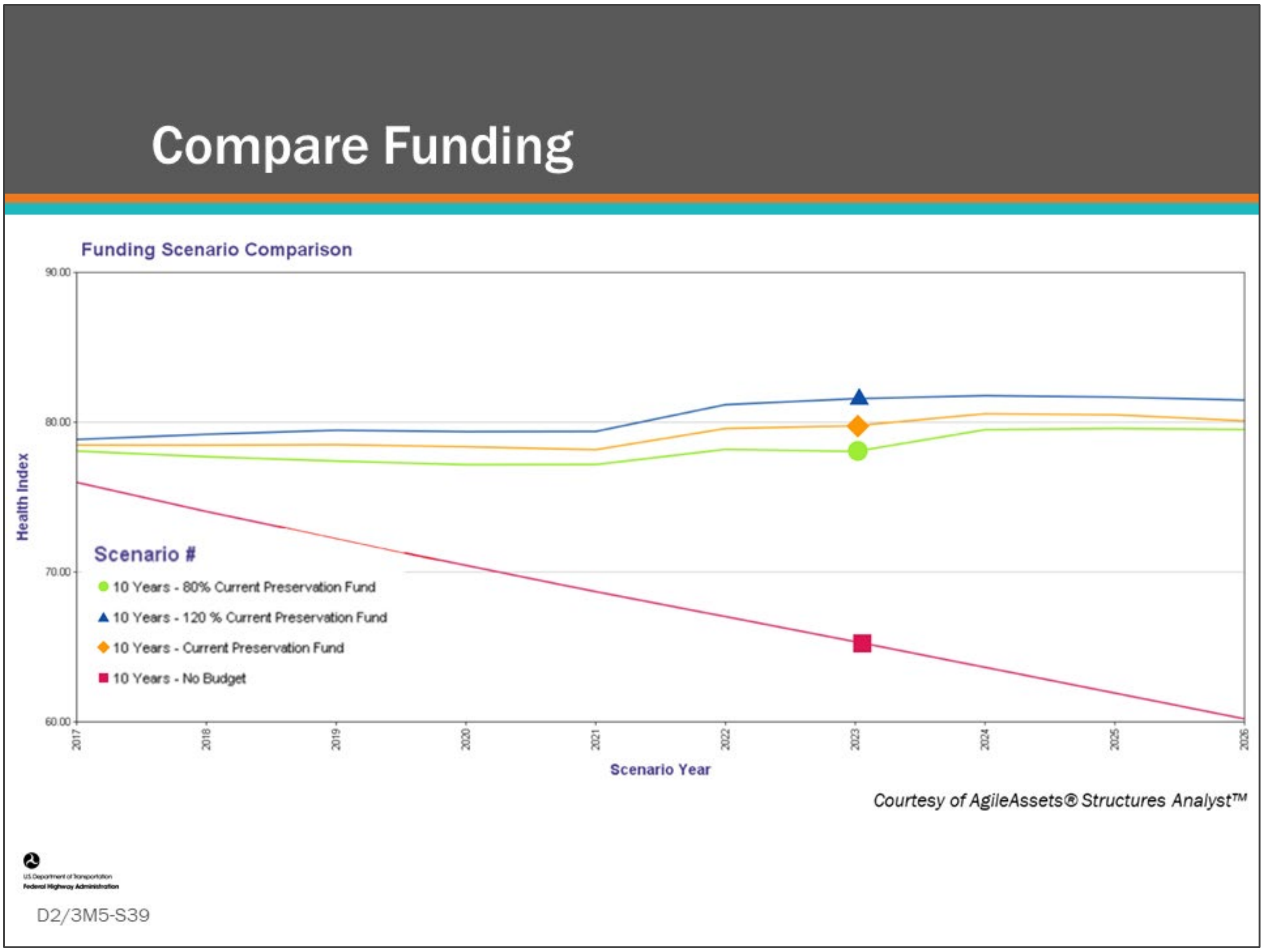


Key Message

A simple way to compare investment strategies is to plot projected performance over time for each strategy as demonstrated in the previous section. If an agency has prescribed performance measure targets or minimum acceptable performance measure values, they can be compared with the projections to see in what years the projections satisfy and do not satisfy the values. The performance measures need to be summary point-in-time statistics for the whole network for each year. A simple statistic could, for instance, be the weighted average Health Index (HI) across the network. However, it is valuable to track more detailed statistics that allow assessment of the "Good" and "Poor" ends of the spectrum.

As a result, separate metrics may be plotted for "Percent Good" and "Percent Poor" for instance. In the case of HI, the statistics could be "Percent of Deck Area with HI greater than 85", and "Percent Deck Area less than 60."

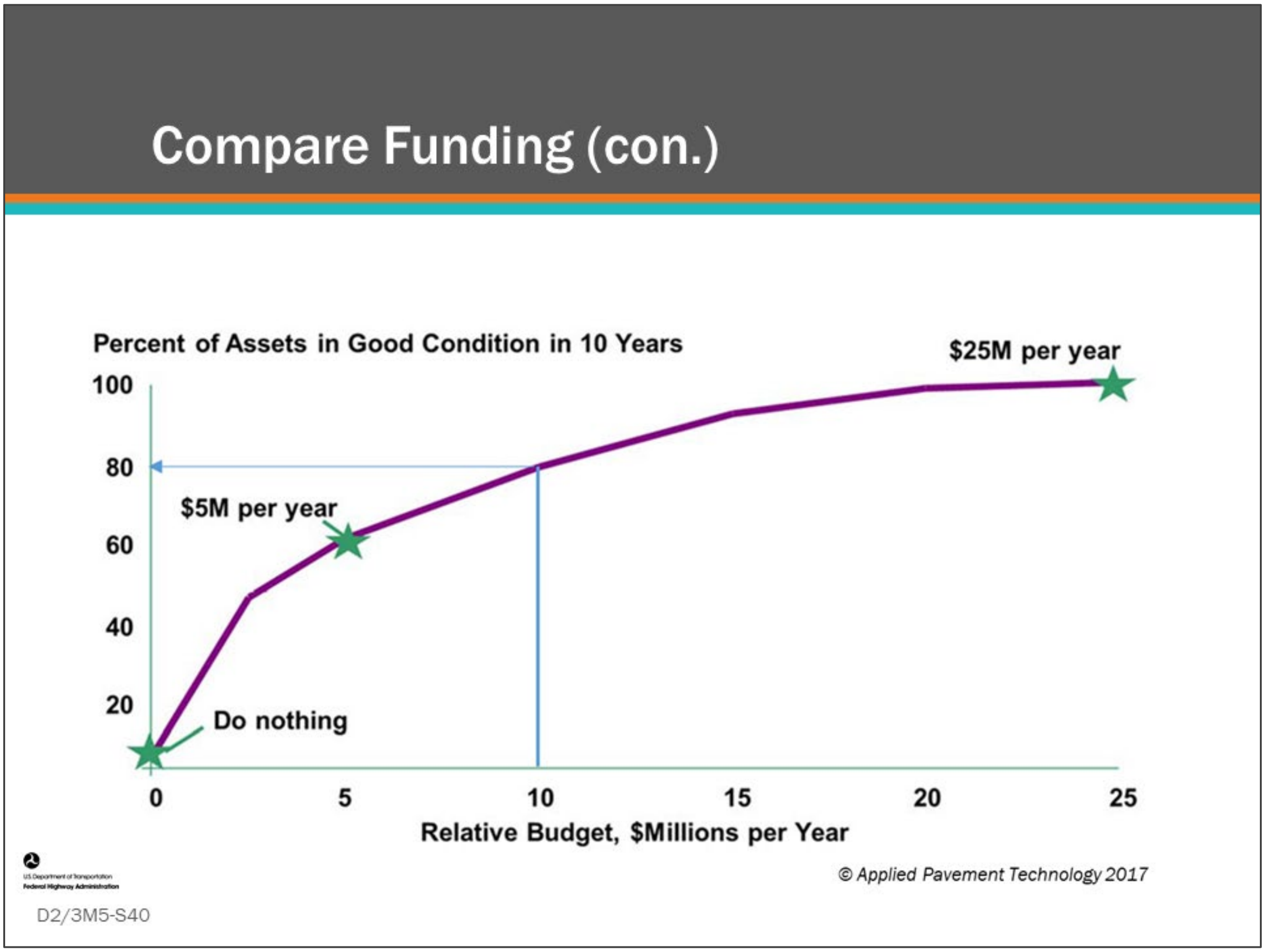
D2/3M5-Slide 39



Key Message

BMS software will typically support reports that compare multiple saved scenarios based on performance and budget requirements and, and for instance, show the projected performance of the bridge network over time. This can be used to select a planned investment strategy and determine budget needs.

D2/3M5-Slide 40

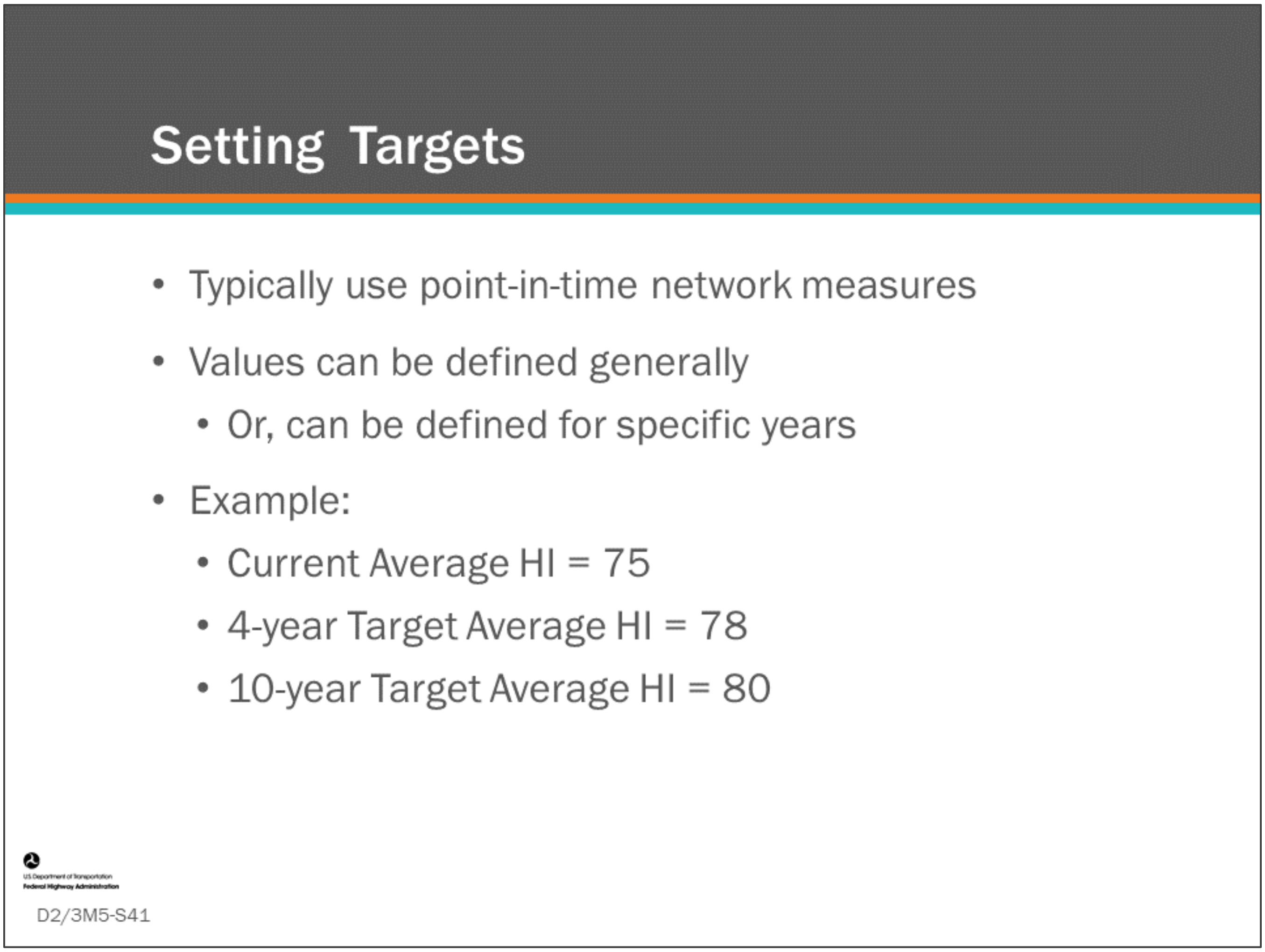


Key Message

Multiple saved scenarios can also be used to evaluate different overall investment levels as shown on this slide. The slides shows that an annual budget of $10 Million per year will result in 80 percent of assets in good condition in ten years. The chart also shows that as funding is increased there is a diminishing return on investment.

Assuming that the scenarios results are generated by a network optimization analysis, given the constraints of the scenario, the overall network performance forms a benefit frontier. Plotting the frontier can aid in selecting a funding level and associated performance target. When these plots are developed for different bridge segments or subprograms, or different asset classes, they can be used to perform funding tradeoff analysis.

D2/3M5-Slide 41



Key Message

A top-down approach is often used for setting targets in accordance to an agency's goals and objectives. To do this, an investment strategy is developed with available funds, and network performance (e.g., network HI) is forecast for a specific number of years to set the target that the bridge population will achieve with the given funding and strategy.

