2016 TRB Webinar

Using Asset Valuation as a Basis for Bridge Maintenance and Replacement Decisions

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Presentation Outline

1. **Calculate the current value and condition of bridges in an inventory**
   - **Modified Health Index (MHI)**
   - **Element Condition Data**

2. **Using current valuation (equity) as the basis for engineering decisions on maintenance/replacement**
   - **Action-effectiveness models and associated cost estimates to develop comparative cost/benefit ratios**
   - **Long-term predictions of asset values for various alternatives to perform life cycle analysis using estimates**

3. **Using Modified Health Index and other indices to select bridge projects with a Multi-Objective Prioritization Formula**

Modified Health Index (MHI)

Using detailed information about bridge conditions from element level data, cost data to develop

- **Publicly-owned assets have value but no revenue in most cases**
- **How do we measure current value (depreciation)**
- **Thinking like a business**

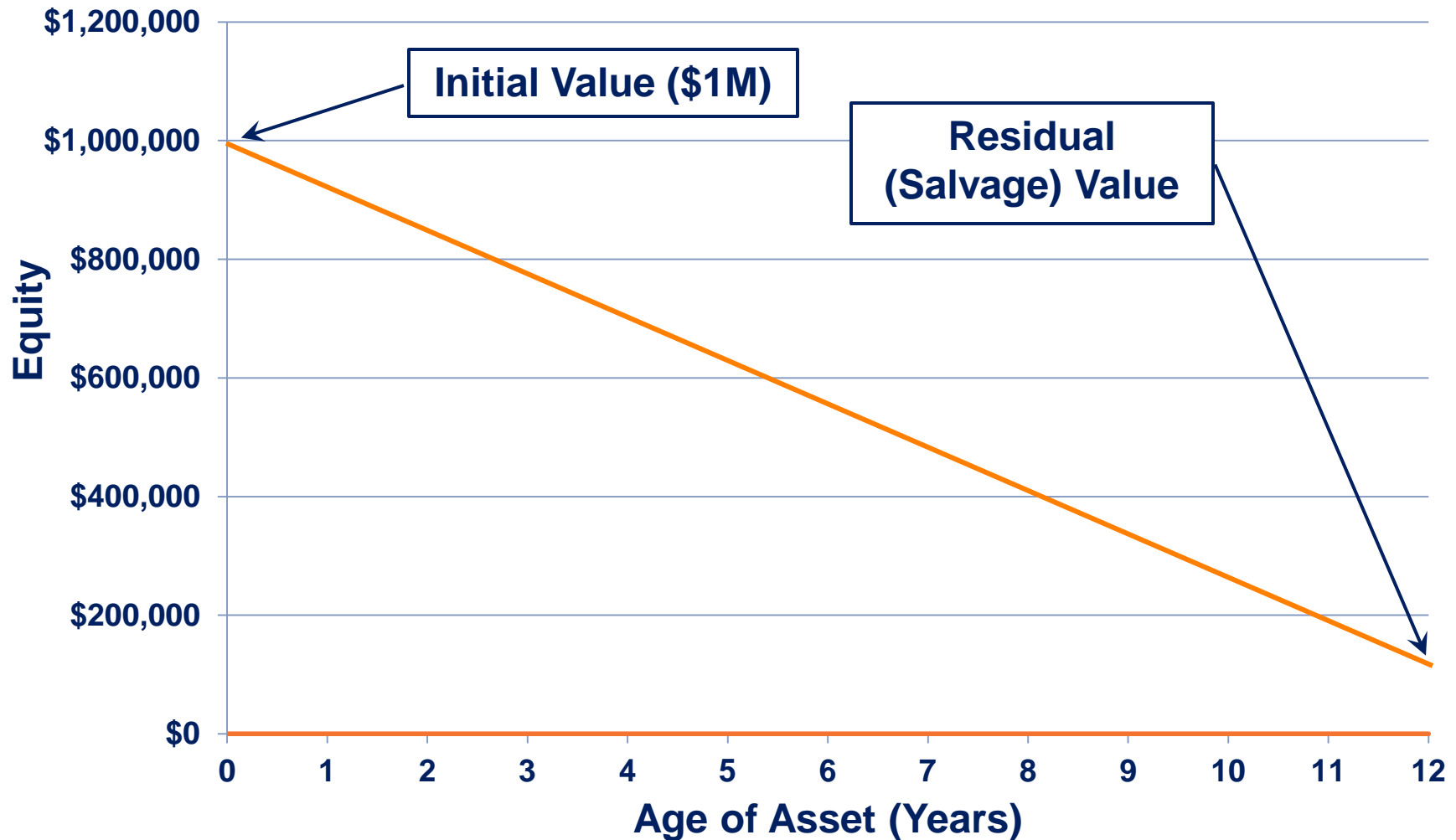## *WWUPSD?*
(What Would UPS Do?)

Current Valuation (Equity) – Multiple Uses

Equity can be a powerful tool in guiding bridge management

- **Can determine the most cost-effective actions on a given structure**
- **Helpful in selecting which structures should be worked on**
- **Can be used to measure effectiveness of various work programs**
- **Helpful as a measurement of progress**

Measuring Equity – Common Practice (IRS): Time Based Depreciation

Typical Straight-Line Depreciation Curve

Initial Value ($1M)

Residual (Salvage) Value

Equity (y-axis): $0 to $1,200,000

Age of Asset (Years) (x-axis): 0 to 12

Modified Health Index: Basic Equation

If a structure has the following characteristics:

- **0 to 100 scale**
- **0 means end of service life**
- **100 for a new (ideal) structure**
- **Example: If a structure has deteriorated 32%, the MHI = 68 (100 - 32)**

$$MHI = \frac{\Sigma\ (MHI_{Element}\ *Replacement\ Value_{Element})}{\Sigma\ Replacement\ Value_{Elements}}$$

