National Performance Management Measures: Bridge Condition to Assess the National Highway Performance Program

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HOW WE GET THERE

Bridge Sessions

- Session 1: Asset Management Plans
- Session 2: Bridge Management Systems
- Session 3: Bridge Performance Measures & Target Setting

Acronyms

AMP	asset management plan
BMS	bridge management systems
LCC	life-cycle cost
LCCA	life-cycle cost analysis
NBIS	National Bridge Inspection Standards
NHPP	National Highway Performance Program
NHS	National Highway System
PM	performance measure
STIP	State Transportation Improvement Program

Session 1: Asset Management Plans

U.S. Department of Transportation
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Asset Management Plans

- Purpose & Definitions
- Development Processes & Requirements
- Deadlines & Penalties
- Process Certification
- Resources

Asset Management Plans

- Law: 23 USC 119(e)(8), 144, 150(c)
- Regulation: 23 CFR 515 - AMPs
  - Published Oct. 24, 2016
  - Effective Oct. 2, 2017

23 CFR 515.1: Purpose

- Establish processes State DOT must use
- Establish minimum development requirements
- Describe penalties
- Set forth minimum standards for developing and operating bridge management systems

23 CFR 515.5: Key Definitions

- Asset
- Asset class
- Asset condition
- Asset management
- Asset management plan
- Asset sub-group
- Bridge
- Critical infrastructure
- Financial plan
- Investment strategy
- Life-cycle cost
- Life-cycle planning
- Minimum practical cost
- NHS bridges
- Performance of the NHS
- Performance gap
- Risk
- Risk management
- STIP
- Work type

Key Definitions

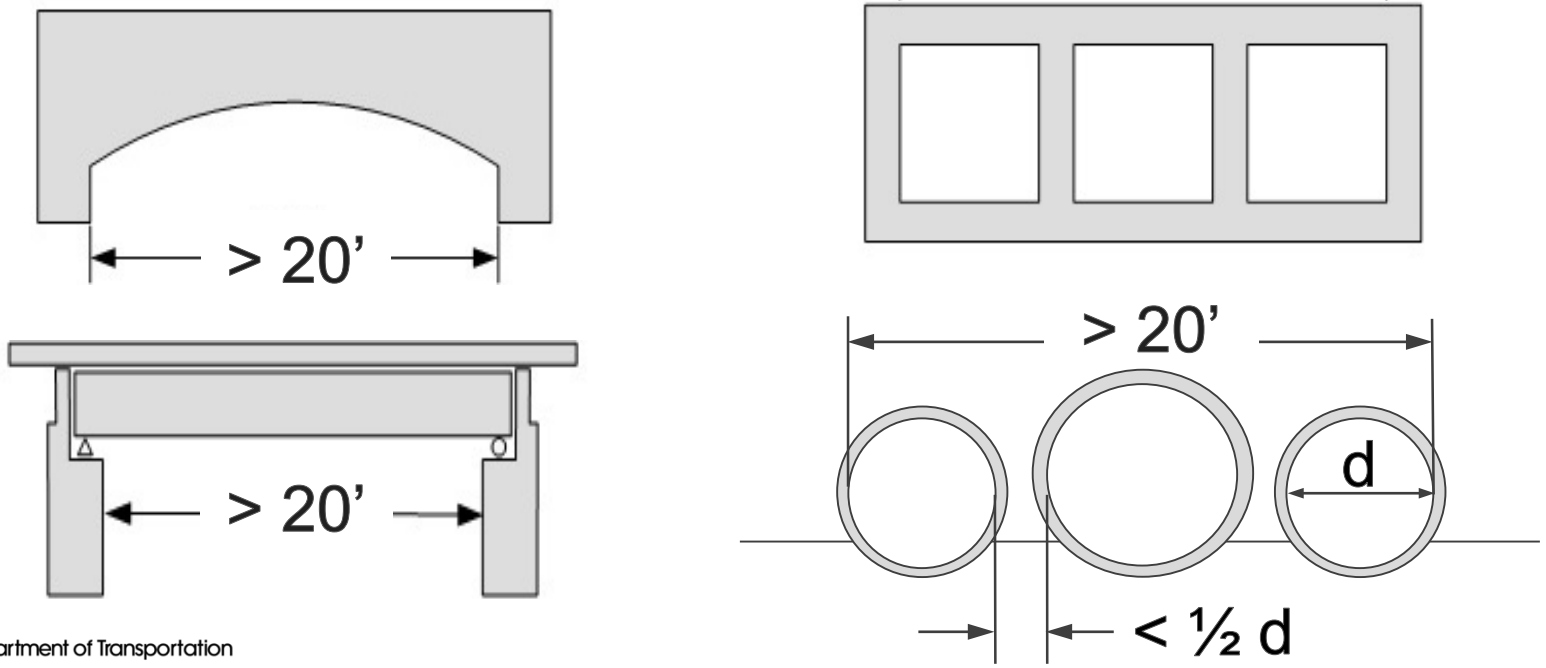
- Asset: physical highway infrastructure
  - Bridges
  - Tunnels
  - Ancillary structures
- Asset class: same characteristics and function
  - Bridges
  - Culverts
- Asset sub-group: concrete, steel, movable….
- Asset management

Key Definitions

- Bridge (23 CFR 650 Subpart C – National Bridge Inspection Standards)
  - A structure including supports erected over a depression or an obstruction
  - Has a track or passageway for carrying traffic or other moving loads
  - Has an opening measured along the center of the roadway of **more than 20 feet** between undercopings of abutments or spring lines of arches or extreme ends of openings for multiple boxes

Bridge Definition

- May also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening



Bridge Examples

Bridge Definition

- Must be on a public road
- 23 USC 101: “The term ‘public road’ means any road or street under the jurisdiction of and maintained by a **public authority** and **open to public travel**”

Key Definitions

- Investment strategy
  - Set of strategies that result from evaluating various levels of funding to achieve State DOT targets for bridge condition and system performance effectiveness at a minimum practicable cost while managing risks
- Life-cycle cost
  - Cost of managing an asset class or sub-group for its whole life, from initial construction to its replacement
- Life-cycle planning
  - Process to estimate the cost of managing assets over its whole life
  - Considers minimizing cost while preserving or improving condition
- Minimum practicable cost
  - Lowest feasible cost to achieve the objective

Key Definitions

- NHS Bridges
  - Bridges that carry the NHS (including on and off ramps connected to NHS)
- Performance of the NHS
  - Effectiveness of the NHS in providing for the safe and efficient movement of people and goods
  - Where performance can be affected by physical assets
- Performance gap
  - Gaps between the current asset condition and State DOT targets for asset condition
  - Gaps in system performance effectiveness that are best addressed by improving the physical assets

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Questions?

23 CFR 515.7: AMP Establishment Processes

- Plans describe how NHS will be managed to :
  - achieve system performance effectiveness and targets for asset condition
  - manage risk
  - minimize cost
  - over the life-cycle of assets

AMP Establishment Processes

- Minimum processes
  - Performance gap analysis
  - Life-cycle planning
  - Risk management planning
  - Financial plan
  - Investment strategy development
  - NHS bridge data collection from all owners

AMP Establishment Process

- Performance gap analysis
  - To identify deficiencies hindering progress to achieving a state of good repair and system performance effectiveness
  - Can look for immediate gaps that need closed in the near term and long-term gaps that need closed in stages
    - Examples of immediate gaps: Higher risk/lower reliability bridges based on condition or risk hazard
    - Examples of long-term gaps: condition and needs representative of sustainable state of good repair

AMP Establishment Process

- Life-Cycle Planning (LCP)
  - *"A process to estimate the cost of managing an asset class, or asset sub-group, over its whole life with consideration for minimizing cost while preserving or improving the condition."* (23 CFR 515.5)
  - Provides the long-term view to decision making and includes
    - identification of deterioration models
    - identification of work types and costs
    - strategy for managing assets by minimizing life-cycle cost

Life-Cycle Planning (LCP)

- FHWA LCP guidance document
  - Compares costs and benefits of different treatment strategies
    - Should have basis in preservation (minimizing life-cycle cost)
    - Can include other objectives (mobility, risk hazards, etc.)
  - Fits treatment strategies to budgets for inclusion in the selected investment strategy

Life-Cycle Planning

- What is the definition of a treatment strategy?
- Complete set of actions
  - Preventive maintenance
  - Preservation
  - Major rehabilitation
  - Replacement
- Actions address condition and cost drivers of elements/components

Life-Cycle Planning

- LCP Guidance Document
  1. Select asset classes and networks to be analyzed
  2. Evaluate asset strategies
  3. Set LCP scenario inputs
  4. Develop the LCP scenarios
  5. Provide input to financial planning

LCP Guidance: Step One

STEP ONE	**Select asset classes and networks to be analyzed**

At minimum, include NHS bridges and pavements

LCP Guidance: Step Two

STEP TWO	Evaluate asset strategies

- Evaluate different treatment strategies
  - Asset class or subgroup evaluation
  - Composed of different actions, timing/intervals, and sequencing
- Complement of strategies to fit to later imposed constraints (budget, performance, etc.)

LCP Guidance: Step Three

STEP THREE	**Set LCP scenario inputs**

- Network level evaluation
- Minimum acceptable condition and reliability for safety
- Performance gaps that need to be closed
- Other?

LCP Guidance: Step Four

STEP FOUR	Develop & evaluate LCP scenarios

- Apply different asset treatment strategies to network to predict outcome
- Constrained by Step Three inputs and funding
- Long-term outcome measured (bridges 50+ years common)

LCP Guidance: Step Five

STEP FIVE	**Provide input to financial planning**

Results inform:

- Cross asset tradeoff evaluation and budget allocation (bridge vs. pavement)
- Investment strategy selection

AMP Establishment Process

- Risk Management Planning
  - Identification of risks that can affect condition and performance
  - Prioritization of risks
  - Mitigation planning
  - Monitoring of top risks
  - Assessment of likelihood of occurrence and impact and consequence

AMP Establishment Process

- Financial Planning
  - Annual costs for 10-year period minimum
  - Cost to implement investment strategy by State FY and work type
  - Estimated funding levels by FY and funding sources
  - Value of agency's NHS bridges and required annual investment to maintain value

AMP Establishment Process

- Investment Strategies
  - Process for developing investment strategies shall be influenced at a minimum by
    - Performance gap analysis
    - Life-cycle planning
    - Risk management analysis
    - Financial plan

Investment Strategies & Target Setting

- It is important to consider the information produced by analyses done during the development of an asset management plan, and to fully utilize bridge management systems, when establishing State targets.
- The analyses help identify needs, resources, and investment strategy outcomes. These can inform target setting.

AMP Establishment Process

- NHS bridge data
  - Process for obtaining data from other owners
- Bridge Management System (BMS)
  - use to develop/implement AMP
  - can support analysis, investment strategy development, and target setting

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Questions?

23 CFR 515.9: AMP Minimum Content Requirements

- Objectives
- Measures and targets
- Summary condition description
- Performance gap identification
- Life-cycle planning
- Risk management analysis
- Financial plan
- Investment strategies

AMP Requirements

- Objectives, Measures and Targets
  - Asset management objectives
  - Performance measures
    - Required FHWA measures
    - Additional State measures (optional)
  - Targets
  - Complement of measures recommended

Objectives & Measures (Examples)

High-level Decision Making	Low-level Decision Making
• identifying investment strategy • cross asset allocation • (bridges vs. pavements vs. other) • bridge budget allocation among owners, regions, roadway classes, etc.	• implementing investment strategy • project prioritization • work type selection & scoping

Objectives & Measures

- Measure(s) Selection: In selecting additional optional measures, some questions that need asked include;
  - Will it be used for high level decisions?
  - Will it be used for low level decisions?
  - Will it be used for both?
  - Does it adequately represent the objective?
  - Is a complement of measures needed to represent each objective?

AMP Requirements

- Summary condition description
  - All NHS bridges regardless of ownership
  - Including condition based on FHWA performance measures

Example

STATE_CODE 1	STRUCTURE_NUMBER 8	FEATURES_DESC 6A	FACILITY_CARRIED 7	OWNER 22	YEAR_BUILT 27	Deck Area (sq. m.)	Bridge Condition Classification	Minimum Condition Rating
01	605	BRANCH	US 82	1	1929	47.36	Fair	6
01	608	BRANCH	SR 9	1	1929	48.91	Good	7
01	611	SWEETWATER CREEK	US 43	1	1929	82.62	Fair	6
01	624	BENNETTS CREEK RELIEF	US 45	1	1929	64.6	Fair	5
01	662	BRANCH TO ESLAVA	US 98	1	1929	58.29	Fair	6
01	663	BRANCH TO MAGNOLIA RIVER	US 98	1	1929	65.36	Fair	6
01	664	SPRING BRANCH	US 98	1	1929	146.16	Fair	6
01	735	JENKINS CREEK	US 82 WBL	1	1930	715.86	Fair	5
01	749	PAULINES BRANCH	US 43	1	1930	218.54	Fair	5
01	784	TENNESSEE RIVER	SR 35	1	1930	4180.48	Poor	4
01	882	CEDAR CREEK	US 31	1	1931	372.28	Fair	6
01	893	BRANCH	US 43	1	1931	74.46	Fair	6
01	900	HURRICANE BRANCH	US 45	1	1931	54.4	Fair	6

AMP Requirements

- AMP approved by head of the State DOT
- Make available to the public
- Integrate AMP into planning processes leading to the STIP

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23 CFR 515.11: Deadlines & Phase-in

- April 30, 2018: initial State-approved risk-based AMP submittal to FHWA
  - Describes State DOT processes: policies, procedures, documentation, and implementation approach
  - May exclude 1 or more analyses: life-cycle planning, risk management, financial plan
  - Review and process certification by FHWA
- June 30, 2019: State-approved risk-based AMP submittal to FHWA with all requirements

23 CFR 515.13: Process Certification/Recertification

- 90-day process certification review by FHWA
- Process recertification every 4 years
- 90 days for State DOT to address deficiencies if certification was denied
  - FHWA may extend upon request
- FHWA may certify if only minor deficiencies to be corrected by State DOT within 90 days

23 CFR 515.13 Annual Consistency Review

- FHWA determination:
  - By Aug. 31, 2019
  - By July 31 each year thereafter
  - Not an approval/disapproval of strategies or other decisions
  - Ensure development with certified processes and includes required content
  - Ensure implementation of AMP

23 CFR 515.15: Penalties

- Beginning Oct. 1, 2019 and each fiscal year thereafter if State DOT does not develop and implement an AMP **consistent with statute and regulations**
  - Maximum Federal share for NHPP projects reduced to 65% for that FY

23 CFR 515.15: Penalties

- If State DOT does not develop and implement an **AMP consistent with statute and regulations and with the Part 150 performance targets by** 18 months after effective date of NHS bridge performance measure rule (by Nov. 20, 2018)
  - FHWA will not approve any further NHPP-funded projects
  - Deadline may be extended if State DOT has made a good faith effort as determined by FHWA

23 CFR 515.17: Minimum BMS Standards

- Documented procedures for:
  - Collecting, processing, storing, and updating inventory and condition data
  - Forecasting deterioration
  - Determining the benefit-cost over the life cycle of bridges to evaluate alternative actions (including no action decisions) for managing condition
  - Identifying short- and long-term budget needs for managing condition

Minimum BMS Standards

- Documented procedures for:
  - Determining the strategies for identifying potential NHS bridge projects that maximize overall program benefits within the financial constraints
  - Recommending programs and implementation schedules to manage the condition of NHS bridges within policy and budget constraints
- Not subject to FHWA certification, but are subject to FHWA oversight

23 CFR 515.19: Organizational Integration

- Establish organizational strategic goals
  - Explain how asset management helps achieve goals
- Conduct periodic self-assessments
  - Identify areas for improvement
  - Develop strategies to close significant gaps
- Not a requirement for State DOTs