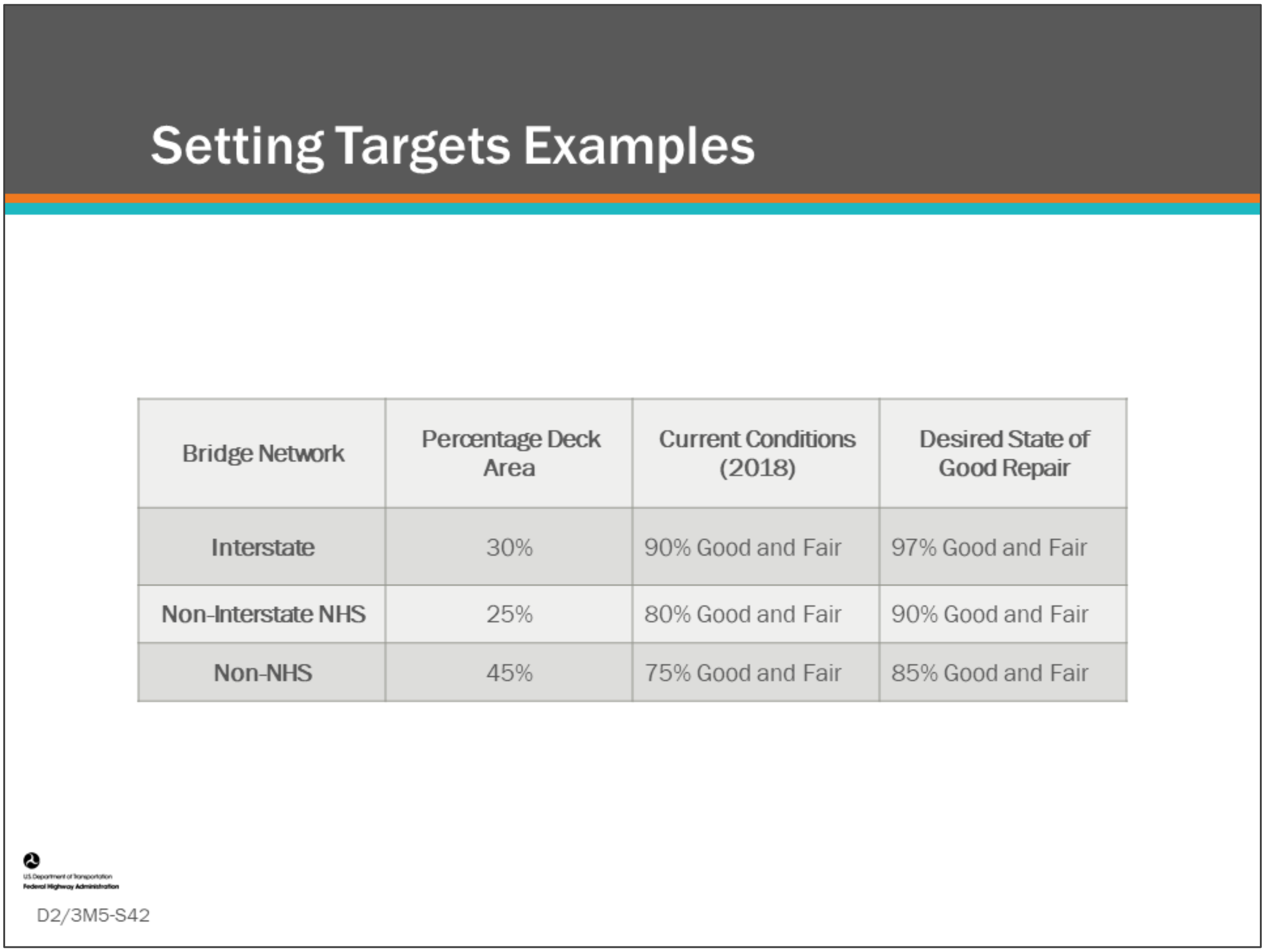
The targets can be general targets which either need to be continuously exceeded, or for which there is no specific timeline for implementation. Conversely, the targets can also include a specific year for attainment.

If the projected measures are significantly over or under the targets, the agency should undertake a gap analysis to learn what may need to be done differently to meet and maintain the targets. Possible outcomes may be to add (or subtract) budget to certain areas or in specific years, check and refine BMS inputs, or possibly change the targets if these prove to be unrealistic.

When setting targets, such as a 2-year target or 4-year target, you may have most, if not all. of your projects already identified. This will produce the most accurate forecast, and that forecast should be more conservative than a forecast that uses all optimization model project selections.

Note: 23 CFR 490 National Performance Management Measures defines target *as* a quantifiable level of performance or condition, expressed as a value for the measure, to be achieved within a time period required by the FHWA). Target setting for FHWA national performance measures requires attainment with 2 and 4-years. Also, per 23 CFR 490.413 there are penalties for not maintaining NHS bridge condition less than or equal to 10.0 percent poor by deck area.

D2/3M5-Slide 42



Bridge Network	Percentage Deck Area	Current Conditions (2018)	Desired State of Good Repair
Interstate	30%	90% Good and Fair	97% Good and Fair
Non-Interstate NHS	25%	80% Good and Fair	90% Good and Fair
Non-NHS	45%	75% Good and Fair	85% Good and Fair

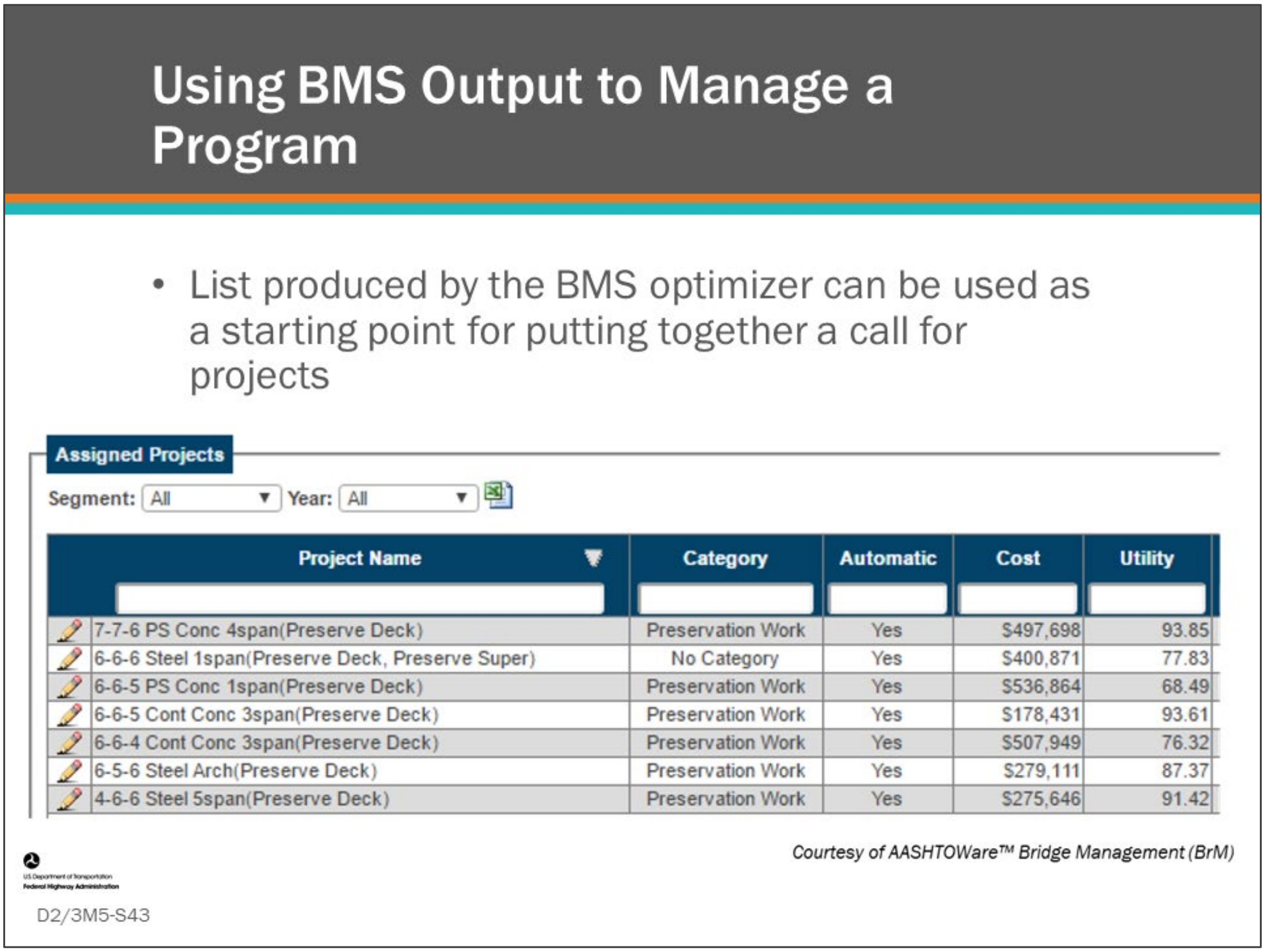
Key Message

Many agencies have multiple targets which the investment strategy needs to take into consideration.

For example, on the slide, targets need to be developed for percent good and fair for the bridge population. This will challenge the bridge manager to reduce their number of poor bridges while also managing their good and fair bridges.

Ideally, the optimization analysis will be able to recommend an optimal simulated program that addresses both poor, and good and fair bridges. Note however, that depending on the bridge manager’s objectives, different weightings may be given to different measures within the index or utility being maximized, or specific constraints may be added that are specific to certain goals. As a result, to meet a target for poor bridges, the bridge manager may use a specific scenario setup to emphasize reducing poor bridges and adopt such an investment strategy. Conversely, a manager may want to maximize bridges in good condition and create a scenario setup and associated investment strategy where preservation is emphasized.

D2/3M5-Slide 43



Key Message

Once a strategic investment strategy is set, the BMS optimizer provides a list of projects that can be used as a starting point for putting together a call for projects. Shown on the slide is the AASHTOWare™ Bridge Management (BrM), “Assigned Projects” page.

D2/3M5-Slide 44

Key Message

In this section of the lesson, you will work with your groups to decide how to create an investment strategy and how to set targets.

D2/3M5-Slide 45

Key Message

With a BMS, you are able to project your performance measures and your budget requirements for any chosen scenario.

- Should you set targets first and then figure out how much it will cost to attain them?
- Or, should you figure out what different levels of funding could achieve, and then set your targets accordingly? Or will it be a combination of both?

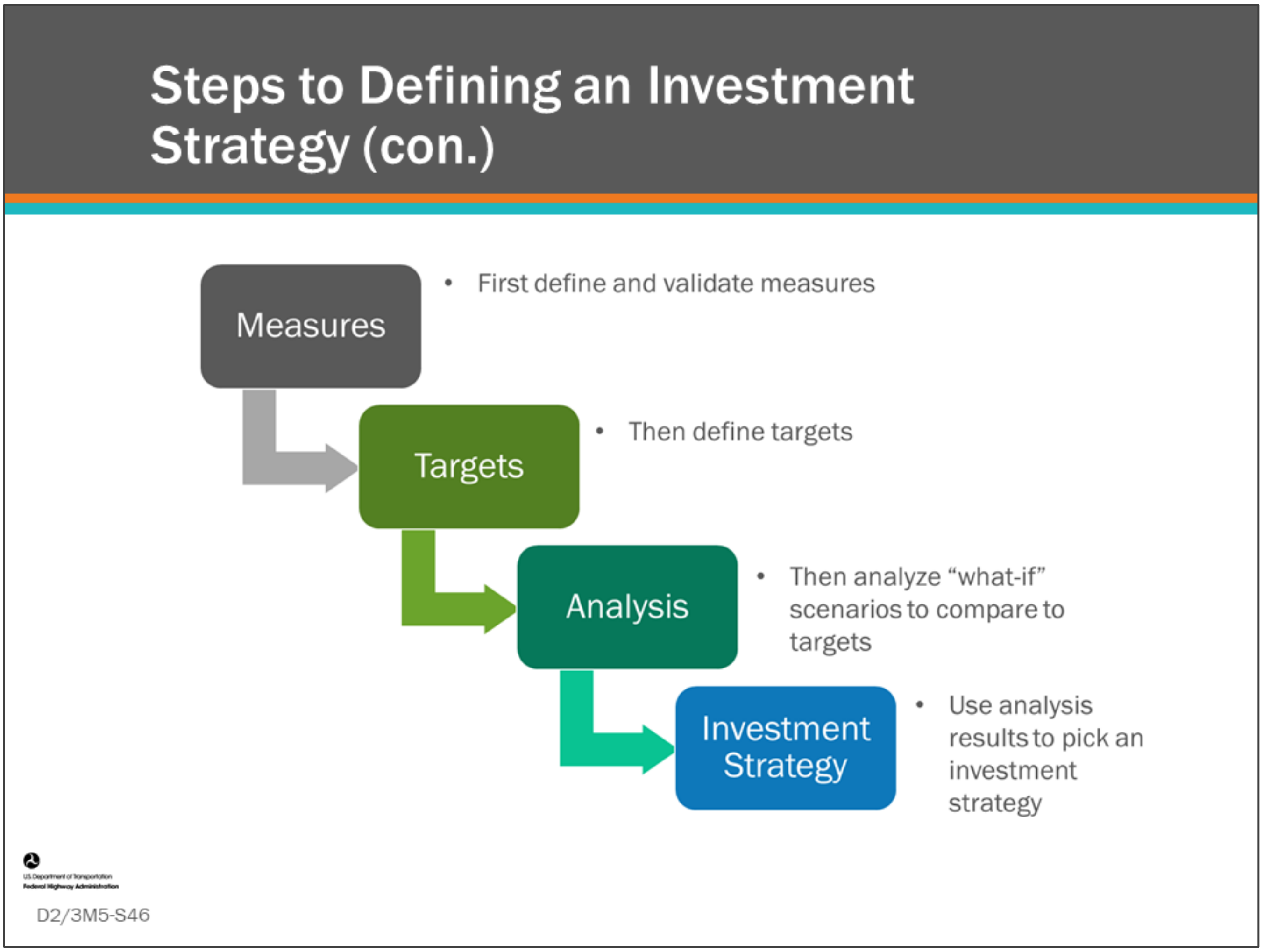
A target is a performance measure value set either generally or with a specific target year that an agency will strive to achieve with their investment plan. Agencies are often required to set targets of one form or another.