If Σ Superstructure Value = 0, then deck = 0

If Σ Substructure Value = 0, then deck and superstructure = 0

Element Data Collected During Inspections AASHTO National Bridge Elements (NBE)
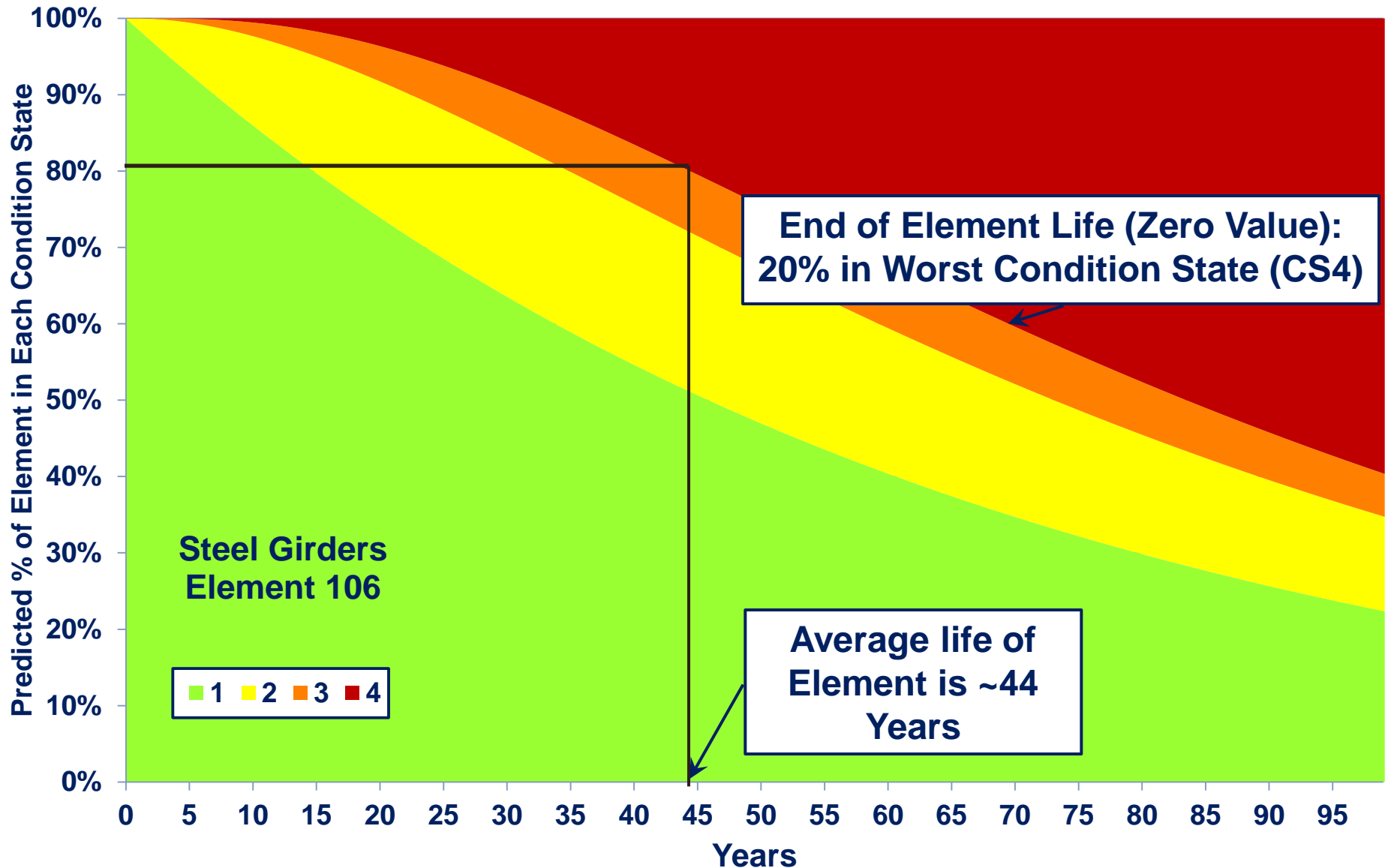
Table 1. Bridge Elements.

Element	Units	Element Number					
		Steel	Prestressed Concrete	Reinforced Concrete	Timber	Masonry	Other
Deck/Slab							
Deck	SF		13	12	31		60
Open Grid Deck	SF	28					
Concrete Filled Grid Deck	SF	29					
Corrugated or Orthotropic Deck	SF	30					
Slab	SF			38	54		65
Top Flange	SF		15	16			
Superstructure							
Closed Web/Box Girder	LF	102	104	105			106
Girder/Beam	LF	107	109	110	111		112
Stringer	LF	113	115	116	117		118
Truss	LF	120			135		136
Arch	LF	141	143	144	146	145	142
Main Cable	LF	147					
Secondary Cable	EA	148					149
Floor Beam	LF	152	154	155	156		157
Pin, Pin and Hanger Assembly	EA	161					
Gusset Plate	EA	162					
Substructure							
Column	EA	202	204	205	206		203
Column Tower (Trestle)	LF	207			208		
Pier Wall	LF			210	212	213	211
Abutment	LF	219		215	216	217	218
Pile Cap/Footing	LF			220			
Pile	EA	225	226	227	228		229
Pier Cap	LF	231	233	234	235		236
Culvert							
Culvert	LF	240	245	241	242	244	243
Bridge Rail							
Bridge Rail	LF	330*		331	332	334	333
Joint							
Strip Seal	LF	300					
Pourable	LF	301					
Compression	LF	302					
Assembly with Seal (Modular)	LF	303					
Open	LF	304					
Assembly without Seal	LF	305					
Other	LF	306					
Bearing							
Elastomeric	EA	310					
Movable (roller, sliding, etc.)	EA	311					
Enclosed/Concealed	EA	312					
Fixed	EA	313					
Pot	EA	314					
Disk	EA	315					
Other	EA	316					

