New Jersey Department of Transportation
Division of Bridge Engineering & Infrastructure Management
Bureau of Structural Engineering & Bridge Management

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Initial Calibration of AASHTOWare's Bridge Management (BrM) for Projects

By

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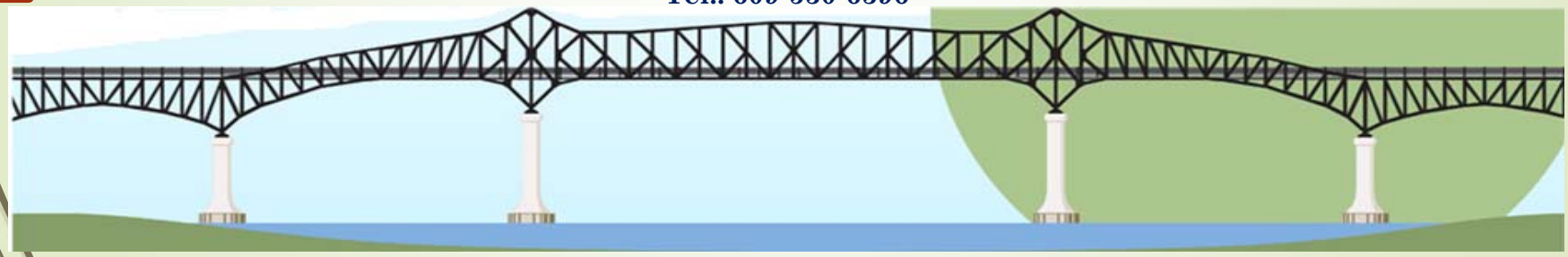

Outline

- Initial TAMP needs
- Bridge Management System
- BMS Challenges
- NJDOT BMS Timeline
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- NJDOT Bridge Elements
- NJDOT Elements Expert Elicitation
- NJDOT Elements Deterioration Modeling
- NJDOT Elements Relative Weights
- NJDOT Bridge Health Index
- NJDOT Conversion Profile
- NJDOT Utility Tree
- NJDOT Action-Benefit-Cost Model
- NJDOT Life Cycle Policies
- NJDOT Risk-Based Analysis Model
- NJDOT Projects and Program Model

Initial TAMP needs

- Out of seven (7) National Goals focus on **Infrastructure Condition**
- Maintain Highway Infrastructure Asset System in a **State of Good Repair**
- Using **Data driven** methodology
  - Develop and evaluate **Performance Measures**
  - Develop and set **Performance Targets**
- Manage network at minimum practical cost to
  - Improve and/or preserve Asset **conditions**
  - Improve Network **Performance**
  - Implement **Risk-based** analysis
- Initial TAMP submitted **April 2018**
- Established Performance Targets **May18, 2018**

[23USC §150(b)]
Safety
Infrastructure Condition
Congestion Reduction
System Reliability
Freight Movement and Economic Vitality
Environmental Sustainability
Reduced Project Delivery Delays

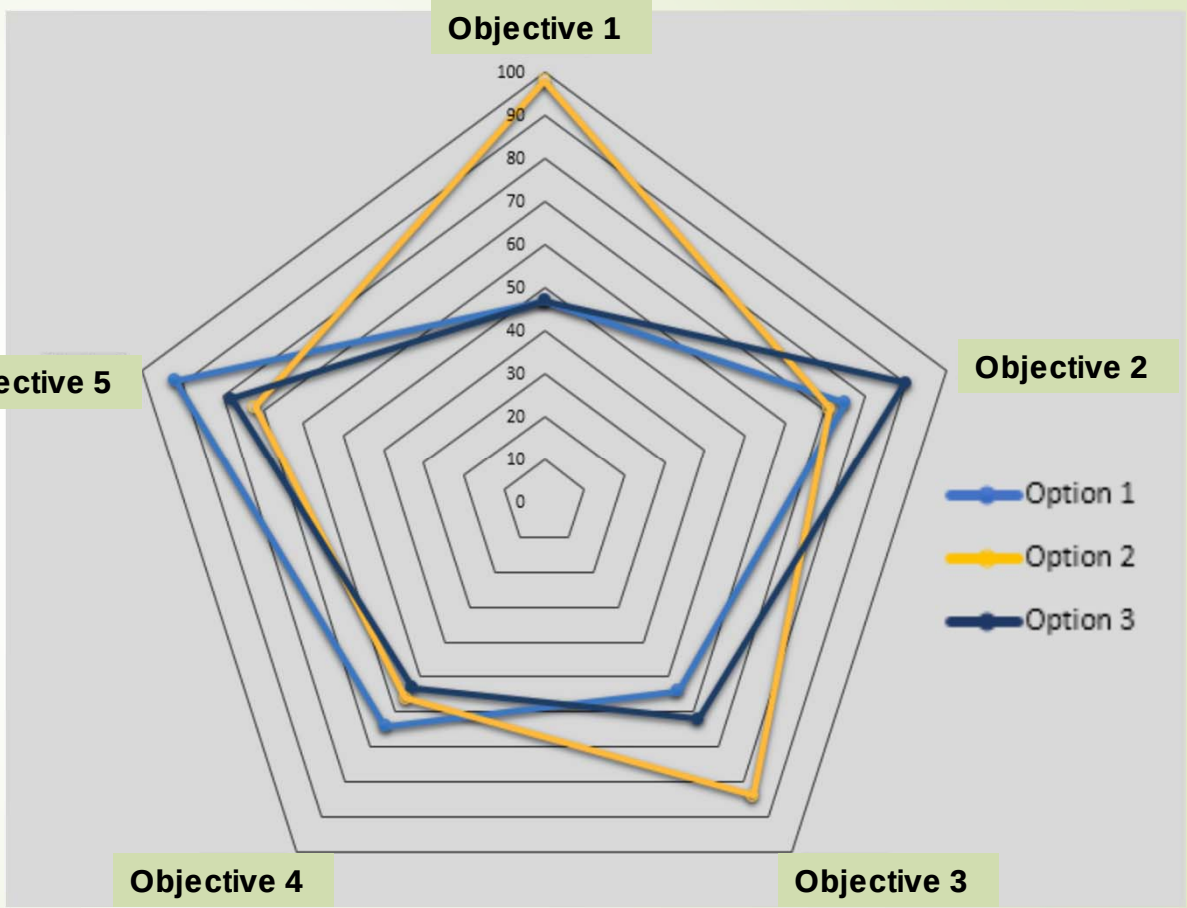
Bridge Management System

- Bridge Management System (**BMS**) assists in fulfilling:
  - National Bridge Inspection Standards (NBIS)
  - **MAP-21** Legislation
  - Asset Management Plan Rule (**23 CFR 515.17**)
- BMS minimum capabilities
  - Data collection, storage and reporting
  - Predictive (Deterioration) Modeling
  - Benefit-Cost Analysis over life of the assets
  - **Identifying short- and long-term budget needs**
  - Compare Alternate strategies to maximize benefits
  - Recommend Projects for a given program
- **Historical Analysis is a key to support decision making**

Source: Victory Bridge, NJ at https://www.flickr.com/photos/jag9889/1362312240

BMS Challenges

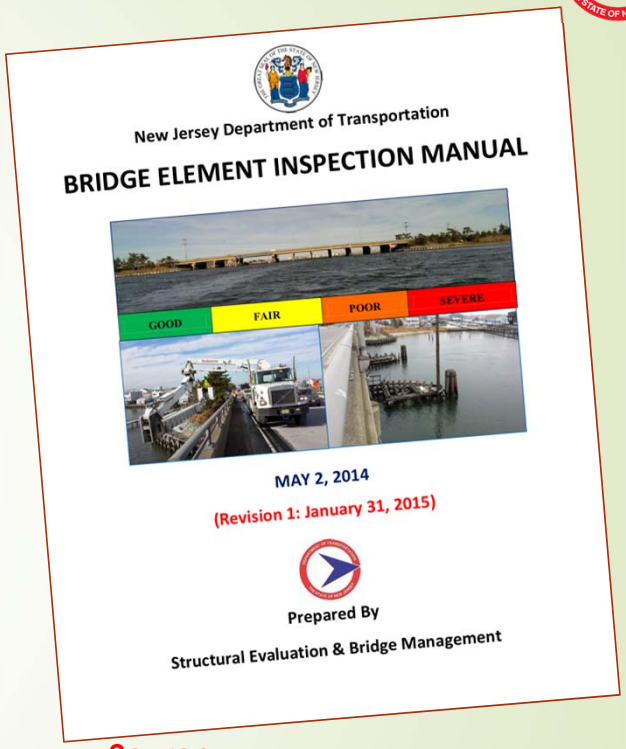
- Work within **limited resources**
  - System information & knowledge
  - Limited history for NBE data
- **Calibrate** Modeling capabilities
- **Standardize** analysis tools & formulas
- Calibrate **Optimizer**
  - Multiple Objectives for decision making utilizing BMS tools
  - Optimal allocation of resources between competing bridges at any given time
  - Logical, quantifiable, data driven, rule-based framework



Source: BrM Technical Manual

NJDOT BMS Timeline

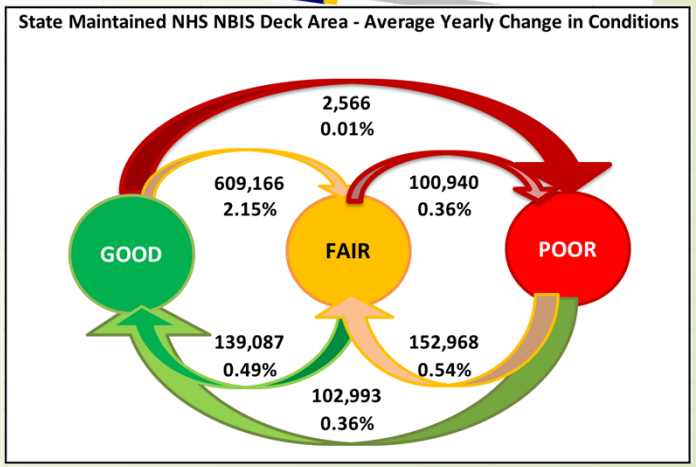
- NJDOT Bridge Elements Inspection Manual – **2014**
  - Training and Field Collection initiated
  - Migration of ***CoRe*** Elements to ***NBE***
- Upgrade *InspectTech* to Version 7.5 – **2014**
- Upgrade *Pontis* 4.3 to *BrM* 5.2.1 – **2014**
- Initial Deterioration Modeling – **2016**
- Upgrade from *BrM* 5.2.1 to *BrM* 5.2.3 – **2017**
  - First Training on *BrM* 5.2.3 –**2016**
  - Initial Action-Benefit-Cost Modeling – **2017**
  - Calibrated *BrM* 5.2.3 for Initial TAMP – **2017-2018**
- Stabilize *InspectTech* 7.5 to *BrM* 5.2.3/5.3 data transfer
  - Web Services – **2017-2019**
- Implement Final TAMP in BMS – **2018-2019**
- Stabilize *BrM* 5.2.3/5.3 and Upgrade to *BrM* 6.0 – **2019-2020**



Source: http://www.nj.gov/transportation/eng/structeval/pdf/BridgeEllnsManual.pdf

Responsibilities of NJDOT BMS

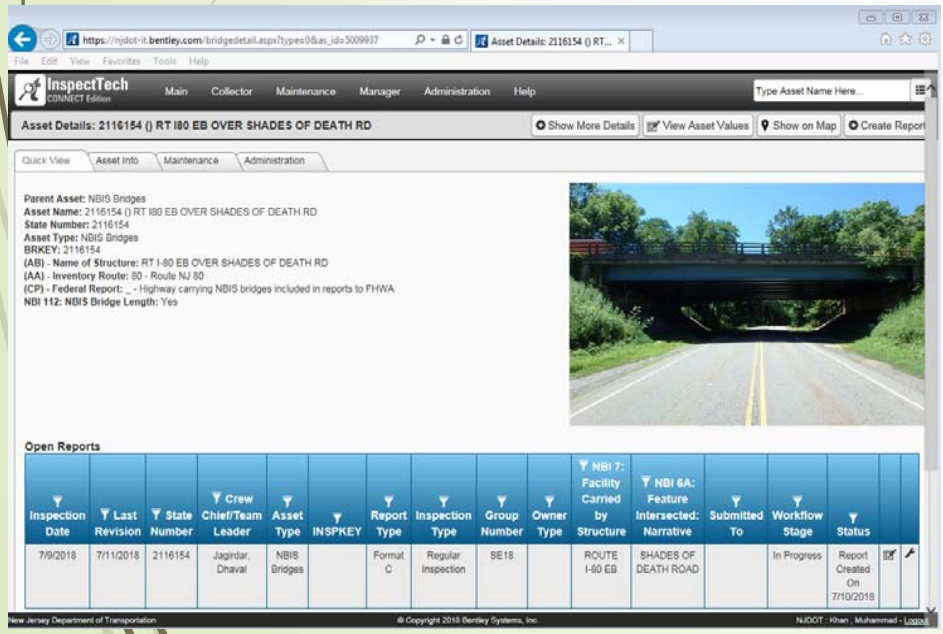
- **Federal Compliance**
  - Data Submittals and Validation as per **MAP 21** Act (now FAST Act)
  - NBIP Oversight – **23 Metrics** for bridges
- **Internal** needs
  - Upper Management data requests
  - Maintenance, support, management, and development **BMS tools**
- **Training** for In-house staff, Consultants and Owners
- Perform **Data Analysis**
- Perform **Historical** Evaluation (Spider chart example)
- Initiate new projects (**Limited and Full scope**)
  - Lifecycle Planning for Future and Planned Projects
  - Risk-Based – Bridge-Level, Network-Level Analyses
  - Budget forecasting



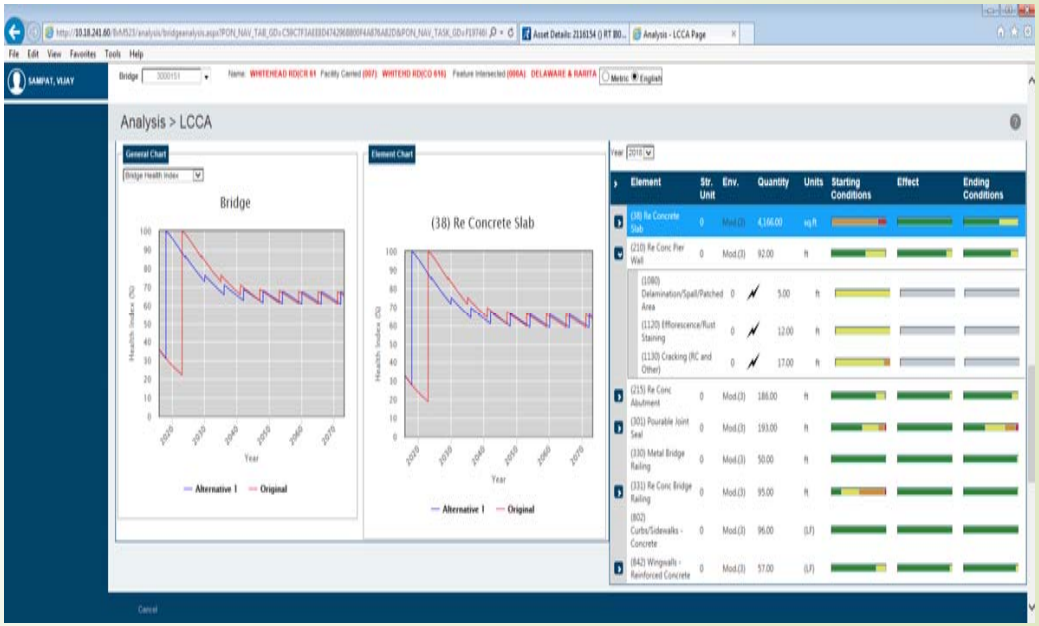
Responsibilities of NJDOT BMS

- Interaction with other systems, data warehouse, Research, **Data Sharing**
- Support to Overweight Permits, Load rating, Cost proposals, Inspection Projects
- Asset Management & Management Reports

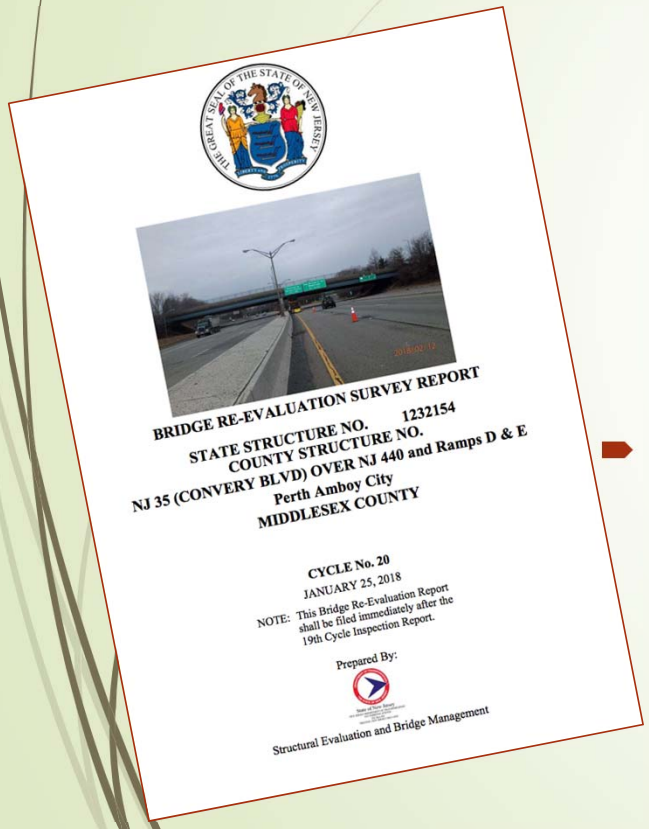
Bentley's *InspectTech* – CombIS 7.5



AASHTOWare's Bridge Management – BrM 5.2.3



Responsibilities of NJDOT BMS



- **Comb**ined **I**nspection **S**ystem (***CombIS***)
  - NJDOT's customized Bentley's ***InspectTech*** Version 7.5
  - Front End Data Collection
  - Repository of Assets - NBIS Bridges, Minor Bridges, OHSS, HMLP
  - Historical Records Storage & Management
  - Online Inspection Reporting and Workflow