Resources

- FHWA Policy and Guidance Center
  - https://www.fhwa.dot.gov/pgc/
- FHWA TPM Website
  - https://www.fhwa.dot.gov/TPM/index.cfm
- FHWA Asset Management Website
  - https://www.fhwa.dot.gov/asset/

FHWA NHI Training Resources: TPM & AM

- 138004 – TPM Overview for MAP-21 & FAST Acts (ILT)
- 138005 – TPM Overview for MAP-21 & FAST Acts (WBT) (Dev.)
- 138007 – Performance-Based Planning and Programming
- 138011 – The Role of Data in TPM
- 138012 – Steps to Effective Target Setting for TPM
- 136002A – Introduction to Financial Planning for Transportation Asset Management (WBT)
- 136065 – Risk Management
- 136106A – Introduction to Transportation Asset Management with Workshop
- 136106B – Developing a Transportation AMP
- 136106C – Introduction to a Transportation AMP (WBT)
- 136113 – Transportation Asset Management Overview (WBT)

FHWA NHI Training Resources: Bridge

- 138008 – TPM for Bridges (future ILT)
- 130055 – Safety Inspection of In-Service Bridges
- 130053 – Bridge Inspection Refresher
- 130106A – Bridge Preservation Fundamentals (WBT)
- 130106B – Establishing a Bridge Preservation Program (WBT)
- 130106C – Communication Strategies for Bridge Preservation (WBT)
- 130109A – Bridge Management Fundamentals (WBT)
- 130109B – Performance-Based Management of Highway Bridges (WBT)
- 130107A – Fundamentals of Bridge Maintenance (WBT)
- 130108 – Bridge Maintenance

Knowledge Checks

Performance measures can be used to assist in (choose all that apply):

a) prioritizing projects
b) measuring progress toward achieving goals and objectives
c) identifying how to allocate funds to different asset classes
d) prioritizing work actions

Knowledge Checks

Life-cycle planning for bridges involves (choose all that apply):

a) quantifying the benefits of preservation
b) evaluating different treatment strategies applied to bridges
c) identifying optimum treatment strategies
d) evaluating different network-level scenarios
e) determining the financial resources available

Knowledge Checks

Asset management plan required development processes include (choose all that apply):

a) life-cycle planning
b) risk management planning
c) permit route planning
d) performance gap analysis
e) investment strategy development

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Session 2: Bridge Management Systems

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Topics

- BMS History
- BMS Purpose & Value
- FHWA Requirements for BMS
- Technical Summary BMS Software
  - Workflow
  - Objectives & Measures
  - Models
  - Analysis & Prioritization
  - Work Selection & Program Development
  - Performance Monitoring and Reporting
- BMS Support of Asset Management Plan Elements, Performance Measure Requirements, & Target Setting

BMS History

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BMS History

Event	Publish/Release Date
NCHRP Report 300 - BMS	1987
FHWA Demo Project 71 - BMS	1989
Intermodal Surface Transportation Efficiency Act	1991
Pontis software version 1 (by FHWA)	1992
BRIDGIT software version 1 (by NCHRP)	1994
Pontis software version 3 (by AASHTO)	1995
National Highway System Designation Act	1995
AASHTO Guide to Commonly Recognized Structural Elements	1997
Followed by proprietary development resulting in upgrades and new software; continued Federally assisted research	

BMS Purpose & Value

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BMS Purpose & Value

- In practice, bridge management systems
  - Estimate how inventory looks present and future
  - Estimate how investments change how inventory looks present and future
  - Estimate how deferred investments change how inventory looks
  - Help allocate funding and select combination of projects that achieve largest benefit

BMS Purpose & Value

- Asset management: "A strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both 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 over the lifecycle of the assets at minimum practicable cost." (23 USC 101)

FHWA Requirements for BMS

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FHWA Requirements for BMS

- MAP-21 legislation
  - Secretary shall establish minimum standards for States to use in developing and operating bridge and pavement management systems
- Asset Management Plan Rule
  - Minimum Standards for bridge and pavement management systems (23 CFR 515.17)
  - Shall use bridge and pavement management systems for developing and implementing the plan (23 CFR 515.7)

FHWA Requirements for BMS

- Minimum Standards: shall include documented procedures for
  a) Data collection and retrieval
  b) Forecasting deterioration
  c) Benefit-cost analysis over the life-cycle of assets
  d) Identifying short and long-term budget needs
  e) Identifying strategies that maximize benefits
  f) Recommending work programs

FHWA Requirements for BMS

- Procedures shall be documented (23 CFR 515.17)
  - Should include
    - Technical aspects of each procedure
    - Integrated business processes (supporting input, using the output)
- Management systems are **not** subject to AMP certification (23 CFR 515.17) but are subject to FHWA oversight

FHWA Requirements for BMS

- FHWA minimum standards do not specify the form of BMS: what they must look like, how they work

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Technical Summary BMS Software

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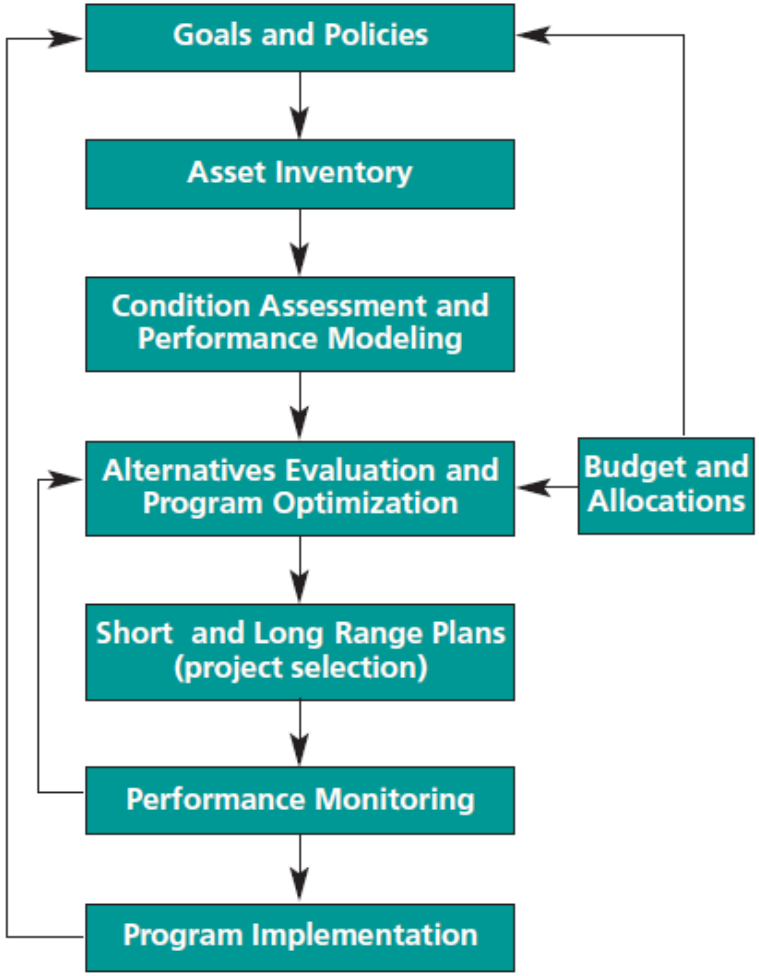
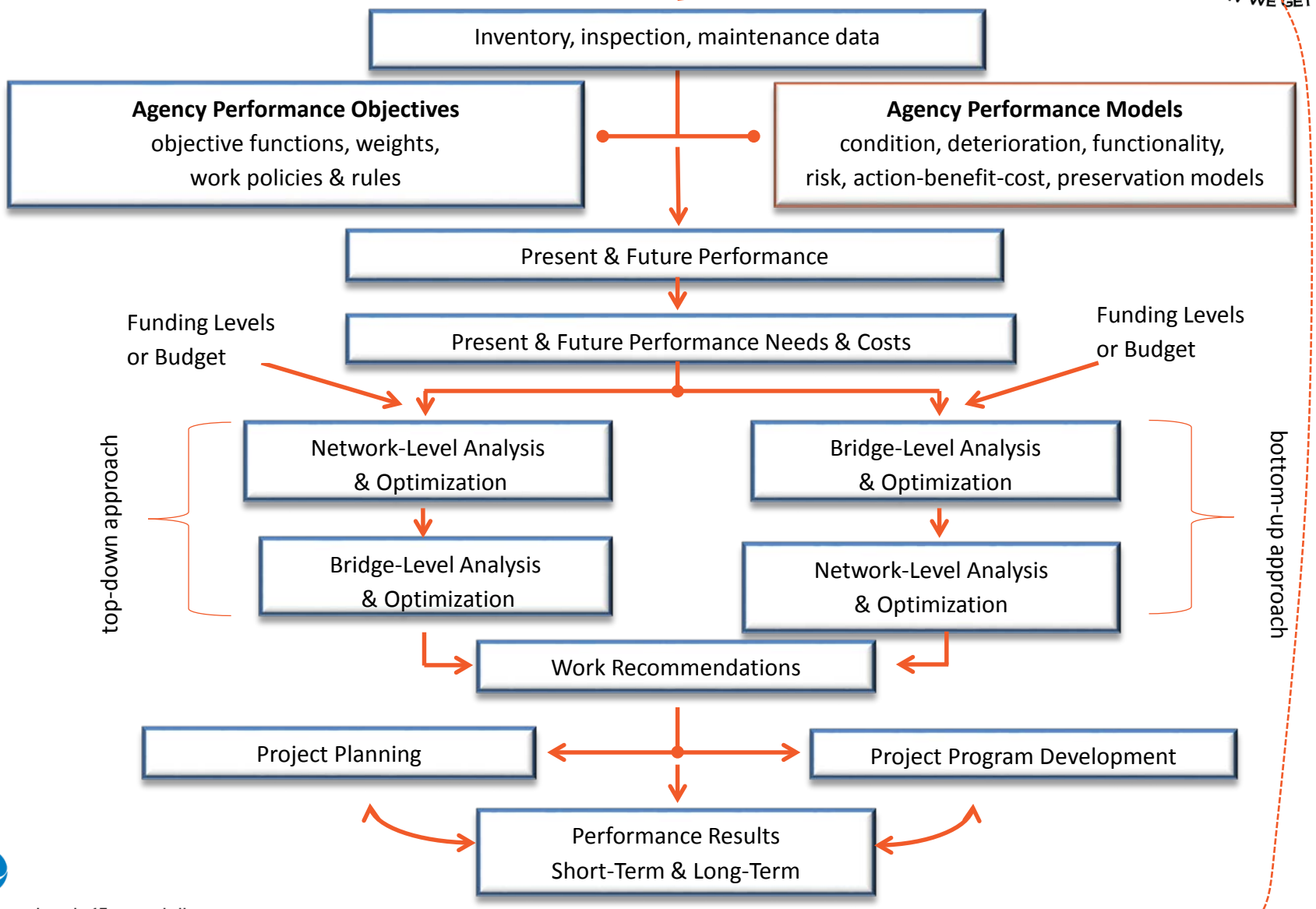
Workflow: Example



Workflow: Example



Objectives & Measures

- BMS in practice use objectives & measures to determine benefits and prioritize work
- In practice, agencies establish objectives & measures that BMS use to evaluate and recommend investment strategy
- In practice, agencies establish objectives & measures that BMS uses to recommend work actions and projects (implement investment strategy)

Objectives & Measures (Examples)

High-level Decision Making	Low-level Decision Making
• identifying investment strategy • cross asset allocation (bridges vs. pavements vs. other) • bridge budget allocation among owners, regions, roadway classes, etc.	• implementing investment strategy • project prioritization • work type selection & scoping

- In practice, BMS support analysis of investment strategies to identify the strategy that maximizes achievement of objectives and measures.
- In practice, BMS support implementation of the chosen strategy by selecting work that maximizes achievement of objectives and measures

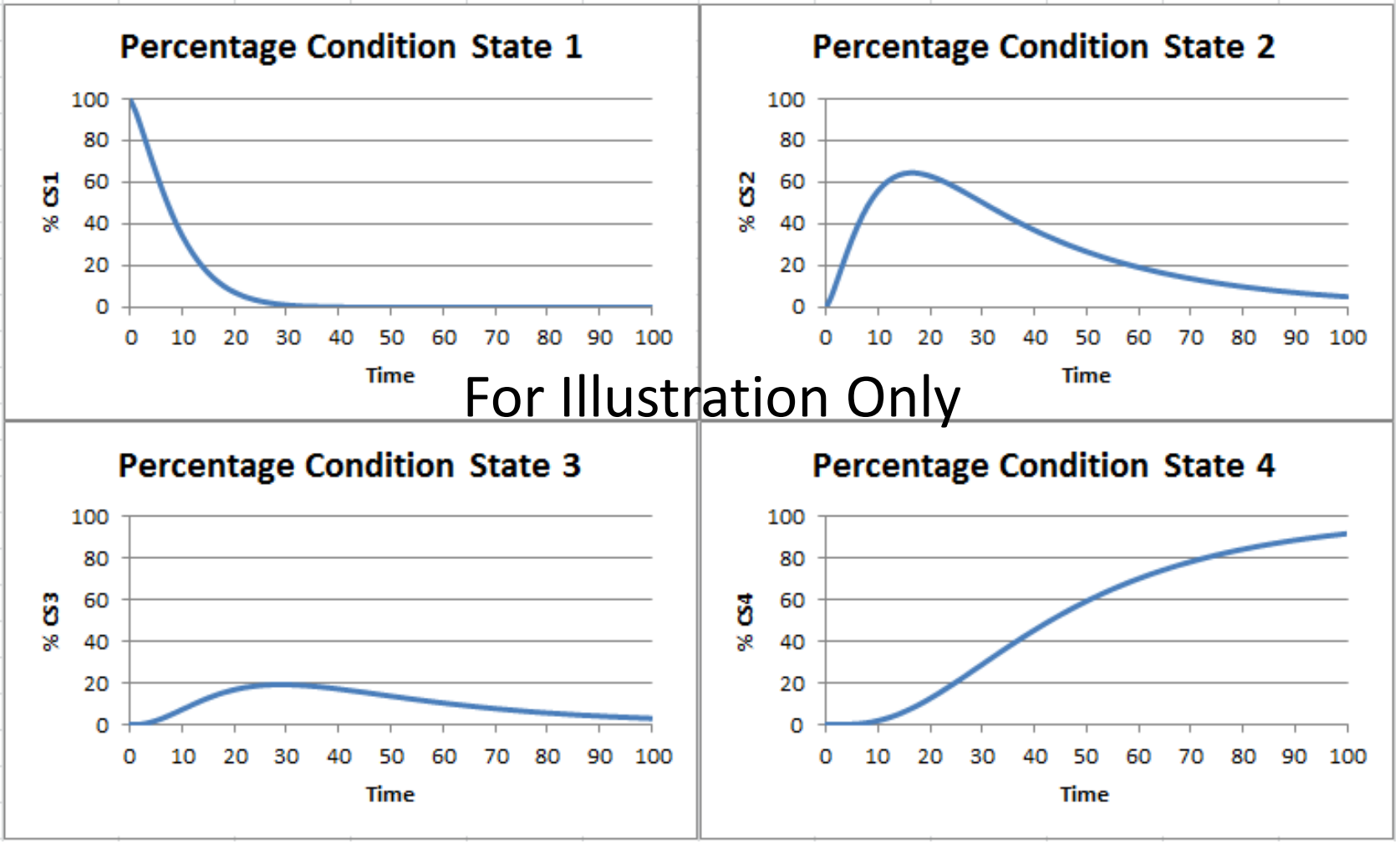
Models

- Definition: A set of ideas and numbers that describe the past, present, or future state of something (Merriam-Webster)
- BMS Model Types
  - Performance
    - Condition assessment, deterioration, functional assessment, risk assessment
  - Action-Benefit-Cost
  - Life-Cycle Cost & Preservation
- FHWA minimum standards do not specify the form of BMS. In practice, models are used.