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Additional VDOT Elements

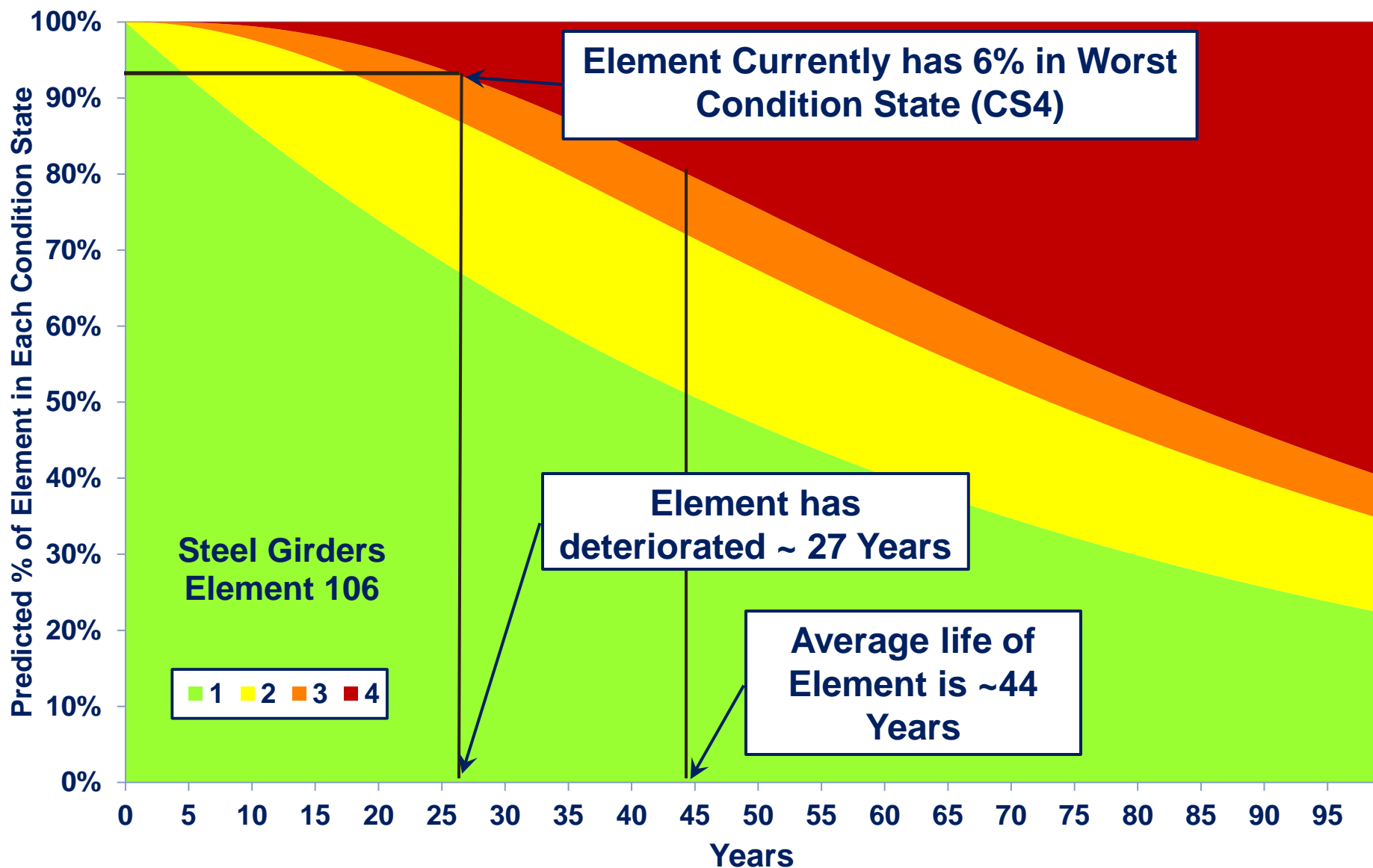| Component	Number	Title
Deck	801	Sidewalk
	802	Deck Drains
Superstructure	811	Beam/Girder End
	812	Reinforced Concrete Frame
Substructure	821	Steel Abutment
	822	Steel Wingwall
	823	Reinf.\ Concrete Abutment
	824	Reinf.\ Concrete Wingwall
	825	Timber Abutment
	826	Timber Wingwall
	827	Masonry Abutment
	828	Masonry Wingwall
	829	MSE Abutments
	830	MSE Wingwall
Culverts	831	Concrete Culvert Endwall/Headwall
	832	Concrete Cuvlert Wingwall
	833	Roadway Over Culvert
Joints	841	Asphalt Plug Joint
	842	Elastomeric Concrete Plug Joint
	843	Link Slab
	844	Slab Extension
	845	Joint Effectiveness
Slopes & Channels	851	Unprotected Slope
	852	Protected Slope - Paved
	853	Protected Slope - Riprap
	854	Channel
Protective	881	Wearing Surface - Unprotected Asphalt Wearing Surface
	882	Wearing Surface - Protected Asphalt Wearing Surface
	883	Wearing Surface - Thin Overlay
	884	Wearing surface - Rigid Overlay
	885	Wearing Surface - Other

Using Deterioration Models to Determine Current Value:
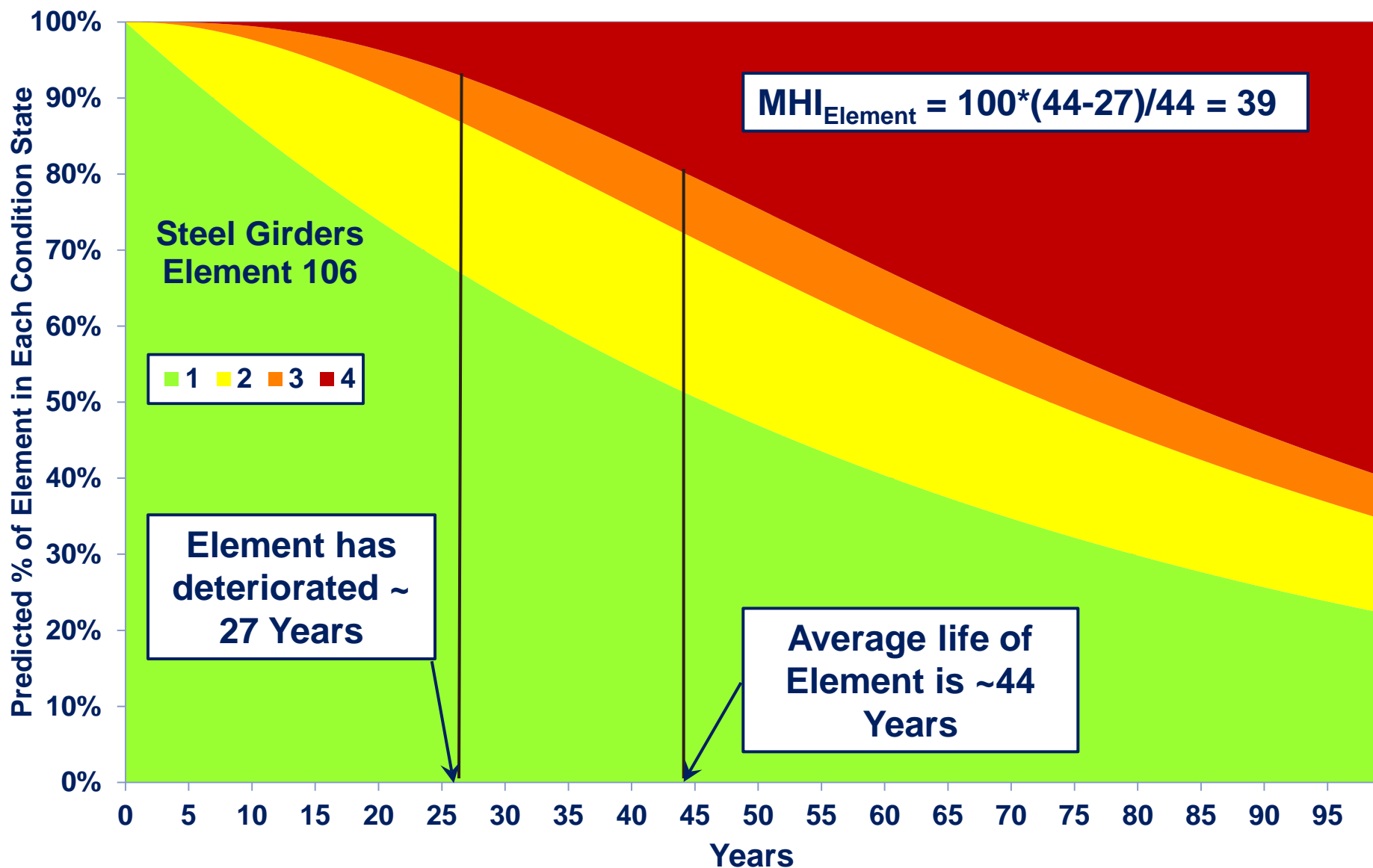## Step 1: Define End of Life of Elements in Terms of Condition States