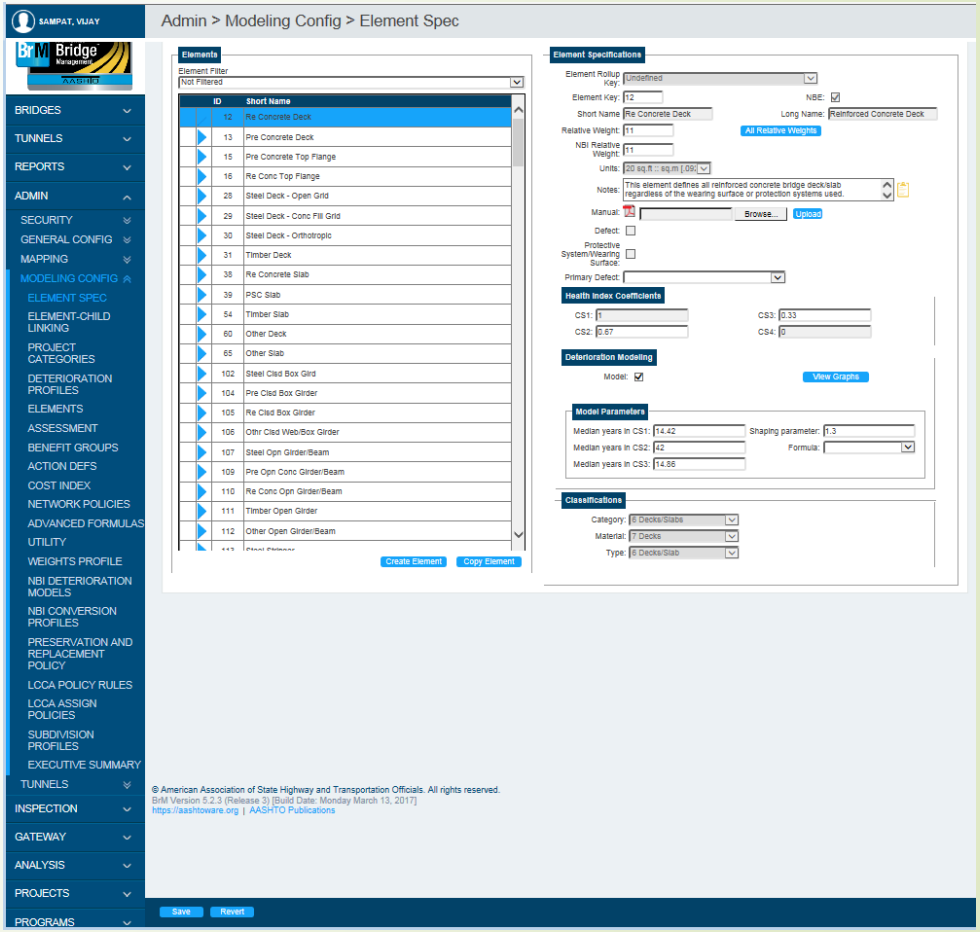
- AASHTOWare's **Br**idge **M**anagement (***BrM***) Version 5.2.3
  - Repository of Assets - NBIS Bridges, State Minor Bridges, Tunnels
  - Data Analysis tool for NJDOT
  - Deterioration and Action-Benefit-Cost Modeling
  - Program Optimization & Scenarios
  - Project creation and alignment with STIP

Responsibilities of NJDOT BMS

- **NJDOT adopted BrM 5.2.3 for BMS, PM2, & TAMP**
  - Historically used Pontis/BrM for NBI
- BrM User Group Meetings (**BrMUG)**
  - Next annual meeting in **September 2018**
  - Owned by **AASHTO**
  - Voting rights for future enhancements
  - Task Force is made of State DOT representatives (**40+ States**)
- **Additional Benefits of BrM and BrMUG**
  - Aligned with other AASHTOWare products
  - Easy to share customized modules between different States
  - Easy to implement initial settings

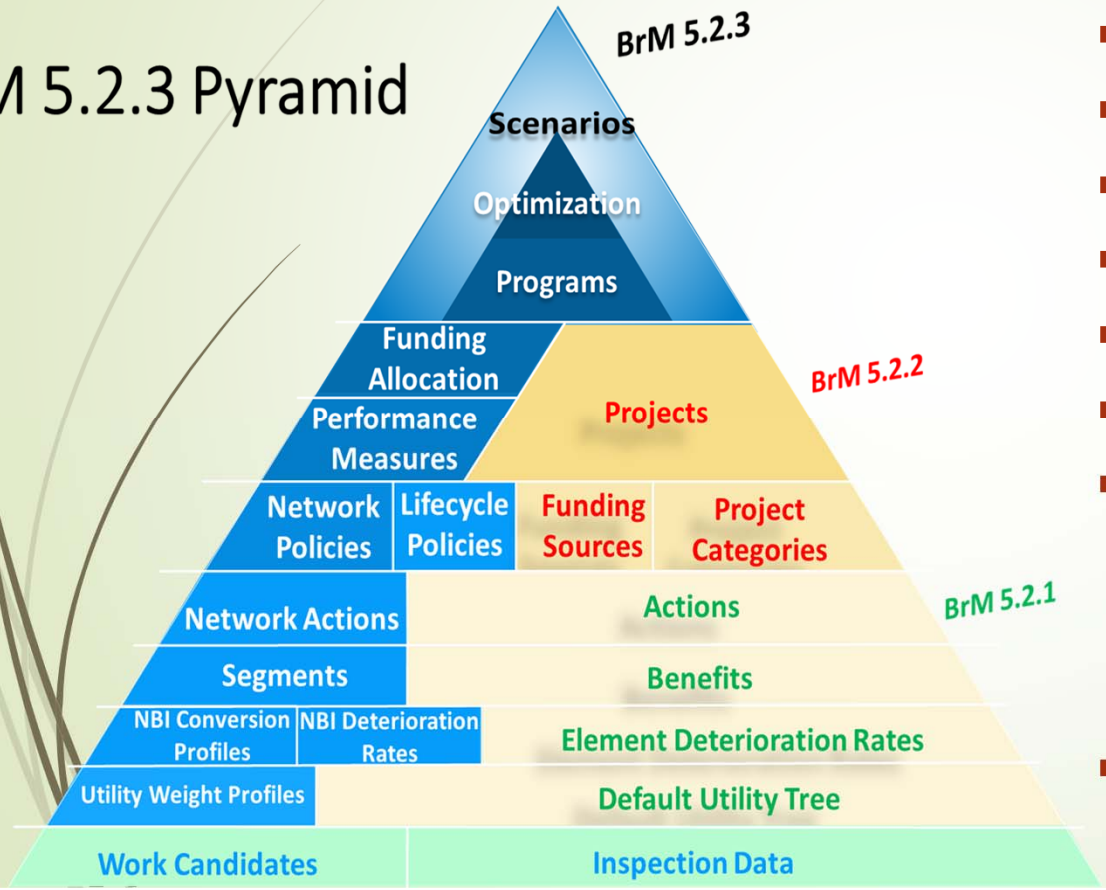
Responsibilities of NJDOT BMS

- Installed BrM 5.2.3 Web Server
  - **BrM 5.2.3 Enterprise version**
- Installed BrM 5.2.3 Database
  - **Oracle 12c**
- Developed NJDOT **Bridge Filters**
- **Security** setup for admins and users
- Updated **Database** Tables
  - Parameters & Data Dictionary
  - USER
- Used **Visual Editor** tool for agency modifications
- **Web Services** setup for importing data from CombIS 7.5



Responsibilities of NJDOT BMS

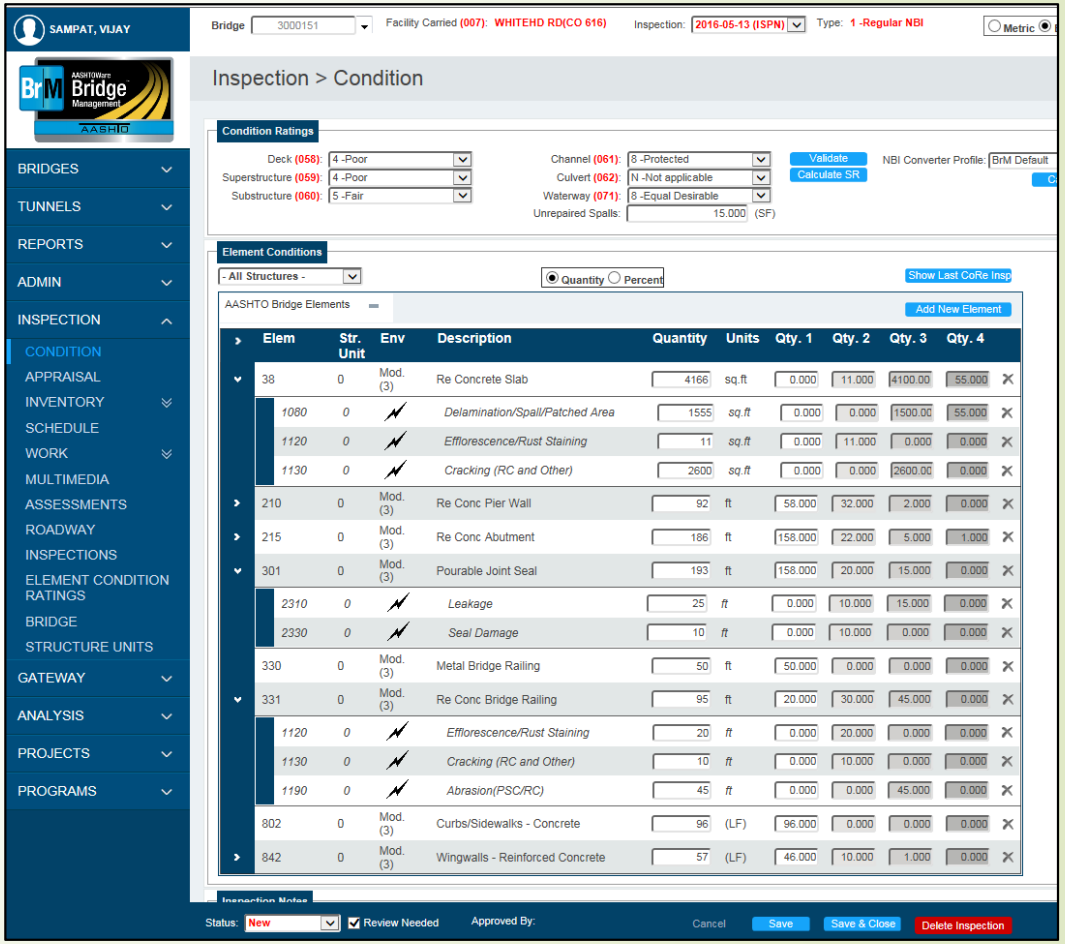
BrM 5.2.3 Pyramid



- **Elements** and Defects setup
- Action-Benefits-Cost
- Network Policies
- Life Cycle Policies
- NBI Converter
- Utility Tree
- Frozen Projects
- Program Planning and Optimization
  - Program Settings
  - Budget allocation
  - Performance Target, Scenarios
- Program Results, Project assignments

NJDOT Bridge Elements

- Implemented in BrM as per ***NJDOT Bridge Element Inspection Manual***
- **Expert Elicitation** used for Transition Year & Relative Weights
- NJDOT uses collected element data
  - For condition forecasting for the entire network
    - Each Element Deterioration is considered individually
  - For condition forecasting of each bridge based on
    - **Bridge Specific Elements** within the bridge
    - Bridge specific **Health Index**
- Adjustment Factors for Transition years
  - Protection, Environment, User defined



NJDOT Bridge Elements

- National Bridge Elements (**NBE**)
  - Simple, flexible, and effective way to **standardize bridge conditions across the nation**
  - Easy to quantify in four (4) condition states
    - **GOOD** (**CS 1**), **FAIR** (**CS 2**), **POOR** (**CS 3**), and **SEVERE** (**CS 4**)
- Structure of ***NJDOT Bridge Elements Inspection Manual***
  - **NBEs** – Primary Structural Components – DECK, SUPERSTRUCTURE, SUBSTRUCTURE, CULVERT
  - **BMEs** – Joints, Wearing Surfaces, Protective coating systems, Deck/Slab protection systems
  - **ADEs** – NJDOT defined Elements, Protective Systems, or Independent
  - UNITS, QUANTITY MEASUREMENT, DEFECTS, COMMENTARY, Examples
  - **Training** to in-house staff and Consultants community
  - **Implement** field collection and recording using *CombIS*
- *RIME Team – Validation of Elements Deterioration*

NJDOT Bridge Elements

2.1 National Bridge Elements

2.1.1 Decks and Slabs

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

2.1.2 Bridge Railings

Element	Units	Steel	Prestressed Concrete	Reinforced Concrete	Timber	Masonry	Other Material
Bridge Railing	ft.	330		331	332	334	333

2.1.3 Superstructure

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

2.1.4 Bearings

Element	Units	Element Number
Elastomeric Bearing	each	310
Moveable (roller, sliding, etc.) Bearing	each	311
Enclosed/Concealed Bearing	each	312
Fixed Bearing	each	313
Pot Bearing	each	314
Disk Bearing	each	315
Other Bearing	each	316

2.1.5 Substructure

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

2.1.6 Culverts

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

2.2 Bridge Management Elements

2.2.1 Joints

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

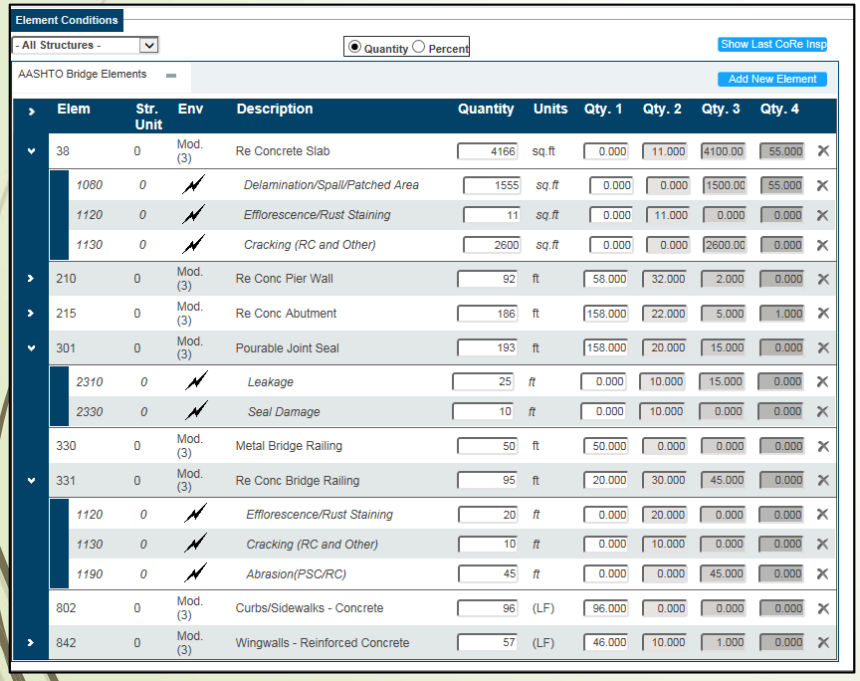
2.2.2 Approach Slabs

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

NJDOT Bridge Elements

2.2.3 Wearing Surfaces, Protective Coatings and Concrete Reinforcing Steel Protective Systems

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



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

2.3.4 Substructure

Element	Units	Steel	Prestressed Concrete	Reinforced Concrete	Timber	Masonry	Other Material
Slope Protection	~~ft.~~ each						841
Wingwalls	ft.			842	843	844	845
Headwalls	ft.			846		847	848
Fender System	each						849
Bulkhead	ft.						850

2.3.5 Joints

Element	Units	Element Number
Elastomeric Flex-Type Joint	ft.	861
Asphaltic Plug Expansion Joint	ft.	862

2.3.6 Other

Element	Units	Element Number
Concrete Encasement	ft.	891
Bridge Drainage	each	892
Temporary Support Structures	each	893

NJDOT Bridge Elements

3.1.9 Element #: 31 — Timber Deck

Description: This element defines all timber bridge decks regardless of the wearing surface or protection systems used.
Classification: AASHTO NBE **Units of Measurement**: sq. ft.
Quantity Calculation: The quantity for this element includes the area of the deck from edge to edge including any median areas and accounting for any flares or ramps present.