Performance Models

- Deterioration Models
  - Predict element and/or component condition over time
  - Influence parameters
    - Element or component type
    - Material and design
    - Environment severity
    - Bridge loading and usage
    - Routine maintenance practice
    - Protective systems present
    - Condition of neighboring elements or components
  - Typically, include only a few of the most significant parameters in the model

Performance Models: Deterioration Example



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From AASHTOWare Bridge Management (BrM)

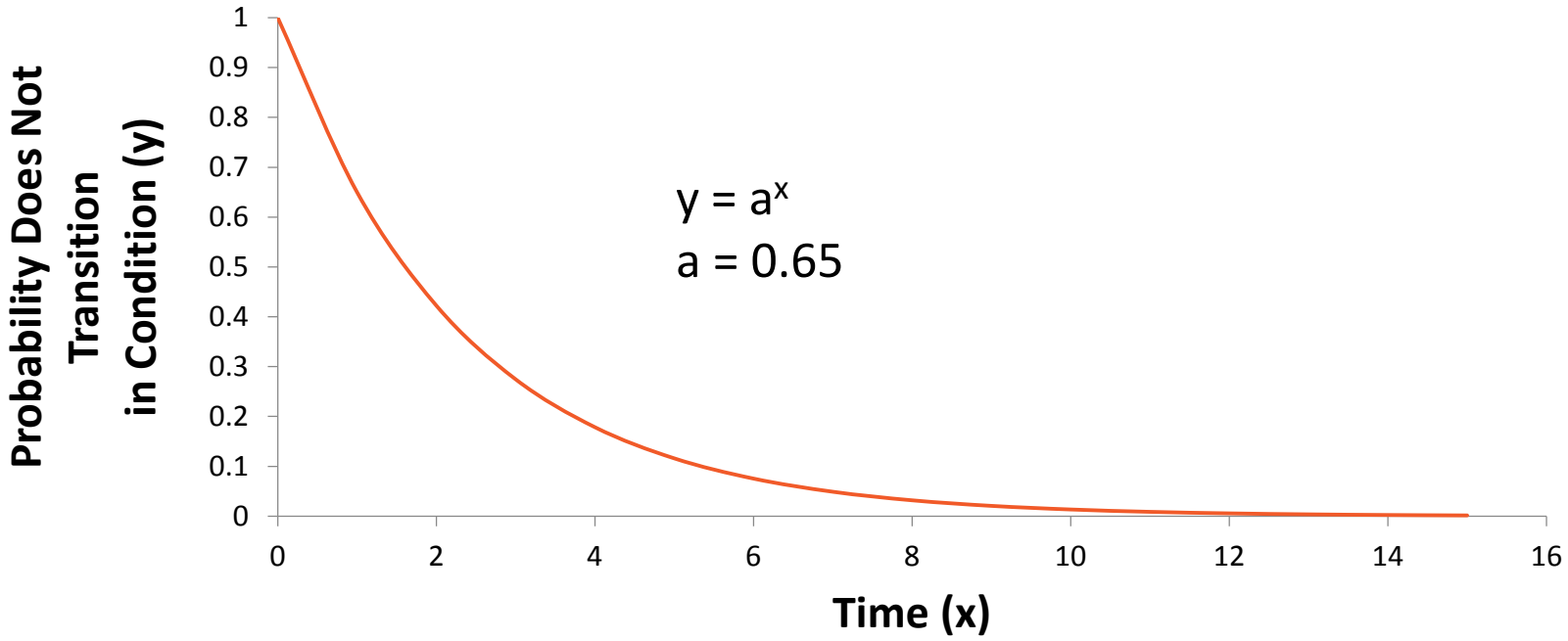
Performance Models: Deterioration

- Model development
  - Deterministic vs. probabilistic
  - Common probability models
    - Markov
    - Weibull

Performance Models: Deterioration Example

- Model development
  - The Markov probability distribution

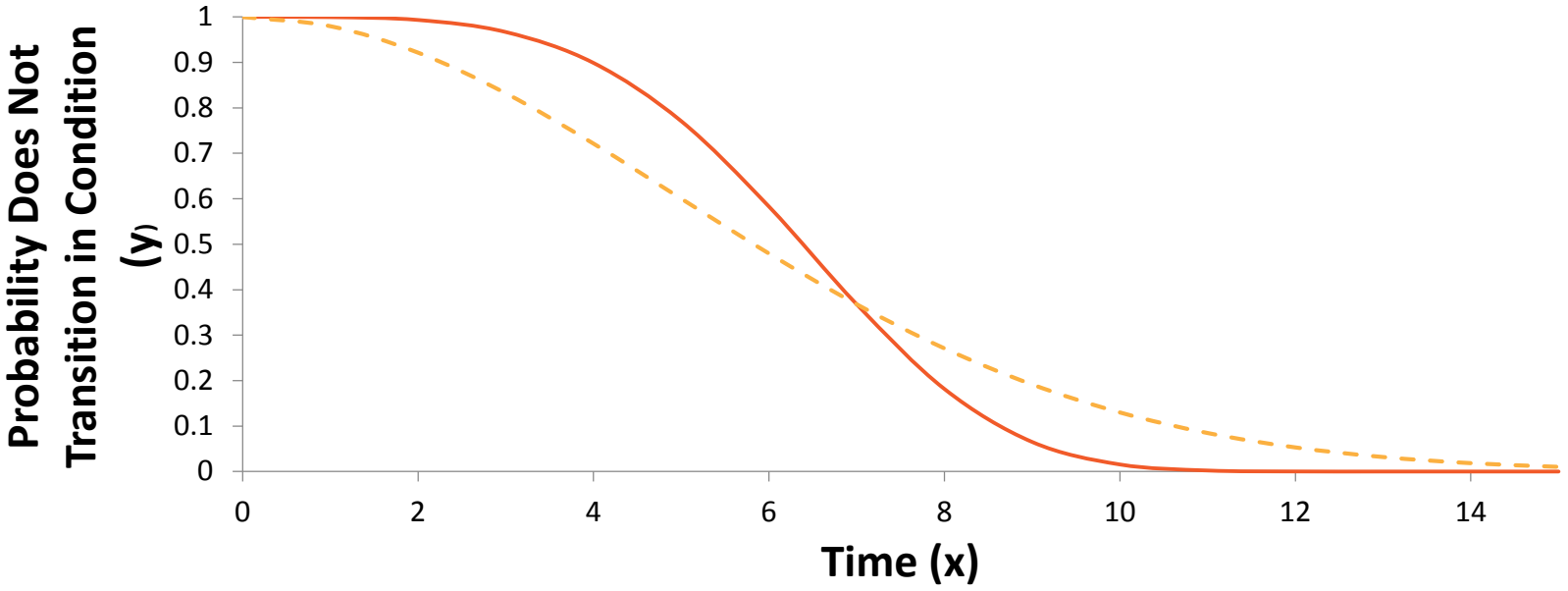
$$y = a^x \quad \text{(exponential curve)}$$



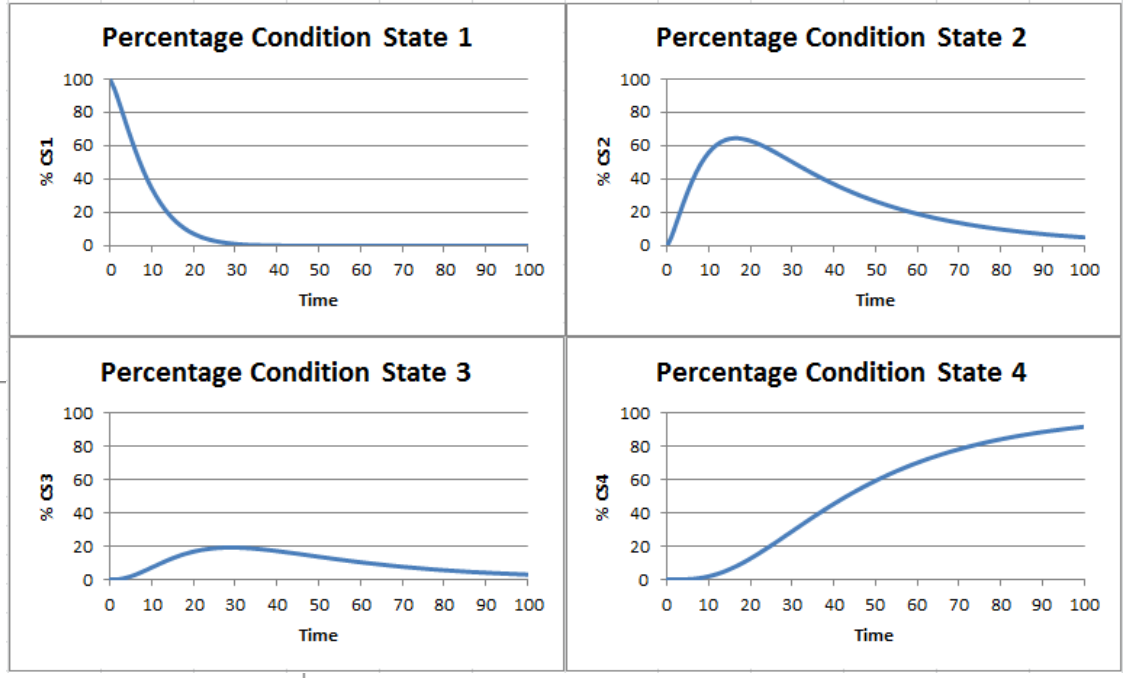
Performance Models: Deterioration Example

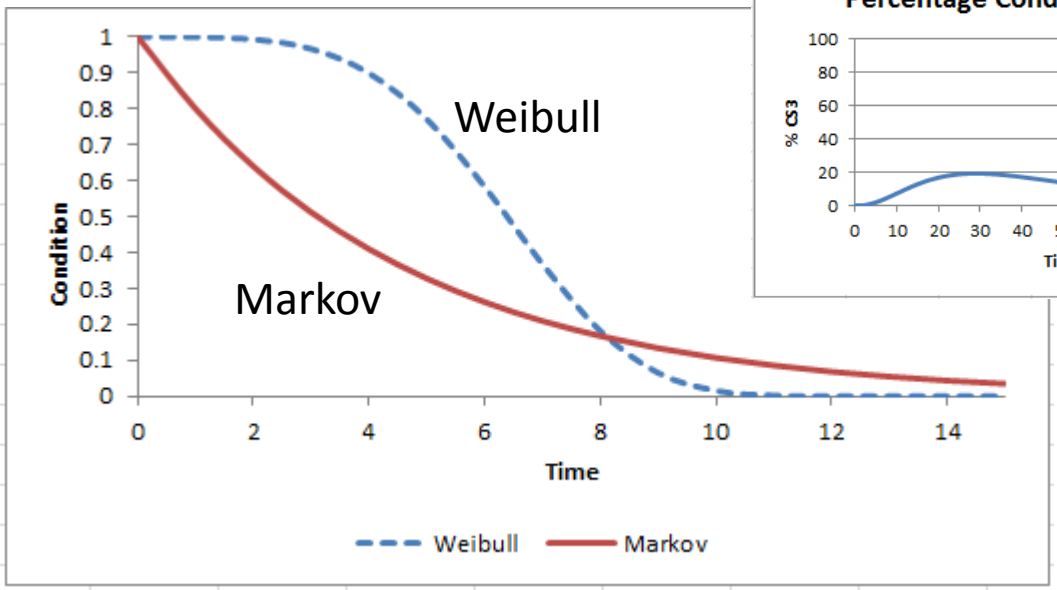
- Model development
  - The Weibull probability distribution

$$y = e^{-(\frac{x}{\alpha})^{\beta}}$$ (exponential curve)



Performance Models: Deterioration Examples





Performance Models: Deterioration Example

Correlating element-level conditions with component-level conditions

NBI	CS1%	CS2%	CS3%	CS4%
9	x	x	x	x
8	100	0	0	0
7		> 0 – 20	0	0
6			> 0 - 5	0
5			> 5 - 20	0
4				> 0 - 20
3				> 20 - 100
2	x	x	x	x
1	x	x	x	x

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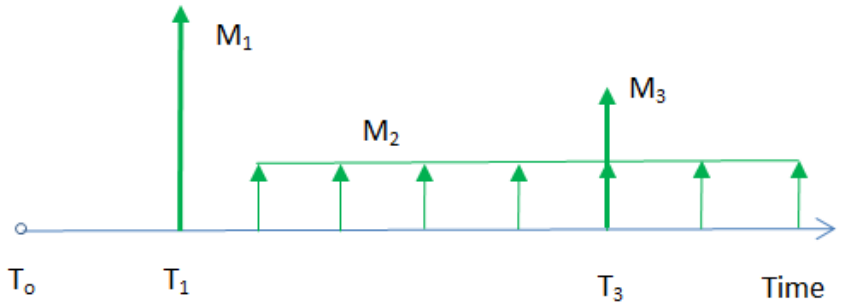
Action-Benefit-Cost Models: Example

ACTION	BENEFIT	COST
Rehab deck	component condition = 7 & element condition = 100% CS2 & life-cycle cost may be reduced*	$45/sf
Patch CS3 & CS4 Spalls/Delam	element condition = CS2 & life-cycle cost may be reduced*	$35/sf
Seal CS2 & CS3 Cracks	element condition = CS2 & life-cycle cost may be reduced*	$8/sf
Apply overlay to bare deck	life-cycle cost reduced	$25/sf
*LCC benefit varies by bridge as function of condition, remaining life, size, etc.		