The advantages of setting a target first are that the bridge manager is able to work with leadership to identify what level of service is deemed desirable. Once this is set, then the manager can analyze what it will take to meet this target: what funding levels it will take and how long it will take to get there.

The disadvantage of this approach is that the target may be unrealistic in terms of needed funding or other factors, or it might be that setting only a slightly lower goal may result in considerable savings.

Selecting a target without the benefit of analyzing different investment strategies can have the outcome of forcing an unintended strategy. For example, selecting a very aggressive short-term target for percent bridges poor by deck area can force a worst first strategy. If one starts by selecting a target, they should have confidence in using the performance measure and have an objective basis to selecting the target.

D2/3M5-Slide 46



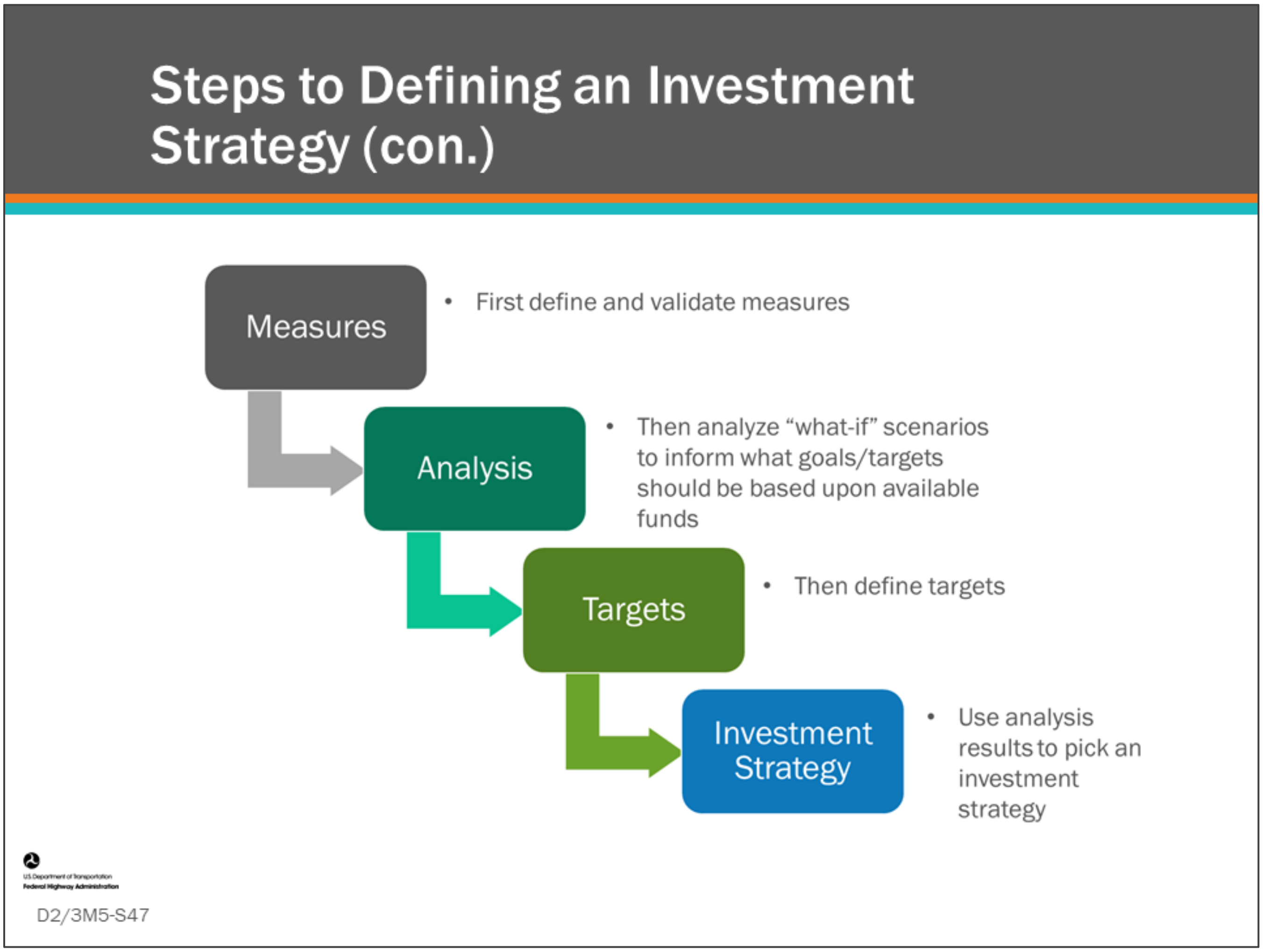
Key Message

One process used to define an investment strategy is shown on this slide. The steps involved in this approach begin with defining and validating the measures.

- Next the targets are defined, followed by performing "what-if" scenarios, used to compare strategies and budgets that meet the target.
- As noted previously, setting a target first allows the manager to perform multiple analyses to determine what it will take to meet this target.
- Finally, an investment strategy is chosen that attains the targets within a reasonable amount of time. But what if there is almost no chance of getting the funding required to support that investment scenario?

Note: This discussion is relative to how BMS have traditionally supported analysis of investment strategies and is not intended to address the requirements of 23 CFR 515 Asset Management Plans process for investment strategy development. 23 CFR 515 requires additional elements to those discussed here.

D2/3M5-Slide 47



Key Message

Another approach is to define and validate measures first, then run various optimization analyses based on available funding to determine what targets are implementable. Then, define the target and pick an investment strategy.

Note: This discussion is relative to how BMS have traditionally supported analysis of investment strategies and is not intended to address the requirements of 23 CFR 515 Asset Management Plans process for investment strategy development. 23 CFR 515 requires additional elements to those discussed here.

D2/3M5-Slide 48

Group Discussion – Setting Targets

Source: Adobe Stock

- Describe your bridge program targets
- Describe how you will use the BMS optimization to set your targets
- Discuss differences between short-term targets and long-term sustainable targets

U.S. Department of Transportation Federal Highway Administration

D2/3M5-S48

Key Message

Describe how you will use your BMS optimization solver to set your agency target.

D2/3M5 - Slide 48: Setting Targets

1. Describe your bridge program targets.

2. Describe how you will use the BMS optimization to set your targets.

3. Discuss differences between short-term targets and long-term sustainable targets.

D2/3M5-Slide 49

Group Discussion – Setting Targets

Source: Adobe Stock

- Define bridge program targets
- Describe how you will use the BMS optimization to set your targets
- Discuss differences between short-term targets and long-term sustainable targets

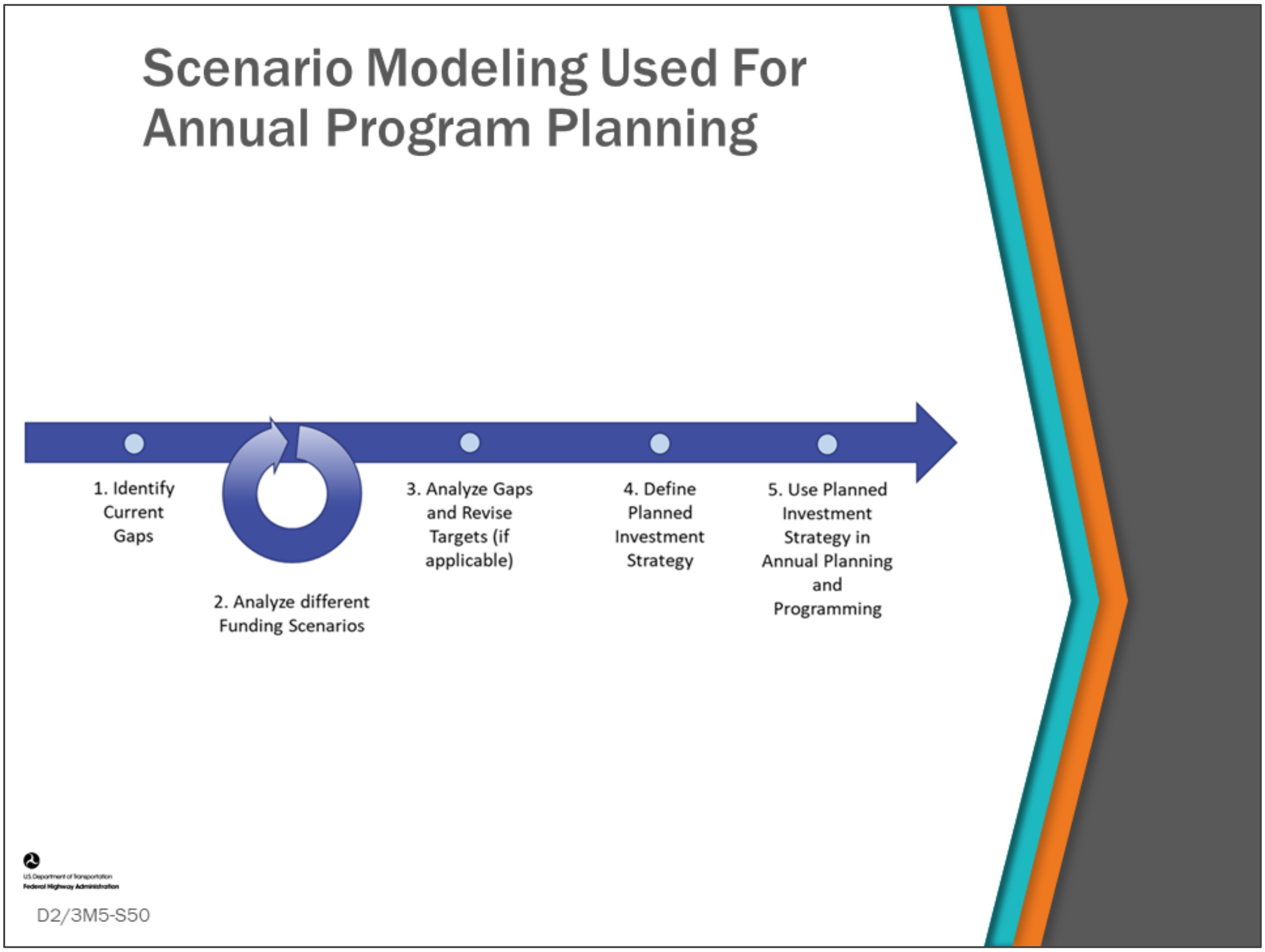
U.S. Department of Transportation Federal Highway Administration

D2/3M5-S49

Key Message

Describe how you will use your BMS optimization solver to set your agency target.