Condition State Definitions

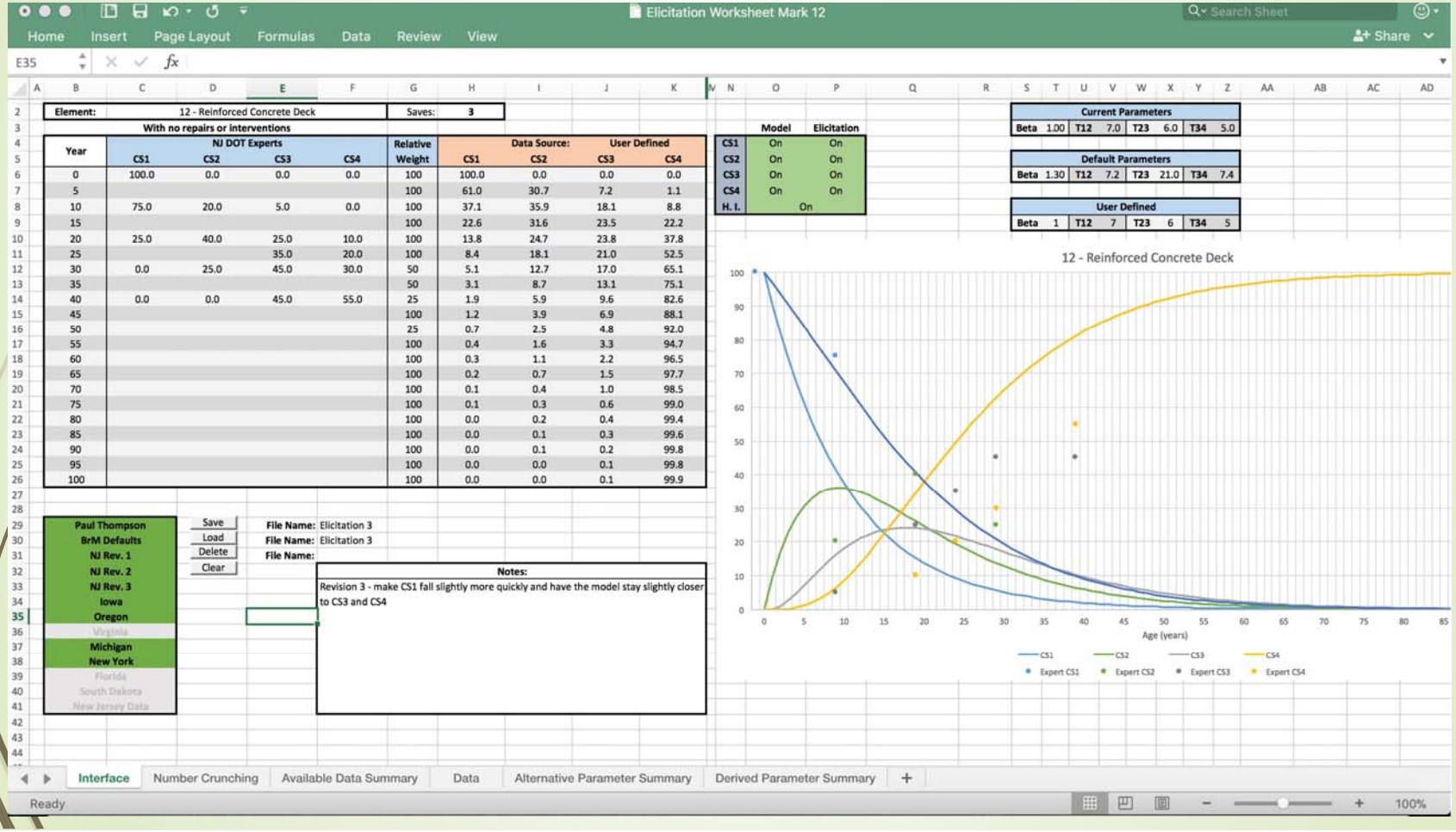
Defects	Condition States			
	1	2	3	4
	GOOD	FAIR	POOR	SEVERE
Connection (1020)	Connection is in place and functioning as intended.	Loose fasteners or pack rust without distortion is present but the connection is in place and functioning as intended.	Missing bolts, rivets, or fasteners; broken welds; or pack rust with distortion but does not warrant a structural review.	The condition warrants a structural review to determine the effect on strength or serviceability of the element or bridge; OR a structural review has been completed and the defects impact strength or serviceability of the element or bridge.
Decay/ Section Loss (1140)	None.	Affects less than 10% of the member section.	Affects 10% or more of the member but does not warrant structural review.	
Check/ Shake (1150)	Surface penetration less than 5% of the member thickness regardless of location.	Penetrates 5% - 50% of the thickness of the member and not in a tension zone.	Penetrates more than 50% of the thickness of the member or more than 5% of the member thickness in a tension zone. Does not warrant structural review.	
Crack (Timber) (1160)	None.	Crack that has been arrested through effective measures.	Identified crack exists that is not arrested, but does not require structural review.	
Split/ Delamination (Timber) (1170)	None.	Length less than the member depth or arrested with effective actions taken to mitigate.	Length equal to or greater than the member depth, but does not require structural review.	

Defects	Condition States			
	1	2	3	4
	GOOD	FAIR	POOR	SEVERE
Damage (7000)	Not applicable.	The element has impact damage. The specific damage caused by the impact has been captured in Condition State 2 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in Condition State 3 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in Condition State 4 under the appropriate material defect entry.

Element Commentary
The deck evaluation is three dimensional in nature with the defects observed on the top and bottom surface, edges or all, and being captured using the defined condition states.

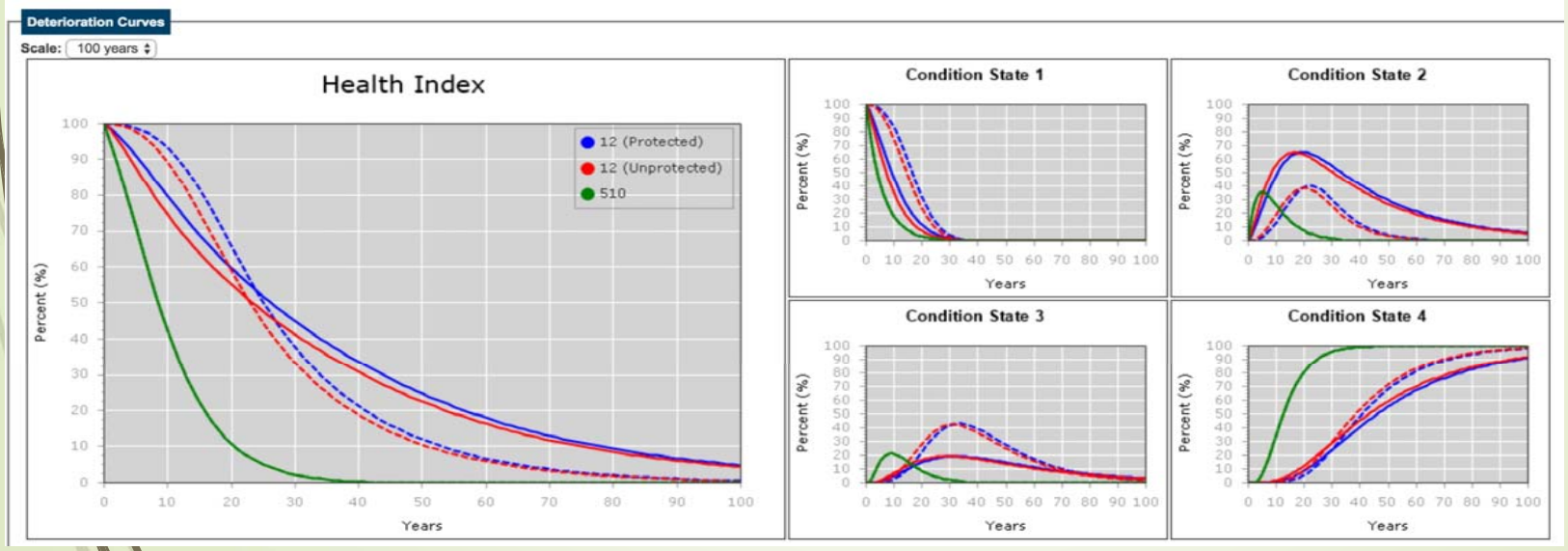
Timber running planks shall be included under the wearing surface assessment.

NJDOT Elements Expert Elicitation



NJDOT Elements Expert Elicitation

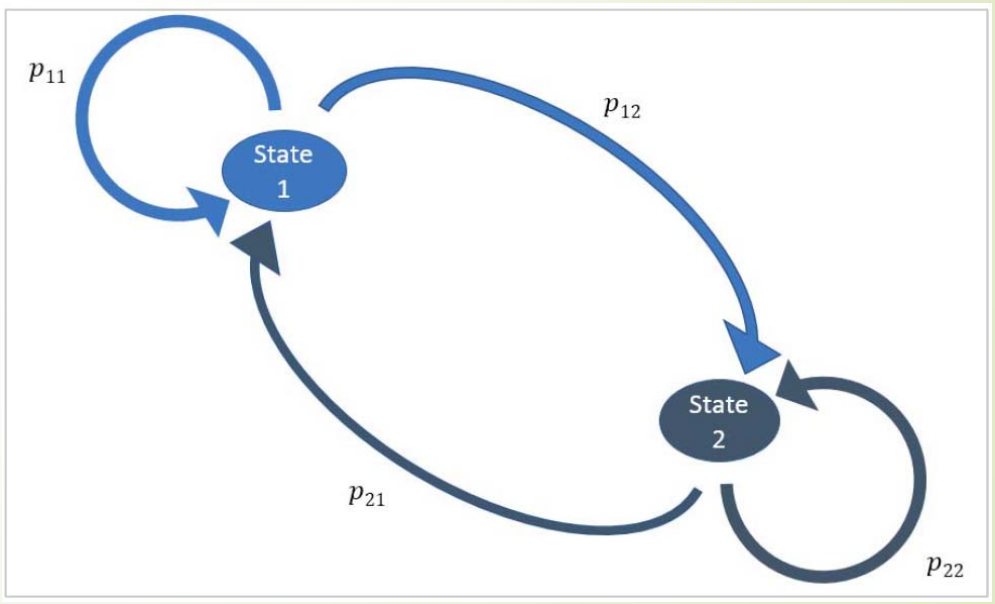
- Assumed no intervention for Element Deterioration Transition Years
- Compared with other States and BrM Defaults
- Included Protective Systems and ADEs
- **Experts** from Bridge Inspection, Design, Maintenance
- Multiple elicitations whenever needed



Example: Elem 12 & Elem 510 Deterioration Curves developed using Expert Elicitation

NJDOT Elements Deterioration Modeling

- **Markovian Model**
  - Uses probability theory to model random changes
  - Assumes, the future state depends on the current state
- Markovian Model can be expressed as a **Transition Probability Matrix**
  - BrM uses four (4) State Transition Probability Matrix
- The **median number of years** that a unit of the element stays in state ***i***, <u>before</u> transition to the next condition state
- The typical median years <u>to</u> transition for state ***i***



NJDOT Elements Deterioration Modeling

- **Markovian Model**
  - Transition Probabilities are used to forecast condition states for each year in the future
- **Limitations** of Markovian Model
  - Element **age** is <u>not</u> considered
  - Future state **depends** on the current state only & does not consider any **past events** such as maintenance or preservation
    - Rate of initial deterioration is too **rapid**
- **To overcome such limitations**
  - Need a separate function that account for improved or had improved conditions
  - Need modifiers or factors that slow deterioration

Year	CS1	CS2	CS3	CS4
0	100.0%	0.0%	0.0%	0.0%
1	97.3%	2.7%	0.0%	0.0%
2	94.6%	5.3%	0.1%	0.0%
3	92.0%	7.6%	0.4%	0.0%
4	89.5%	9.8%	0.7%	0.0%
5	87.1%	11.8%	1.1%	0.0%
6	84.7%	13.6%	1.6%	0.0%
7	82.4%	15.3%	2.2%	0.1%
[illegible]6	[illegible]	[illegible]	2.9%	0.1%
[illegible]6	[illegible]	[illegible]	3.6%	0.1%
[illegible]6	[illegible]	[illegible]	4.4%	0.2%
[illegible]6	[illegible]	[illegible]	5.2%	0.2%
[illegible]6	[illegible]	[illegible]	6.1%	0.3%
[illegible]6	[illegible]	[illegible]	7.0%	0.4%
[illegible]6	[illegible]	[illegible]	7.9%	0.5%
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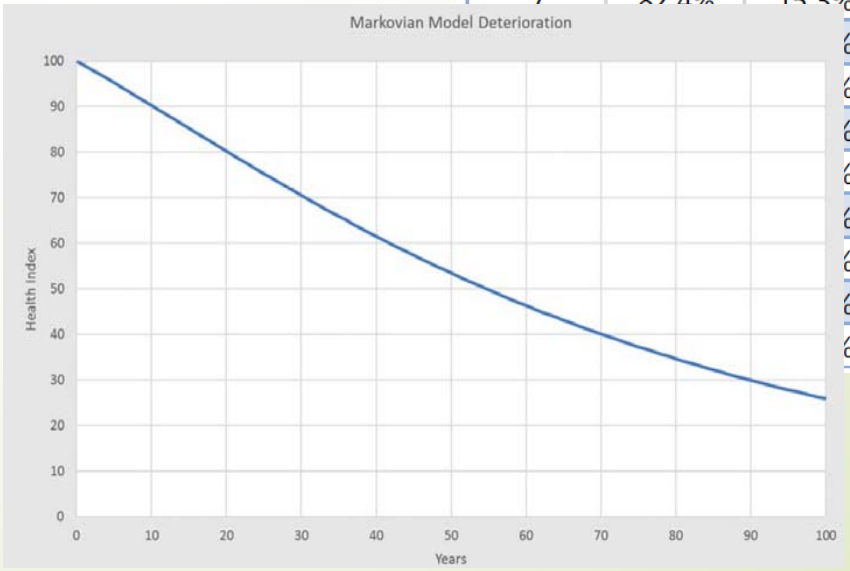
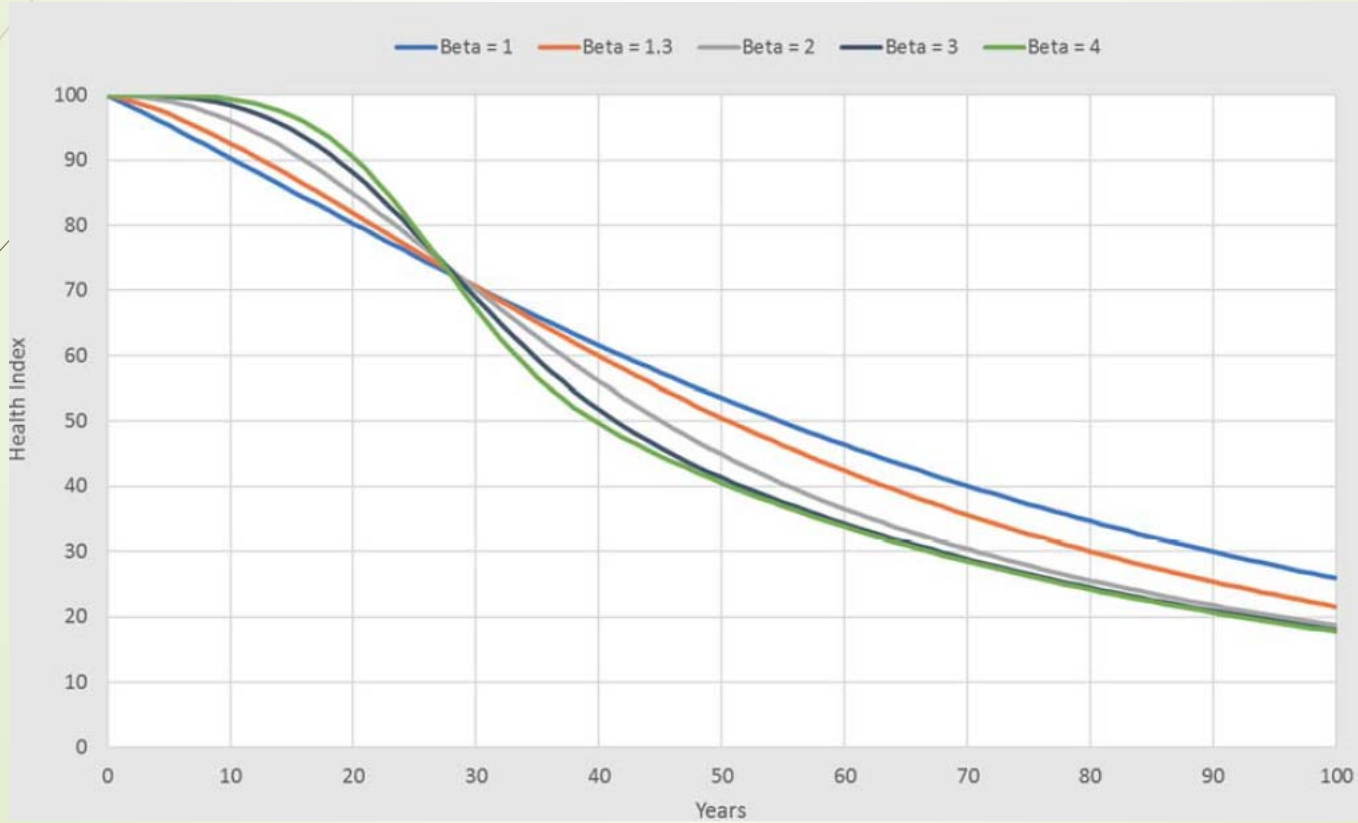