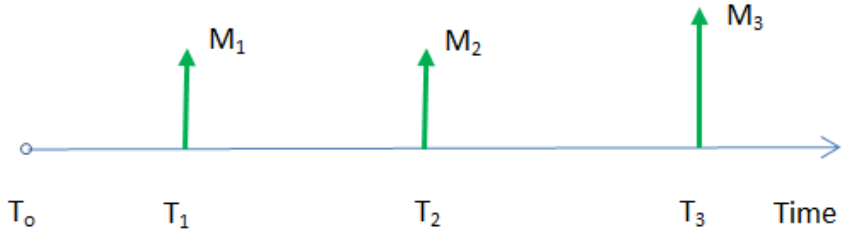
Life-Cycle Cost Analysis & Preservation Models

LCCA compares the LCC that results from alternative work actions. (LCCA is not the same as life-cycle planning. LCCA can be used to support AMP required life-cycle planning)

M_i = action & cost



⇒ LCC = $ X



⇒ LCC = $ Y

LCCA & Preservation Models

Equivalent Present Cost	=	Future Cost at Year *t*	x	Present Cost Factor

$$\text{Present Cost Factor} = \frac{1}{(1+i)^t}$$

t = year the future cost expenditure occurs
i = discount factor

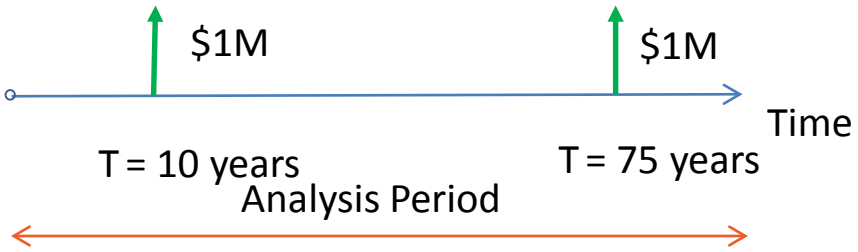
LCCAs & Preservation Models: Example

Present Cost of **$1M** spent in Year **10** = $1M * $\frac{1}{(1+0.03)^{10}}$

= $1M * 0.744 = **$744K**

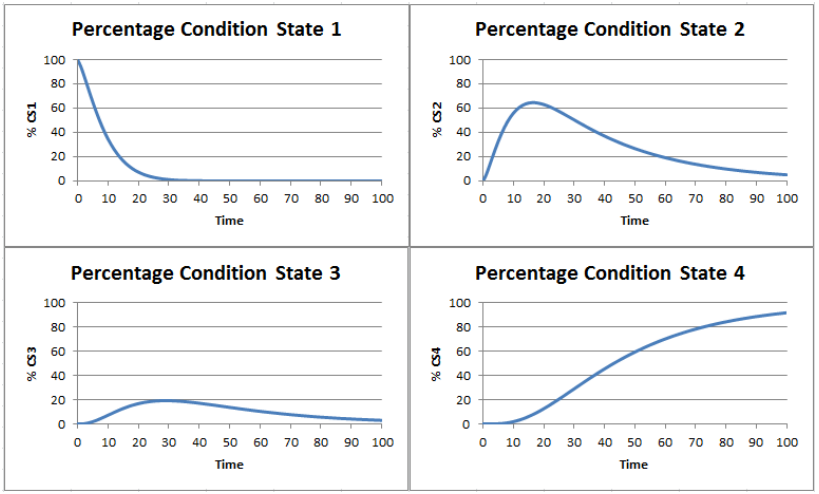
Present Cost of **$1M** spent in Year **75** = $1M * $\frac{1}{(1+0.03)^{75}}$

= $1M * 0.109 = **$109K**



LCCA & Preservation Models: Example

Deterioration Models



Action-Benefit-Cost Models

ACTION	BENEFIT	COST
Rehab deck	Component Condition = 7 Element Condition = 100% CS2	$45/sf
Patch CS3 & CS4 Spalls/Delam	Element Condition = CS2	$35/sf
Seal CS2 & CS3 Cracks	Element Condition = CS2	$8/sf
Apply overlay to bare deck	Life-Cycle Cost reduced (benefit differs by bridge as function of condition, remaining life, size, etc.)	$25/sf

Bridge-Level LCCA

Network-Level Optimization
using Bridge-Level LCCA Output

LCCA & Preservation Models

- BMS LCCA is not the same as project LCCA
- Analysis is only as good as action, cost, benefit & deterioration data/models
- Additional LCCA benefit is quantifying the life-cycle cost increase from deferring work

LCAA & Preservation Models: Example

Preservation Model: Sometimes used in lieu of bridge-level LCCA to simplify computations

Example Deck Element Preservation Model for Spalls, Delamination, and Exposed Rebar Defects					
Condition State	Least Life-Cycle Cost Action	Probable Change in Condition State			
1	no action	-	-	-	-
2	type 1 patch	90% CS1	10% CS2	0% CS3	0% CS4
3	type 2 patch, scarify and overlay	98% CS1	2% CS2	0% CS3	0% CS4
4	replace	100% CS1	0% CS2	0% CS3	0% CS4
Cyclical actions independent of condition state: ▪ **Sweep and flush deck each spring** ▪ **Clean out and flush scuppers and drainage piping each spring and fall**					

TPM
HOW WE GET THERE

Questions?

Analysis & Prioritization

- Analysis Purpose: Identify work needs, determine the optimum approach to address needs, and forecast future performance from intended work
- Analysis Utilities
  - Bridge-Level Analysis
  - Network-Level Analysis
  - Prioritization
  - Simulation & Scenario Investigation
- FHWA minimum standards do not specify the form of BMS; in practice, these analyses are used

Analysis: Bridge vs. Network

Bridge-Level Analysis	Network-Level Analysis
• individual bridge(s) • alternative work actions analyzed • compares benefit-cost of alternative work actions	• network of bridges • uses results of bridge-level analysis to evaluate alternative bridge projects composed of optimal bridge-level actions • compares benefit-cost of alternative projects

Generally BMS perform both levels of analysis

Analysis: Prioritization

- A primary goal of analysis
- Orders work by effectiveness
  - In practice:
    - First, potential work actions on each bridge are prioritized to identify projects and scopes
    - Second, projects are prioritized to identify programs
- Ranking vs. optimization

Analysis: Prioritization

RANKING	OPTIMIZATION
• Ordered by relative score	• All possible combinations of work and projects analyzed
• Simplified analysis that uses simplified scoring	• Complex iterative analysis
• Attempts to consider multiple objectives by using aggregate indexes	• Considers multiple objectives and multiple analysis years
• Cannot handle multiple constraints	• Can handle multiple constraints (budget, programming rules, minimum acceptable performance, etc.)
• Does not yield most cost-effective solution	• Yields most cost-effective solution

Aligns w/ minimum standard (e)

Analysis: Prioritization by Optimization

- Fill a knapsack with 20 pounds of free food from options that can include one of each

Nuts: 4 lbs for $10 Fruit: 10 lbs for $6 Candy: 2 lbs for $3

Juice: 3 lbs for $5 Cheese: 5 lbs for $15

COMBINATION ONE		
cheese	5 lbs	$15
nuts	4 lbs	$10
fruit	10 lbs	$6
TOTAL	**19 lbs**	**$31**

COMBINATION TWO		
candy	2 lbs	$3
juice	3 lbs	$5
nuts	4 lbs	$10
cheese	5 lbs	$15
TOTAL	**14 lbs**	**$33**

Analysis: Prioritization by Optimization

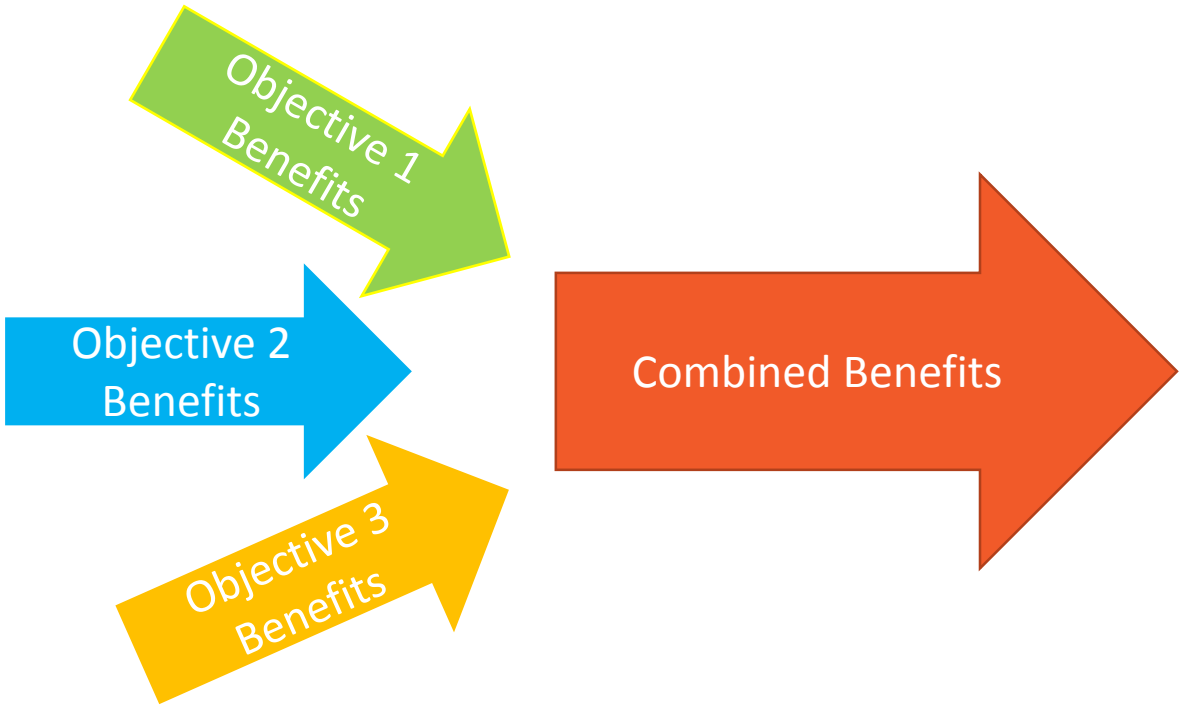
- Benefit-Cost Ratio

$$BCR_i = \frac{B_i}{C_i}$$

Analysis: Prioritization

- Benefits Measurement

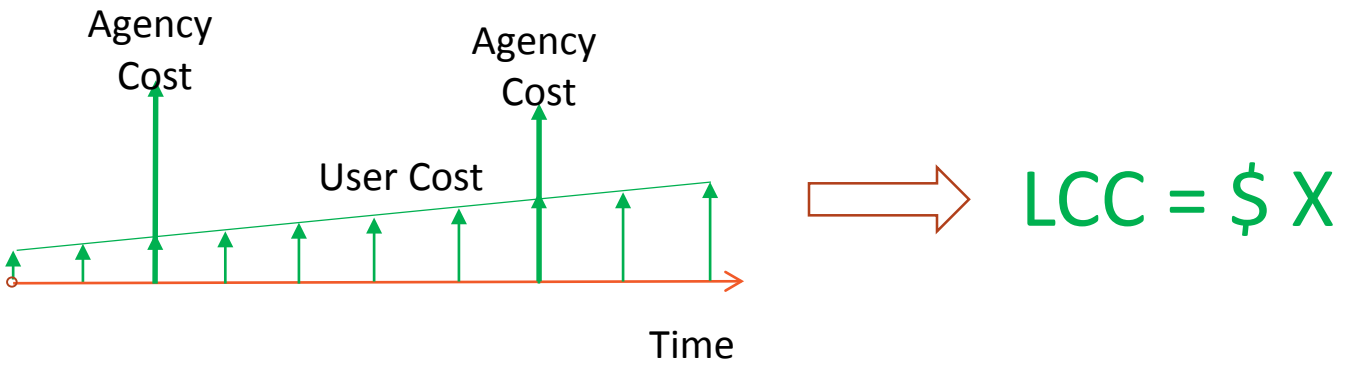
Work Action / Project / Program Benefits



Analysis: Prioritization

- Benefits Measurement
  - Monetization
    - Suits objective types that are measurable by cost impacts

Monetization



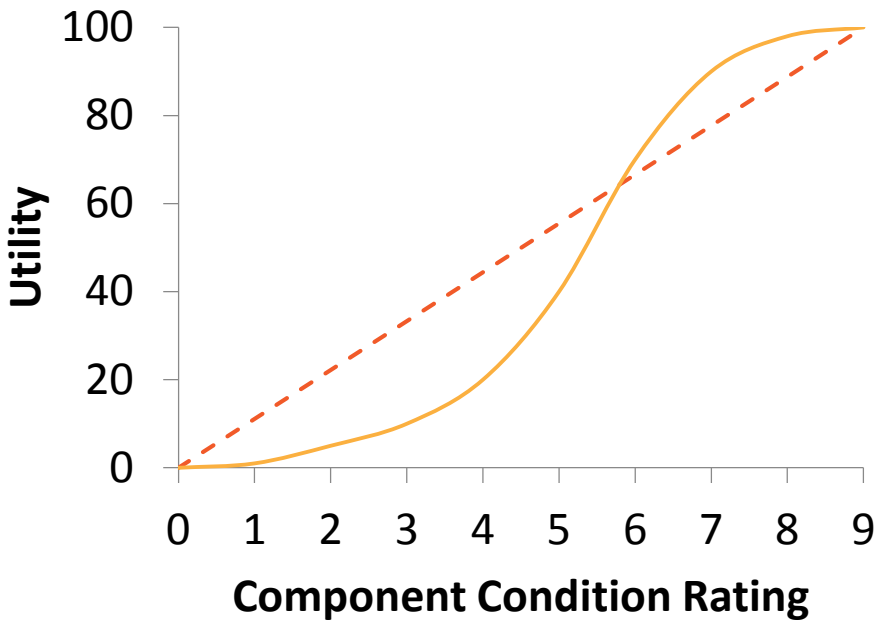
Analysis: Prioritization

- Benefits Measurement
  - Utility: suits multiple objective types
    - Utility theory
      - Used in customer management to assess satisfaction or value
      - Combines different factors by uniform scaling & relative weighting

Analysis: Prioritization

Benefits Measurement: Utility Example

Utility Function

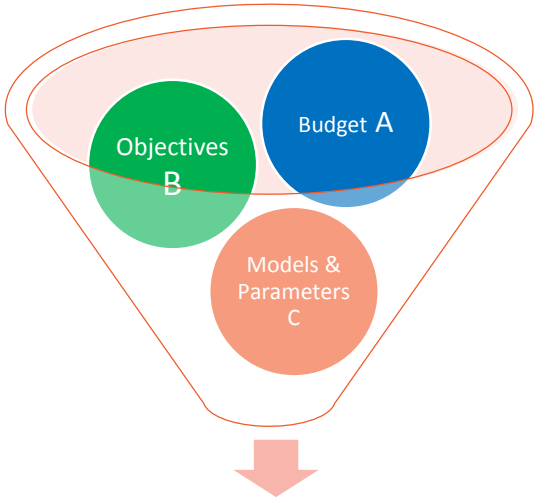


Utility Weights

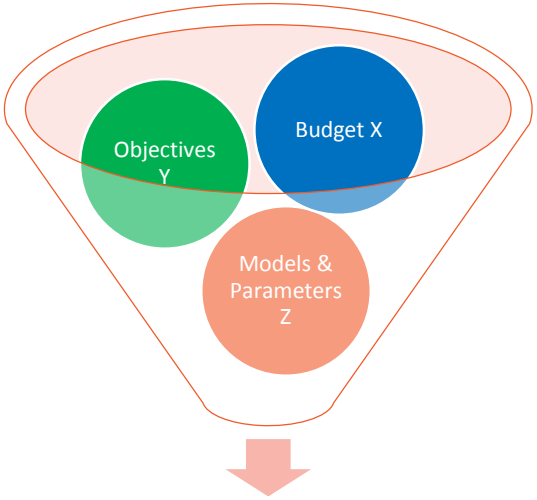
OBJECTIVE	MEASURE	ASSIGNED WEIGHT
Condition	Component Ratings	15%
	Health Index	30%
Life-Cycle Cost	Life-Cycle Cost Reduction	40%
Extreme Event Failure Risk	Risk Score	15%
Total		100%

Analysis: Network Simulation & Scenario Investigation

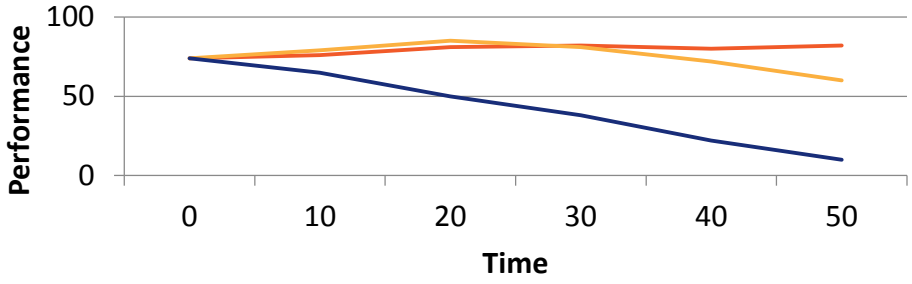
Forecasts outcomes from different strategies