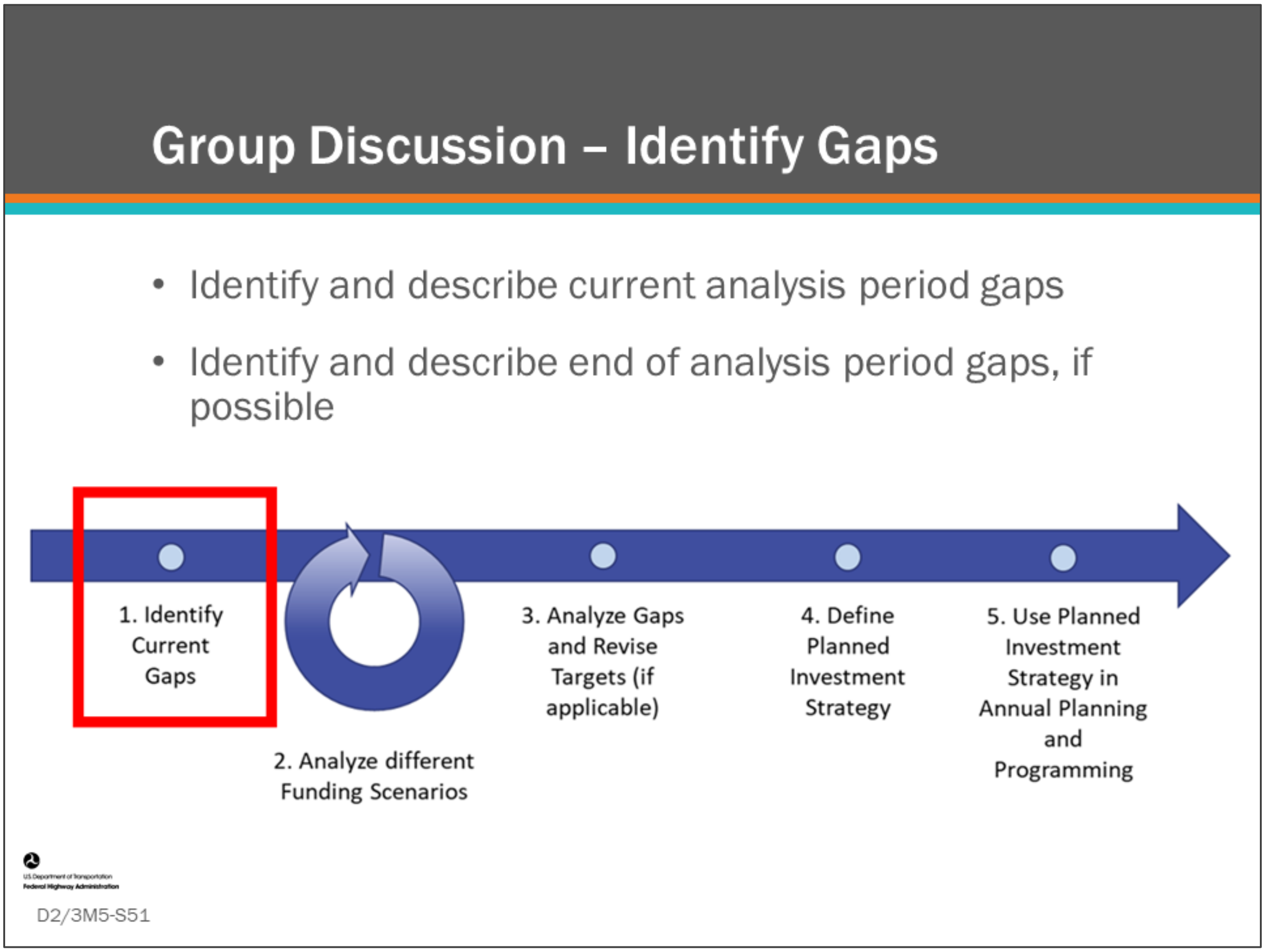
D2/3M5-Slide 50



Key Message

You have validated performance measures, a high level investment strategy, and targets. You can now use BMS scenario modeling to help develop your annual program by identifying how different funding scenarios, fixed project selections, and strategies perform with respect to agency targets. The difference between your set objective and expected outcome at a specific point in time is the "gap". Scenario modeling can be used to perform a gap analysis. As shown in the chart on this slide, this is done by selecting different funding scenarios, fixed project selections, and strategies and analyzing the results. If there is a gap, you can refine fixed project selection, strategy and, if possible, adjust funding (overall and to specific portions of the bridge program). In this section we will look at the steps taken to do this.

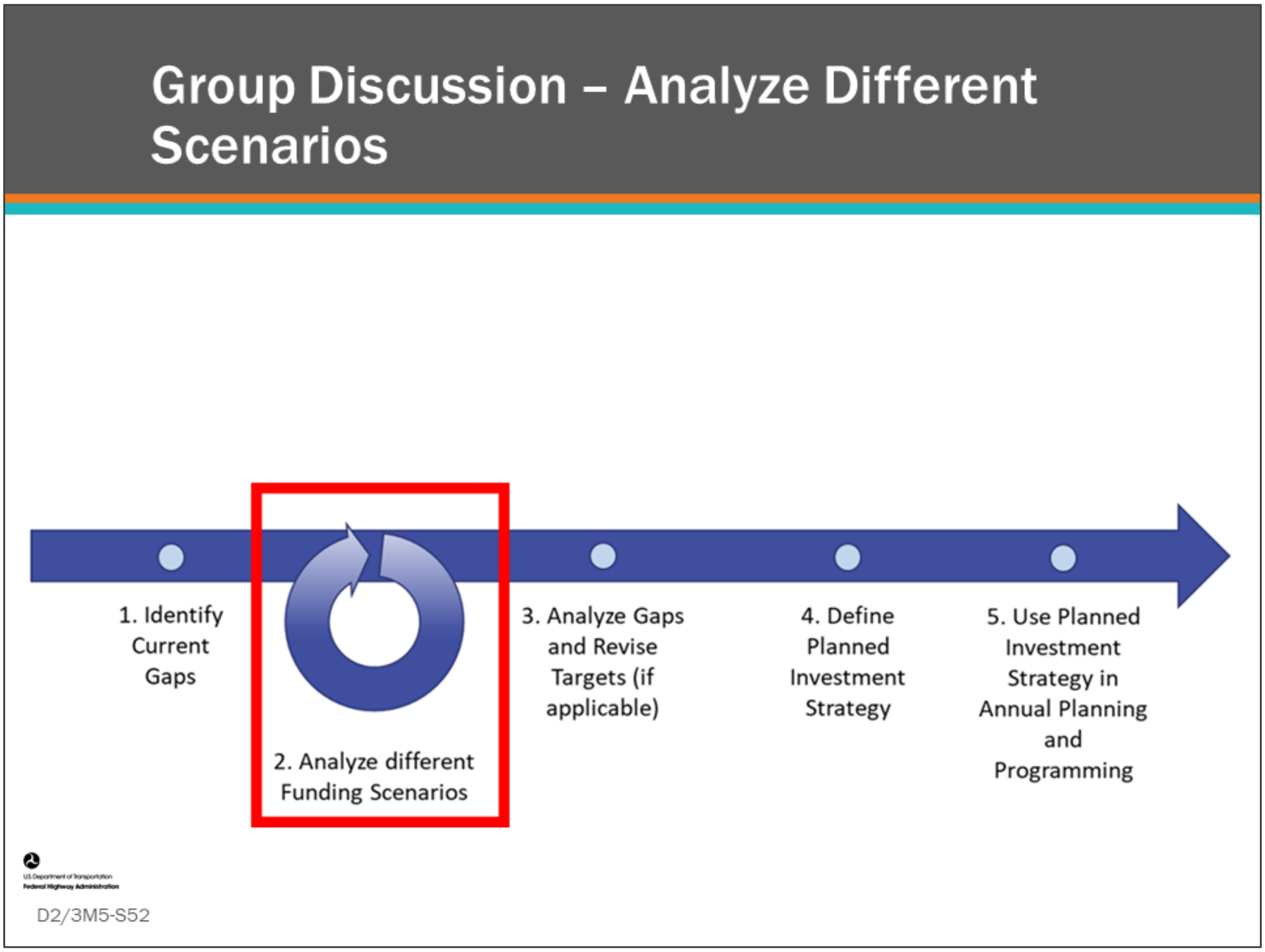
D2/3M5-Slide 51



Key Message

Targets for performance measures were discussed in the previous section. To check progress against these targets, the trend of these metrics during the current performance period is plotted against the targets to identify current gaps in performance.

D2/3M5-Slide 52



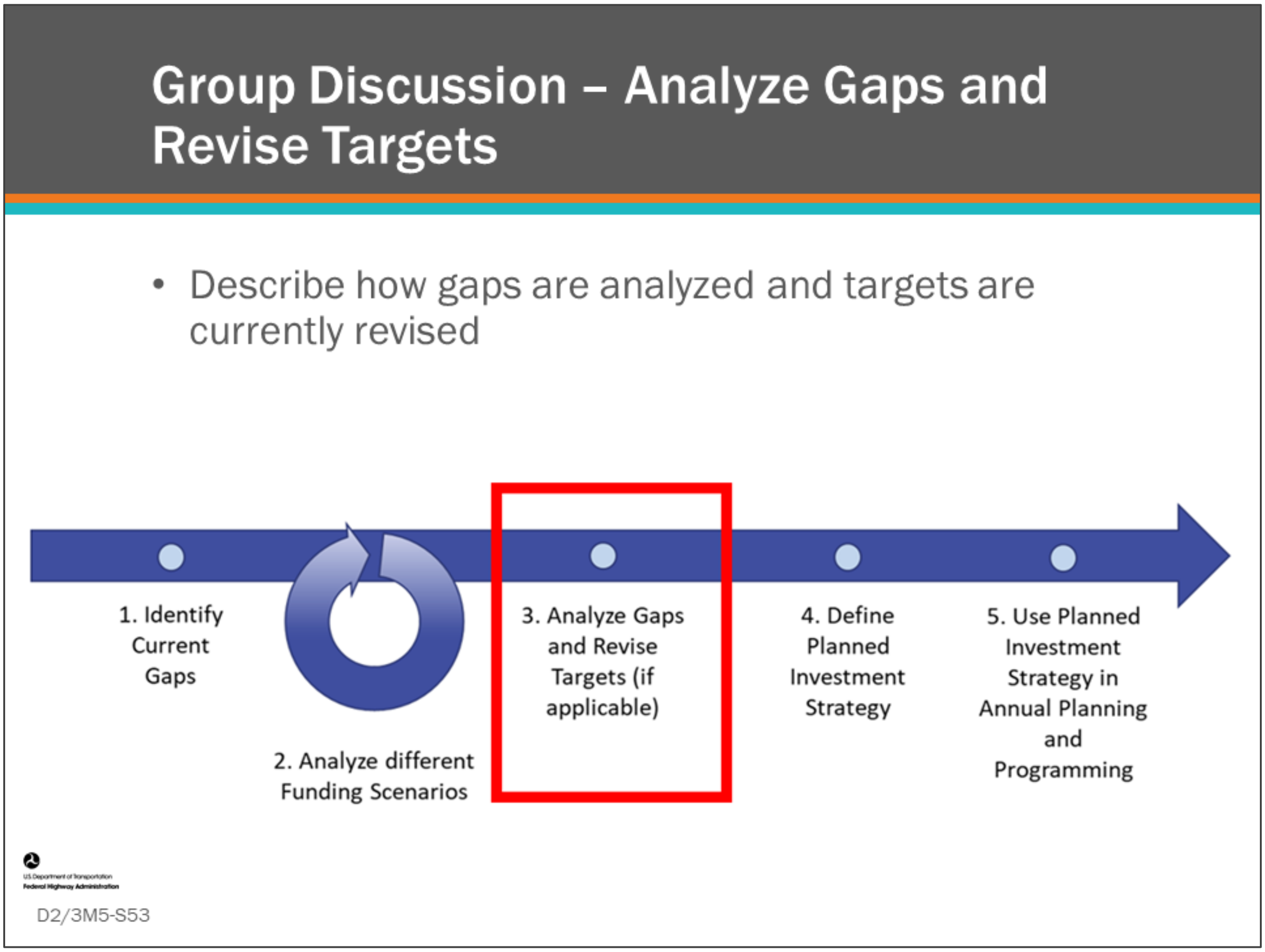
Key Message

You can run scenarios using varied budgets, fixed projects, and/or strategies.

Steps that are taken are as follows:

- Define funding and strategy. These can be obtained from agency leadership, an asset management team, and/or bridge management team.
- Update various parameters, policies, objectives, and constraints to run in the scenarios.
- Include fixed projects.
- Run optimization. This generates a set of projects for each bridge over the analysis period that represent the fixed projects and optimal set of projects to undertake. This analysis takes into account incremental benefit-cost when maximizing the index (performance measure) over the lifecycle of the bridge using the deterioration models and network policies.

D2/3M5-Slide 53

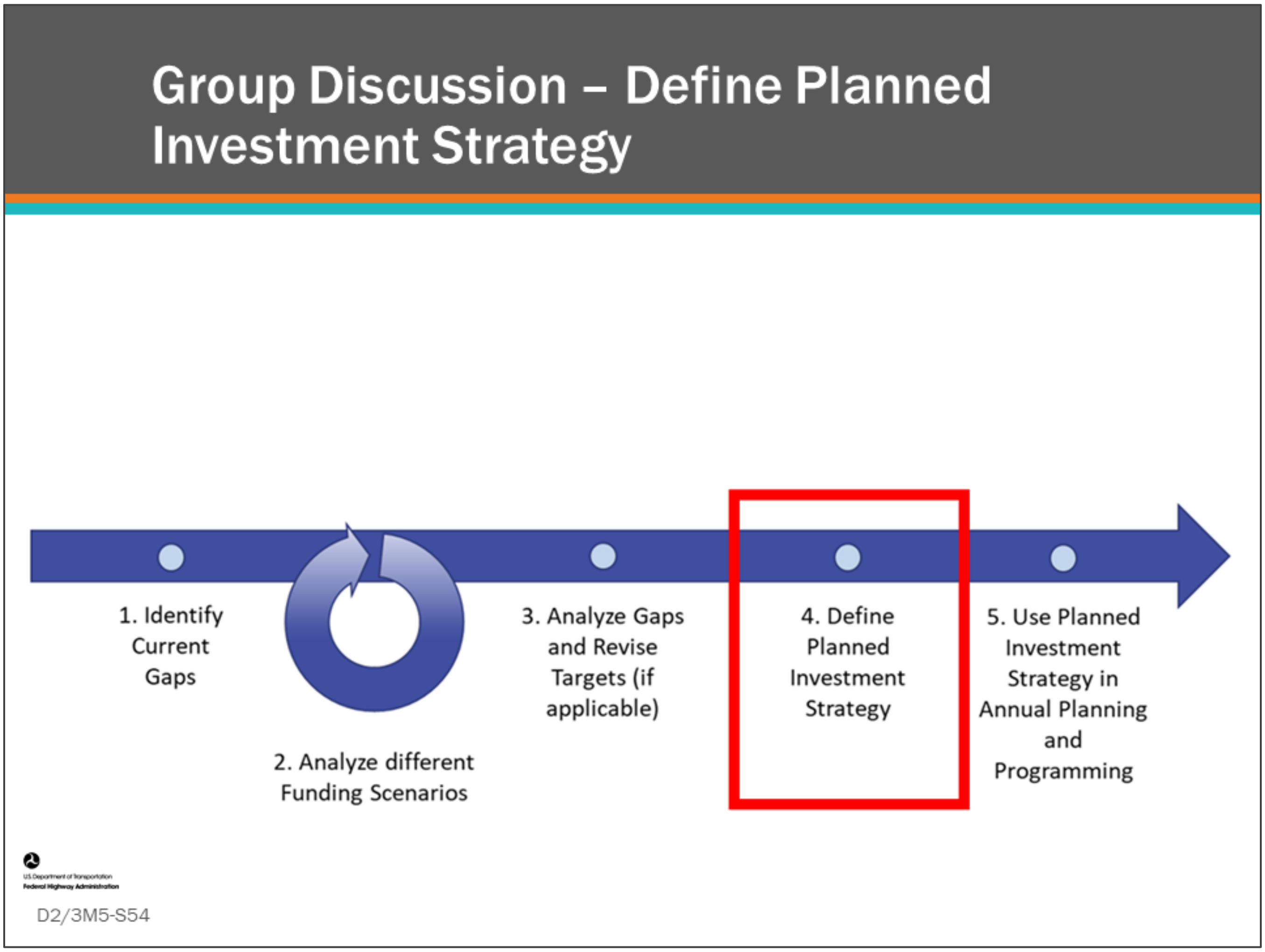


Key Message

The scenario results can be analyzed which may show a gap between target setting and projected results. The gap analysis can be used to make agency decisions as the following example shows:

- All scenario results are compiled by the bridge asset management team.
- The projected performance measures are compared against analysis period targets and key issues hindering progress toward achieving and sustaining the objectives, as well as strategies to close any gaps are discussed with the asset groups and documented.
- If applicable, based on the results of the gap analysis, the bridge asset management team may include recommendations for revising the targets which may be adopted by the agency leadership.
- If revised targets are adopted, one or more scenarios may need to be revised to show the budgets needed to attain the new targets. In establishing or revising targets, agencies can consider historical levels of service, the results of customer surveys, industry practice, and any applicable laws and regulations.

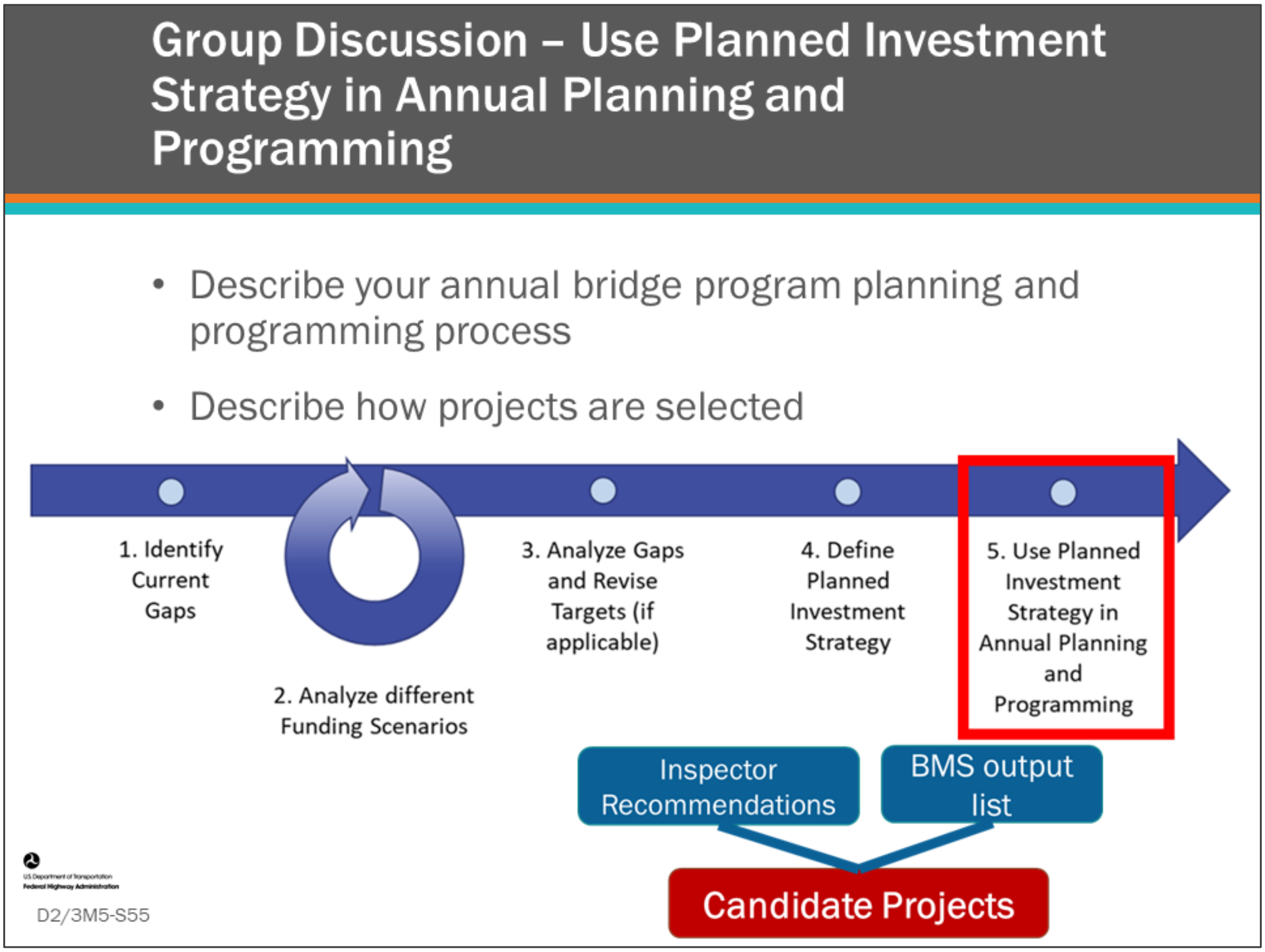
D2/3M5-Slide 54



Key Message

Based on the results of the gap analysis, an investment strategy and targets are finalized. This can involve agency leadership in consultation with the bridge asset management team. The adopted strategy consists of planned funding for the bridge program in each year of analysis period.

D2/3M5-Slide 55



Key Message

Once the planned investment strategy has been agreed upon by agency leadership and has been documented, it can be used by bridge managers in their annual planning and programming. Depending on agency and organizational structure, an investment strategy may be very general or very detailed.

- If the agency is decentralized, there should be a process to communicate the strategy to regional bridge managers.
- If the strategy is general and performance based, local bridge managers may use the BMS to make project selections in accordance to the strategy.

Candidate projects can be selected from BMS output lists which provide results from prioritization and optimization routines in the software. Bridge managers can also use inspector recommendations in selecting candidates, or review both when making selections.

D2/3M5-Slide 56

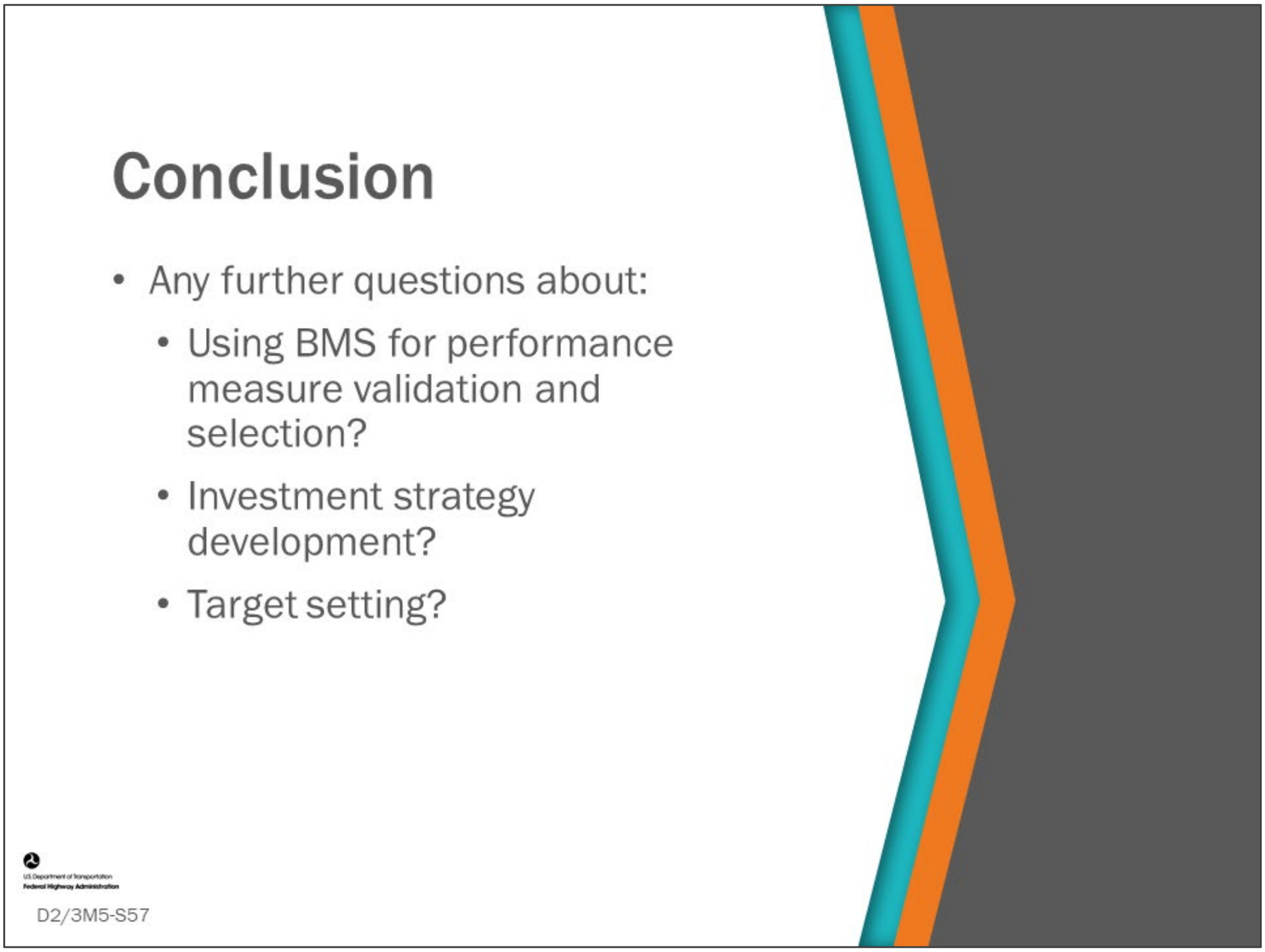
Key Message

Describe how you will use your BMS optimization functionality to set your annual bridge program.

D2/3M5 - Slide 56: Using BMS Optimization Results to Set Up Annual Bridge Program

1. With your investment strategy set and targets established, how will you use your BMS optimizer to help set your annual bridge program?

D2/3M5-Slide 57



Key Message

This concludes Module 5: Using BMS for Performance Measure Validation and Selection, Investment Strategy Development, and Target Setting.

D2/3M5-Slide 58

Slide #	Image Description	Source Information
6	Screenshot showing AgileAssets® Structures Analyst™ filter Segments screen.	AgileAssets® Structures Analyst™.
8	A screen shot of AASHTOWare™ BrM shows Action Definitions screen.	AASHTOWare™ Bridge Management (BrM).
9	A screenshot ofAgileAssets® Structures Analyst™ Budget Category screen.	AgileAssets® Structures Analyst™.
9	A screen shot of AASHTOWare BrM Funding Source Targets Screen.	AASHTOWare™ Bridge Management (BrM) .
10	A screenshot of AASHTOWare™ Bridge Management (BrM)showing Project Categories and work types for Preservation Work Category.	AASHTOWare™ Bridge Management (BrM) .
11	Screenshot of Deighton dTIMS© objective function drop down list.	Deighton dTIMS©.
12	A screenshot of AgileAssets® Structures Analyst™ Objective Constraints screen.	AgileAssets® Structures Analyst™.
12	A screenshot of AASHTOWare™ Bridge Management (BrM) Optimize Program screen.	AASHTOWare™ Bridge Management (BrM) .
16	A screenshot of AASHTOWare™ Bridge Management (BrM) Program Editor Screen.	AASHTOWare™ Bridge Management (BrM).
17	A screenshot of AASHTOWare™ Bridge Management (BrM)Program Editor Screen.	AASHTOWare™ Bridge Management (BrM).