End of Element Life (Zero Value): 20% in Worst Condition State (CS4)

Steel Girders Element 106

Average life of Element is ~44 Years

Legend: 1 2 3 4

Predicted % of Element in Each Condition State

Years

Using Deterioration Models to Determine Current Value:
Step 2: Determine Current Value in Terms of Current Condition

Predicted % of Element in Each Condition State

Element Currently has 6% in Worst Condition State (CS4)

Steel Girders Element 106

Legend: 1 (green) 2 (yellow) 3 (orange) 4 (red)

Element has deteriorated ~ 27 Years

Average life of Element is ~44 Years

Years

Using Deterioration Models to Determine Current Value:
Step 3: Determine MHI for Each Element

$$MHI_{Element} = 100*(44-27)/44 = 39$$

Steel Girders
Element 106

Legend: 1 (green), 2 (yellow), 3 (orange), 4 (red)

Element has deteriorated ~ 27 Years

Average life of Element is ~44 Years

Y-axis: Predicted % of Element in Each Condition State

X-axis: Years

Determination of Current Valuation (Equity): Example Equation

Equity = MHI * Structure Replacement Cost

Example Structure:

MHI = 39

Replacement Value = $2,000,000

Equity = .39 * 2,000,000 = $780,000

Modified Health Index and Current Valuation: Example Calculation #1

Element Name	MHI$_{Element}$		Element Replacement Value		MHI * Replacement Value
Columns	63	x	$25,000	=	$15,750
Pier Caps	54	x	$30,000	=	$16,200
Abutments	75	x	$60,000	=	$45,000
Girders	83	x	$160,000	=	$132,800
Diahragms	86	x	$30,000	=	$25,800
Deck	92	x	$180,000	=	$165,600
Joints	65	x	$30,000	=	$19,500
Parapet	92	x	$40,000	=	$36,800
Sum	**82**		**$555,000**		**$457,450**

MHI = ($457,450 ÷ $555,000)100 = 82

Modified Health Index and Current Valuation: Example Calculation #2

Element Name	MHI$_{Element}$		Element Replacement Value		MHI * Replacement Value
Columns	63	x	$25,000	=	$15,750
Pier Caps	54	x	$30,000	=	$16,200
Abutments	75	x	$60,000	=	$45,000
Girders	83	x	$160,000	=	$132,800
Diahragms	86	x	$30,000	=	$25,800
Deck	0	x	$180,000	=	$0
Joints	0	x	$30,000	=	$0
Parapet	0	x	$40,000	=	$0
Sum	**42**		**$555,000**		**$235,550**

Note: Replacement Cost of Bridge < ΣElement Replacement Values

$$MHI = (\$235{,}550 \div \$555{,}000)100 = 42$$

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Using Current Valuation to Evaluate Performance of an Entire Inventory of Structures

District	Available Funds (Millions)			Aggregate Valuation of Structures (Billions)			Average MHI		
	Mainte-nance	Construction	Total	Start of year	End of year	Difference (Millions)	Start of year	End of year	Difference
A	$19.1	$12.5	$31.6	$5.23	$5.21	-$23	67.1	66.8	0.3
B	$23.1	$15.5	$38.6	$7.22	$7.21	-$10	71.5	71.4	0.1
C	$20.4	$14.0	$34.4	$6.05	$5.76	-$293	70.2	66.8	3.4
Total	$62.6	$42.0	$104.6	$18.5	$18.17	-$327	69.6	68.3	1.3

MHI is used as both a condition index and a measurement of current value

Using current valuation (equity) as the basis for engineering decisions on maintenance/replacement

Measuring Equity Benefits for Various Alternatives

Immediate Benefit = Increase in Valuation due to Interventions

Example:

For a structure with MHI = 32 and a replacement cost of $2,600,000

1. **Repair Option 1 will increase MHI to 92 for a cost of $600,000**
   - **Benefit = (92 − 32)*$2,600,000 = $1,560,000**
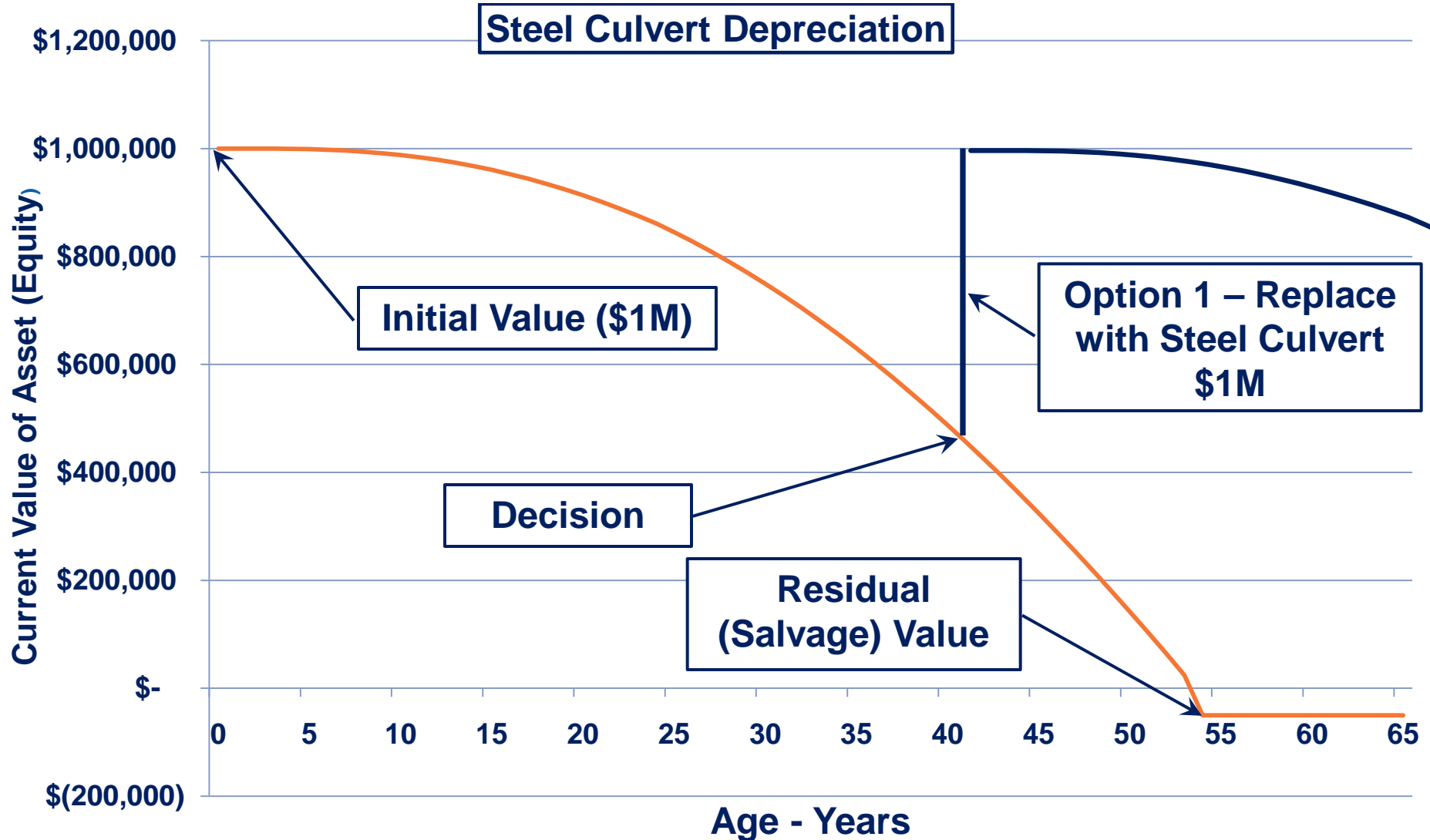   - **Benefit/Cost = $1,560,000/ $600,000 = 2.6**