NJDOT Elements Deterioration Modeling

- **Weibull Model:** A continuous Probabilistic Model, Time, Age of the element

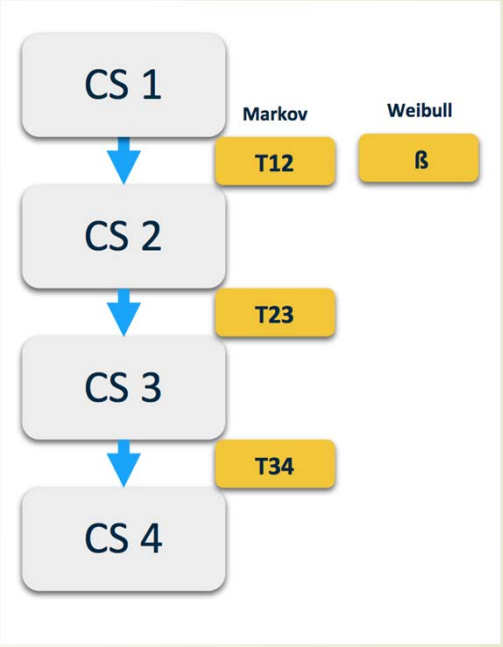


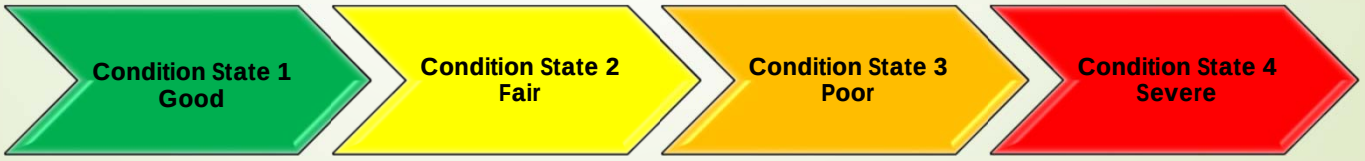
NJDOT Elements Deterioration Modeling

- **BrM Deterioration Model**
  - uses **Weibull** (*Modified Markovian*) for
    - CS1 to CS2
  - uses **Markovian** for
    - CS2 to CS3
    - CS3 to CS4

NOTE:

Pure Markovian Model is not being used for **CS1 to CS2,** due to the unrealistic steady deterioration rate





NJDOT Elements Deterioration Modeling

- **Combined Adjustment Factor**
  - All the factors are multiplied together to estimate:
    - An overall adjustment factor
    - Adjust the median years to transition for the element

$$f = f^E * f^F * f^M_{combined}$$

Where:

- f is the adjustment factor
- f^E is the environment factor
- f^F is a formula factor estimated from a user-customized formula
- $f^M_{combined}$ is the combined modifier factor all protective systems

Source: BrM Technical Manual

NJDOT Elements Deterioration Modeling

- **Combined Protection Factor**
  - Models Protective System on the Primary (or Base) Element
  - Increases median years of the base element
  - Value ≤ 1.0
  - **Example:**
    - A new Protective System will mitigate the existing rate of deterioration and provide **better protection** to the base element
    - Protective system with a higher deterioration rate and in poor condition state provides **no or minimal protection** for the base element

NJDOT Elements Deterioration Modeling

- **Environment Factors**
  - NJDOT uses Moderate (3), Severe (4)

Environment	Description
1—Benign	Neither environmental factors nor operating practices are likely to significantly change the condition of the element over time, or their effects have been mitigated by the presence of highly effective protective systems. **Not used in New Jersey**.
2—Low	Environmental factors, operating practices, or both either do not adversely influence the condition of the element, or their effects are substantially lessened by the application of effective protective systems. **Not used in New Jersey**.
3—Moderate	Any change in the condition of the element is likely to be quite normal as measured against the environmental factors, operating practices, or both that are considered typical by the agency. **Used for typical environment in New Jersey.**
4—Severe	Environmental factors, operating practices, or both, contribute to the rapid decline in the condition of the element. Protective systems are not in place or are ineffective. **Used for severe environmental conditions in New Jersey such as saltwater (marine), brackish water (part saltwater) or industrial.**

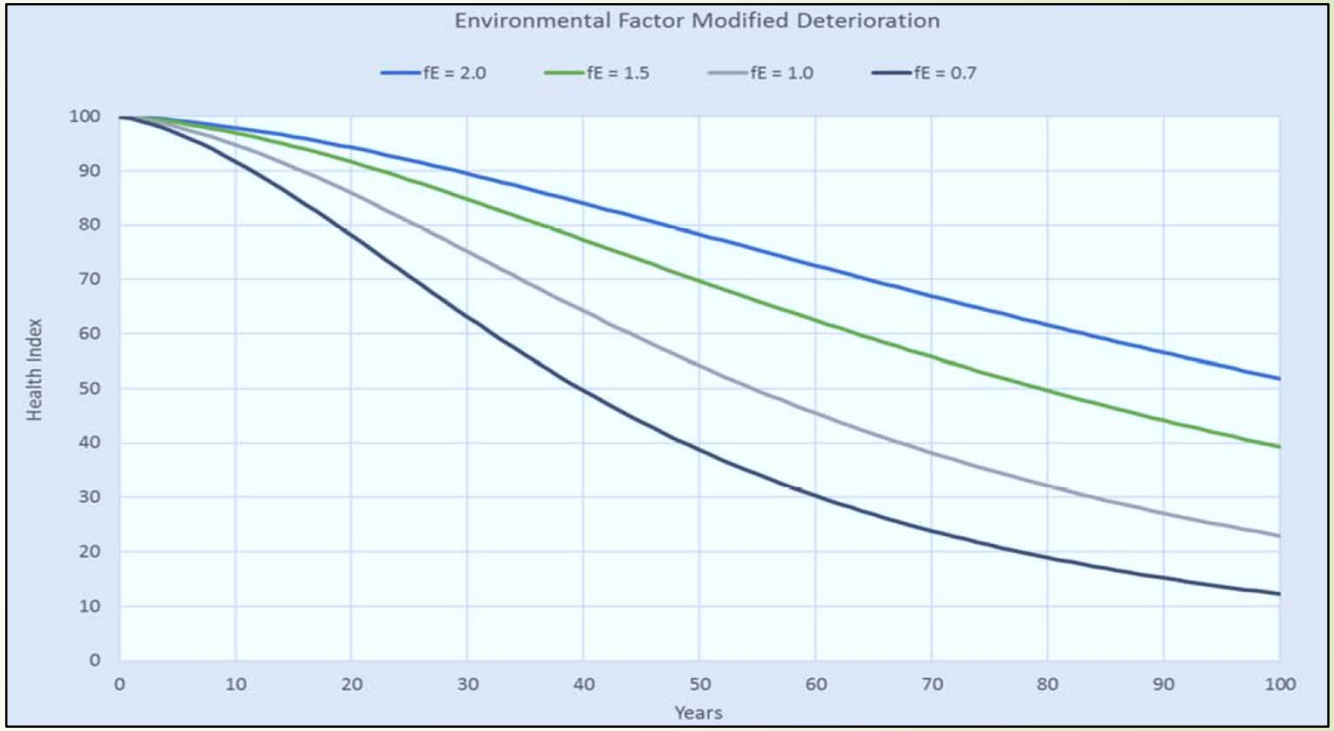
Source: NJDOT Bridge Element Inspection Manual

NJDOT Adopted BrM Default Environments:

1. Ben. = 2.0
2. Low = 1.5
3. Mod. = 1.0
4. Sev. = 0.7

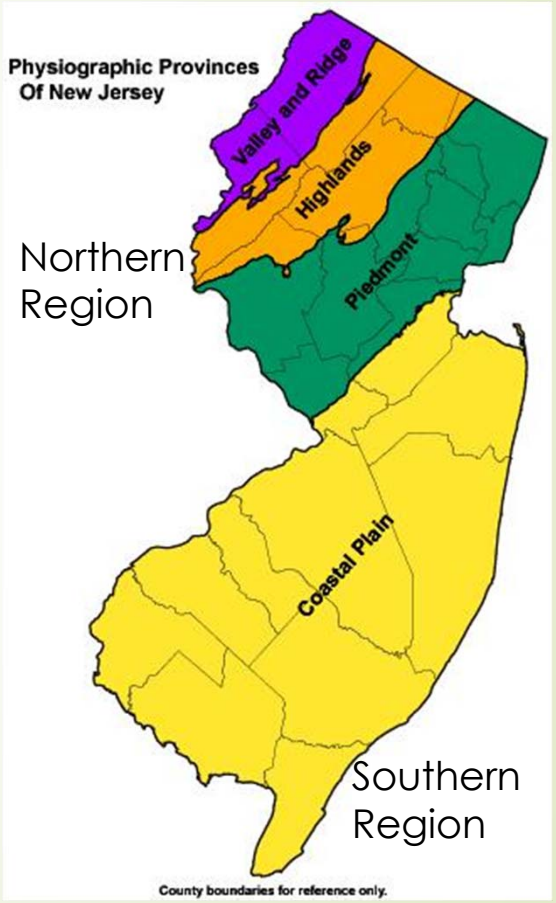
NJDOT Elements Deterioration Modeling

- **Environmental Factors**
  - Elements deteriorate at different rates based on the surrounding conditions & exposure
  - Every element has an environmental factor
  - Constant factor associated with a corresponding environment
  - Dry arid climate Vs. Moisture & Salt in a coastal environment



NJDOT Elements Deterioration Modeling

- **Formula Factor**
  - Modifies the deterioration curves for other than Protection and Environment factors
  - User defines their own formulas
- For example
  - **Local** Environments Factors for Bearing Elements
    - Varies as a function of Joint Element versus no Deck Joints
  - **Global** Environments for Statewide zones
    - Weather and/or Deicing Chemical Zones versus Coastal Zone
    - Northern versus Southern New Jersey Regions
- Limitation
  - Only <u>one formula per element</u>



Source: https://www.state.nj.us/dep/njgs/geodata/dgs02-7.htm#Image

NJDOT Elements Relative Weights

- Used in ***Health Index*** calculation for a bridge
- Definition:
  - Relative importance of one element to the other elements (**within BrM World)**
- ***Cost-based*** analysis is performed initially to compare quantities (***q***) in different units
  - Element Unit Cost (***uc***) based on Bid Express (BidX)
- Rutgers University - RIME Team Approaches:
  - (1) $$RW_i = \frac{uc_i \cdot q_i}{\sum_{i=1}^{N} uc_i \cdot q_i}$$ (2) $$RW_i = \frac{uc_i \cdot \frac{q_i}{I_i}}{\sum_{i=1}^{N} uc_i \cdot \frac{q_i}{I_i}}$$

NJDOT Element Relative Weights

- Refined by **Cluster-based analysis** based on Main Material and Design Type
- 6702 NBIS Bridges analyzed
- **67 Clusters** of bridges based on
  - NBI ITEM 43A (Material)
  - NBI ITEM 43B (Structure Type)

Cluster	Category	Number of Bridges
1	PS Concrete Box Beam-Mult.	539
2	Steel Stringer-Multi-beam	2667
3	PS Concrete Stringer-Multi-beam	491
4	Wood-Timber Stringer-Multi-beam	121
5	Steel Cont. Stringer-Multi-beam	461
6	PS Concrete Slab	411
7	Wood-Timber Slab	108
8	Concrete Slab	190
9	Concrete Cont. Slab	62
10	Steel Truss-Thru	149
11	Concrete Culvert	515
12	Steel Floorbeam	165
13	Masonry Arch-Deck	59
14	Concrete Arch-Deck	201
15	PS Concrete Box Beam-Sing.	40
16	Concrete Frame	142
	Partial Total	**6321**

NJDOT Element Relative Weights

Comparison		Category	PS Conc Box Beam-Mult.		Steel Stringer-Multi-beam		PS Conc Stringer-Multi-beam		Wood-Timber Stringer-Multi-beam		Steel Cont. Stringer-Multi-beam		PS Conc Slab	
		Approach	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Elm. Key	Description	#Bridges	539		**2,667**		491		121		461		411	
		Unit Cost												
12	Re Concrete Deck	66	11	2	**16**	3	20	4	2	4	22	4	8	1
13	Pre Concrete Deck	75	1	2	0	0	0	0	0	0	0	0	1	1
15	Pre Concrete Top Flange	75	1	2	1	1	0	0	0	0	0	0	2	1
16	Re Conc Top Flange	66	1	1	0	0	0	0	0	0	0	0	1	1
28	Steel Deck - Open Grid	65	1	1	1	1	1	1	0	0	1	1	1	1
29	Steel Deck - Conc Fill Grid	82	0	0	1	2	0	0	0	0	1	1	1	1
30	Steel Deck - Orthotropic	1,000	2	7	1	5	1	5	1	5	1	4	2	5
31	Timber Deck	48	1	1	1	1	1	1	7	2	0	0	1	1
38	Re Concrete Slab	90	2	2	1	2	1	4	0	0	1	7	2	1
39	PSC Slab	100	0	0	0	0	0	0	0	0	0	0	0	0
54	Timber Slab	96	1	1	1	1	0	0	2	6	1	1	1	1
60	Other Deck	-	0	0	0	0	0	0	0	0	0	0	0	0
65	Other Slab	-	0	0	0	0	0	0	0	0	0	0	0	0
102	Steel Clsd Box Gird	790	0	0	1	1	0	0	0	0	1	1	0	0
104	Pre Clsd Box Girder	275	12	2	1	1	1	2	0	0	1	2	8	1
105	Re Clsd Box Girder	200	1	1	1	1	0	0	0	0	1	1	1	1
106	Othr Clsd Web/Box Girder	-	0	0	0	0	0	0	0	0	0	0	0	0
107	Steel Opn Girder/Beam	650	3	2	21	4	1	2	3	3	26	4	3	1
109	Pre Opn Conc Girder/Beam	350	1	1	1	6	15	3	0	0	1	6	1	1
110	Re Conc Opn Girder/Beam	275	1	1	1	1	1	2	0	0	1	1	1	1
111	Timber Open Girder	290	1	3	1	1	1	2	22	5	1	1	1	2
112	Other Open Girder/Beam	-	0	0	0	0	0	0	0	0	0	0	0	0
113	Steel Stringer	550	1	2	2	6	1	3	0	0	3	5	1	1
115	Pre Conc Stringer	300	1	1	0	0	1	3	0	0	0	0	6	46
116	Re Conc Stringer	250	0	0	1	1	1	1	0	0	1	1	1	1
117	Timber Stringer	72	0	0	1	1	0	0	1	2	0	0	1	1
118	Other Stringer	-	0	0	0	0	0	0	0	0	0	0	0	0
120	Steel Truss	3,840	2	6	1	6	1	3	0	0	1	4	2	5

NJDOT Bridge Health Index

- **Bridge Health Index**
  - Numerical value reflecting the overall condition of the bridge
  - Weighted average of the percentage distribution in each condition state

$$HI = \frac{(\Sigma_e \, qe \, We \, HIe)}{\Sigma_e \, qe \, We}$$

Where:

- $\boldsymbol{HI_e}$ is the forecasted health index of the element ***e***.
- $\boldsymbol{q_e}$ is total quantity of the element e
- $\boldsymbol{W_e}$ is the weight of the element e

$$HI_e = y_1 + \left(\frac{2}{3}\right) y_2 + \left(\frac{1}{3}\right) y_3$$

- $\boldsymbol{y_i}$ is the forecasted percentage of element ***e*** in State ***i***

Source: BrM Technical Manual

NJDOT Bridge Health Index

- **Bridge Health Index Example**

The coefficients in the previous equation are the default values, however the user can modify these values to fit their practices. The following are example calculations for elements 38 – Reinforced Concrete Slab, 215 – Reinforced Concrete Abutment and 330 – Metal Bridge Railing and the overall health index which includes all the elements. The data for the example is provided in the following image.