Year 1, Year 2, Year 3, … Year X Performance



Year 1, Year 2, Year 3, … Year X Performance



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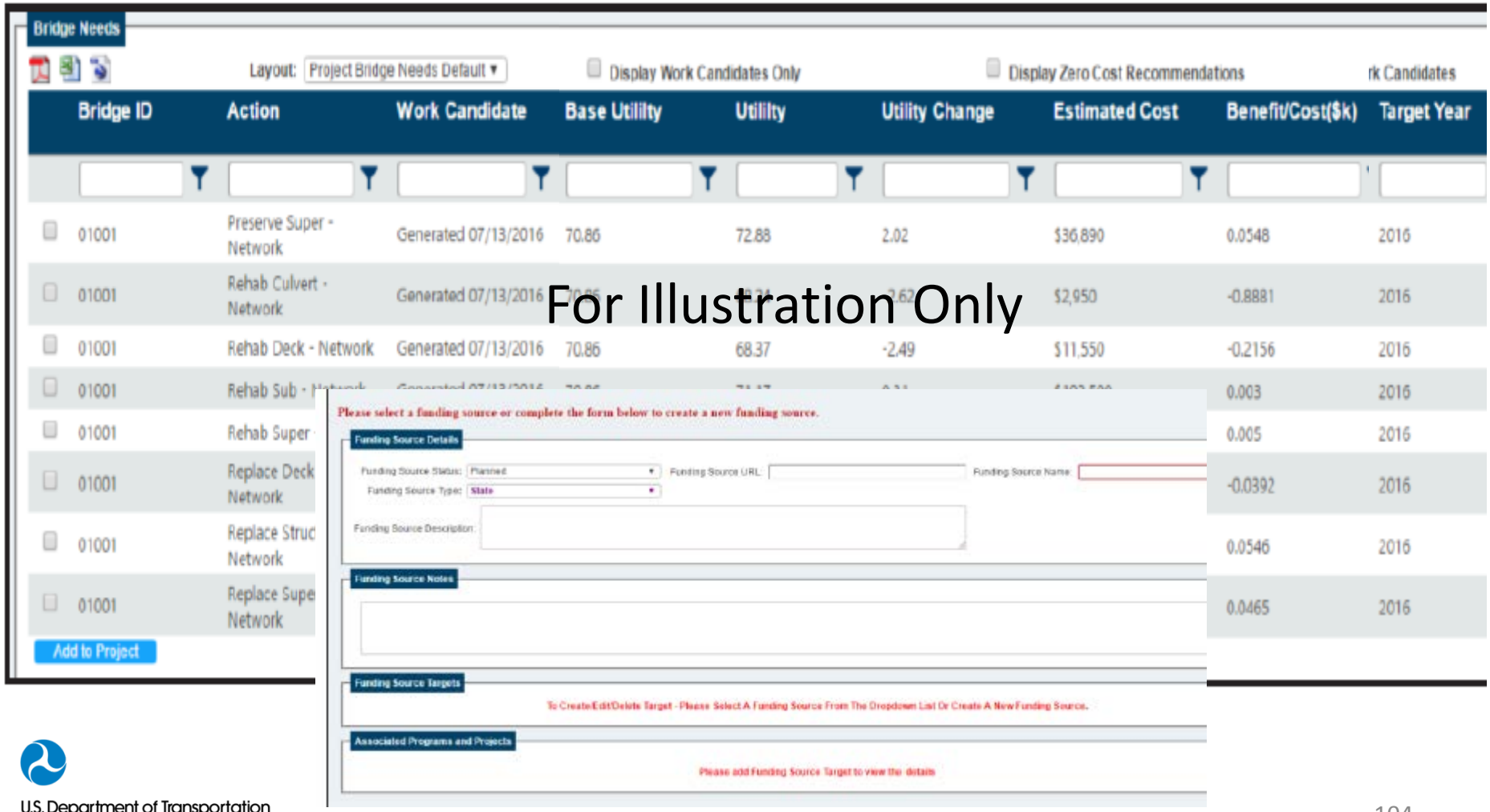
HOW WE GET THERE

Questions?

Work Selection & Project Programming

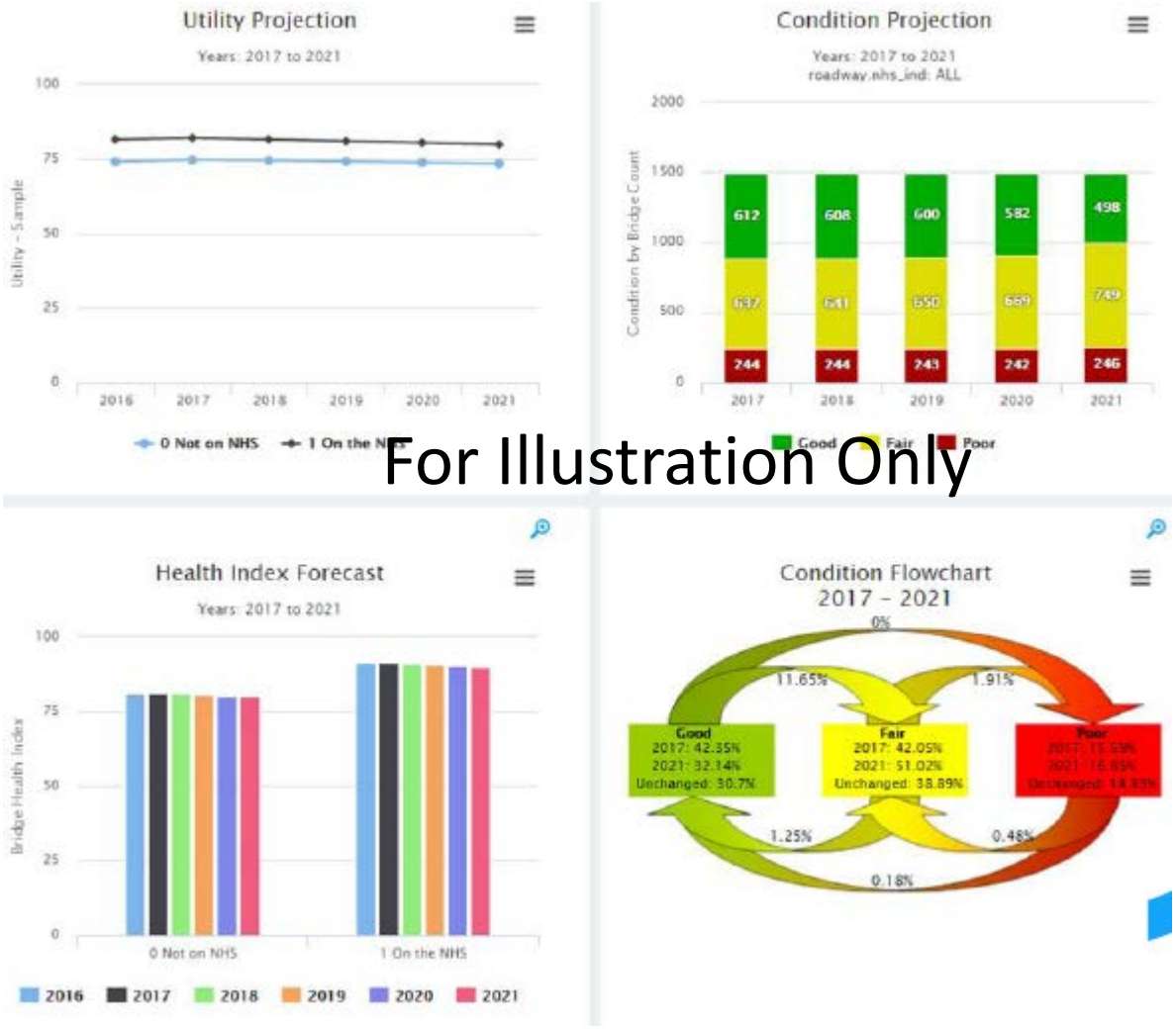
FHWA minimum standards do not specify the form of BMS. In practice, project and programming functions like this are used.



For Illustration Only

From AASHTOWare Bridge Management (BrM)

Performance Monitoring: Examples



For Illustration Only

From AASHTOWare Bridge Management (BrM)

BMS Support of Asset Management Plan Elements, Performance Measure Requirements & Target Setting

U.S. Department of Transportation
Federal Highway Administration

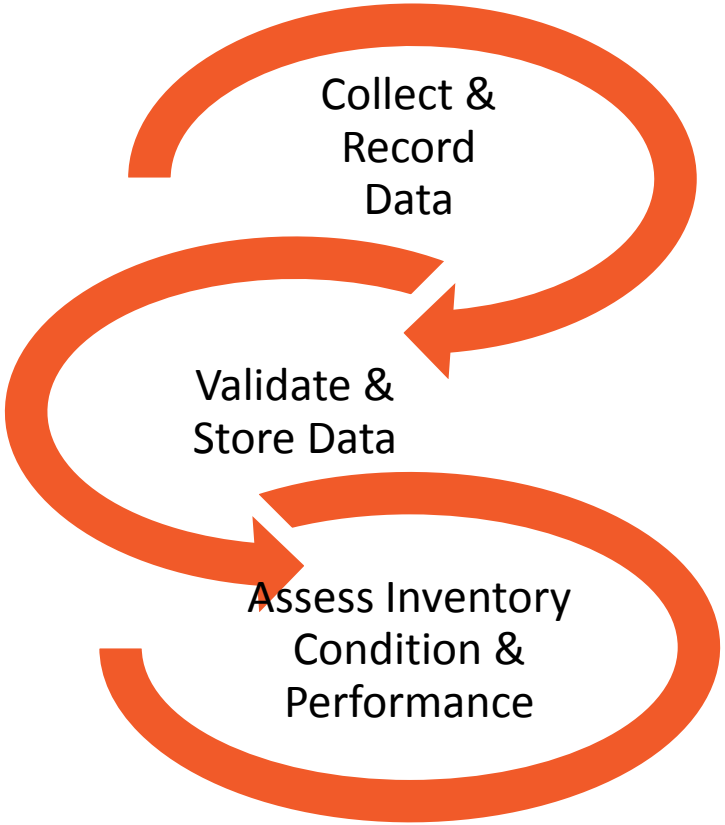
BMS Support of Asset Management Plan Elements, PM Requirements & Target Setting

- How can BMS support development and implementation of AMP?
- Illustrations of how BMS should support AMP development and implementation

BMS Support of Asset Management Plan Elements, PM Requirements & Target Setting

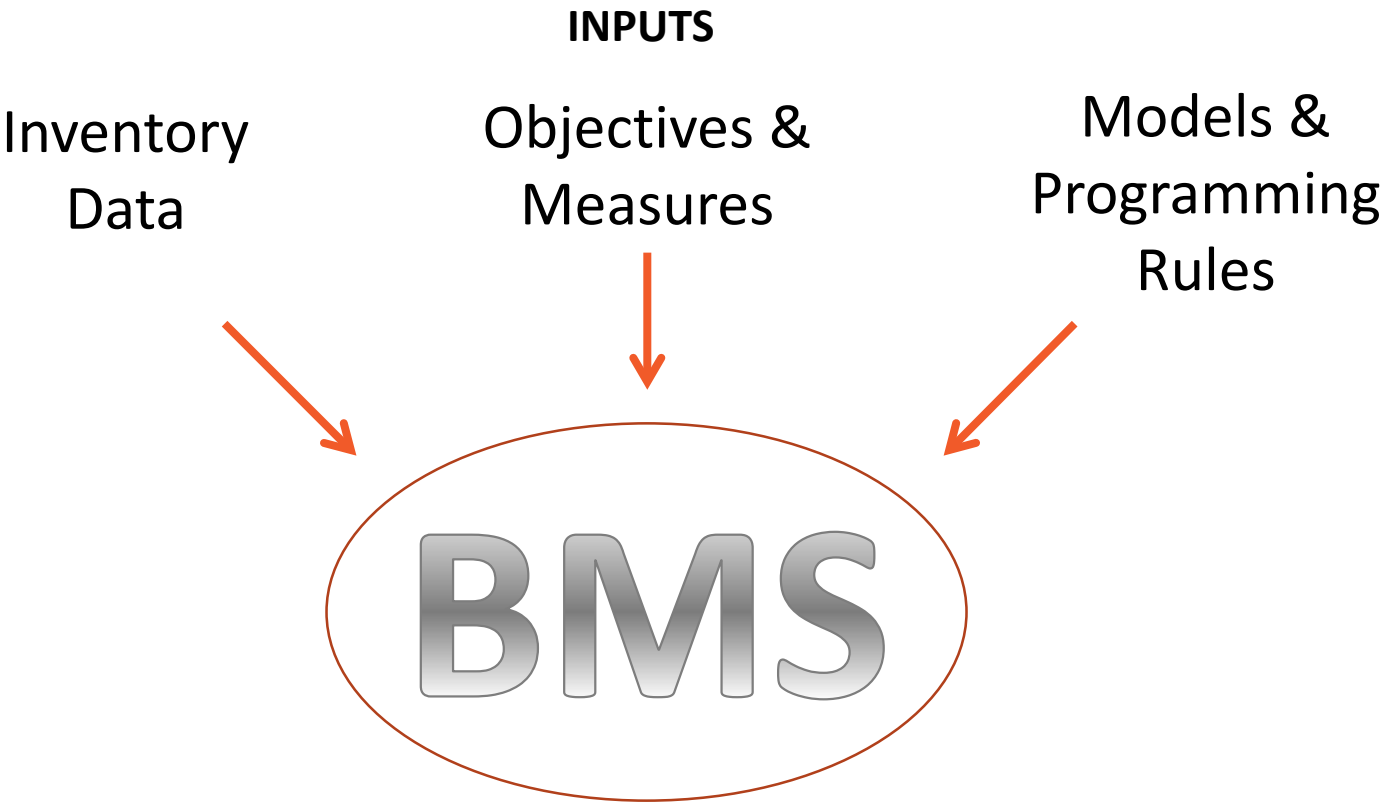
- AM Plan Element: Inventory

BMS



BMS Support of Asset Management Plan Elements, PM Requirements & Target Setting

AM Plan Element: Objectives & Measures



BMS Support of Asset Management Plan Elements, PM Requirements & Target Setting

AM Plan Element: Performance Gap Analysis

Minimum Acceptable Condition & Performance

or

Targeted Condition & Performance

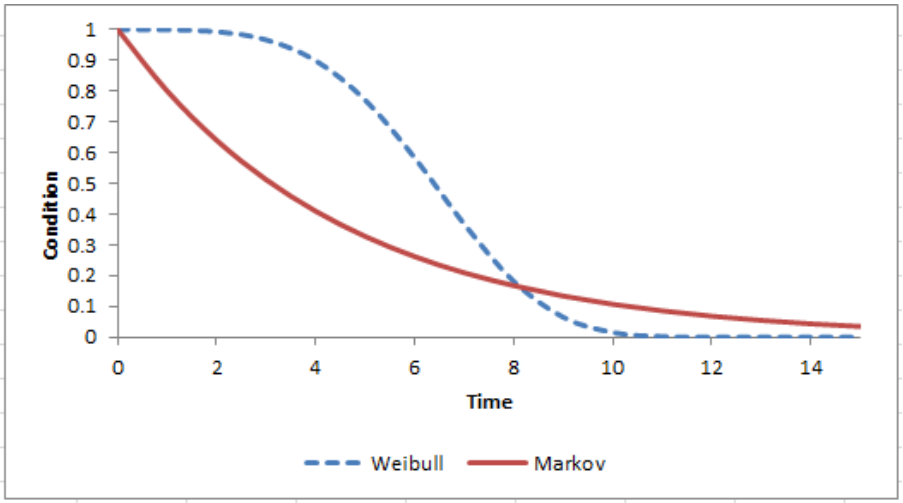
Current & Predicted Bridges & Costs

and

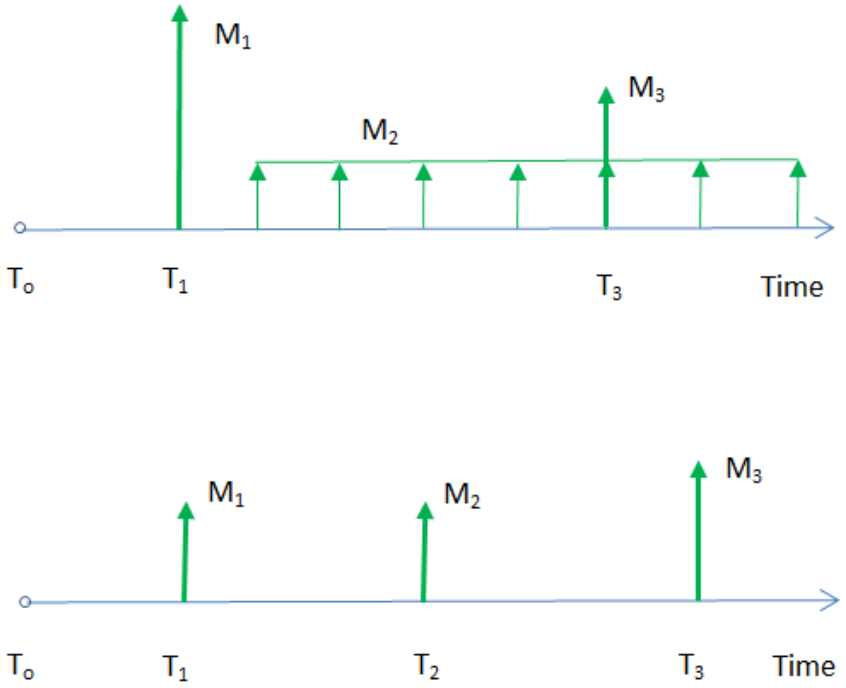
Lost Opportunities from Work Deferral (decline in performance, increased life-cycle cost)

BMS Support of Asset Management Plan Elements, PM Requirements & Target Setting

AM Plan Element: Life-Cycle Planning Examples



Deterioration Models



Life-Cycle Cost Analysis

BMS Support of Asset Management Plan Elements, PM Requirements & Target Setting

AM Plan Element: Investment Strategies & Target Setting

BMS Support of Asset Management Plan Elements, PM Requirements & Target Setting

AM Plan Element: Work Program Development Processes

Knowledge Checks

BMS can analyze and make recommendations for (choose all that apply):

a) asset classes
b) asset subgroups
c) individual bridges
d) individual bridge elements

Knowledge Checks

Deterioration models (true or false):

a) are detailed enough to assess bridge work needs and costs
b) account for slowed deterioration from protective systems
c) model component deterioration only
d) identify work action costs and benefits

Knowledge Checks

BMS project recommendations often do not account for and therefore need to be adjusted for (choose all that apply):

a) field knowledge
b) performance measures
c) long-range plans for capacity and corridor improvement
d) life-cycle cost

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HOW WE GET THERE

Questions?