2. **Repair Option 2 will increase MHI to 74 for a cost of $350,000**
   - **Benefit = (74 − 32)*$2,600,000 = $1,092,000**
   - **Benefit/Cost = $1,092,000/ $350,000 = 3.12**
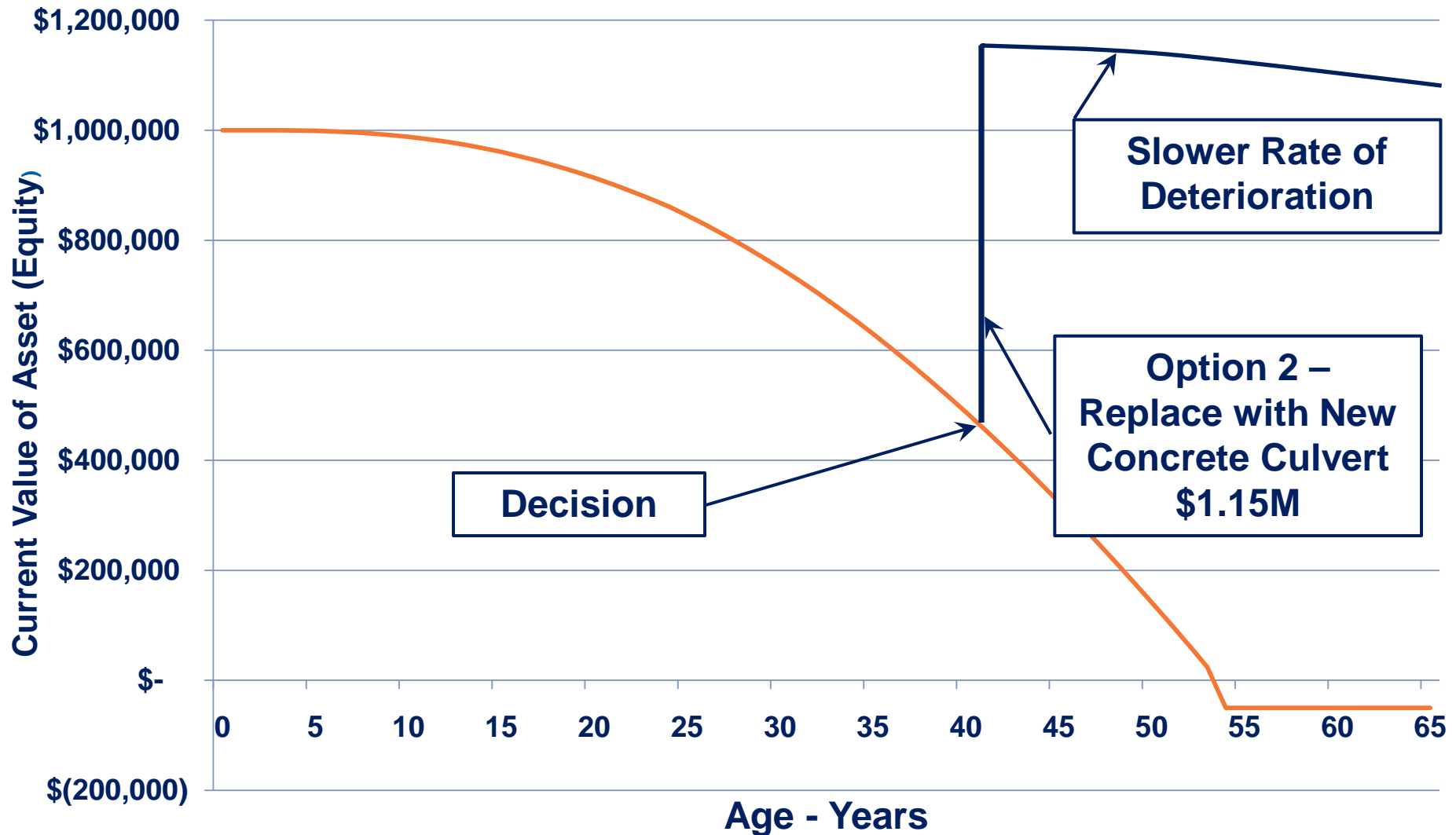
3. **Replace Option will increase MHI to 1.00 for a cost of $2,600,000**
   - **Benefit = (100 − 32)*$2,600,000 = $1,768,000**
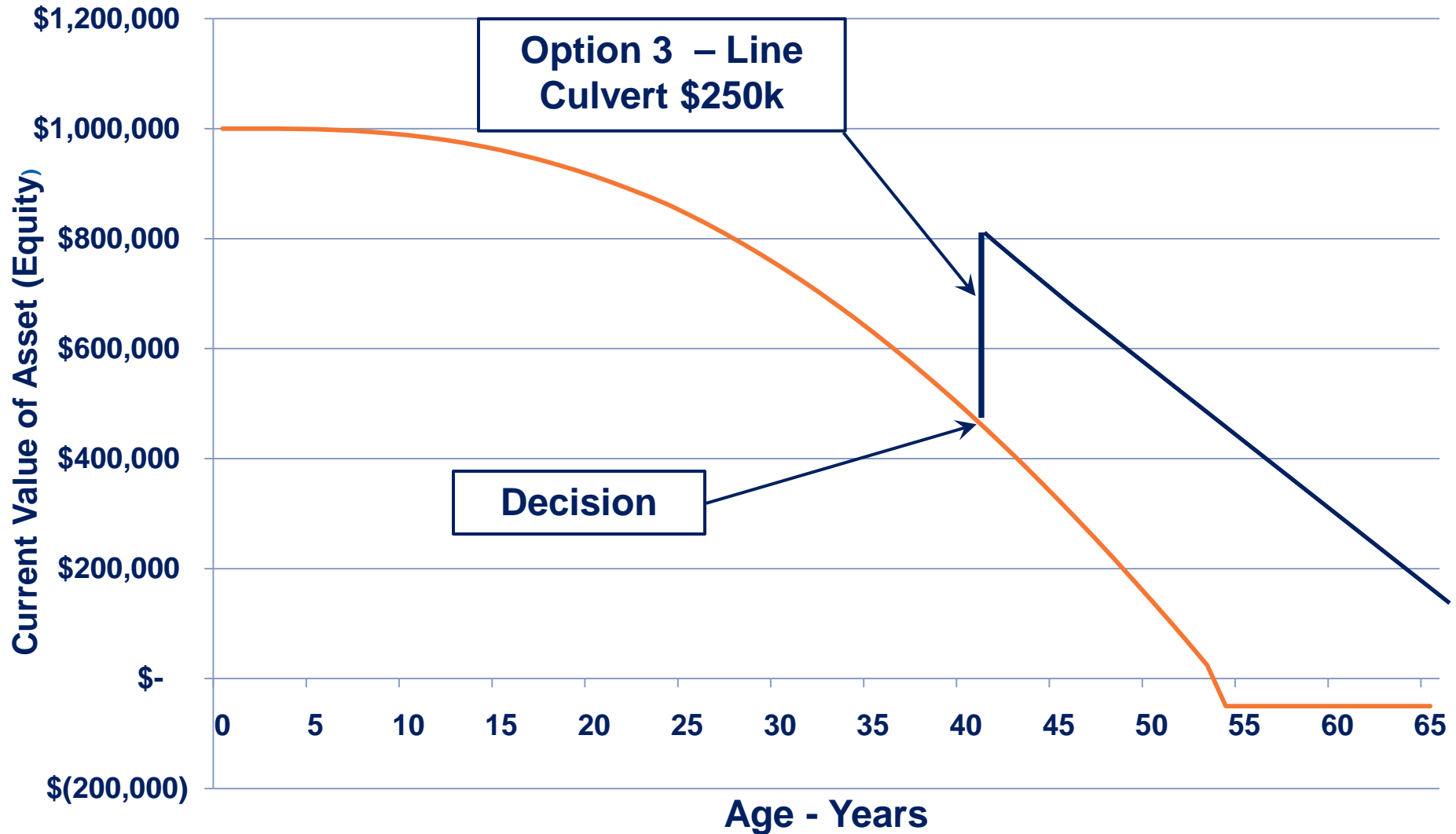   - **Benefit/Cost = $1,768,000/$2,600,000 = .68**

The Benefits of Using Equity as the Basis for Engineering Decisions

Steel Culvert Depreciation

Initial Value ($1M)

Option 1 – Replace with Steel Culvert $1M

Decision

Residual (Salvage) Value

Current Value of Asset (Equity)

Age - Years

The Benefits of Using Equity as the Basis for Engineering Decisions

Current Value of Asset (Equity) vs. Age - Years

- **Slower Rate of Deterioration**
- **Decision**
- **Option 2 – Replace with New Concrete Culvert $1.15M**

Y-axis: $(200,000), $-, $200,000, $400,000, $600,000, $800,000, $1,000,000, $1,200,000

X-axis: 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65

The Benefits of Using Equity as the Basis for Engineering Decisions

With Equity Curves Simple Life Cycle Analysis is Practical

	Name	Initial Costs				Estimated Maintenance Costs Per 10 Year Interval	Replace ment Year	Present Value (calculated)
		Initial Construction	Traffic Control	Engineering, Inspection, R/W	Total Initial Cost			
Option 1	Coated Steel	$748,400	$64,500	$187,100	$1,000,000	$4,000	53	-$1,131,192
Option 2	Precast Concrete	$850,240	$87,200	$212,560	$1,150,000	$6,000	110	-$893,554
Option 3	Steel Liner	$190,000	$12,500	$47,500	$250,000	$4,000	30	-$1,380,666

Discount Rate	**1.50%**

Suggested PE, CEI, R/W Factor	**0.25**

Steel Liner Option Assumes New Steel Culvert Required in 25 Years

Similar Effort was Recently Performed on Hampton Roads Bridge Tunnel Approaches using Life Cycle Principles