Element	Total Quanty (q_e)	% in CS 1	% in CS 2	% in CS 3	% in CS 4	Element Weight (w_e)
38	960	84.9%	14.8%	0.3%	0.0%	40
215	106	56.8%	24.6%	18.6%	0.0%	50
330	26	25.7%	50.9%	23.4%	0.0%	10

$$HI_{38} = .849 + \frac{2}{3} \times .148 + \frac{1}{3} \times .003 = 0.95$$

$$HI_{215} = .568 + \frac{2}{3} \times .246 + \frac{1}{3} \times .186 = 0.79$$

$$HI_{330} = .257 + \frac{2}{3} \times .509 + \frac{1}{3} \times .234 = 0.67$$

$$HI = \frac{(960 \times 40 \times .95) + (106 \times 50 \times .79) + (26 \times 10 \times .67)}{(960 \times 40) + (106 \times 50) + (26 \times 10)} = 0.928 = 92.8\%$$

Source: BrM Technical Manual

NJDOT Conversion Profile

- Bridge Condition Ratings are evaluated using **two philosophies**
  - **COMPONENT (NBI)** Condition Ratings
    - Deck, Superstructure, Substructure, Culvert
  - **ELEMENT (NBE)** Condition Rating
    - Four (4) Condition States for different elements
- **Converter**
  - NJDOT utilizes Element Deterioration based on NBE Condition State Ratings
  - Performance Measures are reported based on NBI Component Ratings
  - **BrM Converter translates NBE Condition State Ratings to NBI Component Ratings**
- Classify each element into their **functional** components
  - Generic, Deck, Superstructure, Substructure

RATINGS:

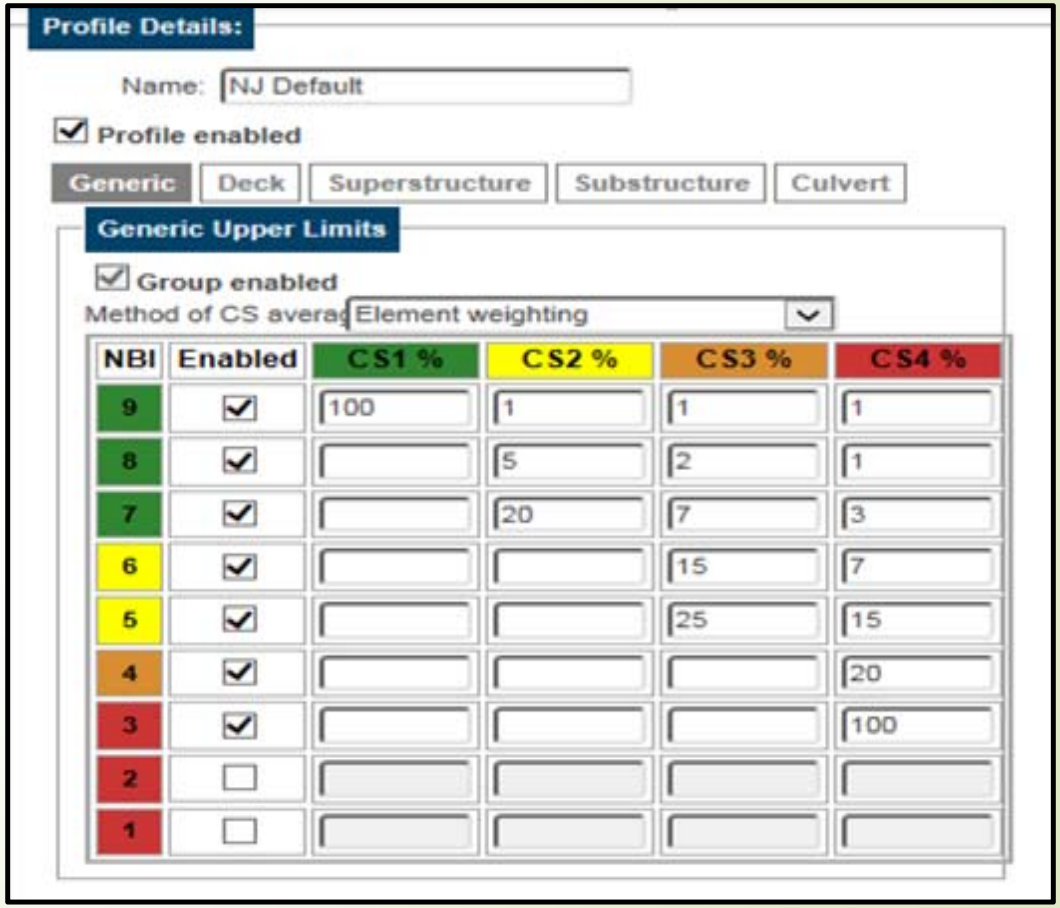
N	Not applicable.
9	Excellent Condition.
8	Very Good Condition - no problems noted.
7	Good Condition - some minor problems.
6	**Satisfactory Condition - some minor deterioration of structural elements.**
5	Fair Condition - minor section loss to primary structural elements.
4	Poor Condition - advanced section loss to primary structural elements.
3	Serious Condition - seriously deteriorated primary structural elements.
2	Critical Condition - facility should be closed until repairs are made.
1	Imminent Failure Condition - facility closed. Study of repairs is feasible.
0	Failed Condition - facility is closed and beyond repair.

NJDOT Conversion Profile

- FHWA Converter too strict to produce reasonable results.
  - Resulting in too many FAIRs

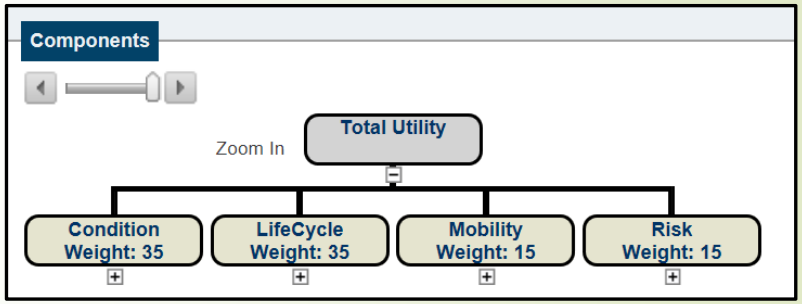
NBI	CS1%	CS2%	CS3%	CS4%
9	x	x	x	x
8	100	0	0	0
7		> 0 – 20	0	0
6			> 0 - 5	0
5			> 5 - 20	0
4				> 0 - 20
3				> 20 - 100
2	x	x	x	x
1	x	x	x	x

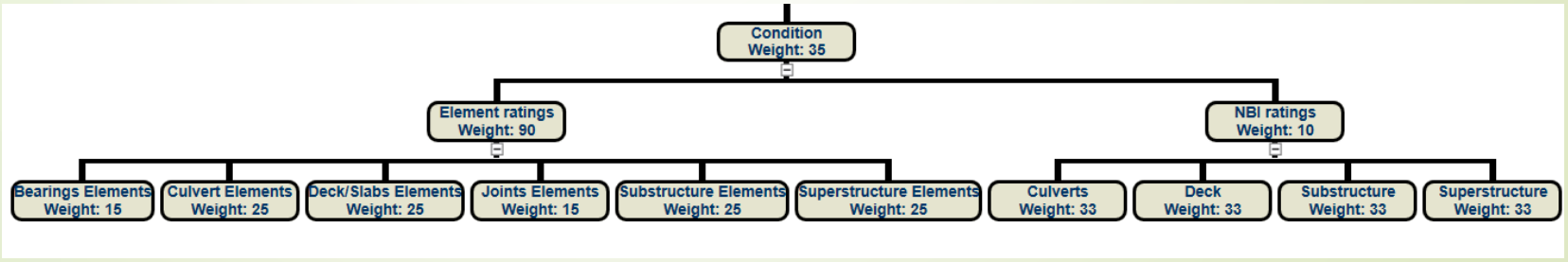
- NJDOT Converter design to **soften** around the GOOD and FAIR conditions
  - Helps in correctly getting benefits of Major Rehab work to GOOD than FAIR.



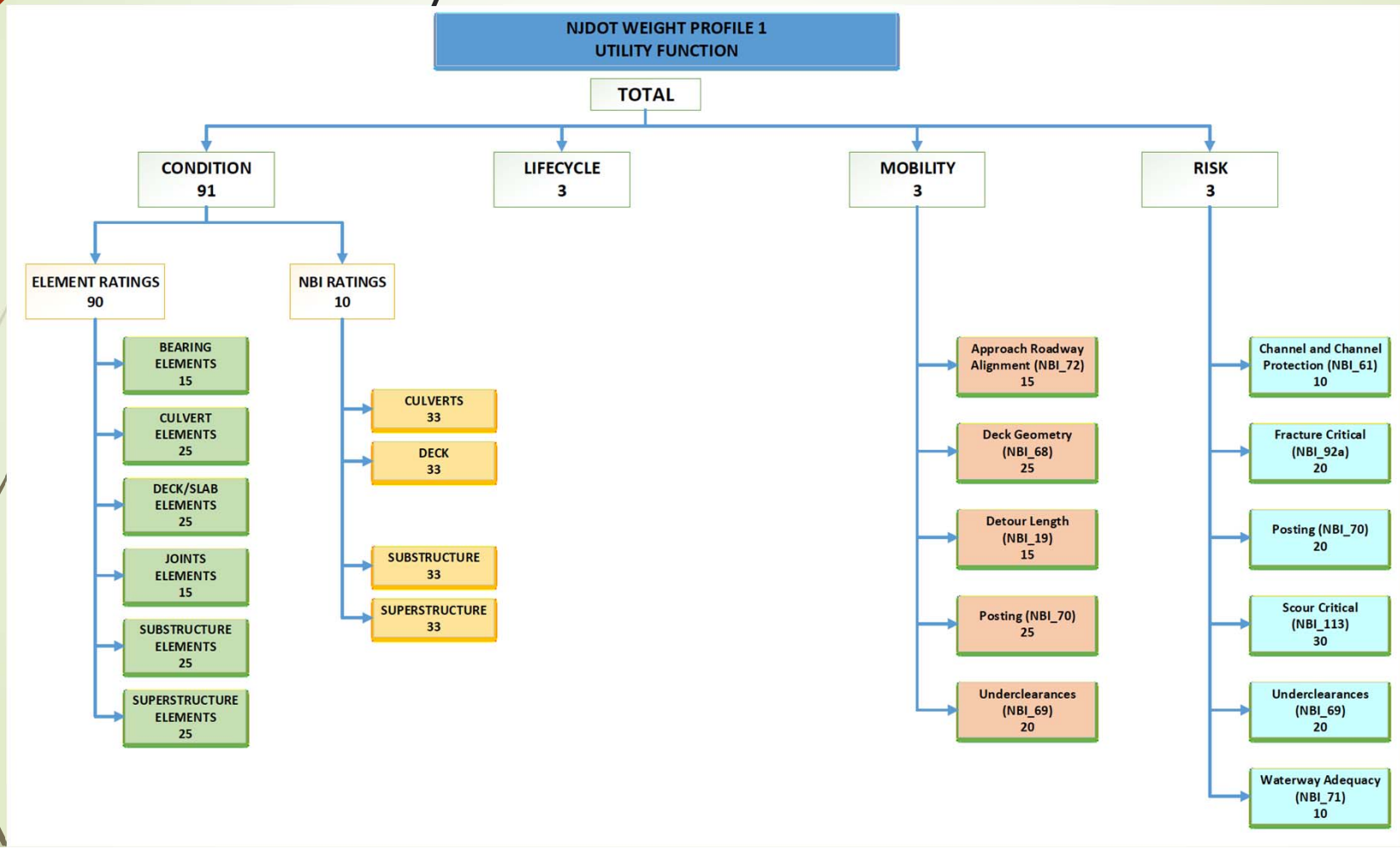
NJDOT Utility Tree

- Utility Theory-Quantify the amount of satisfaction
- Structure of Utility Tree in BrM 5.2.3
  - **Goals** are represented in the first layer of Utility Tree – To maximize Total Utility value
  - **Objectives** are represented in the second layer of Utility Tree
    - Condition Value- Maximum Structural Condition
    - Life Cycle value- Minimize Life Cycle Cost
    - Mobility Value- Maximize Mobility of Travelers
    - Risk Value- Minimize Risk
  - **Criteria** is represented in the third layer of Utility Tree
    - Assessment of the objectives
    - Example: Condition is assessed by Element Health indices as well as NBI Components





NJDOT Utility Tree



NJDOT Utility Tree

- NJDOT Utility Tree is refined specific to New Jersey by utilizing
  - Research partner Rutgers University (RIME Team)
  - Survey questions
- RIME (Onur Kalan, PhD) is supporting BMS through a Sensitivity Analysis
  - Default Utility Tree Values and its Relative Weights in BrM to Bridge Ranking during project selection
  - Changes in bridge rankings when the missing data of an utility criterion is filled with the max value and min value of that criterion
  - Will provide answer to the question - Which criteria is most sensitive for an objective?

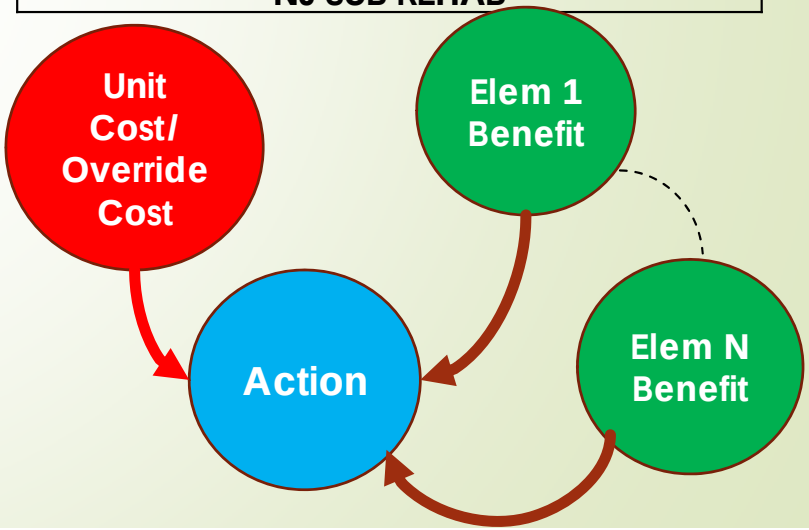
NJDOT Action-Benefit-Cost Model

- **Why Actions are needed?**
  - Representation of work to be done on the bridge
  - Proactive strategy rather than reactive
  - Predictive Modeling and Forecasting performance
  - Optimal action at an optimal time
- **Why Benefits are Needed?**
  - To claim future credit for a future action
  - Overall goal is to keep the asset in a State of Good Repair
  - To mitigate deterioration
- **Why Cost Modeling is needed?**
  - Common unit of measure for comparison is $
  - MAP-21 requires – Minimum Practical Cost
- **These modeling concepts are collectively used in BrM 5.2.3 Optimization**

NJDOT Action-Benefit-Cost Model

- Initial setup include creating seven (7) NJDOT **Actions**
- NJDOT approach:
  - **Less** number of major Actions for initial setup, and
  - **More** granular Benefit groups
- Network Level actions created
- Scope-based actions
  - Complete Scope - Bridge Replacement
  - Limited Scope – Deck and/or Super Replacement
  - Bridge preservation scope
- Future Needs:
  - Include bridge maintenance actions
  - Include more granular preservation actions
  - Focus on bridge level actions also

NJDOT Actions used in BrM 5.2.3 for Initial TAMP
NJ BRIDGE REPLACE NETWORK
NJ DECK REPLACE
NJ SUPER REPLACE
NJ BRIDGE PRESERVE
NJ DECK REHAB
NJ SUPER REHAB
NJ SUB REHAB