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D2/3M5-S58

D2/3M5 Figure Source List

D2/3M5-Slide 59

Slide #	Image Description	Source Information
18	Screenshot of AgileAssets® Structures Analyst™ Optimization Analyst screen.	AgileAssets® Structures Analyst™.
19	A screenshot of a spreadsheet shows an example of Deighton dTIMS Scenario Results.	Deighton dTIMS©.
23	A line chart titled, Health Index Projection has Average Health Index on the y-axis and Years on the x-axis.	This Workshop.
30	Graph showing an example of an aggressive preservation strategy. Life-Cycle Cost Utility Value vs. Calendar Year is presented for several different budgets. A horizontal dashed line is indicated as Objective.	FHWA. *Using an LCP (Life Cycle Planning) Process to Support Asset Management: A Handbook on Putting the Federal Guidance into Practice.* Publication No. FHWA-HIF-19-006. Washington, DC. January 2019. Figure 23.
31	Graphs showing aggressive preservation strategies. Results are shown given two different measures; Percent Good and Fair Bridges (top) and Life-Cycle Utility Value (Bottom).	FHWA. *Using an LCP (Life Cycle Planning) Process to Support Asset Management: A Handbook on Putting the Federal Guidance into Practice.* Publication No. FHWA-HIF-19-006. Washington, DC. January 2019. Figures 22 and 23.
34	Graphic showing structure numbers at the top; 62234, 18934, 23899, 11145, 10122, 5555. Below that is a text box with the text; "Agency Rules, Current Conditions, Funding Scenario Constraints."	This Workshop.

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D2/3M5-S59

D2/3M5 Figure Source List

D2/3M5-Slide 60

Slide #	Image Description	Source Information
36	Four line charts are shown. In the top left a chart has Network Performance on the y-axis and Time (Years) on the x-axis.	This Workshop.
37	Five line charts are shown. In the top left a chart has Network Performance on the y-axis and Time (Years) on the x-axis.	This Workshop.
38	A line chart has Network Performance on the y-axis and Time (Years) on the x-axis.	This Workshop.
39	A screenshot shows AgileAssets® Structures Analyst™ line chart titled Funding Scenario Comparison with Health Index on the y-axis and Scenario Year on the x-axis.	AgileAssets® Structures Analyst™.
40	Line chart showing Percent of Assets in Good Condition in 10 Years.	FHWA. *Using a Life Cycle Planning Process to Support Asset Management*. Washington, DC, 2017.
43	Screenshot of the AASHTOWare™ Bridge Management (BrM)Assigned Projects page with a list of sample projects. The list includes the project name, category, how it was generated, cost, and utility	AASHTOWare™ Bridge Management (BrM) .

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D2/3M5-S60

D2/3M5 Figure Source List

Module Title: D2/3M6 – Integrating Business Processes and BMS Software

Module Time: 120 Minutes

Module Summary

A BMS works best when it is integrated into an agency's business process. This module will go over the bridge management business processes that are dependent upon, or supportive of a BMS. This module is primarily a group class discussion. This module will provide opportunity for the class to review their own bridge management business processes and discuss how a BMS is, or can be, used to support it.

Expected Outcome(s)

The expected outcome of this module is to discuss host agency business processes and identify what are best practice and desired enhancements to these processes that would support good bridge management using a BMS.

Resource List

Slide	Reference Information
9	Appian.com Website: Definition of a Business Process. The Business Process Management Guide: Accelerate Your Organization with Business Process Management (BPM).

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D2/3M6-Slide 1

Key Message
A BMS works best when it is integrated into an agency's business process and it has a connection to agency goals and objectives with meaningful performance measures that are an integral part of your BMS.

This module will go over the bridge management business processes that are dependent upon, or supportive of a BMS.

This module will also provide opportunity for the class to review their own business processes and discuss how a BMS is, or can be, used to support it.

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FHWA does not promote or endorse patented and proprietary products. Bridge management software is largely proprietary. Workshop content pertaining to proprietary software is included only to illustrate how bridge management system concepts and analyses are applied in practice. The included content shall not be construed as promotion or endorsement of specific software.

D2/3M6-Slide 2

Key Message

This module aligns agency bridge management processes with the BMS. In group activities, the class will discuss their current business processes that typically are supported by or supportive of a BMS. They will also discuss enhancements they would like to make to better support their BMS and how the BMS can support their business processes in the future. This will be compared with an instructor's ongoing list of business processes involving a BMS.

D2/3M6-Slide 3

Group Formation for Module Discussions

Source: Adobe Stock

- Divide into equal groups
- Gather group materials
- Assign a group representative for note keeping
- Brainstorm about integrating your agency business processes with BMS software

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D2/3M6-S3

Key Message

Throughout this module, there will group discussions. Form your groups now.

D2/3M6-Slide 4

Key Message

It takes a team working together to set up and operate a BMS. In this section, we will review and discuss who should be on a Bridge Asset Management Team and how they work together.

- Shown on this slide is an example State DOT bridge asset management team structure.
    - The team should be made up of bridge managers (business process decision makers) and BMS operational support staff.
    - The bridge managers need to give direct feedback to the BMS specialist regarding what is wanted, and the BMS specialist needs to advise the bridge managers as to what is possible.

A major benefit of including all senior bridge engineers on a bridge asset management team is the BMS becomes an integrated part of the agency's business process and BMS decisions are made with the combined skill and experience of the agency's most knowledgeable bridge engineers and managers.

D2/3M6-Slide 5

Key Message

Example bridge asset management team roles and responsibilities are shown on this slide.

- The actual database maintenance and running of the BMS is done by a separate group, and data quality assurance may be in this team or it may be part of bridge inspection team.

D2/3M6-Slide 6

Group Activity – Create Your Agency Bridge Asset Management Team


Source: Adobe Stock

- Group tasks:
  - Describe your current bridge asset management team
  - Identify the responsibilities of the team
  - How can the team be enhanced?
  - Record on flip chart and summarize for class

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D2/3M6-S6

Key Message

In your groups, list and discuss the makeup of your current bridge asset management team and describe the responsibilities of the team.

- Provide a description of their current team and a possible future team, if possible

D2/3M6 - Slide 6: Create Your Agency Bridge Asset Management Team

1. Describe your bridge asset management team.

2. What are the responsibilities of the team?

3. How can the team be enhanced?

D2/3M6-Slide 7

Group Activity – Create Your BMS Support Team

Source: Adobe Stock

- Group tasks:
  - Describe your current BMS Support team
  - Identify the responsibilities of the team
  - How can the team be enhanced?
  - Record on flip chart and summarize for class

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D2/3M6-S7

Key Message

List and discuss the makeup of your current BMS Support team and describe the responsibilities of the team.

- Provide a description of their current team and a possible future team, if possible

D2/3M6 - Slide 7: Create Your BMS Support Team

1. Describe your BMS support team.

2. What are the responsibilities of the team?

3. How can the team be enhanced?

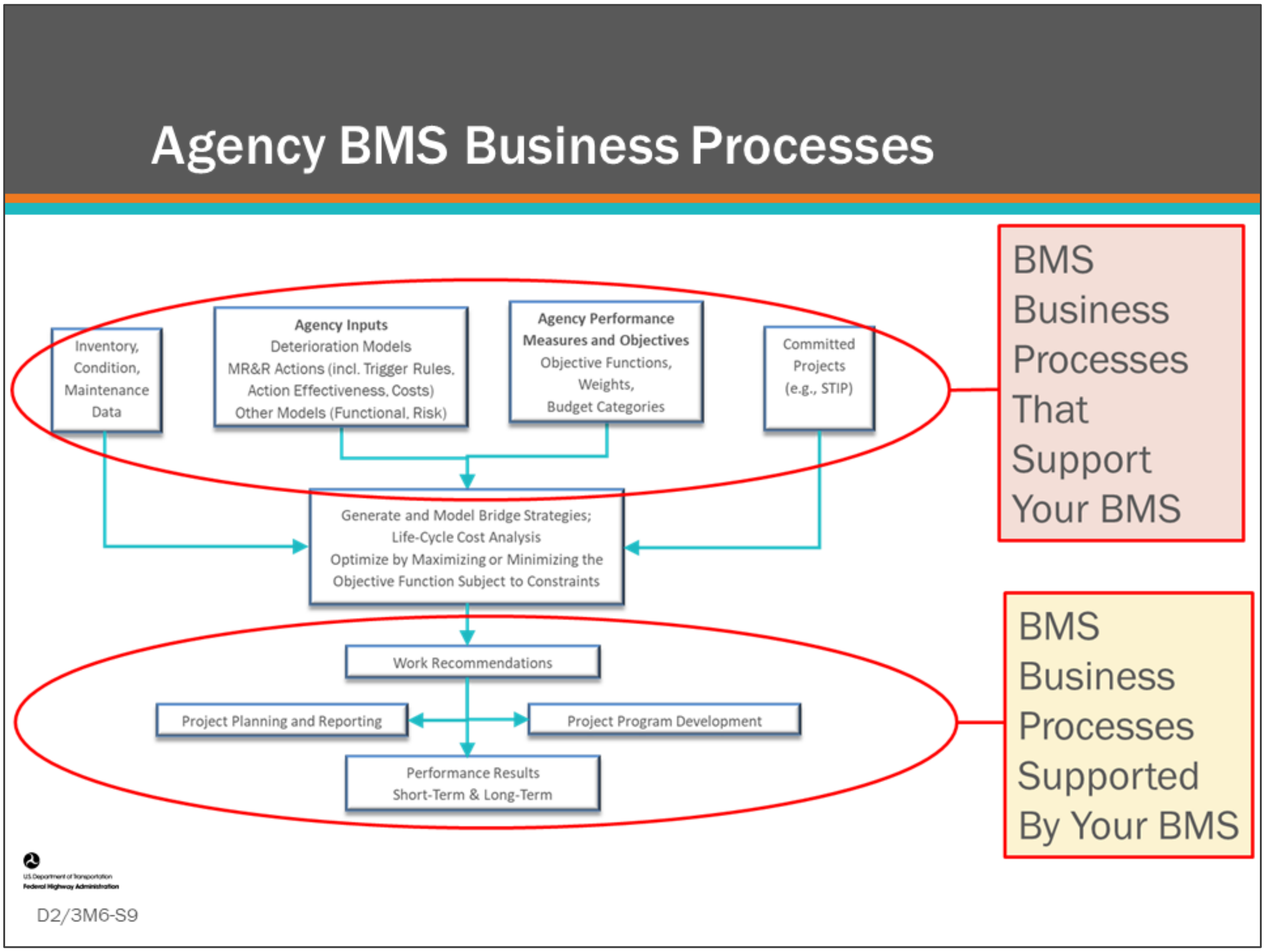
D2/3M6-Slide 8

Key Message

In this section, we will give you an opportunity to review and discuss your BMS business processes.

- This includes your current business processes that are supported by your BMS.
- We will then look at enhancements you can make to your bridge business process given what you learned in this workshop.
- Then, we will compare your class list to our ongoing list of BMS implementation steps and discuss any differences.

D2/3M6-Slide 9



Key Message

Shown on this slide is the BMS workflow diagram. Business processes within an agency are simply those regular activities and tasks that, once completed, will accomplish an organizational goal. Business process that support your BMS are those that will accomplish your goal of implementing and running your BMS. Business processes supported by your BMS are those tasks and activities that BMS results such as scenario modeling, strategic investment planning, and program and project planning. In this section we will do several group activities to examine your agency BMS business processes.

D2/3M6-Slide 10

Key Message

Each group is asked to discuss and list the following:

- Describe your agency business processes that currently support your BMS

D2/3M6 - Slide 10: Agency BMS Business Process, Discussion 1

1. Describe your business processes that currently **support your** BMS.

D2/3M6-Slide 11

Key Message

Each group is asked to discuss and list the following:

- Describe your agency business processes that are currently supported by your BMS

D2/3M6 - Slide 11: Agency BMS Business Process, Discussion 2

1. Describe your business processes that are currently **supported by** your BMS.

D2/3M6-Slide 12

Group Activity – Agency BMS Business Process, Discussion 3

Source: Adobe Stock

- Describe any challenges you are having with either:
  - Your business processes supporting your BMS
  - Business processes that are supported by your BMS

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D2/3M6-S12

Key Message

Each group is asked to discuss and list the following:

- Describe any challenges you are having with your business processes that either are supporting your BMS, or business processes that are supported by your BMS

D2/3M6 - Slide 12: Agency BMS Business Process, Discussion 3

1. Describe any challenges you are having with your business processes that either are supporting your BMS, or business processes that are supported by your BMS.

D2/3M6-Slide 13

Key Message

Each group is asked to discuss and list the following:

- Describe enhancements you would like to make to your agency bridge business processes using your BMS
- How can your business process be improved using a BMS?