Structure (Fed ID#)	Current Status			Rehabilitate (Work in 2018)				Replace (Work in 2038)		
	Age	MHI	Current Equity (A)	Cost	2018 Post-Repair Value (B)	2048 MHI	2048 Value (C)	2038 Cost = Post-Construct. Value (B)	2048 MHI	2048 Value (C)
20339	41	.67	$48.1	$7.47	$67.5	.62	$41.6	$71.8	.88	$63.2
20355	41	.63	$83.2	$17.95	$124.1	.62	$76.6	$132.0	.88	$116.3
20352	58	.54	$77.3	$6.24	$134.6	.63	$84.6	$143.2	.88	$126.2
20353	58	.68	$51.4	$4.32	$71.1	.63	$44.6	$75.6	.88	$66.6
20913	43	.64	$71.1	$6.44	$104.4	.62	$64.4	$111.1	.88	$97.9
20914	43	.61	$67.8	$6.44	$104.4	.62	$64.4	$111.1	.88	$97.9
Σ or Avg.	**47.3**	**.63**	**$398.9**	**$48.9**	**$606.1**	.62	**$376.1**	**$644.8**	**.88**	**$568.1**

Present Value Calculation with 20 Year Horizon

Present Value Comparison - Replace vs. Repair 6 HRBT Approach Bridges - All Values in Millions of 2015 (uninflated) dollars												
Option	Initial Costs	Estimated Annual Maintenance Costs			Equity								Present Value calculated
		2019 - 2028	2029 - 2038	2039 - 2048	Current Value (2016) MHI = .63	Post Repair 2018	Predicted Values			Lost or Gained Equity per interval			
	Project Cost						2028	2038 (pre-Const-ruction)	2048	2019 - 2028	2029 - 2038	2039 - 2048	
Repair 2016	-$49	-$0.4	-$0.6	-$0.8	$399	$606	$561	$516	$376	-$45	-$45	-$140	$ (293)
Replace '36-'38	-$645	-$1.1	-$1.9	-$2.4	$399	$395	$360	$322	$568	-$39	-$38	$174	$ (596)

Replace or repair all structures. Maintenance costs are applied at year 5 in each interval. All values are expenditures. There are no revenues associated with either option.

Lost equity is applied at the end of each 10 year interval

Comparison is based solely on value of structures and maintenance needs associated with each option. User costs & other factors not included

Discount Rate	7.00%

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Using MHI and Other Indices to Select Bridge Projects with a Multi-Objective Prioritization Formula

Multi-Objective Prioritization Formula
Selection of Structures for Intervention

Priority = a(IF) + b(CF) + c(RF) + d(SCF) + e(CEF)

All five unitless variables have a 0 to 1.0 scale

- *IF = Importance Factor*

    measures the relative importance of each bridge to the overall highway network

- *CF = Condition Factor*

    measures the overall physical condition of each bridge based on the condition of each individual element

- *RF = Risk Factor*

    measures four important risk factors: Redundancy, Scour Susceptibility, Fatigue, and Earthquake vulnerability

- *SCF = Structure Capacity Factor*

    measures the capacity of the structure to convey traffic, including the effects of weight restrictions, waterway adequacy, vertical clearance and deck width

- *CEF = Cost-Effectiveness Factor*

    measures the cost-effectiveness of the required work

- **a, b, c, d, e are coefficients that may be selected to suit the particular evaluation being performed**
- **a + b + c + d + e = 1.0**

Multi-Objective Prioritization Formula
Selection of Structures for Intervention

By separating the five variables users can readily understand why one project has a higher priority than another

Coefficients can be selected to align with the programmatic goals of the agency

Coefficients currently envisioned for VDOT's Bridge Construction Program:

a = 0.30 (Importance)
b = 0.25 (Condition)
c = 0.15 (Risk)
d = 0.10 (Structure Capacity)
e = 0.20 (Cost-Effectiveness)

Importance Factor

IF = Importance Factor.

Measures relative importance of the structure to the roadway network

Uses these variables:
- **Traffic (ADT/Lane)**
- **Truck traffic (ADTT/Lane)**
- **Predicted future ADT growth**
- **Proximity to schools, hospitals and emergency facilities**
- **Detour vs. traffic**
- **Functional class of roadway**

Condition Factor (CF)

Condition is measured using the Modified Health Index (MHI)

CF = 1.0 – (Modified Health Index/100)

- **MHI is a 0 to 100 measurement of condition**
- **MHI value of 100 represents a bridge without defects**
- **MHI value of zero represents a bridge that has reached the end of its service life**
- **MHI provides an overall condition measurement by weighting each element's condition as a proportion of its relative value to the whole bridge**
- **MHI is calculated using element-level data provided during bridge safety inspections, along with element replacement costs**

Risk Factor

RF = Risk Factor

measures the risk to structures, with an emphasis on redundancy

RF = Part A + Part B ≤ 1.0

Part A:

= 0.75 if one of Scour Critical or Fracture Critical exists

= 0.90 if both of Scour Critical and Fracture Critical exists

Part B:

= 0.10 if one of Seismic Critical or Fatigue Prone Details exists

= 0.20 if both of Seismic Critical and Fatigue Prone Details exists

Structure Capacity Factor

SCF = Structure Capacity Factor

measures the load and geometric capacity of the structure to convey traffic, including the effects of weight restrictions, waterway adequacy, vertical clearance and deck width

SCF = .40(Weight Reduction Factor) + .30(Waterway/Vertical Clearance Factor) + .30(Deck Width Factor)

- **Weight Reduction Factor (WRF) = 0 to 1.0 score measuring ability of structure to carry Fire Trucks, Ambulances, School Buses and Design Vehicles**
- **Waterway/Vertical Clearance Factor = 0 to 1.0 score measuring the adequacy of vertical clearance for waterways, railways and trucks**
- **Deck Width Factor = 0 to 1.0 score measuring adequacy of deck width vs. need**

The Weight Reduction Factor is the subject of a forthcoming paper that will be published through the Virginia Transportation Research Council.