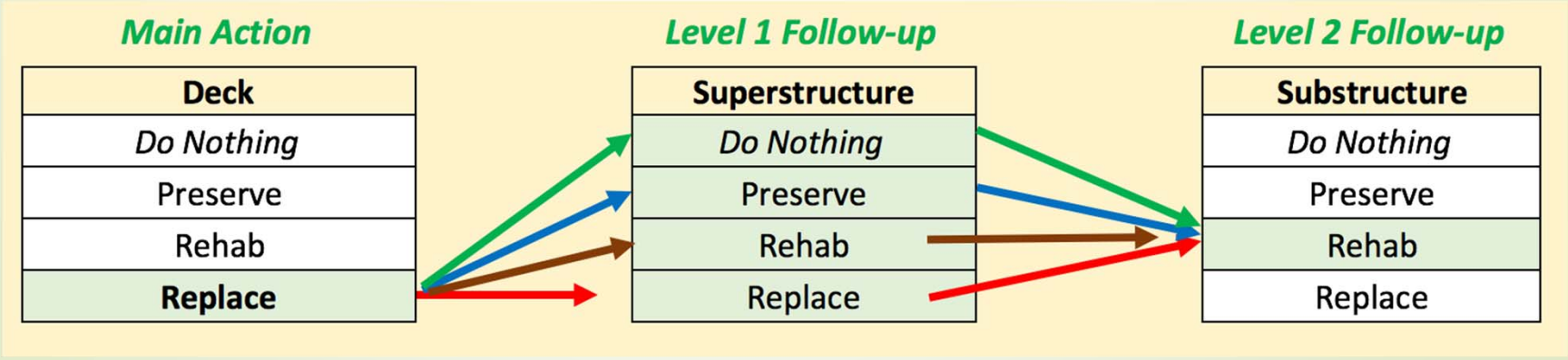
NJDOT Action-Benefit-Cost Model

- **Action Deferment Rules** for each of the action

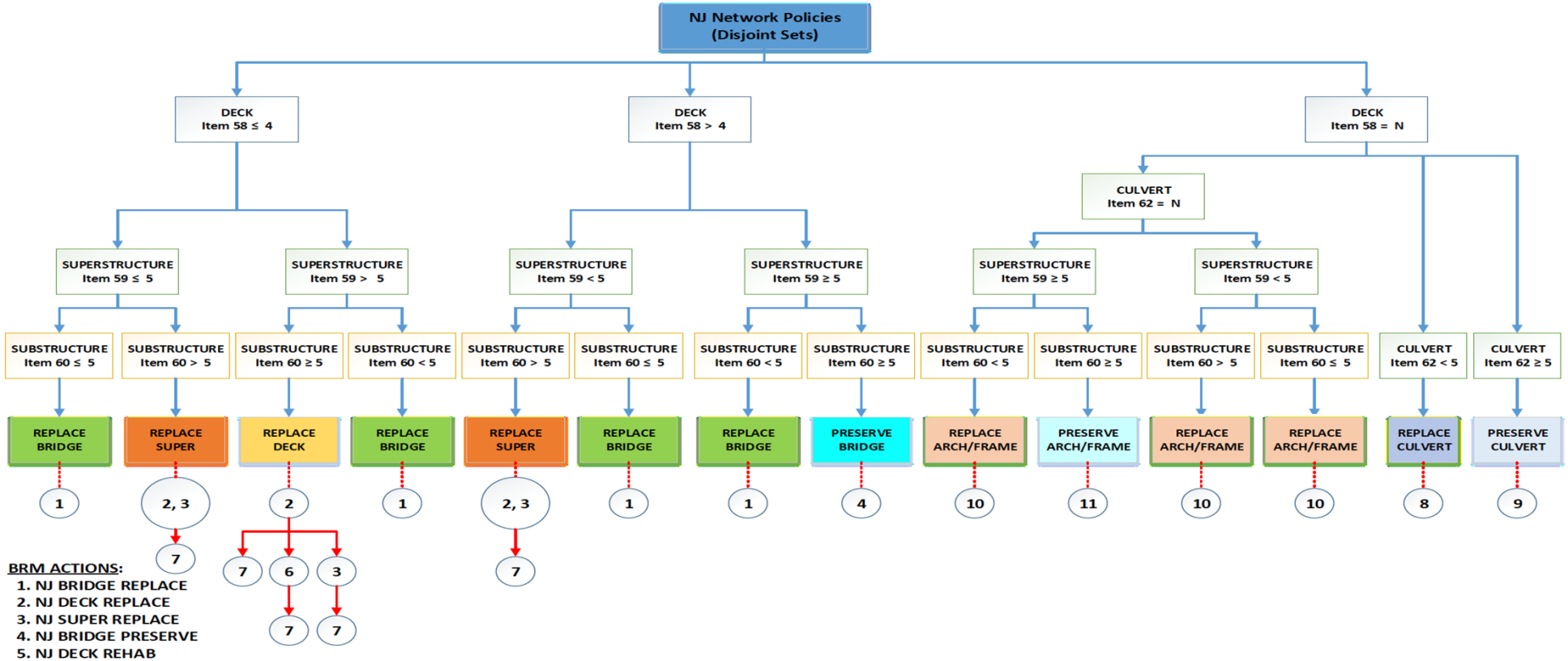
Deferment Years for each BrM 5.2.3 Action	NJ Bridge Replace Network	NJ Deck Replace	NJ Super Replace	NJ Bridge Preserve	NJ Deck Rehab	NJ Super Rehab	NJ Sub Rehab
NJ BRIDGE REPLACE NETWORK	75	35	50	10	x	x	x
NJ DECK REPLACE	40	35	30	6	x	x	x
NJ SUPER REPLACE	50	35	50	6	x	x	x
NJ BRIDGE PRESERVE	10	6	6	6	x	x	x
NJ DECK REHAB	x	x	x	x	x	x	x
NJ SUPER REHAB	x	x	x	x	x	x	x
NJ SUB REHAB	x	x	x	x	x	x	x

NJDOT Action-Benefit-Cost Model

- Initial calibration was done by focusing on **CONDITION** parameter only
- Four (4) Network Policies implemented using NBI 58, NBI 59, NBI 60, NBI 62
  - NJ Bridge Replace
  - NJ Deck Replace
  - NJ Super Replace
  - NJ Bridge Preserve
- **Follow-up actions** were included based on feasible combinations



NJDOT Action-Benefit-Cost Model



BRM ACTIONS:

1. NJ BRIDGE REPLACE
2. NJ DECK REPLACE
3. NJ SUPER REPLACE
4. NJ BRIDGE PRESERVE
5. NJ DECK REHAB
6. NJ SUPER REHAB
7. NJ SUB REHAB
8. NJ CULVERT REPLACE
9. NJ CULVERT PRESERVE
10. NJ ARCH/FRAME REPLACE
11. NJ ARCH/FRAME PRESERVE

Created -BVP_20170926 Rev3 HSB_20171101 Rev2-BVP_20170929

NJDOT Action-Benefit-Cost Model

- **Benefit Modeling** (Initially utilized Rutgers University – CAIT Team)
  - **Granular** benefit groups, Utilized **child-linking** to already created benefits
- **Future Benefit Group Modeling (ELEMENT and DEFECT Combinations)**
  - Benefit Groups for Cyclical Activities
  - **Preventive Maintenance Cyclical Activities**
  - **Condition-Based Actions for Steel Elements**
  - Condition-Based Actions for Reinforced Concrete Elements
  - Condition-Based Actions for Pre-Stressed Concrete Elements
  - Condition-Based Actions for Timber Elements
  - Condition-Based Actions for Masonry Elements
  - Condition-Based Actions for Drainage System Elements
  - Condition-Based Actions for Bearings
  - Condition-Based Actions for Joints
  - Condition-Based Actions for Protective System Elements

NJDOT Action-Benefit-Cost Model

Preventive Maintenance. Cyclical Actions

Bridge Element	Bridge Element Group	Element	Element Code	Material	BENEFIT GROUP	#	Cyclical Action	#	Action Code	Frequency (years)	Unit of measure
ADE	Bearings	Bond Breaker Bearing - Expansion/Moveable	835	Others	Cleaning - Bearings and Pedestals	01	Power Wash Bearings	28	ADE18350000028	2 years	each
NBE	Bearings	Disk Bearing	315	Others	Cleaning - Bearings and Pedestals	01	Power Wash Bearings	28	NBE13150000028	2 years	each
NBE	Bearings	Elastomeric Bearing	310	Others	Cleaning - Bearings and Pedestals	01	Power Wash Bearings	28	NBE13100000028	2 years	each
NBE	Bearings	Enclosed/Concealed Bearing	312	Others	Cleaning - Bearings and Pedestals	01	Power Wash Bearings	28	NBE13120000028	2 years	each
NBE	Bearings	Fixed Bearing	313	Others	Cleaning - Bearings and Pedestals	01	Power Wash Bearings	28	NBE13130000028	2 years	each
ADE	Bearings	Isolation Bearing	831	Others	Cleaning - Bearings and Pedestals	01	Power Wash Bearings	28	ADE18310000028	2 years	each
NBE	Bearings	Moveable (roller, sliding, etc.) Bearing	311	Others	Cleaning - Bearings and Pedestals	01	Power Wash Bearings	28	NBE13110000028	2 years	each
NBE	Bearings	Other Bearing	316	Others	Cleaning - Bearings and Pedestals	01	Power Wash Bearings	28	NBE13160000028	2 years	each
NBE	Bearings	Pot Bearing	314	Others	Cleaning - Bearings and Pedestals	01	Power Wash Bearings	28	NBE13140000028	2 years	each
ADE	Bearings	Rocker Bearing - Expansion/Moveable	833	Others	Cleaning - Bearings and Pedestals	01	Power Wash Bearings	28	ADE18330000028	2 years	each
ADE	Bearings	Sliding Plate Bearing - Expansion/Moveable	832	Others	Cleaning - Bearings and Pedestals	01	Power Wash Bearings	28	ADE18320000028	2 years	each
ADE	Bearings	Spherical Bearing	834	Others	Cleaning - Bearings and Pedestals	01	Power Wash Bearings	28	ADE18340000028	2 years	each
NBE	Substructure	Abutment	217	Masonry	Cleaning - Bearings and Pedestals	01	Power Wash Pedestals and Top of Substructure	32	NBE12170000032	2 years	ft.
NBE	Substructure	Abutment	218	Others	Cleaning - Bearings and Pedestals	01	Power Wash Pedestals and Top of Substructure	32	NBE12180000032	2 years	ft.
NBE	Substructure	Abutment	215	RC	Cleaning - Bearings and Pedestals	01	Power Wash Pedestals and Top of Substructure	32	NBE12150000032	2 years	ft.
NBE	Substructure	Abutment	219	Steel	Cleaning - Bearings and Pedestals	01	Power Wash Pedestals and Top of Substructure	32	NBE12190000032	2 years	ft.
NBE	Substructure	Abutment	216	Timber	Cleaning - Bearings and Pedestals	01	Power Wash Pedestals and Top of Substructure	32	NBE12160000032	2 years	ft.
NBE	Substructure	Pier Cap	236	Others	Cleaning - Bearings and Pedestals	01	Power Wash Pedestals and Top of Substructure	32	NBE12360000032	2 years	ft.
NBE	Substructure	Pier Cap	233	PSC	Cleaning - Bearings and Pedestals	01	Power Wash Pedestals and Top of Substructure	32	NBE12330000032	2 years	ft.
NBE	Substructure	Pier Cap	234	RC	Cleaning - Bearings and Pedestals	01	Power Wash Pedestals and Top of Substructure	32	NBE12340000032	2 years	ft.
NBE	Substructure	Pier Cap	231	Steel	Cleaning - Bearings and Pedestals	01	Power Wash Pedestals and Top of Substructure	32	NBE12310000032	2 years	ft.
NBE	Substructure	Pier Cap	235	Timber	Cleaning - Bearings and Pedestals	01	Power Wash Pedestals and Top of Substructure	32	NBE12350000032	2 years	ft.
ADE	Bearings	Bond Breaker Bearing - Expansion/Moveable	835	Others	Cleaning - Bearings and Pedestals	01	Remove Debris from Bearings	34	ADE18350000034	2 years	each
NBE	Bearings	Disk Bearing	315	Others	Cleaning - Bearings and Pedestals	01	Remove Debris from Bearings	34	NBE13150000034	2 years	each
NBE	Bearings	Elastomeric Bearing	310	Others	Cleaning - Bearings and Pedestals	01	Remove Debris from Bearings	34	NBE13100000034	2 years	each
NBE	Bearings	Enclosed/Concealed Bearing	312	Others	Cleaning - Bearings and Pedestals	01	Remove Debris from Bearings	34	NBE13120000034	2 years	each
NBE	Bearings	Fixed Bearing	313	Others	Cleaning - Bearings and Pedestals	01	Remove Debris from Bearings	34	NBE13130000034	2 years	each
ADE	Bearings	Isolation Bearing	831	Others	Cleaning - Bearings and Pedestals	01	Remove Debris from Bearings	34	ADE18310000034	2 years	each
NBE	Bearings	Moveable (roller, sliding, etc.) Bearing	311	Others	Cleaning - Bearings and Pedestals	01	Remove Debris from Bearings	34	NBE13110000034	2 years	each
NBE	Bearings	Other Bearing	316	Others	Cleaning - Bearings and Pedestals	01	Remove Debris from Bearings	34	NBE13160000034	2 years	each
NBE	Bearings	Pot Bearing	314	Others	Cleaning - Bearings and Pedestals	01	Remove Debris from Bearings	34	NBE13140000034	2 years	each
ADE	Bearings	Rocker Bearing - Expansion/Moveable	833	Others	Cleaning - Bearings and Pedestals	01	Remove Debris from Bearings	34	ADE18330000034	2 years	each
ADE	Bearings	Sliding Plate Bearing - Expansion/Moveable	832	Others	Cleaning - Bearings and Pedestals	01	Remove Debris from Bearings	34	ADE18320000034	2 years	each
ADE	Bearings	Spherical Bearing	834	Others	Cleaning - Bearings and Pedestals	01	Remove Debris from Bearings	34	ADE18340000034	2 years	each
NBE	Substructure	Abutment	217	Masonry	Cleaning - Bearings and Pedestals	01	Remove Debris from Pedestals and Top of Substructure	35	NBE12170000035	2 years	ft.
NBE	Substructure	Abutment	218	Others	Cleaning - Bearings and Pedestals	01	Remove Debris from Pedestals and Top of Substructure	35	NBE12180000035	2 years	ft.
NBE	Substructure	Abutment	215	RC	Cleaning - Bearings and Pedestals	01	Remove Debris from Pedestals and Top of Substructure	35	NBE12150000035	2 years	ft.

NJDOT Action-Benefit-Cost Model

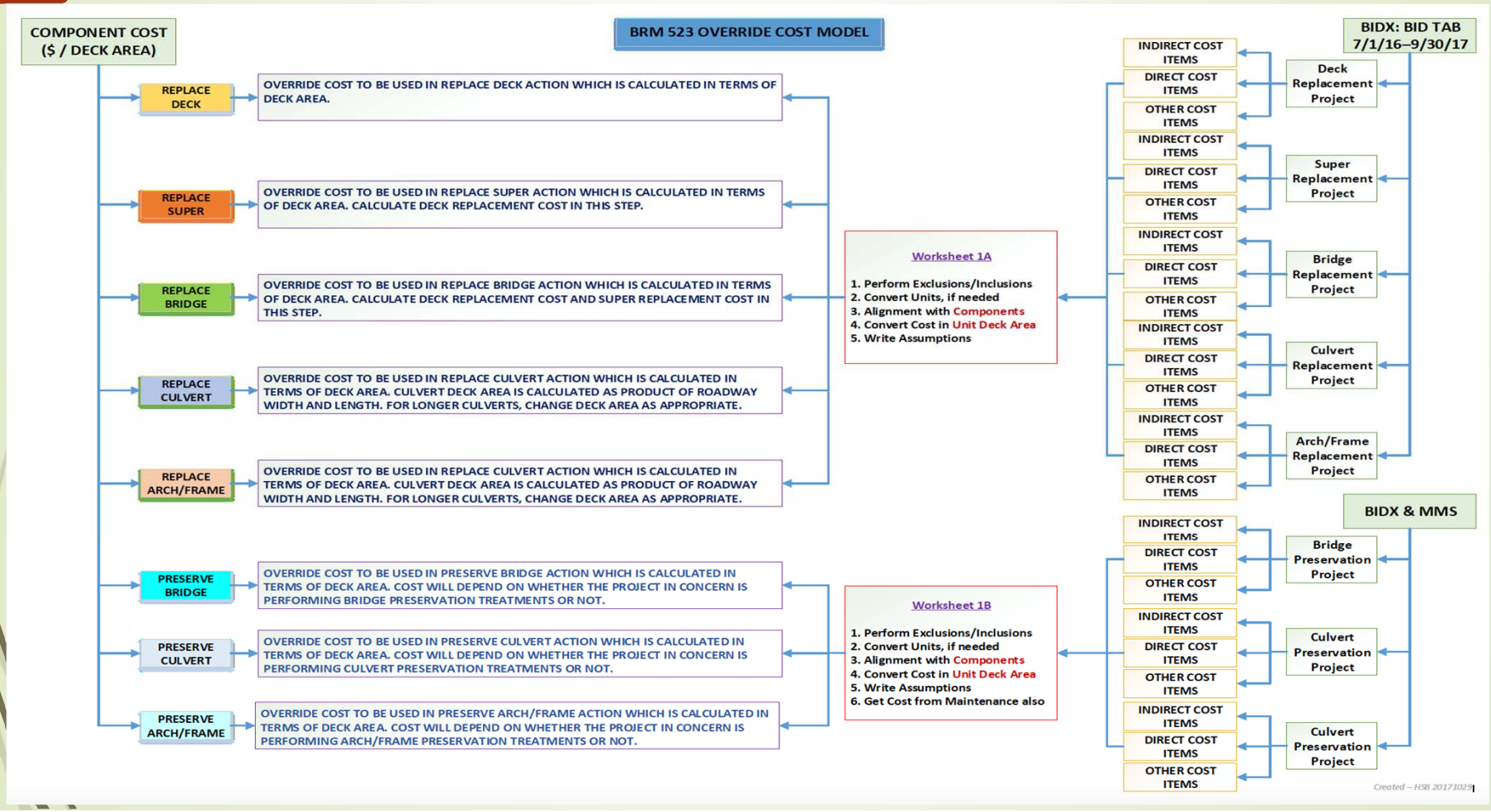
Condition-Based Actions and Defects for Steel Elements