D2/3M6 - Slide 13: Agency BMS Business Process, Discussion 4

1. Describe enhancements you would like to make to your agency bridge business process using your BMS.

2. How can your business processes be improved using a BMS?

D2/3M6-Slide 14

Group Activity Debrief – Agency BMS Business Process Review


Source: Adobe Stock

- Inventory data collection and storage
- Collection and storage of inspector work recommendations
- Estimating project cost
- Maintenance recommendations
- Historical archiving
- Initial project planning and scoping
- Long-term planning

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D2/3M6-S14

Key Message

In this section of the module, we will explore agency business processes that involve a BMS and compare them to what each group produced in the Group Activity: Agency BMS Business Process, Discussions 1 through 4. These include:

- Inventory Data Collection and Storage
  - Inventory and Condition Data QA
- Collection and Storage of Inspector Work Recommendations
- Estimating Project Cost
  - Capital vs Non-Capital
  - Direct and Indirect Costs
- Maintenance Recommendations
  - Using BMS or Send to MMS
  - Populated by Inspectors
- Historical Archiving
  - Condition and inventory data
  - Work and cost history
- Initial project planning and scoping
- Long-term planning

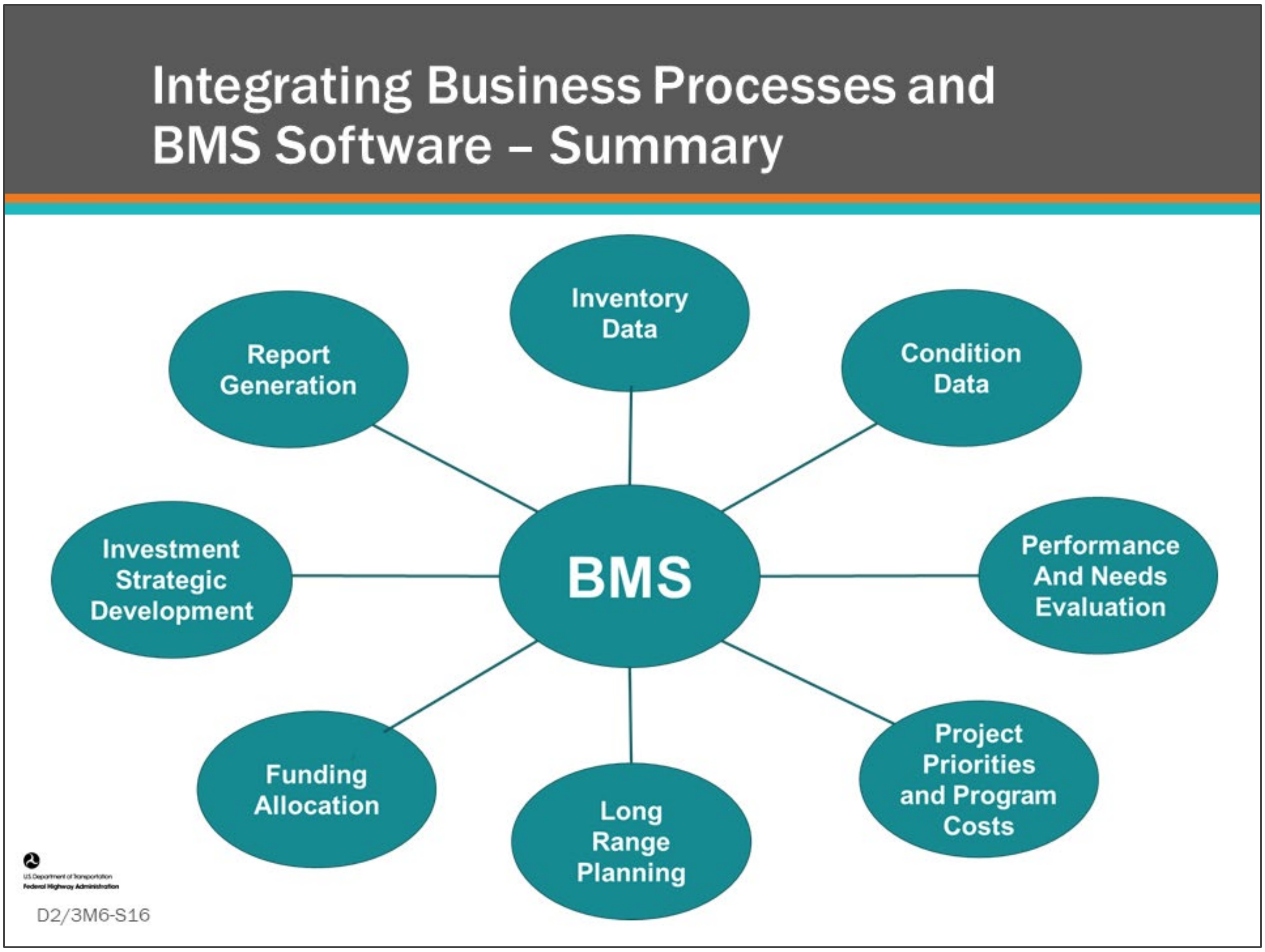
D2/3M6-Slide 15

Key Message

Continued from the previous slide, agency business processes that involve a BMS include:

- Capital program development
- Coordinate project- and program-level decisions
- Provide basis for prioritizing projects to supplement BCA or aid in decision tree development
- Project planning and programming
- Group work activities on bridges
- Coordinating, communicating and documenting actions
- Reporting
- Historical Trend Monitoring
- Current Performance Measures
- Call for Project Reports
- Forecasted Performance Measures
- Prioritization and Optimization Reports

D2/3M6-Slide 16



Key Message

In this module, we saw that a BMS can be an integral part of an agency's business processes.

- Shown here are some of the processes that a BMS can support and enhance with the BMS being central to all of these activities.

There is a lot of work to setting up and implementing a BMS, and we think you will find that what you learn along the journey is as valuable as what you will learn at the end when you press the "optimization" button!

D2/3M6-Slide 17

Key Message

This concludes Day 2/3, Module 6: Integrating Business Processes and BMS Software.

- What questions do you have?

D2/3M6-Slide 18

Slide #	Image Description	Source Information
16	Graphic showing processes that can be supported by BMS.	This Workshop.

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D2/3M6-S18

D2/3M6 Figure Source List

Module Title: D2/3M7 – Host Agency BMS Software Program and Analysis Tools Review

Module Time: 4 hours

Module Summary

For this customized module, the Host Agency will demonstrate their BMS. This will be done by presentation, and/or demonstration, and group discussion. The FHWA Contractor will assist the Host Agency with preparations for this module by facilitating conference calls with the project team and Host Agency subject matter experts, resulting in the development of an outline for the module.

Guidelines for the Host Agency outline for their presentation and/or demonstration are provided below. The list includes many of the topics covered during the workshop. The Host Agency may not be do of the activities shown. During their presentation and/or demonstration the host agency is encouraged to cover topics that they are doing well and which they consider a best practice. They are also encouraged to reserve time for open discussion about what they would like from their BMS in the future and discuss what steps they need to do to get there.

Expected Outcome(s)

The expected outcome of this module will be an in-depth demonstration and review of the Host Agency’s BMS resulting in identification of best practice and desired enhancements to the Host Agency’s BMS and their bridge management business practice. Workshop facilitators will provide verbal feedback on enhancements that may improve BMS outputs and implementation of recommendations.

Module Workbook

The following provides the key message and visual of each slide, along with space for you to take notes.

D2/3M7-Slide 1

Key Message

For this module, the host agency will demonstrate their BMS. This will be done by presentation, and/or demonstration, and group discussion.

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D2/3M7-Slide 2

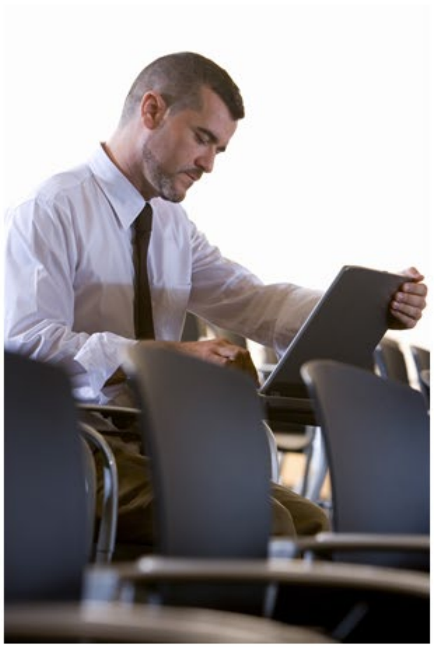
Key Message

This module provides the Host Agency with the opportunity to share their BMS and associated topics and details, such as their:

- BMS value and how it fits into their overall agency asset management
- Agency inputs
- Life-cycle modeling
- Risk Assessment
- Strategy generation
- Program and Project Planning
- Communication and reporting

D2/3M7-Slide 3

Host Agency Presentation and/or Demonstration Development



Source: Adobe Stock

- Prepare your presentation or demonstration (done ahead of time)
  - Give thought to the steps of agency BMS implementation, included in the worksheet activity in D2M1: BMS Software Implementation Steps

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D2/3M7-S3

Key Message

Recall from your worksheet activity in D2M1: BMS Software Implementation Steps, which discussed the potential steps of agency BMS implementation.

These steps included:

1. Set up bridge data base
2. Set up and maintain bridge inventory data
3. Create communication link between inspection system and BMS (If they are not the same)
4. Collect bridge condition data (GCR and element)
5. Create agency defined elements and protective systems
6. Do QA/QC of bridge inspection system and resulting condition data
7. Set up goals, objectives, and performance measures
8. Create deterioration models
9. Set element environments
10. Set element to GCR convertor profile (needed if using GCRs as performance measures)
11. Develop a risk assessment process
12. Populate work candidates or work recommendations and determine how you will use them
13. Organize your bridge network in segments (subdivisions of the network)
14. Develop program and project types
15. Develop agency rules and practice

16. Build decision trees or matrices with trigger values that set actions based upon element or component condition and inventory items
17. Write rules for grouping actions into practical projects
18. Write rules for removing or replacing elements when major actions (rehab or replacement) are taken
19. Develop life-cycle cost analysis parameters and policies
20. Generate action benefits
21. Populate direct and indirect cost for actions
22. Develop user costs
23. Set project and program funding sources
24. Create and track fixed projects
25. Create deferment rules (used with LCCA)
26. Create optimization objective function and multi-objective scaling, weighting, and amalgamation rules (utility tree)
27. Set constraints for the optimization problem

D2/3M7-Slide 4

Key Message

Topics in your presentation or demonstration may include:

- BMS Value to your organization and how if fits within your agency's asset management processes
- Agency Inputs
- Life-Cycle Modeling
- Risk Assessment
- Investment Strategy
- Program and Project Planning
- Communication and Reporting
- Items for Discussion

D2/3M7-Slide 5

Participant Presentation or Demonstrations

Source: Adobe Stock

- The Host Agency will step through their BMS via presentation or demonstration

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D2/3M7-S5

Key Message

Participants step through their BMS via presentation or demonstration.

D2/3M7-Slide 6

Discussion and Review

Source: Adobe Stock

- Discussion and review of findings
  - What were the best practices regarding each of the topics?
  - What were the items for improvement regarding each of the topics?

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D2/3M7-S6

Key Message

Review the findings for best practices and items for improvement identified during the presentation or demonstration.

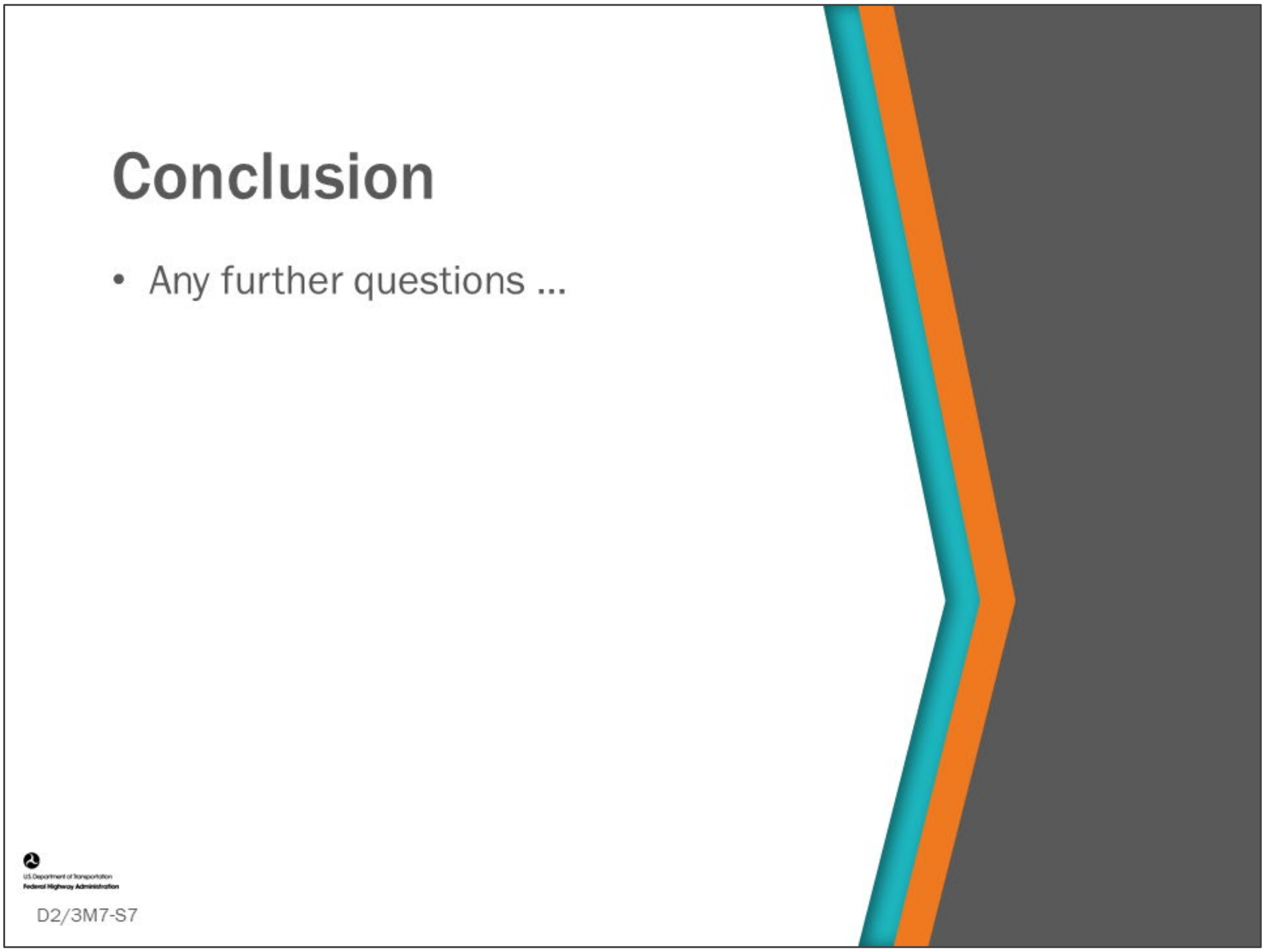
D2/3M7 - Slide 6: Host Presentation Feedback Notes

Use this space to take notes regarding feedback on the host presentation or demonstration.