Session 3: Bridge Performance Measures & Target Setting

U.S. Department of Transportation
Federal Highway Administration

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HOW WE GET THERE

Bridge Performance Measures & Target Setting

- Purpose & Definitions
- Data
- Bridge Performance Measures & Minimum Condition Level
- Setting Bridge Performance Targets
- Performance Reporting

Purpose & Definitions

U.S. Department of Transportation
Federal Highway Administration

23 USC 119: National Highway Performance Program

- National goal for infrastructure condition = maintain the highway infrastructure asset system in a state of good repair [23 USC 150(b)(2)]
- States shall develop a risk-based asset management plan for the NHS to improve or preserve the condition of the assets and the performance of the system [23 USC 119(e)]

23 USC 119: National Highway Performance Program

- Ensure that Federal-aid investments in highway bridge construction are directed to support progress toward the achievement of the goal by meeting targets established in an asset management plan. [23 USC 119(b)(3)]

Bridge TPM Regulations

- Detailed in 23 CFR 490
  - **Subpart A – General Information**
  - Subpart C - National Performance Management Measures for Assessing Pavement Condition
  - **Subpart D – National Performance Management Measures for Assessing Bridge Condition**

Definitions of Key Terms

Measure	Expression based on a metric that is used to establish targets and to assess progress toward achieving the established targets	Example: % of bridges by deck area in good or poor condition
Target	Quantifiable level of performance or condition, expressed as a value for the measure, to be achieved within a time period required by FHWA	Example: no more than 10% of NHS bridges by deck area classified as poor by 2020

Data

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Federal Highway Administration

Data Sources

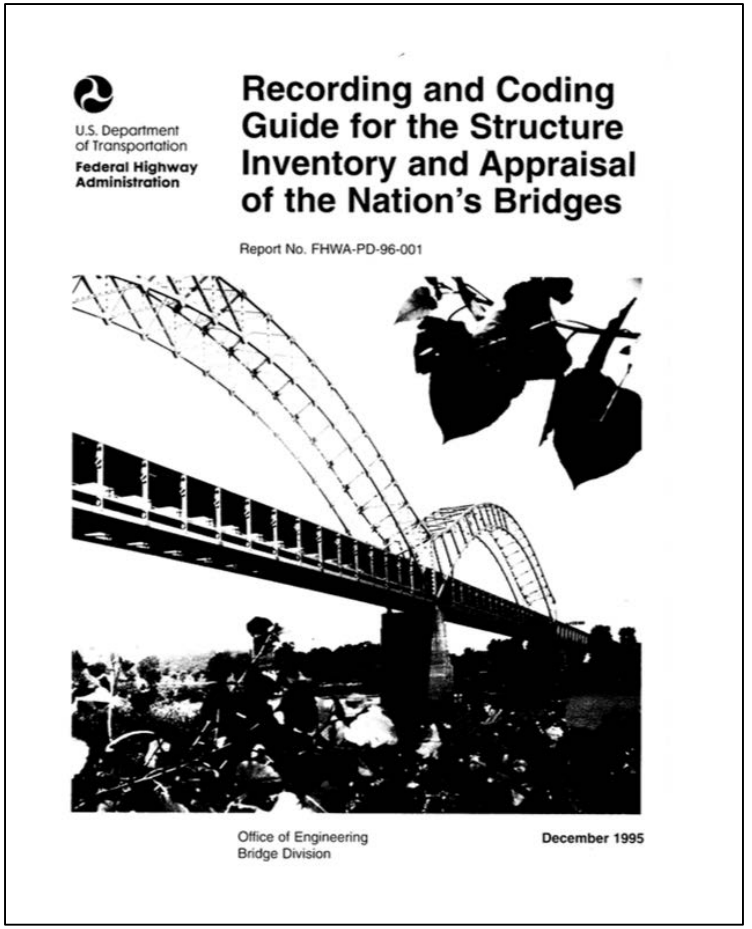
- States and other agencies utilize a variety of bridge data sources
  - Federal National Bridge Inventory (NBI) data
  - Agency data items (often more detail than NBI items)
  - Plans and inspection photographs
  - Construction and maintenance history
  - Detailed roadway characteristics
  - GIS location and network relationships
  - Ownership and custodial agreements

NBI Data

- Well-established data set for all bridges
- Each State and Federal agency maintains an inventory of bridges (23 USC 144: National Bridge Inventory & Inspection Standards)
- Bridges typically inspected every 24 months or more frequently as needed
- States and Federal agencies report inventory and condition data annually

NBI Data

- Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges (1995)



NBI Data Types

- Identification
- Structure type and materials
- Age and service
- Geometric data
- Inspection types and dates
- Classification
- Condition
- Load rating and posting
- Appraisal
- Proposed improvements
- Navigation data

Structure Inventory & Appraisal Sheet of NBI Data: Example

Structure Inventory and Appraisal Sheet

Bridge Key: 11 0013 | Agency ID: 11 0013 | Sufficiency Rating: 96.8

IDENTIFICATION

State 1:	06 California	Struc Num 8:	11 0013
Facility Carried 7:	STATE ROUTE 162	Location 9:	03-GLE-162-_-73.55
Rte.(On/Under)5A:	Route On Structure	Rte. Signing Prefix 5B:	3 State Hwy
Level of Service 5C:	1 Mainline	Rte. Number 5D:	00162
Directional Suffix 5E:	0 N/A (NBI)	% Responsibility :	Unknown
GHD District 2:	District 3	County Code 3:	(11)GLENN
Place Code 4:	Unknown	Kilometer Post 11:	73.6 km
Feature Intersected 6:	BRUSH CANAL		
Latitude 16:	39d 31' 18"	Longitude 17:	122d 03' 42"
Border Bridge Code 98:	Unknown (P)		
Border Bridge Number 99:	Unknown		

STRUCTURE TYPE AND MATERIALS

Number of Approach Spans 46: 0 Number of Spans Main Unit 45: 2

Main Span Material/Design 43A/B:

2 Concrete Continuous 01 Slab

INSPECTION

Frequency 91:	24 months	Inspection Date 90:	10/28/1997	Next Inspection:	10/28/1999
FC Frequency 92A:	NA	FC Inspection Date 93A:	NA	Next FC Inspection:	NA
UW Frequency 92B:	NA	UW Inspection Date 93B:	NA	Next UW Inspection:	NA
SI Frequency 92C:	NA	SI Date 93C:	NA	Next SI:	NA
Element Frequency:	24 months	Element Inspection Date:	12/11/1997	Next Elem. Insp. Due:	10/28/1999

CLASSIFICATION

Defense Highway 100:	0 Not a STRAHNET hwy	Parallel Structure 101:	No ‖ bridge exists
Direction of Traffic 102:	2 2-way traffic	Temporary Structure 103:	Unknown (NBI)
Highway System 104:	0 Not on NHS	NBIS Length 112:	Long Enough
Toll Facility 20:	3 On free road	Functional Class 26:	06 Rural Minor Arterial
Historical Significance 37:	5 Not eligible for NRHP		
Owner 22:	1 State Highway Agency		
Custodian 21:	1 State Highway Agency		

CONDITION

Deck 58:	7 Good	Super 59:	7 Good	Sub 60:	7 Good
Culvert 62:	N N/A (NBI)	Channel/Channel Protection 61:		8 Protected	

Component-Level Data

- Provides a single condition rating for 4 components
  - Deck
  - Superstructure
  - Substructure
  - Culvert
- An overall characterization of the general condition of the entire component (FHWA Recording and Coding Guide)

Element-Level Data

- States collect additional condition data at an *element level* to supplement the deck, superstructure, substructure and culvert component condition ratings
- Element-level data first collected on a voluntary basis in the mid-1990s
- Element data can provide better indication and quantification of needs than component data

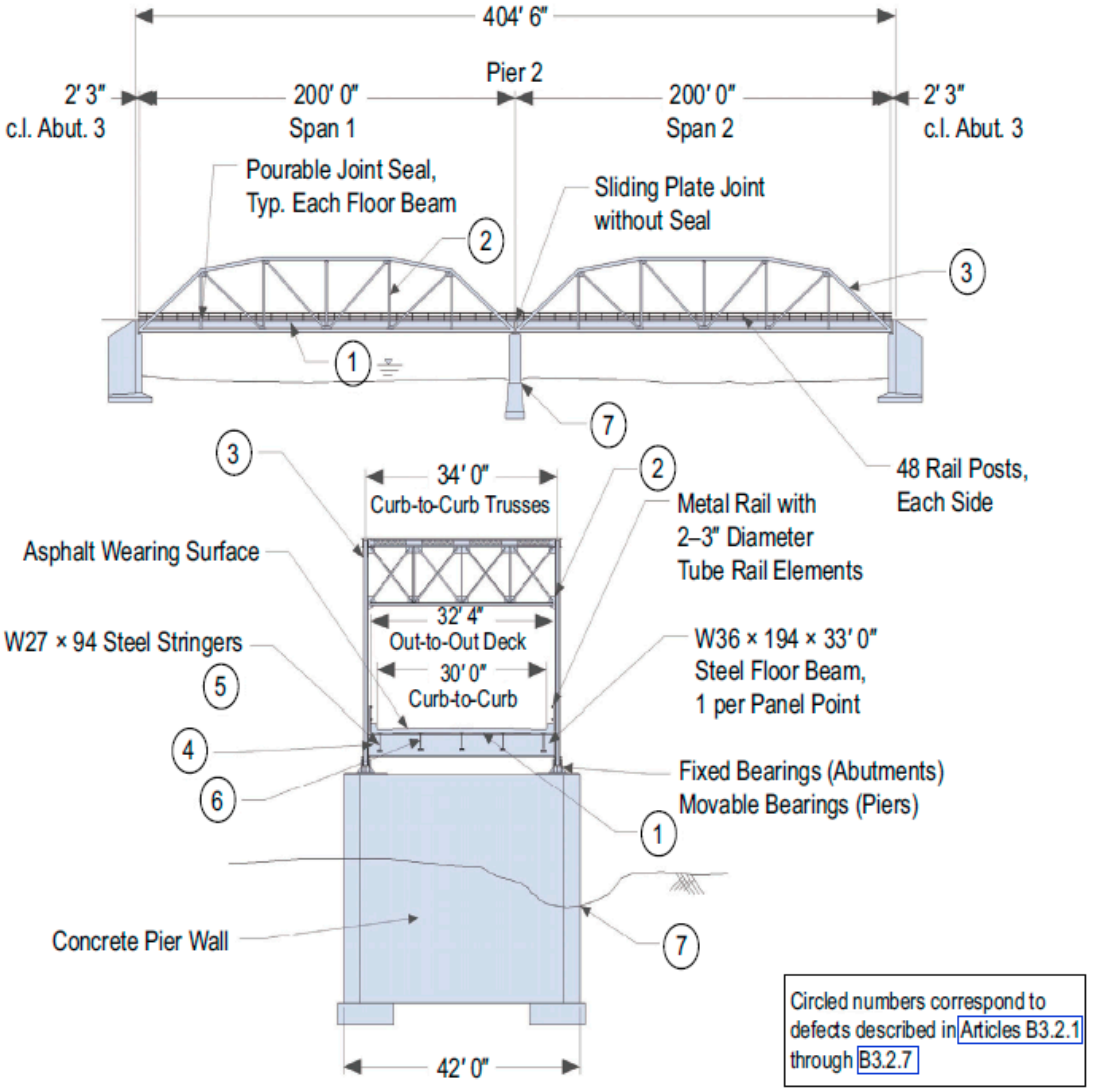
Element-Level Data

Recent developments:

- AASHTO Manual for Bridge Element Inspection (MBEI); supersedes the earlier Commonly Recognized Element (CoRe) Guide
- In 2015, States and Federal agencies began reporting NHS bridges element data to FHWA as required by MAP-21 [23 USC 144(d)(2)]

Element-Level Representation: Example

Circled numbers are examples of specific defects



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Questions?