Bridge Element	Element	Element Code	Defect	Defect #	Condition-Based Action	#	Action Code	Lower Threshold	Criteria	Benefit	Unit of measure	Cost (unit/$)	BENEFIT GROUP
NBE	Abutment	219	Connection	1020	Bolt with supplemental welds	104	NBE22191020104	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Connection	1020	Nails	124	NBE22191020124	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Connection	1020	Replace member	134	NBE22191020134	CS4> 50%	CS4 > 0	CS1	ft.		
NBE	Abutment	219	Connection	1020	Replace other fastener	135	NBE22191020135	CS4 > 0	CS3 = 25%	CS1	ft.		
NBE	Abutment	219	Connection	1020	Replace rivets or bolts	137	NBE22191020137	CS4 > 0	CS3 = 25%	CS1	ft.		
NBE	Abutment	219	Connection	1020	Weld	157	NBE22191020157	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Corrosion	1000	Cathodic protection	105	NBE22191000105	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Corrosion	1000	Laser cleaning	122	NBE22191000122	CS4 > 0	CS2 > 75%, CS3 >30%	CS2	ft.		
NBE	Abutment	219	Corrosion	1000	Painting	125	NBE22191000125	CS4 > 0	CS2 > 75%, CS3 >30%	CS1	ft.		
NBE	Abutment	219	Corrosion	1000	Protective coating	129	NBE22191000129	CS4 > 0	CS2 > 75%, CS3 >30%	CS1	ft.		
NBE	Abutment	219	Corrosion	1000	Sandblasting	139	NBE22191000139	CS4 > 0	CS2 > 75%, CS3 >30%	CS1	ft.		
NBE	Abutment	219	Corrosion	1000	Spot coating	141	NBE22191000141	CS4 > 0	CS2 > 25%	CS1	ft.		
NBE	Abutment	219	Corrosion	1000	Substructure restoration	143	NBE22191000143	CS4 > 0	CS4 > 0%	CS1	ft.		
NBE	Abutment	219	Cracking (Steel)	1010	Hole Drilling	119	NBE22191010119	CS4 > 0	CS3 > 30%	CS2	ft.		
NBE	Abutment	219	Cracking (Steel)	1010	Substructure restoration	143	NBE22191010143	CS4 > 0	CS4 > 0%	CS1	ft.		
NBE	Abutment	219	Cracking (Steel)	1010	Surface Treatment - Gas tungsten arc (GTA) Remelting	145	NBE22191010145	CS4 > 0	CS3 > 30%	CS2	ft.		
NBE	Abutment	219	Cracking (Steel)	1010	Surface Treatment - Peening Impact Treatment	146	NBE22191010146	CS4 > 0	CS3 > 30%	CS2	ft.		
NBE	Abutment	219	Cracking (Steel)	1010	Surface Treatment - Reshape by grinding (burr or disc)	147	NBE22191010147	CS4 > 0	CS3 > 30%	CS2	ft.		
NBE	Abutment	219	Cracking (Steel)	1010	Surface Treatment - Ultrasonic Impact Treatment	148	NBE22191010148	CS4 > 0	CS2 > 75%, CS3 >30%	CS2	ft.		
NBE	Abutment	219	Cracking (Steel)	1010	Vee-and-Weld	149	NBE22191010149	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Cracking (Steel)	1010	Weld	157	NBE22191010157	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Damage	7000	Replace member	134	NBE22197000134	CS4> 50%	CS4 > 0	CS1	ft.		
NBE	Abutment	219	Damage	7000	Replace section	138	NBE22197000138	CS4> 50%	CS4 > 0	CS1	ft.		
NBE	Abutment	219	Damage	7000	Substructure Restoration	143	NBE22197000143	CS4 > 0	CS4 > 0%	CS1	ft.		
NBE	Abutment	219	Distortion	1900	Bolt loosening	103	NBE22191900103	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Distortion	1900	Doubler / Splice plate addition	112	NBE22191900112	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Distortion	1900	Hole drilling	119	NBE22191900119	CS4 > 0	CS3 > 30%	CS2	ft.		
NBE	Abutment	219	Distortion	1900	Substructure Restoration	143	NBE22191900143	CS4 > 0	CS4 > 0%	CS1	ft.		
NBE	Abutment	219	Distortion	1900	Web-gap softening - Gross material removal	150	NBE22191900150	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Distortion	1900	Web-gap softening - Large hole retrofit	151	NBE22191900151	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Distortion	1900	Web-gap stiffening - Adhesives	152	NBE22191900152	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Distortion	1900	Web-gap stiffening - Bolted connection	153	NBE22191900153	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Distortion	1900	Web-gap stiffening - Hybrid connection	154	NBE22191900154	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Distortion	1900	Web-gap stiffening - Nails	155	NBE22191900155	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Distortion	1900	Web-gap stiffening - Welded attachment	156	NBE22191900156	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Scour	6000	Armoring Device - Planting vegetation	101	NBE22196000101	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Scour	6000	Armoring Device - Riprap, gabions, blocks, tires	102	NBE22196000102	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Scour	6000	Channel Modification - Concrete or bituminous pavement	106	NBE22196000106	CS4 > 0	CS3 = 25%	CS2	ft.		
NBE	Abutment	219	Scour	6000	Channel Modification - Dredging, clearing of channel	107	NBE22196000107	CS4 > 0	CS3 = 25%	CS2	ft.		

NJDOT Action-Benefit-Cost Model

- Initial **Cost Modeling** setup by using BrM 5.2.3 **OVERRIDE COST BY DECK AREA**
  - For each of the **seven (7) NJDOT Action** in BrM 5.2.3
  - Analysis done by using actual Construction cost from Bid Express (**BidX**)
  - Project by project analysis performed
  - Data used from years **2015, 2016, 2017**
- **Component level** Costs were evaluated by prorating the total bridge and project cost
  - About 121 bridges were analyzed for component cost evaluation
- **Future Cost Modeling: Element level Unit Costs**
  - Construction ITEMS Units **versus** BrM 5.2.3 ELEMENT Units
  - Cost of $1 is same
  - Needs alignment of quantities
  - Validate by utilizing Rutgers University - RIME Team

NJDOT Action-Benefit-Cost Model

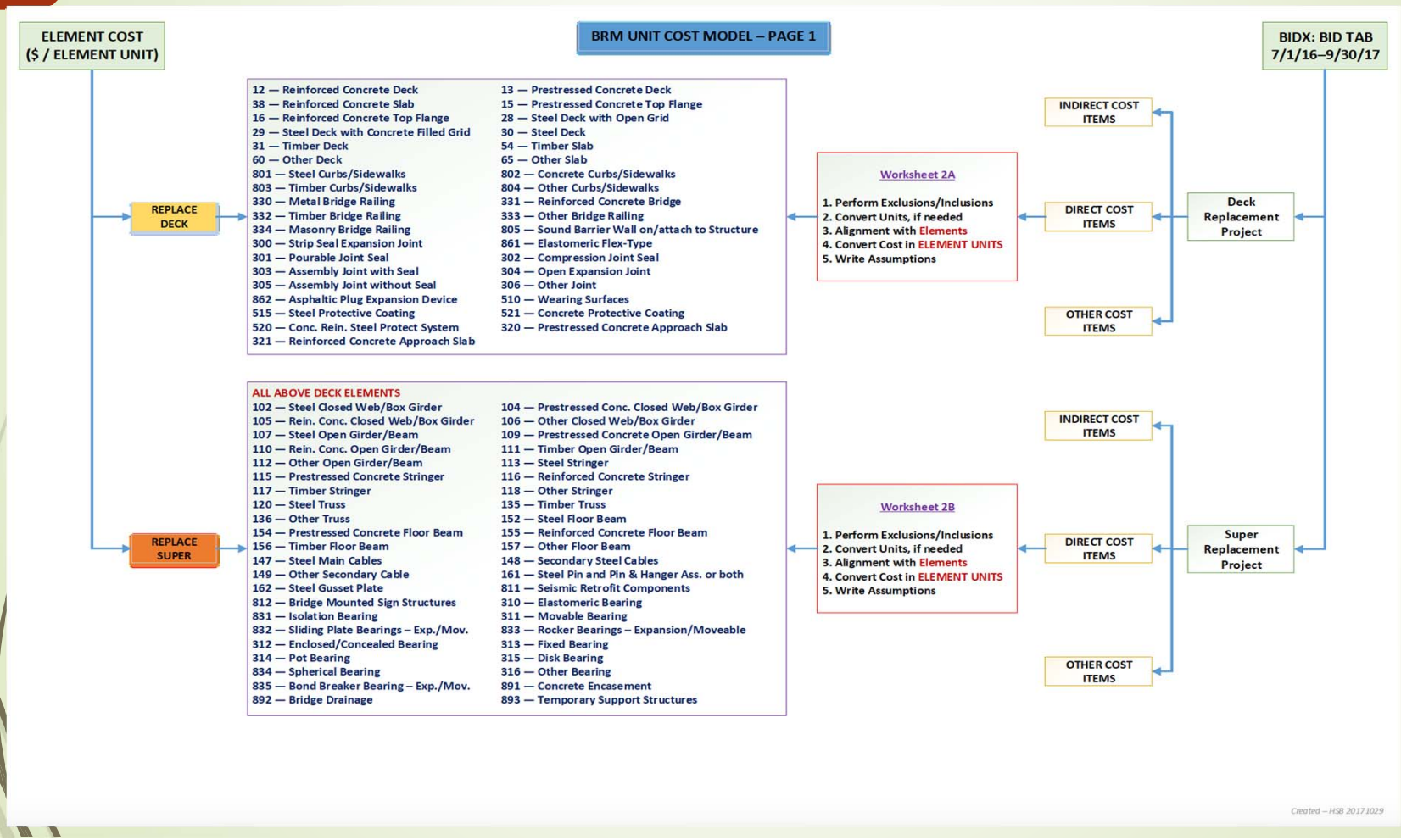


NJDOT Action-Benefit-Cost Model

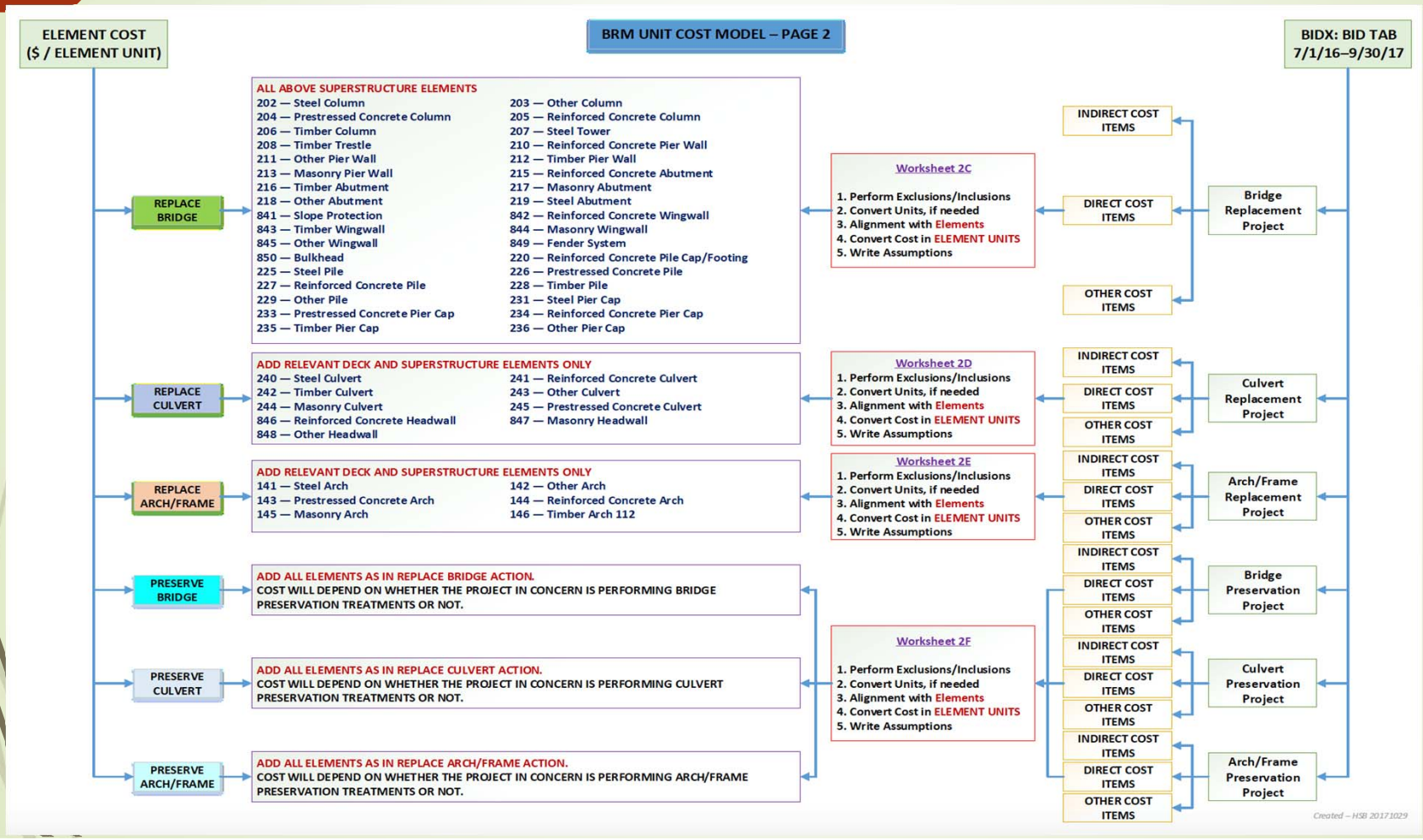
- Initial **Action Override Cost** by Component level approach

NJDOT Actions in BrM 5.2.3	Direct Construction Cost in $ per Deck Area SF	Indirect Construction Cost in % of Direct Construction Cost	Total Construction Cost in $ per Deck Area SF	Other Cost in % of Total Construction Cost	Total Cost in $ per Deck Area SF	BrM 523 Overriding Cost in $ per Deck Area in SF	BrM 523 Indirect Cost in % of Overriding Cost
NJ BRIDGE REPLACE	$1,081	18%	$1,278	60%	$2,045	$1,672	18%
NJ DECK REPLACE	$264	19%	$314	30%	$408	$330	19%
NJ SUPER REPLACE	$444	21%	$538	30%	$700	$552	21%
NJ BRIDGE PRESERVE	$125	10%	$138	0%	$138	$125	10%
NJ DECK REHAB	$75	15%	$86	0%	$86	$75	15%
NJ SUPER REHAB	$90	15%	$104	0%	$104	$90	15%
NJ SUB REHAB	$75	15%	$86	0%	$86	$75	15%