Improvement Ideas:

Action Items:

D/32M7-Slide 7



Key Message

This concludes Day 2, Module 7: Host Agency BMS Software Program and Analysis Tools Review.

D2/3M7-Slide 8

Slide #	Image Description	Source Information
3	Photo of a person sitting at a desk looking at a computer.	Adobe Stock.
4	Photo of a person sitting at a desk looking at a computer.	Adobe Stock.
5	Photo of a person giving a presentation to a group of people.	Adobe Stock.
6	Photo of a group working at a table.	Adobe Stock.

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D2/3M7-S8

D2/3M7 Figure Source List

FHWA Bridge Management Systems Workshop
Glossary of Terms

Action Effects (Benefit)
Action effects or benefits are the improvement in the condition data, inventory data, or other data or indicator resulting from an action.

Actions (or Treatments)
Any activity done to a bridge, component or element to improve or preserve the bridge.

Agency Defined Element (ADE)
Custom bridge elements defined by an agency in accordance with the element framework prescribed in the AASHTO Manual for Bridge Element Inspection. May be subsets of the AASHTO defined elements, or entirely independent representing features that are not included in the AASHTO Manual.

Amalgamation
The process of combining multiple criteria into a single criterion (single measure) utility function. The decision maker's preference toward the different criteria are reflected by relative weighting the criteria before combining.

Asset Management
23 CFR 515.5 - Asset management is a strategic and systematic process of operating, maintaining, and improving physical assets with a focus on engineering and economic analysis based upon quality information to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair (SOGR) over the lifecycle of the assets at minimum practicable cost.

Benefit Cost Analysis
A systematic approach for selecting optimal projects or implementation alternatives by determining the monetary costs and benefits for each project or alternative.

Benefit Cost Ratio (BCR)
An indicator used in benefit-cost analysis used to compare the cost-effectiveness of projects or implementation alternatives by dividing the benefits by the costs. May also be used within an optimization procedure as an approach to find a set of projects that yield the greatest benefit for that procedure.

Bridge-Level Analysis
Analysis of an individual bridge conducted to estimate present and future performance and needs and evaluate the benefits and costs of alternative projects or life-cycle strategies. May be more detailed than the bridge-level analysis performed during network-level analysis as it may include refined performance data and needs, action types, and costs, as well as manual identification of preferred work which may not occur during the automated procedures of a network-level analysis. Sometimes referred to as project-level analysis.

Bridge Management Element (BME)
Elements such as deck joints, wearing surfaces, protective coating systems, concrete reinforcing steel protection systems and approach slabs, as defined by the AASHTO Manual for Bridge Element Inspection, that are typically managed by agencies utilizing a BMS.

Bridge Management System (BMS)
A comprehensive system for storing and updating bridge data, forecasting deterioration, evaluating alternative actions and strategies, identifying short and long-term needs, and determining the strategies, projects, programs, and implementation schedules that will achieve and sustain a desired state of good repair (SOGR) over the lifecycle of the assets at minimum practicable cost. For the Federal description refer to FHWA's 23 CFR 515.17 Minimum Standards for Developing and Operating Bridge and Pavement Management Systems.

Business Processes with an Agency
Those regular activities and tasks that, once completed, will accomplish an organizational goal.

Component (Major)
As defined by the FHWA Recording and Coding Guide for the National Bridge Inventory (NBI), bridge major components include the deck, superstructure, substructure, or culvert.

Consequence
A measure of the effects of a structure being out of service. This translates into a measure of the importance to the community or "criticality" of the structure.

Constraint
Limitations set in an optimization procedure. Examples include limiting annual program budget or setting a minimum allowable bridge condition.

Cost (Direct)
In a BMS, direct agency costs are those that can be attributed directly to specific components and elements in their unit of measure.

Cost (Indirect)
In a BMS, indirect agency costs are those that cannot be attributed directly to specific components and elements. Examples include mobilization, traffic control, engineering (design and construction), and road work (road work can also be input as a direct cost).

Elicitation
Collecting and synthesizing the opinions of experts, often when data is lacking or does not yield credible results.

Extended Benefit
When the method of showing benefit is area under the performance curve, extended benefit is the additional area under the performance curve after the end of the analysis period until the performance curve reaches a terminal serviceability.

Functional Assessment
A functional assessment model measures how well the bridge meets the needs of society. Often relates to bridge geometric attributes (width, clearances, alignment, etc.), load capacity, or frequency of service disruption due to flooding or other events.

Functional Improvement Action
Action that enhances the ability of the bridge to meet the needs of society.

Functional Improvement Model
Methods that quantify the effects or benefits of making functional improvements to a bridge.

Future Value (or Future Cost)
Future value is the cost incurred for an action at some time in the future.

General Condition Rating (GCR)
Condition ratings on a 0 to 9 scale for the major components (deck, superstructure, substructure, or culvert) of a highway bridge structure and culverts in accordance with the FHWA Recording Guide for the National Bridge Inventory.

Goals
Broad primary outcomes towards which effort and actions are directed.

Health Index
An element health index (sometimes referred to as an element condition index) is a measure of an element's condition compared to its perfect condition on a 0 to 100 scale. A bridge health index is a measure of a bridge's condition compared to its perfect condition by amalgamation of all elements comprising the bridge. An inventory health index is the amalgamation of all elements comprising the inventory. There are multiple ways a health index can be measured as discussed in FHWA-HRT-15-081, May 2016; A reference for Synthesis of National and International Methodologies Used for Bridge Health Indices.

Incremental Benefit Cost Ratio (IBCR)
A measure used to quantify the economic effectiveness of a project when compared to the next less costly alternative. It is computed by dividing the increase in benefit of the more expensive project by the increase in cost incurred when selecting that alternative. May also be used within an optimization procedure as an approach to finding a set of projects that yield the greatest benefit for that procedure.

Investment Strategy
The systematic allocation of funds among programs, work categories, and projects in order to best satisfy one or more objectives. For the Federal definition of investment strategy relative to Asset Management Plans refer to 23 CFR 515.5.

Life-Cycle
A sequence of actions, outcomes, events, and consequences that characterize a bridge's design, construction, management and use through its service life.

Life-Cycle Agency Cost
All costs that an agency incurs to maintain, repair, rehabilitate, and reconstruct portions of the bridge during its life-cycle often converted to a Present Value.

Life-Cycle Activity Profile
The representation of a sequence of activities/actions, costs, and year of activities, occurring over a time horizon. Is normally specific to a particular bridge. Sometimes referred to as a bridge life-cycle strategy or life-cycle model.

Life-Cycle Analysis Period (LCAP)
The entire period over which costs of a strategy are evaluated.

Life-Cycle Cost Analysis (LCCA)
A mathematical procedure for evaluating the economic efficiency of a management strategy or preservation model.

Likelihood
The probability of service disruption measured from the probability of occurrence of a specific natural or man-made event combined with the vulnerability of the structure to that event. Typically combined with consequence to evaluate risk.

Markov Chain Transition Probability
The probability of a portion of a system moving from one state to another state in a single time step. Transition probabilities are used in a deterioration modeling method that estimates deterioration of an element, bridge or network of bridges over time.

Model
A set of ideas and numbers that describe the past, present, or future state of something (Merriam-Webster)

National Bridge Inventory (NBI)
A uniform set of bridge condition and inventory data maintained by the Federal Highway Administration that defines the nation's highway bridges.

National Bridge Element (NBE)
Elements that comprise the primary load carrying members of a bridge as defined by the AASHTO Manual for Bridge Element Inspection.

Network Segmentation (Bridge Families)
A method of dividing up an agency's bridges for network analysis.

Network-Level Analysis
Analysis of an inventory or sub-inventory of bridges conducted to estimate present and future performance and needs, and simulate a work program subject to constraints, to determine inventory or sub-inventory outcomes, including from alternative management strategies. Often automates and uses bridge-level analysis including performance and needs assessment, and evaluation of benefits and costs of alternative projects or life-cycle strategies, although computational constraints often allow for lesser detail than a comprehensive bridge-level analysis.

Objectives
Steps an organization takes to achieve its goals that are measurable and specific.

Objective Function
The formulation of objectives into an expression or value which is maximized or minimized during an optimization analysis.

Optimization
A methodology of identifying actions that maximize or minimize an objective function given certain constraints. An example optimization statement reads as follows: Maximize total benefit calculated by summing average performance index for the analysis period across all bridges in the network, subject to a specific budget in each year, by choosing from a set of strategies for each bridge with different sequences of actions and timing of those actions.

Performance Measure
A quantifiable metric that describes the condition and/or adequacy of a bridge or network of bridges that can be used to determine progress toward specific, defined objectives. For the Federal definition refer to 23 CFR 490.101 National Performance Management Measures.

Planning Horizon
The period during which a work program is simulated by a BMS. Different than the planning period which is the timeframe covered by a plan (ex. Statewide Transportation Improvement Program, Long Range Transportation Plan, Transportation Asset Management Plan).

Present Value
The value of a cost incurred at some future time expressed as the equivalent amount if that cost were incurred now. Computed as a function of the discount rate and time period between now and the anticipated time when the cost will be incurred.

Preservation Action
Action taken to bridge major components or elements to improve minor defects and preserve the overall structure in good or fair condition.

Prioritization
A methodology of ranking actions, projects or strategies. Outside more advanced bridge management systems, a prioritization formula is often used to rank bridges for replacement or other actions.

Protective System
Child elements that protect a parent element thereby slowing deterioration and extending life. Examples of these include wearing surface, steel protective coatings, corrosion resistant reinforcing steel, and concrete protective coating.

Reconstruction (or Replacement) Action
An action to reconstruct or replace an existing bridge with a new facility in the same general traffic corridor.

Rehabilitation Action
A major work action required to restore the structural integrity of a bridge, as well as work necessary to correct major safety defects.

Residual Value
The value of the bridge’s remaining life at the end of the Life-Cycle Analysis Period (LCAP).

Risk
AASHTO’s Manual for Bridge Evaluation defines risk as the potential for unplanned adverse events to impact one or more transportation facilities in a way that causes unacceptable transportation system performance according to any or all of the Agency’s performance objectives. For the Federal definition of risk relative to Asset Management Plans refer to 23 CFR 515.5.

Risk Assessment
The systematic evaluation of potential unplanned adverse events, considering the likelihood of the events and the consequences of their occurrence. It is used to prioritize the mitigation of these potential events and minimize their adverse impacts.

Risk Mitigation Action
Actions that improve one or more inventory items that increase the resilience of the bridge making it less susceptible to damage during extreme events.

Risk Utility
Measure of the ability of a bridge to resist hazards.

Scenario
The set of parameters representative of an investment strategy used to perform a scenario analysis. The parameters may include among other things the funding level, objective function, analysis period, economic factors, and constraints. Multiple "what if" scenarios are often conducted to evaluate the outcomes of alternative investment strategies.

Scenario Analysis
An advanced Bridge Management System function that uses condition data, agency inputs such as deterioration models, trigger rules, action costs and effectiveness, objective functions, optimization and constraints to generate work recommendations, develop programs, and predict short- and long-term performance of the bridge network.

Social Cost
The sum of long-term costs borne by the agency, users, non-users, and the environment, which are affected by a proposed decision.

Strategy
A plan of action or policy designed to achieve a major or overall aim.

Targets
The performance level the program is attempting to achieve. These are typically defined as specific values of performance metrics for the bridge network.

Time in Condition Rating (TICR)
A method used for analyzing condition data to estimate deterioration rates. It measures the time a component remains in a specific condition rating.

Trigger
Action triggers are instructions to your BMS to consider an action on a bridge, major component, or element. Actions are often "triggered" when a condition index such as a general condition rating (major component), condition-state (element), or inventory item attribute exceeds a threshold value.

User Costs
Costs borne by bridge users, such as increased fuel consumption and vehicle operating costs occurring from functional deficiencies or construction work zones that cause truck rerouting or vehicle delay.

Utility Function
A mathematical expression, that combines variables representing the user specified objectives and weights, which is used to calculate the utility value of project alternatives.

Utility Scaling
Translates the decision maker's preferences for each performance criterion to a common scale, often 0-100, to allow for amalgamation of different objectives within a utility function. For example, major component general condition ratings 0 to 9 scale would need converted to a 0-100 scale and each general condition value mapped to a value between 0-100 dependent on the decision maker's preferences towards each general condition value.

Utility Value
A calculated number that quantifies the value (not necessarily monetary) of a bridge before and after a work alternative. Results from applying a utility function to the bridge attributes. When utility value is used to quantify the benefit of work alternatives, it may also be termed the benefit.

Utility Weighting
The practice of assigning relative weights to multiple criteria or objectives.