Bridge Performance Measures & Minimum Condition Level

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Federal Highway Administration

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HOW WE GET THERE

Performance Objectives

Condition

Risk

Minimizing Cost

Asset Value

Function

Mobility

Other

Common Bridge Performance Measures

Measure	Description	Notes
Good/Poor Condition	Calculated based on minimum value of NBI deck, superstructure, substructure and culvert ratings	Required for NHS bridges
Structurally Deficient (SD)	Calculated based on minimum value of NBI deck, superstructure, substructure and culvert ratings	Equivalent to Poor condition
Sufficiency Rating (SR)	0-100 measure indicating a bridge's overall sufficiency to remain in service 0 indicates an entirely insufficient bridge; 100 indicates one that is entirely sufficient	Includes structural and functional considerations; formerly used to establish eligibility for Federal funding
Health Index	0-100 measure indicating overall bridge condition based on element-level data; 0 indicates all elements are in CS4, 100 indicates all are in CS1.	Summarizes element level conditions, does not include consideration of functional or geometrical issues

Common Bridge Performance Measures

Measure	Description	Notes
Posted Bridges	Count of bridges posted with load limits; specified through NBI Item 41	A number of States track posted bridges; posting practices vary
Remaining Service Life	A bridge's estimated remaining economic life	Calculation complicated by number of bridge components and feasible treatments
Functionality Obsolete (FO) Status	Identifies bridges with functional or geometrical issues; calculated based on a variety of NBI items	Previously used with SD and SR used by FHWA to establish funding eligibility
High Risk Bridges	Count or % of bridges considered high risk due to likelihood of service disruption and impact of service disruption	Examples include scour critical bridges, fracture critical bridges, bridges with clearance restrictions and seismic vulnerability

Bridge Performance Measures

- FHWA performance measures for assessing bridge condition and setting targets for NHS bridges
  - % of NHS bridges by deck area classified as Good condition
  - % of NHS bridges by deck area classified as Poor condition

Required NBI Data Items

Bridge Condition	58 – Deck 59 – Superstructure 60 – Substructure 62 – Culverts
Deck Area Calculations	32 – Approach Roadway Width 49 – Structure Length 52 – Deck Width

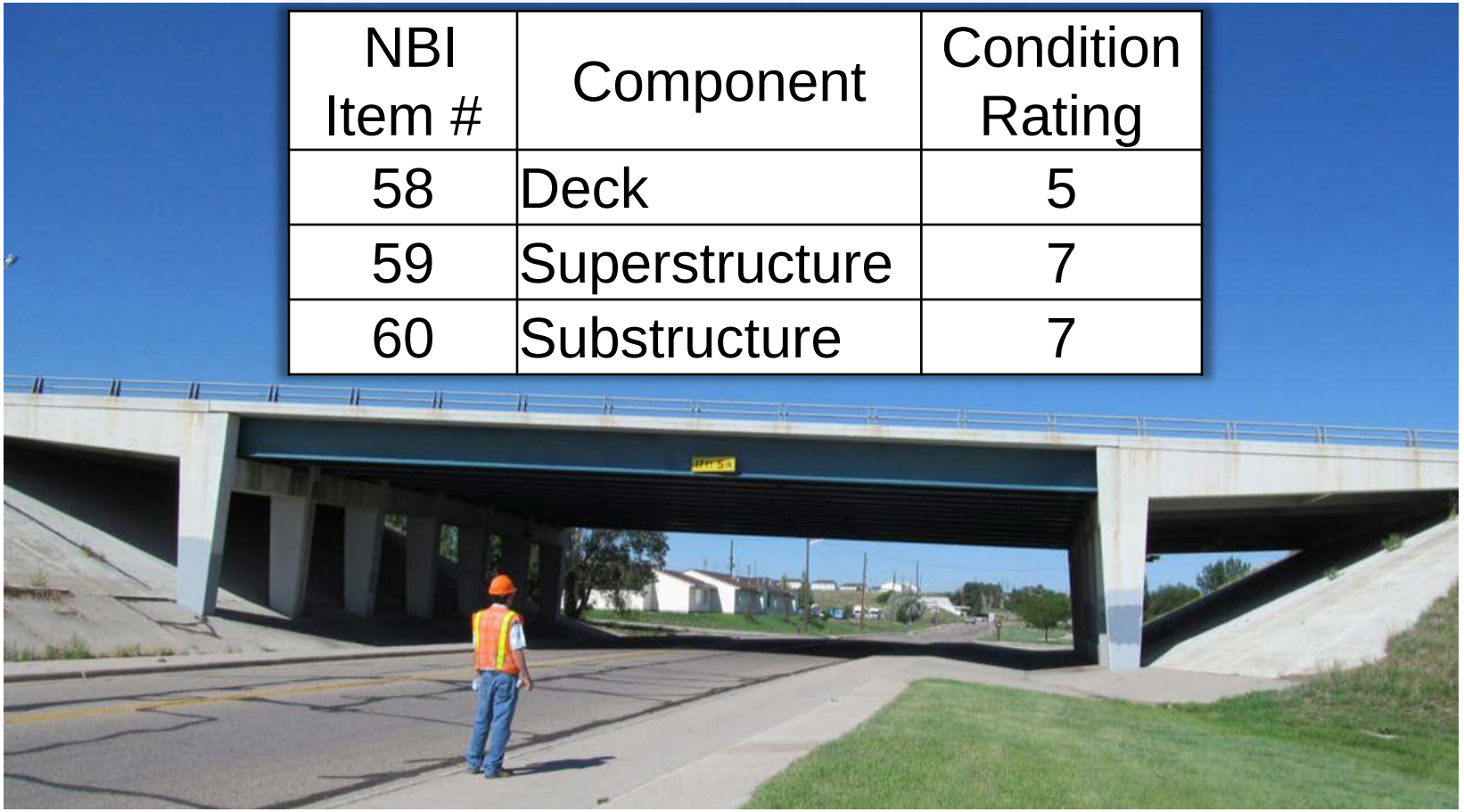
NBI Component Condition Rating Values

9 - Excellent
8 - Very Good
7 - Good
6 - Satisfactory
5 - Fair
4 - Poor
3 - Serious
2 - Critical
1 - “Imminent” Failure
0 - Failed

Condition Rating Thresholds for Classification

NBI Rating Scale *(from 0 – 9)*	9 8 7 Good	6 5 Fair	4 3 2 1 0 Poor
Bridge — Deck *(Item 58)*	≥7	5 or 6	≤4
Bridge — Superstructure *(Item 59)*	≥ 7	5 or 6	≤ 4
Bridge — Substructure *(Item 60)*	≥ 7	5 or 6	≤ 4
Culvert *(Item 62)*	≥ 7	5 or 6	≤ 4

Bridge Classification Example



NBI Item #	Component	Condition Rating
58	Deck	5
59	Superstructure	7
60	Substructure	7

Good and Poor % Calculation

- Determine structure length and width
- Calculate % good and poor as:

$$100 \times \frac{\sum_{g=1}^{GOOD} [\text{Length} \times \text{Width}]_{\text{Bridge g}}}{\sum_{s=1}^{TOTAL} [\text{Length} \times \text{Width}]_{\text{Bridge s}}}$$

$$100 \times \frac{\sum_{p=1}^{POOR} [\text{Length} \times \text{Width}]_{\text{Bridge p}}}{\sum_{s=1}^{TOTAL} [\text{Length} \times \text{Width}]_{\text{Bridge s}}}$$

Bridge Minimum Condition Level

- 23 USC 119 (implemented in 23 CFR 490)
- Maintain NHS bridges at less than 10.0% of deck area as structurally deficient
- If above 10.0% for a 3-year period
  - Penalty provision takes effect
  - Amount equal to 50% of a State's FY09 Highway Bridge Program apportionment is set aside and obligated
  - Remains in effect until structural deficiency drops to 10.0% or less

Minimum Condition Level of Bridges

- FHWA will use NBI data extracted on June 15
- To accommodate penalty data processing and administration of the penalty provision for the following fiscal year, NBI annual data submittal due date changed to March 15
  - New submittal date starts March 15, 2018

Definition of Structurally Deficient

	Until 12/31/17	After 12/31/17
Definition	• Any bridge component in Poor or worse condition or • Adequacy of waterway opening provided by the bridge is insufficient, causing overtopping with intolerable traffic interruptions	• Any component in Poor or worse condition • ***Waterway openings and structural evaluation removed***
Calculation (NBI Items)	• Items 58, 59, 60 or 62 ≤ 4 OR • Items 67 or 71 ≤ 2	• Items 58, 59, 60 or 62 ≤ 4 • ***Items 67 and 71 removed***

Calculation of % Structurally Deficient

- Determine structure length and width
- Calculate % structurally deficient as:

$$100 \times \frac{\sum_{SD=1}^{\text{Structurally Deficient}} [\text{Length} \times \text{Width}]_{\text{Bridge SD}}}{\sum_{s=1}^{\text{TOTAL}} [\text{Length} \times \text{Width}]_{\text{Bridge s}}}$$

Importance of Data Quality

Bridge performance analysis depends on:

- Complete data
- Quality data
- Timely NBI reporting

Importance of Data Quality

Factors influencing data quality include:

- Staff attrition/loss of institutional knowledge
- Field inspection resources & guidance
- Inspector/team experience/credentials
- Quality assurance/quality control (QA/QC) programs
- Information systems
  - Age & maintainability
  - Application coding errors
  - Transcription/data exchange errors
  - Documentation & training
  - Data administration standards & effectiveness

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Questions?

Setting Bridge Performance Targets

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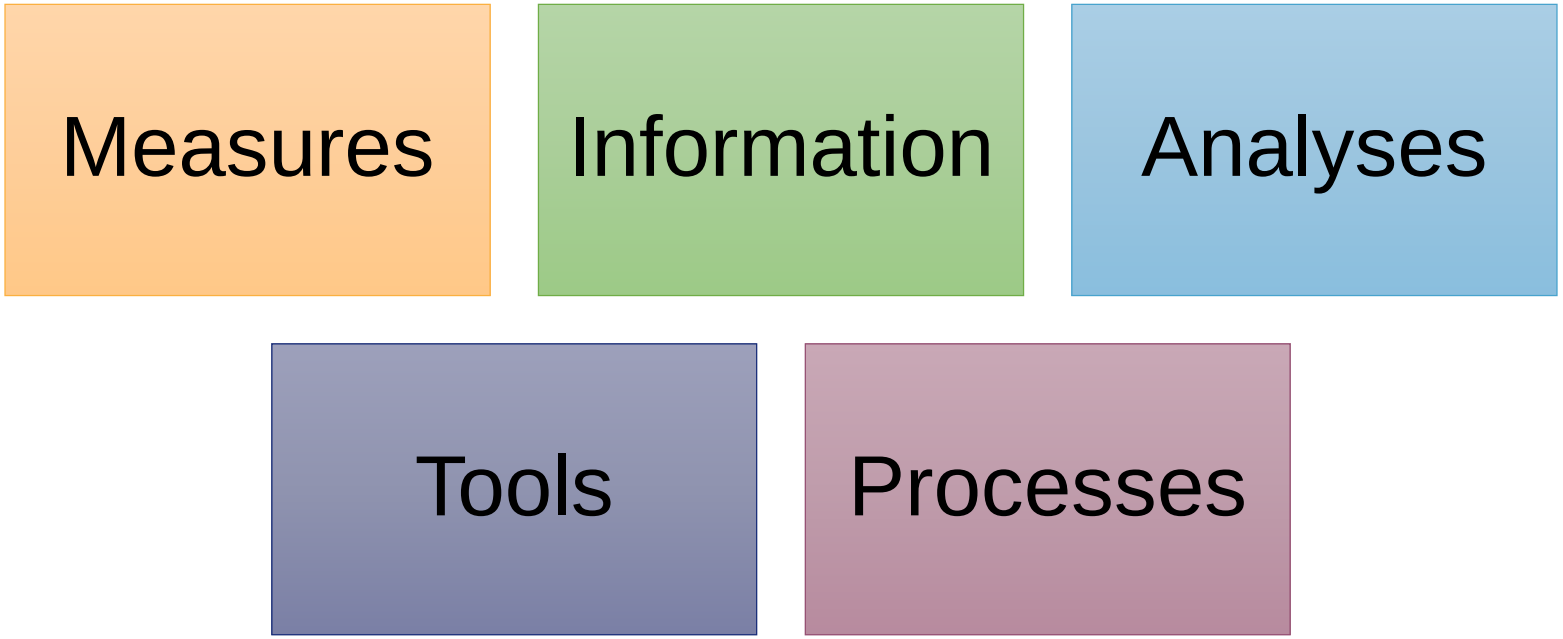
Performance Targets

- Quantifiable level of performance to be achieved within a time period required by FHWA
- Should be influenced by AMP analysis and investment strategy
- Process varies from State to State

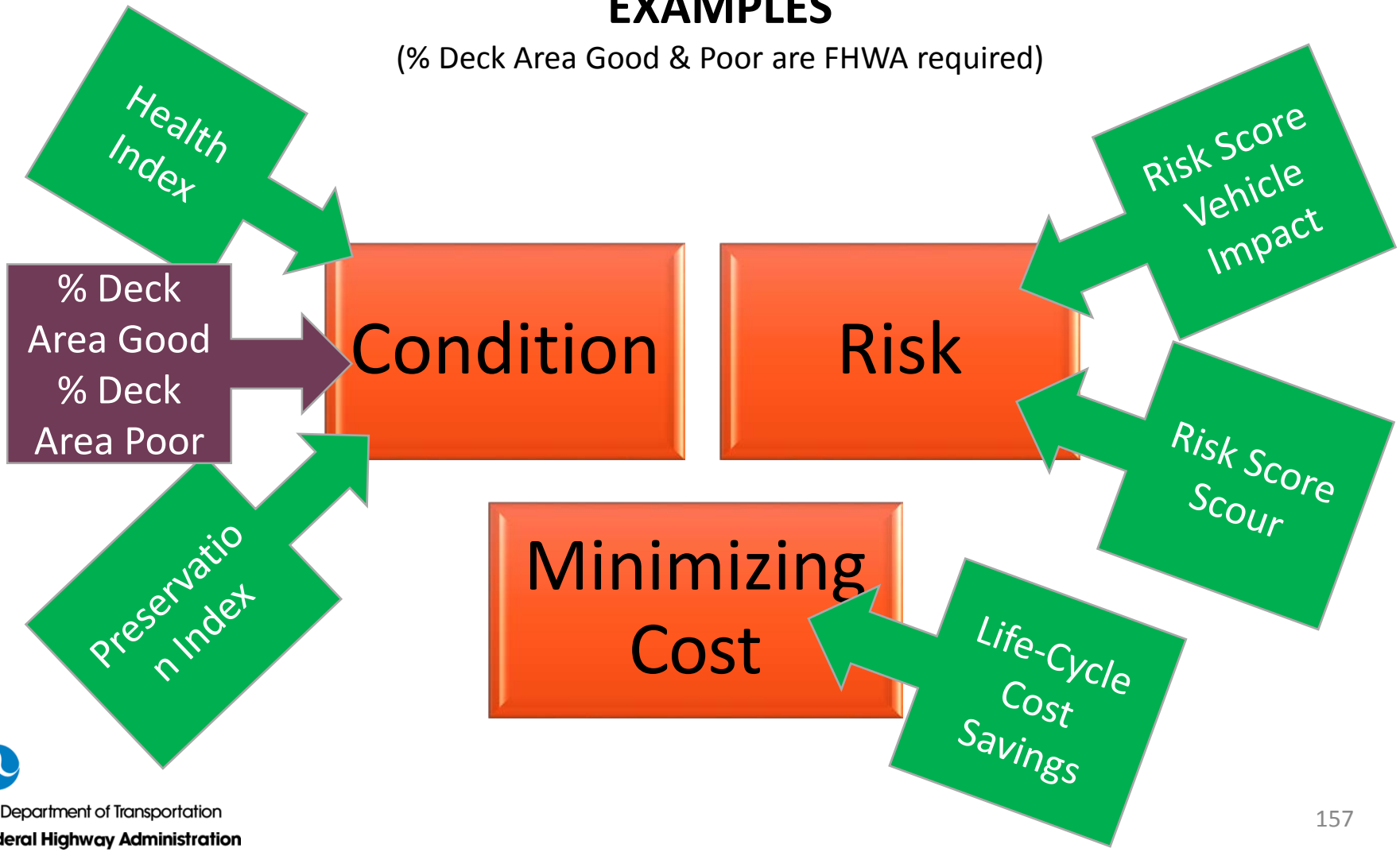
Performance Targets

- Target setting is iterative and continual
- Should include
  - Analysis of historical and current data to determine performance trends and gaps
  - Analysis of alternative funding levels and allocation strategies to compare differences in long-term outcomes

Target-Setting Ingredients



Measures


EXAMPLES
(% Deck Area Good & Poor are FHWA required)
Health Index
% Deck Area Good
% Deck Area Poor
Preservation Index
Condition
Risk
Risk Score Vehicle Impact
Risk Score Scour
Minimizing Cost
Life-Cycle Cost Savings

Information

- Key information and data are used to assess measures' current values, and forecast how they will change over time as a function of investment strategy. This may include
  - Inventory and condition data
  - Deterioration and performance forecasts
  - Bridge treatments
  - Different funding scenarios

Analysis

- Analyses should include
  - Condition and performance forecasting
  - Life-cycle planning
    - FHWA Life-Cycle Planning Guidance
    - FHWA Life-Cycle Cost Analysis Primer
    - Life-cycle cost components: agency, user, risk, uncertainty
  - Risk management analysis
  - Benefit-cost analysis
  - Objective: maximize benefits