Cost-Effectiveness Factor

CEF = Cost-Effectiveness Factor

measures the cost-effectiveness of the required work

CEF = -2(RC/SRC) +1.3   **Max 1.00, Min 0.00**

- **RC = Repair Cost: Initial Prioritization uses Bridge Management System Recommendations. Final Scoring uses refined scope and estimate after pre-scoping phase**

- **SRC = Structure Replacement Cost: Based on statewide replacement cost averages with escalation factors for preliminary engineering, right of way, growth, and construction inspection. Final Scoring may be adjusted using more in-depth cost estimates during pre-scoping phase**
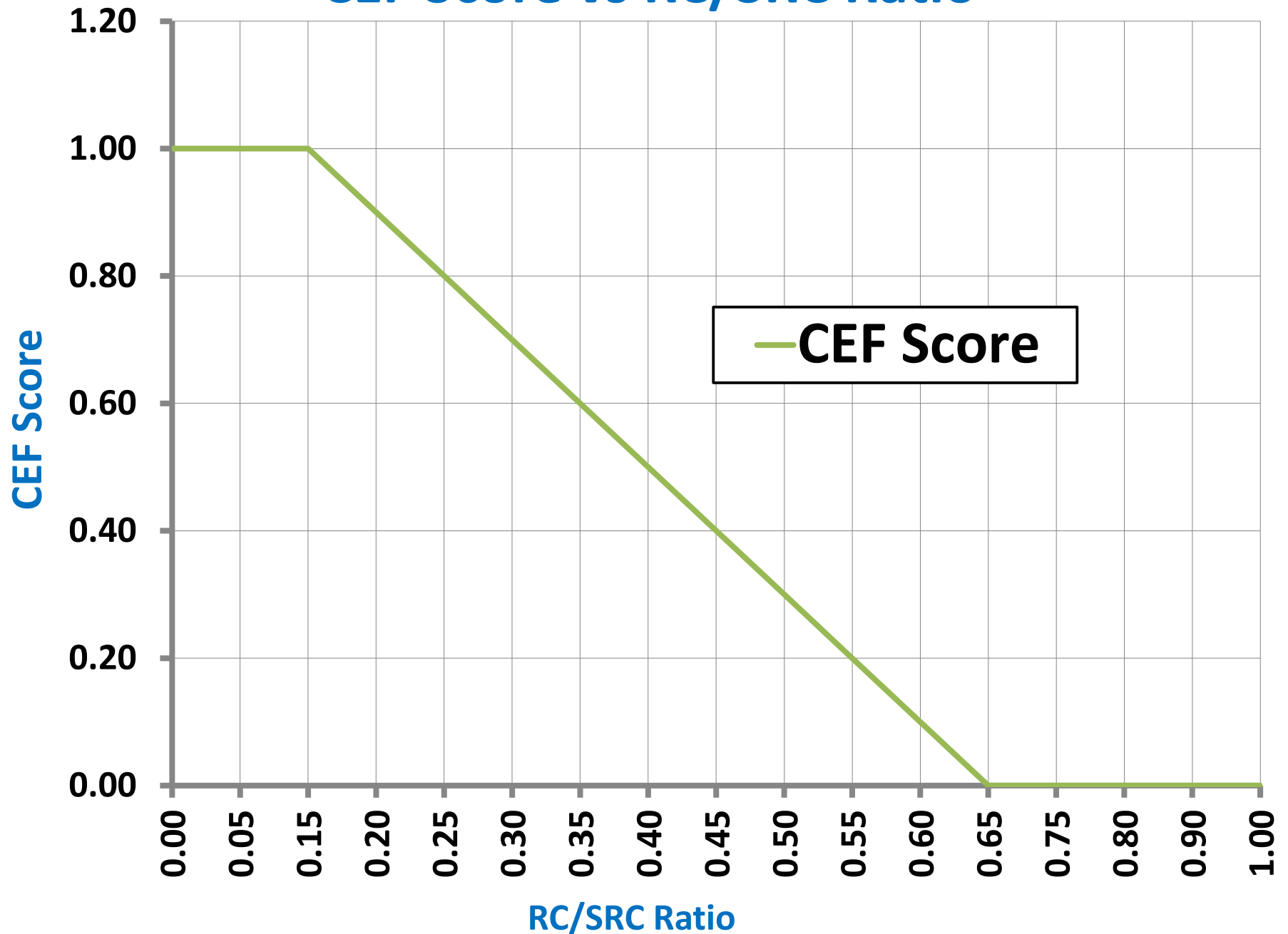
Note:

CEF = 1.00 for ratios of RC/SRC ≤ 0.15

CEF = 0.00 for ratios of RC/SRC ≥ 0.65

CEF varies linearly from 1.00 to 0.00 as ratio of RC/SRC varies from 0.15 to 0.65

Examples of CEF Calculations

Repair Cost (RC)	Structure Replacement Cost (SRC)	Ratio (RC/SRC)	CEF Score
$ 50,000	$ 1,000,000	0.05	1.00
$ 150,000	$ 1,000,000	0.15	1.00
$ 250,000	$ 1,000,000	0.25	0.80
$ 350,000	$ 1,000,000	0.35	0.60
$ 367,523	$ 1,000,000	0.37	0.56
$ 450,000	$ 1,000,000	0.45	0.40
$ 550,000	$ 1,000,000	0.55	0.20
$ 650,000	$ 1,000,000	0.65	0.00
$ 750,000	$ 1,000,000	0.75	0.00
$ 850,000	$ 1,000,000	0.85	0.00
$ 950,000	$ 1,000,000	0.95	0.00

CEF Score vs RC/SRC Ratio

Formula- Produced Prioritized List

Bridge #	Variables					Final Values				
	0.30	0.25	0.15	0.10	0.20					
	Importance Factor	Condition Factor	Risk Factor	Structure Capacity Factor	Cost-Effectiveness Factor	Score	Rank	Scope	Estimate for Recommended Scope	Estimated Total Replacement Cost
16020	0.95	0.90	0.10	0.55	1.00	0.78	1	Major Restoration	$1,652,651	$15,034,241
18399	0.99	0.82	0.10	0.85	0.27	0.66	2	Replace Superstructure	$6,675,231	$13,014,024
8204	0.85	0.82	0.00	0.00	1.00	0.66	3	Major Restoration	$280,579	$3,435,758
16384	0.30	0.97	0.75	0.00	1.00	0.65	4	Major Restoration	$67,619	$837,123
2466	0.95	0.98	0.00	0.29	0.32	0.62	6	Rehabilitate Culvert	$378,938	$769,496
18724	0.89	0.55	0.00	0.19	0.00	0.42	10	Replace Bridge	$4,957,098	$4,957,098
2439	0.79	0.48	0.00	0.59	0.00	0.42	11	Replace Bridge	$2,179,301	$2,179,301
17087	0.77	0.83	0.00	0.36	0.71	0.62	7	Replace Superstructure	$308,190	$1,040,226
10335	0.60	0.70	0.00	0.52	0.00	0.41	12	Replace Bridge	$335,158	$335,158
17878	0.52	0.98	0.00	0.00	1.00	0.60	9	Major Repair	$363,855	$3,678,246
5275	0.87	0.54	0.00	0.64	0.74	0.61	8	Replace Superstructure	$257,366	$924,388
18419	0.98	0.60	0.10	0.00	0.85	0.63	5	Replace Deck	$1,949,697	$8,663,145

Thank you for your time and attention

Questions??