Tools

- Every State is required to have a BMS [23 CFR 515.7(g)]
- BMS must include the procedures identified in the Minimum Standards for Developing and Operating Bridge and Pavement Management Systems [23 CFR 515.17]
- MPOs and other agencies may need to leverage State BMS resources or analyses

Business Processes

- Analysis should yield forecasted performance given a set of operating assumptions and an investment strategy
- Business processes that support target setting may include:
  - Strategic planning
  - Financial planning
  - Cross-asset resource allocation
  - Project programming and delivery

Investment Strategies & Target Selection

- Recommended approach: prioritize investments to maximize performance results
- Factors and objectives to consider
  - Condition
  - Life-cycle costs
  - Risk
  - Other agency objectives

Investment Strategies & Targets Selection

- Typically, the analysis and optimization process is iterative and performed for a set of scenarios with different budget assumptions or performance targets
- Result should be a model of predicted conditions and performance given an assumed investment strategy

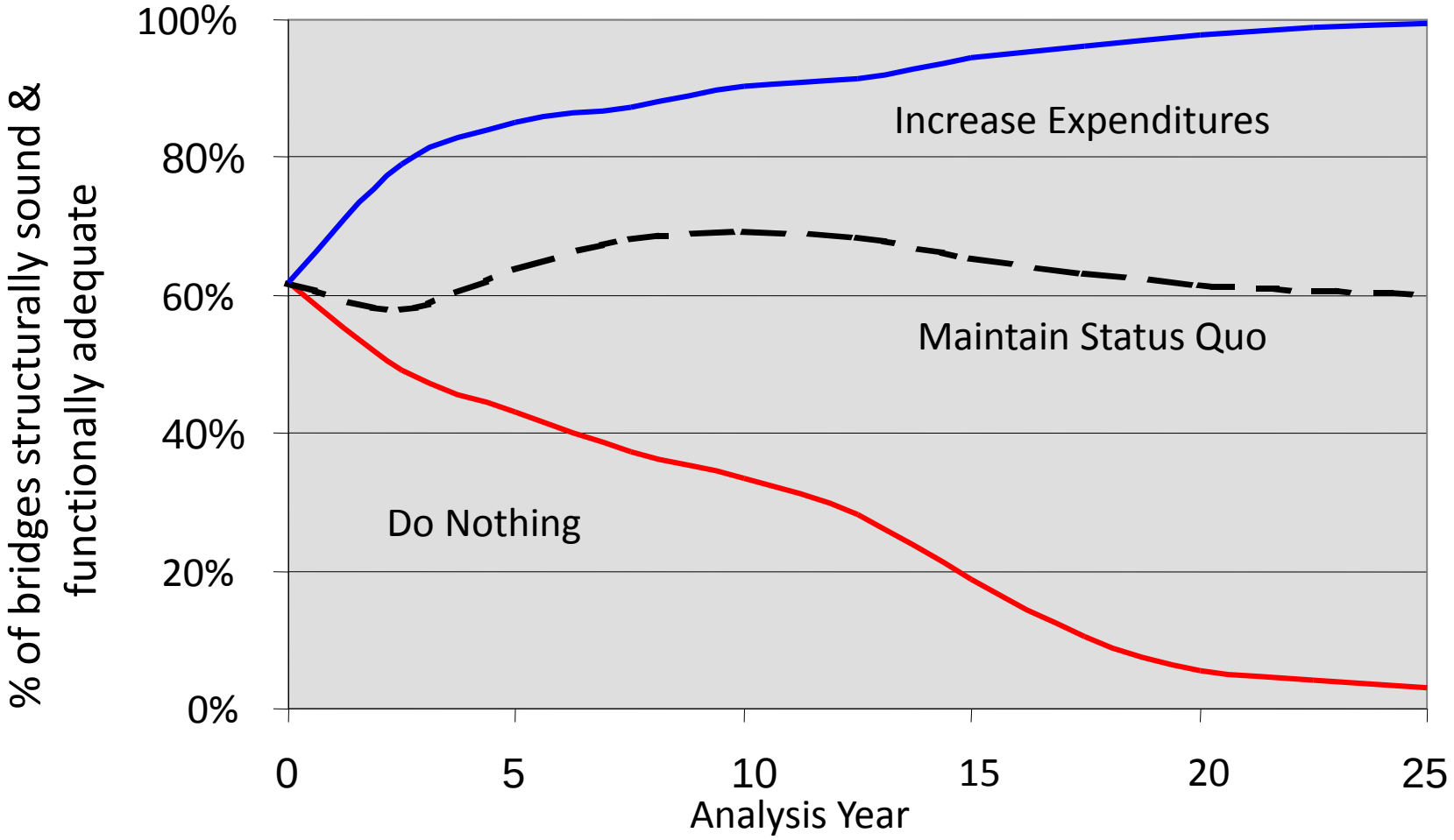
Investment Strategies & Targets Selection

- *"Worst first" approach* not recommended; does not achieve the asset management objective of achieving a state of good repair over the life cycle of assets at minimum practicable cost.
- Large % poor/SD bridges are lagging indicators of an ineffective strategy
  - The most effective strategies perform work to maintain good bridges in good condition

Investment Strategies & Targets Selection

- Asset management plans need to be integrated into the planning processes that lead to the STIP [23 CFR 515.9(h)]

Bridges in Good Condition Projection: Example



Reasons for Lags in Performance Improvement

- Difference in time between when money is allocated and when projects are completed
- Data collection cycle; may take one to several years to observe improved performance following project
- Preventive maintenance shows condition benefits years later
- Actual project costs tend to be higher than projected in current dollars due to delays coupled with construction inflation and project realities

Other Reasons Predicted and Actual Performance May Differ

Expenditures Differ from Projections

Cost Escalation

Agency Behavior Different from Model

Change in Priorities

Different Deterioration Patterns

Changes in Efficiency/Technology

Unplanned Events

Sharknados

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HOW WE GET THERE

Questions?

Performance Reporting

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Uses of Performance Reporting

- Report baseline condition and identify targets
- Determine significant progress or target achievement
- Report to the public on condition and target achievement
- Report to Congress on the condition and performance of the Federal-aid highway system

State Target Setting and Reporting

- State DOTs must set targets for measures
- Different reports required over a four-year performance period
- State Biennial Performance Reports ("150(e) Report"):
  - Baseline Performance Report
  - Mid Performance Period Progress Report
  - Full Performance Period Progress Report

MPO Target Setting & Reporting

- MPOs can choose to set quantifiable targets or support State targets
- If a State changes its four-year target, and an MPO originally chose to support the State's target, an MPO has 180 days to:
  - Agree to plan a program of projects to contribute to the adjusted State target or
  - Commit to a new, quantifiable MPO target
- MPO shall report baseline conditions and progress toward achieving targets in their metropolitan transportation plan

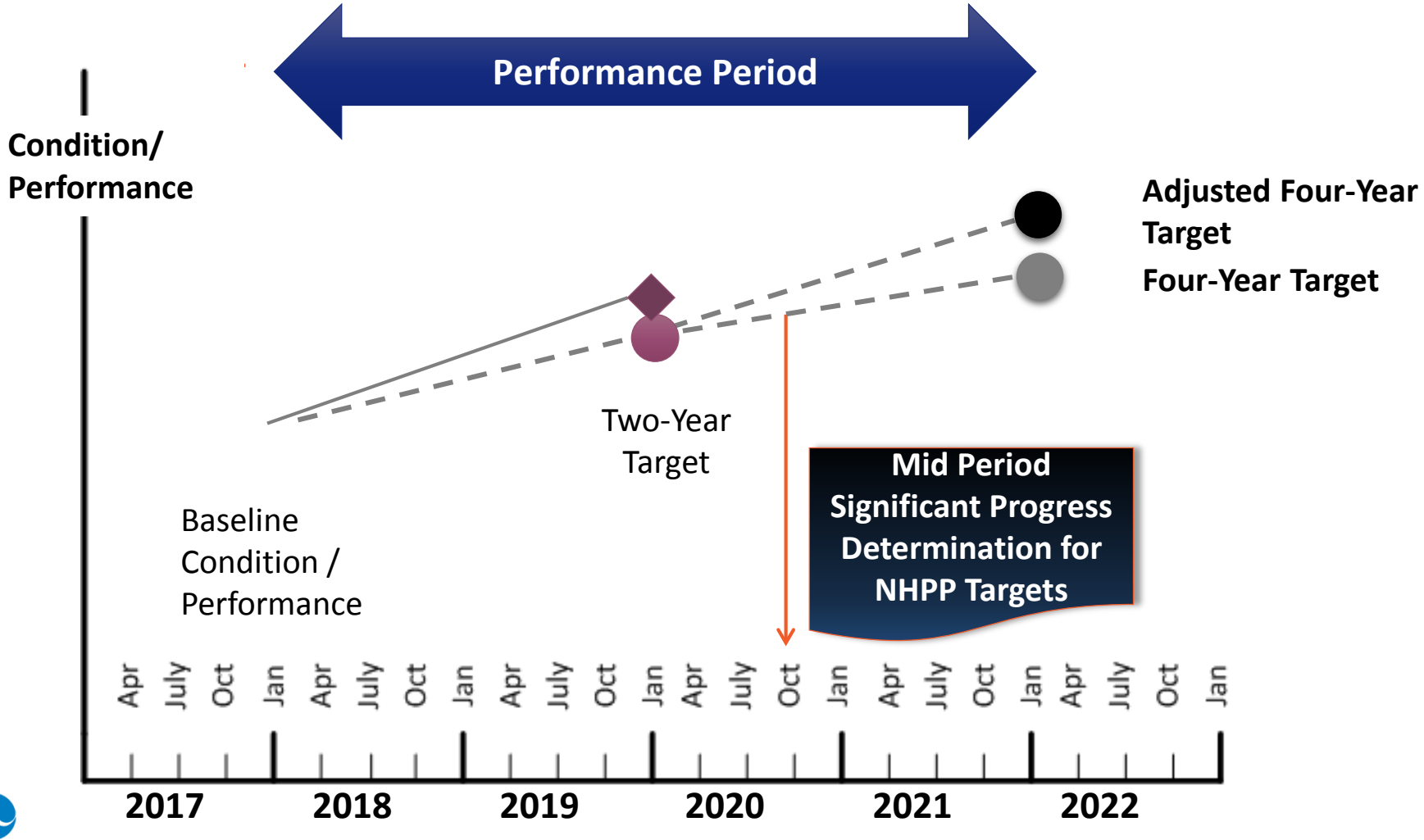
What Do You Have to Report?

Bridge Condition Measures	
Performance Target	**NHS Condition**
Two-year	% Good by deck area
	% Poor by deck area
Four-year	% Good by deck area
	% Poor by deck area

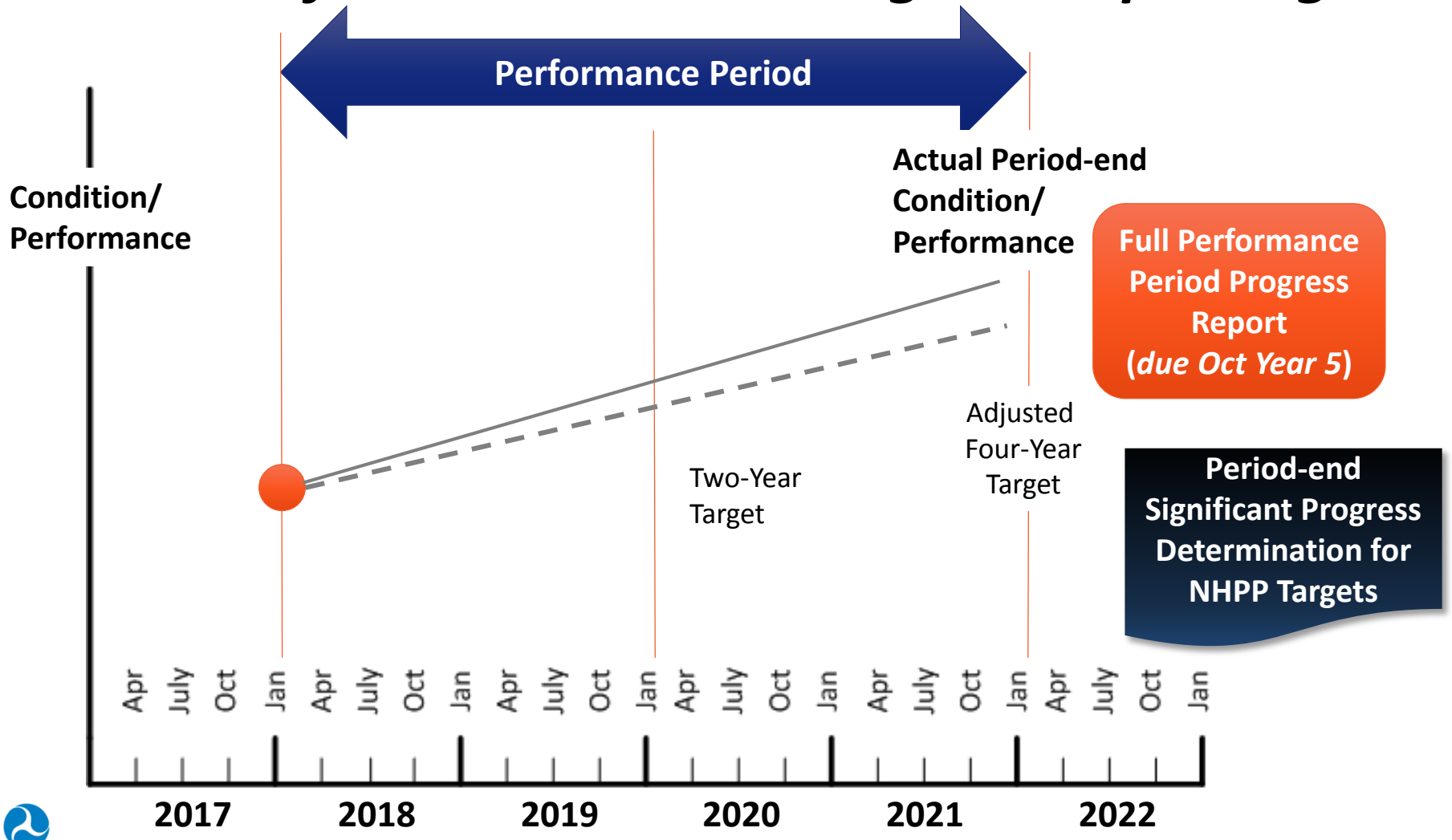
Baseline Performance Report

- Contents related to Bridge performance include:
  - Baseline conditions as of January 1 of the report year
  - 2-year and 4-year targets
  - Basis for targets
  - Relationship of targets to State's long-range plan, State's asset management plan (AMP), other plans
- Initial report due Oct. 1, 2018
- Subsequent reports due every four years

Mid Performance Period Progress Reporting



Full Performance Period Progress Reporting



Assessing Significant Progress Toward Achieving the Performance Targets

Who	• FHWA determines if a State DOT has made significant progress
What	• Make determination for each applicable target
When	• Assess significant progress biennially

Knowledge Checks

The FHWA bridge classification for performance measure calculation is based on (choose all that apply):

a) lowest condition rating of bridge elements
b) structural deficiency status
c) deck area that is structurally deficient
d) lowest condition rating of bridge components

Knowledge Checks

State DOT statewide 2- and 4-year targets for FHWA measures should be selected considering (choose all that apply):

a) outcomes of alternative asset management plan investment strategies
b) effects of data lag
c) neighboring state targets
d) MPO targets

Contacts

For questions or more information, please contact:

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Questions?

U.S. Department of Transportation
Federal Highway Administration

TPM
HOW WE GET THERE