NJDOT Action-Benefit-Cost Model

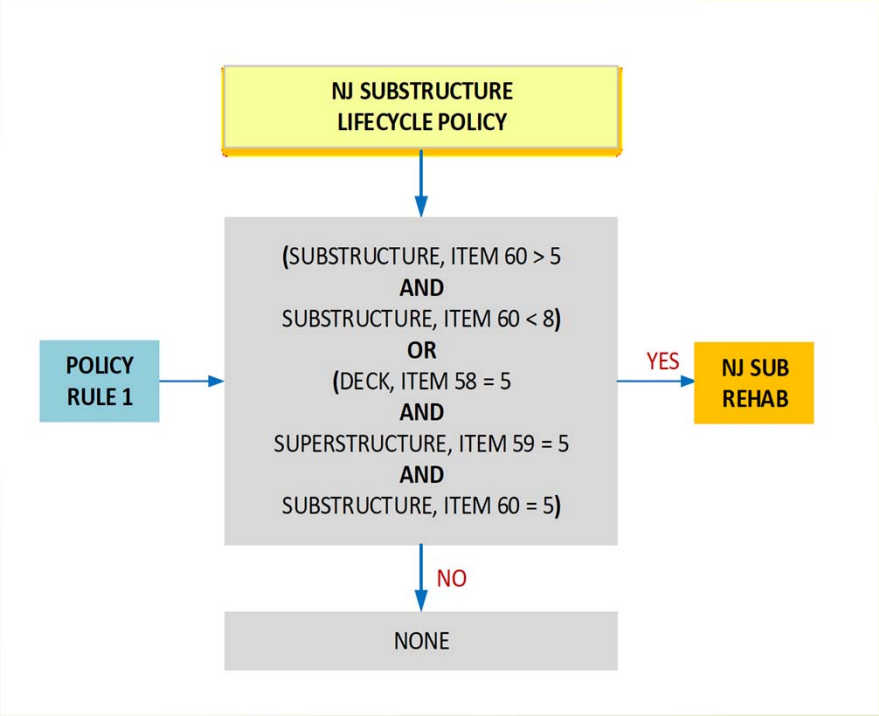


NJDOT Action-Benefit-Cost Model

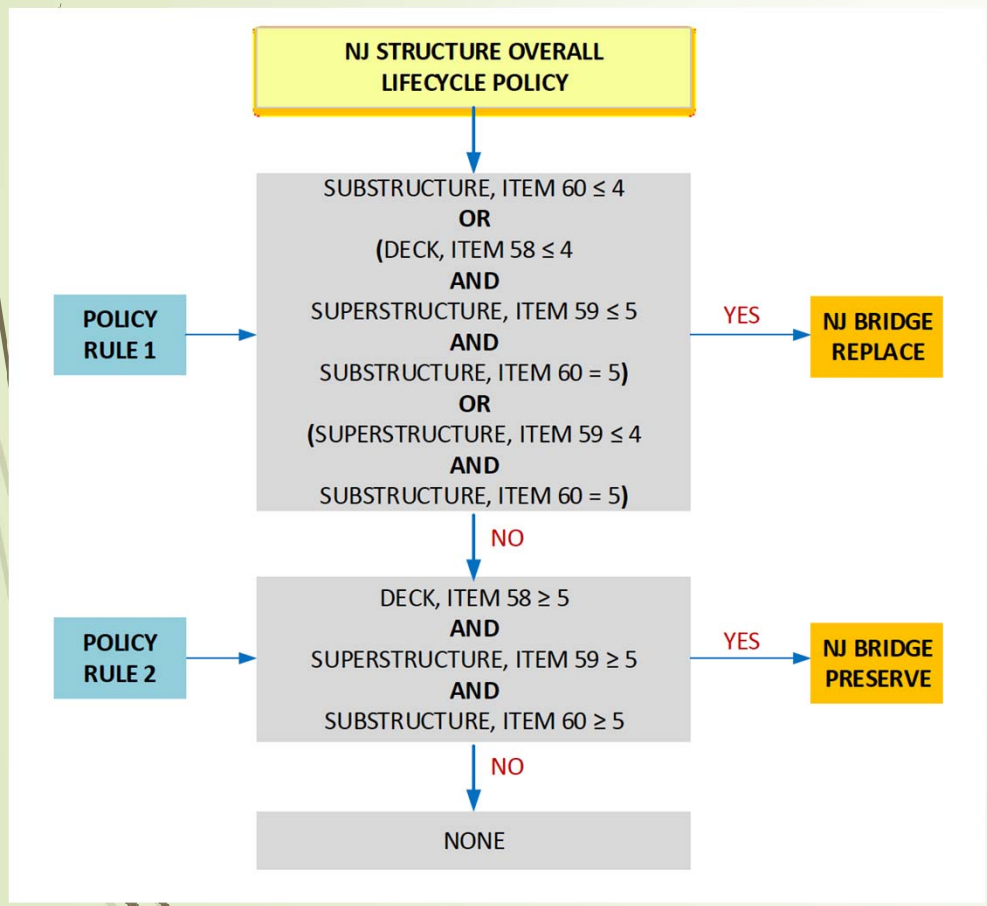


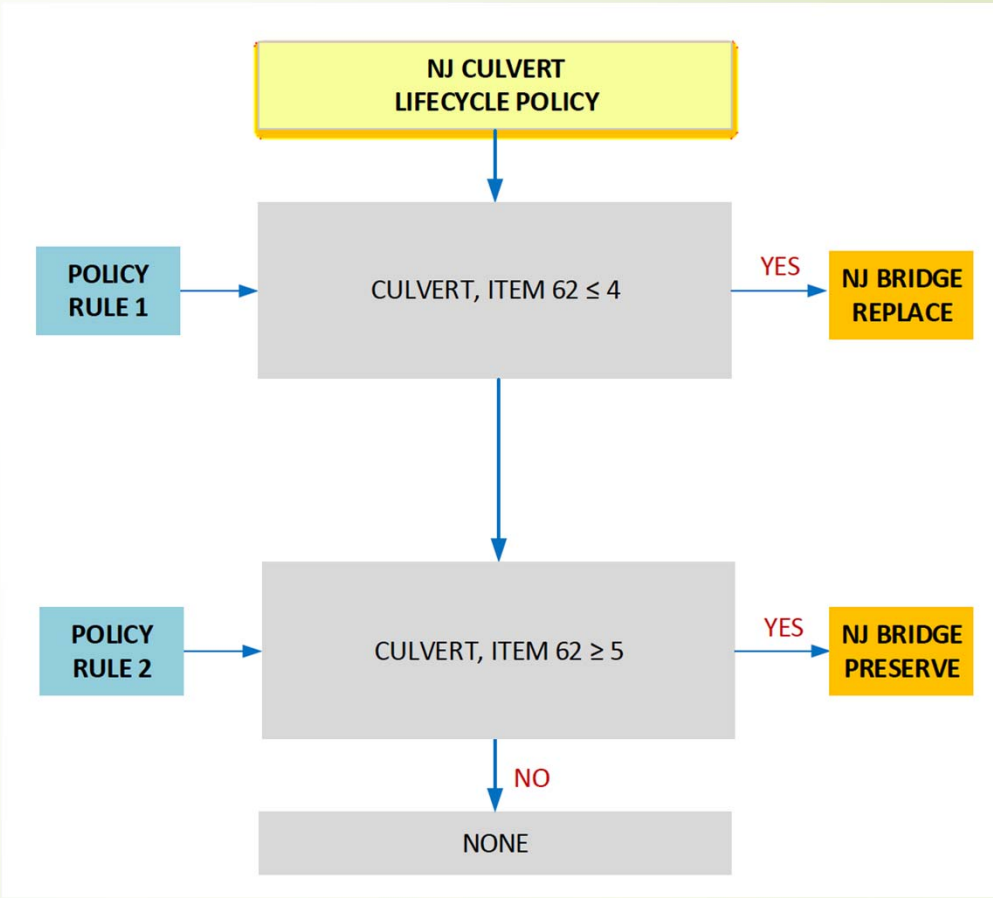
NJDOT Life Cycle Policies

- Life Cycle Policy is independent of budget constraints, but considers conditions, cost, NPV
- Preservation & Replacement Policy
  - **5 Policies** created by NJDOT
  - Each policy includes multiple LCCA Policy Rules listed in order for implementation
- **LCCA Policy Rules**
  - In this case, each rule is assigned to one resulting action
  - Rules are based on NBI Component ratings (Item 58, 59, 60 & 62)
- **LCCA Assign Policies**
  - Life Cycle Policies are applied to each bridge asset

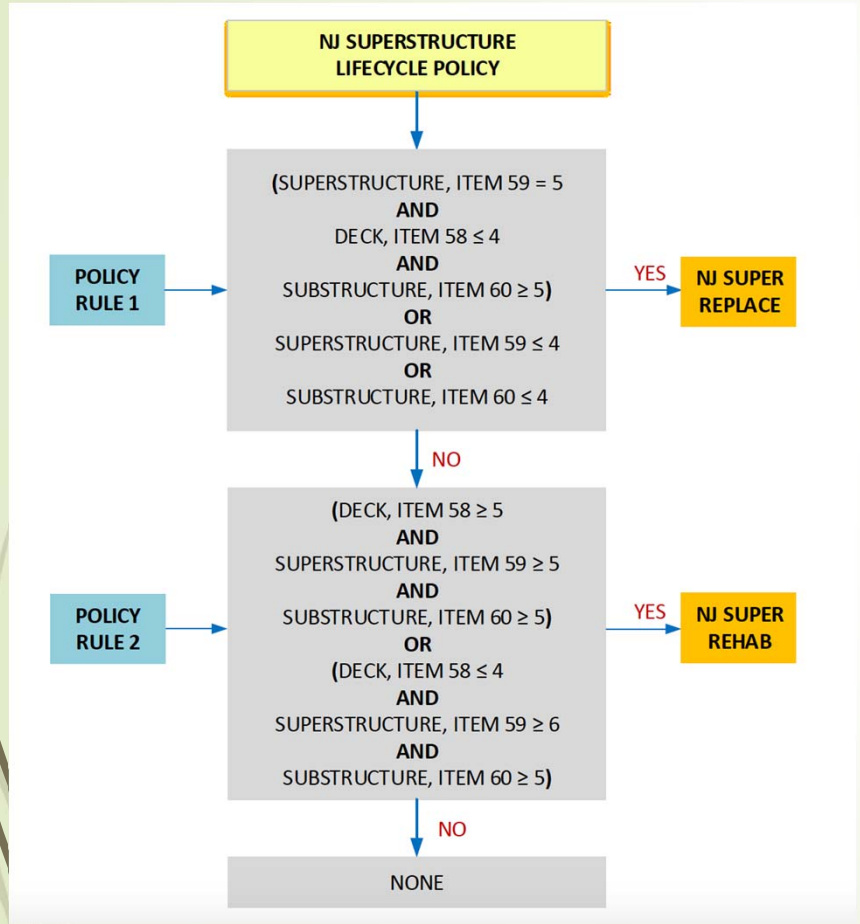


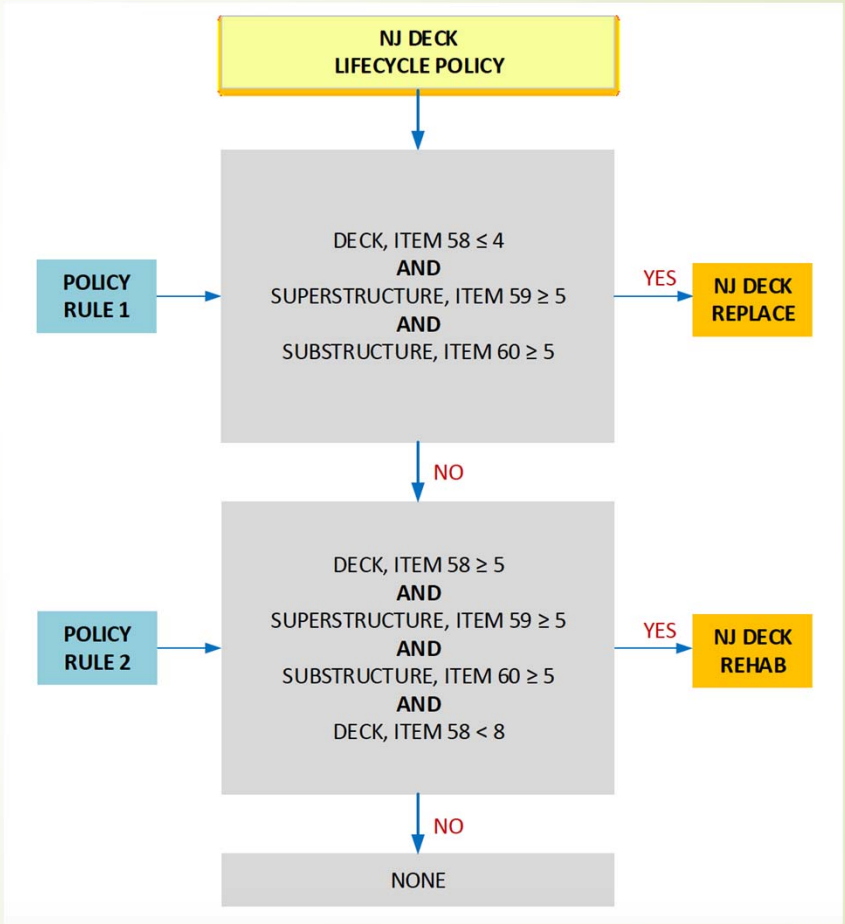
NJDOT Life Cycle Policies



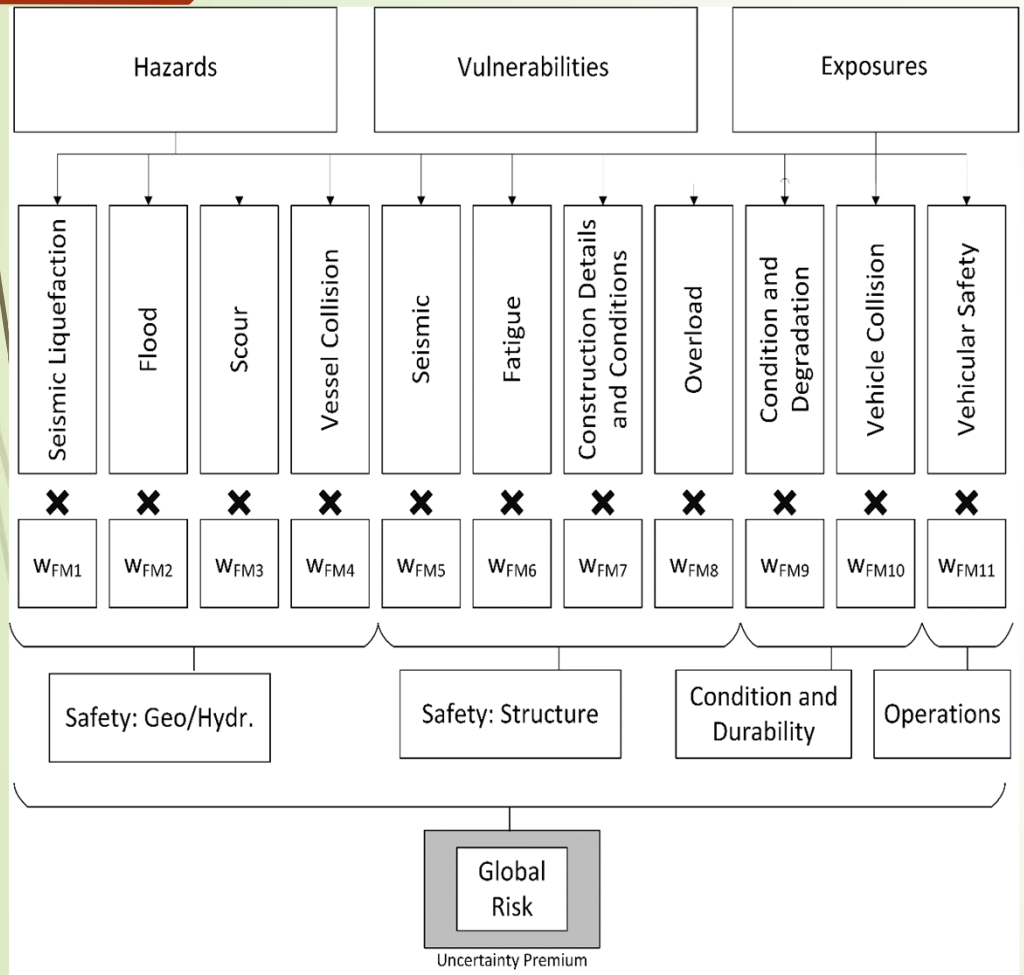


NJDOT Life Cycle Policies



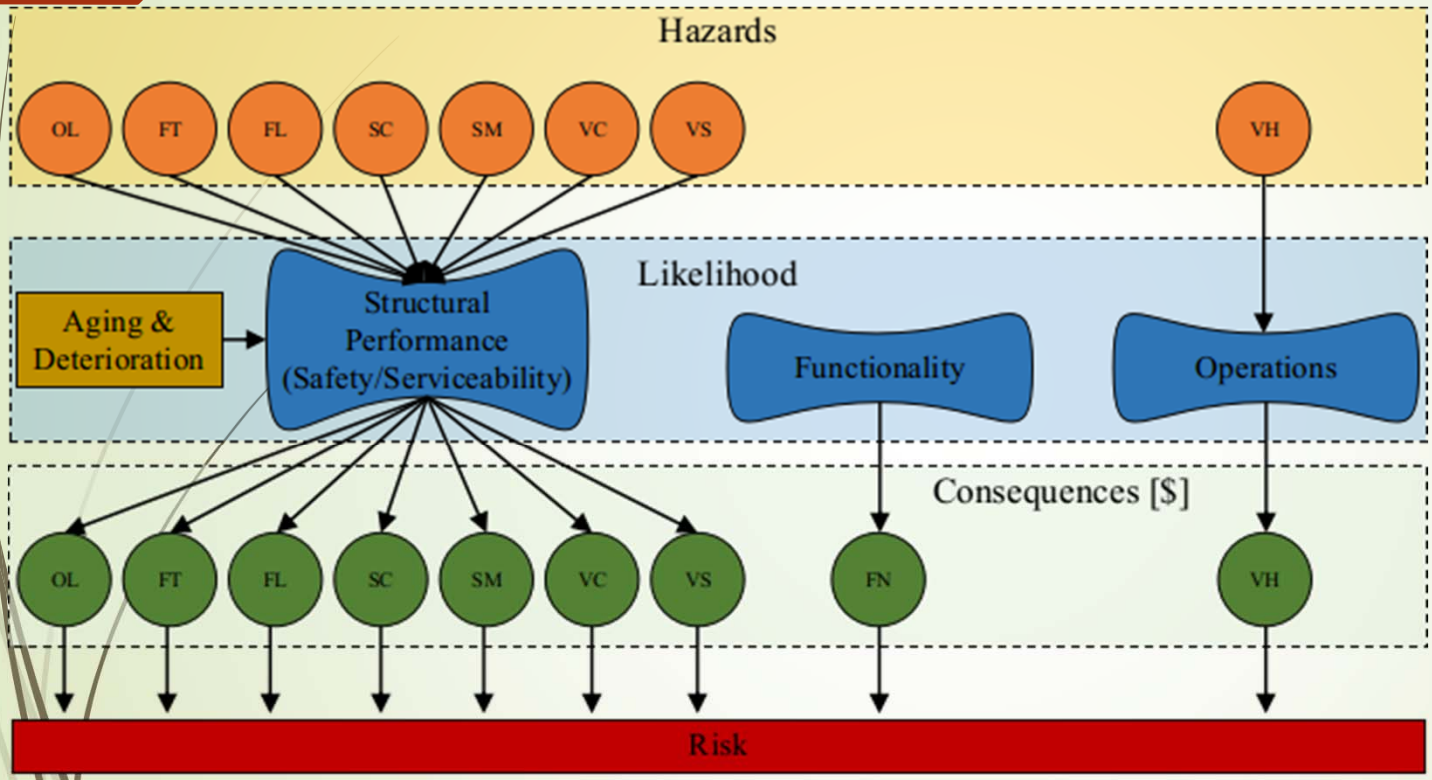


NJDOT Risk-Based Analysis Model



- **Initial RBP Tool by Rutgers University – CAIT**
- Seismic Liquefaction (Safety: Geotech/Hydraulic)
- Flood (Safety: Geotech/Hydraulic)
- Scour (Safety: Geotech/Hydraulic)
- Vessel Collision (Safety: Geotech/Hydraulic)
- Seismic (Safety: Structural)
- Fatigue (Safety: Structural)
- Construction Details & Conditions (Safety: Structural)
- Overload (Safety: Structural)
- Durability (Condition and Durability)
- Vehicle Collision (Condition and Durability)
- Vehicular Safety (Operations)

NJDOT Risk-Based Analysis Model



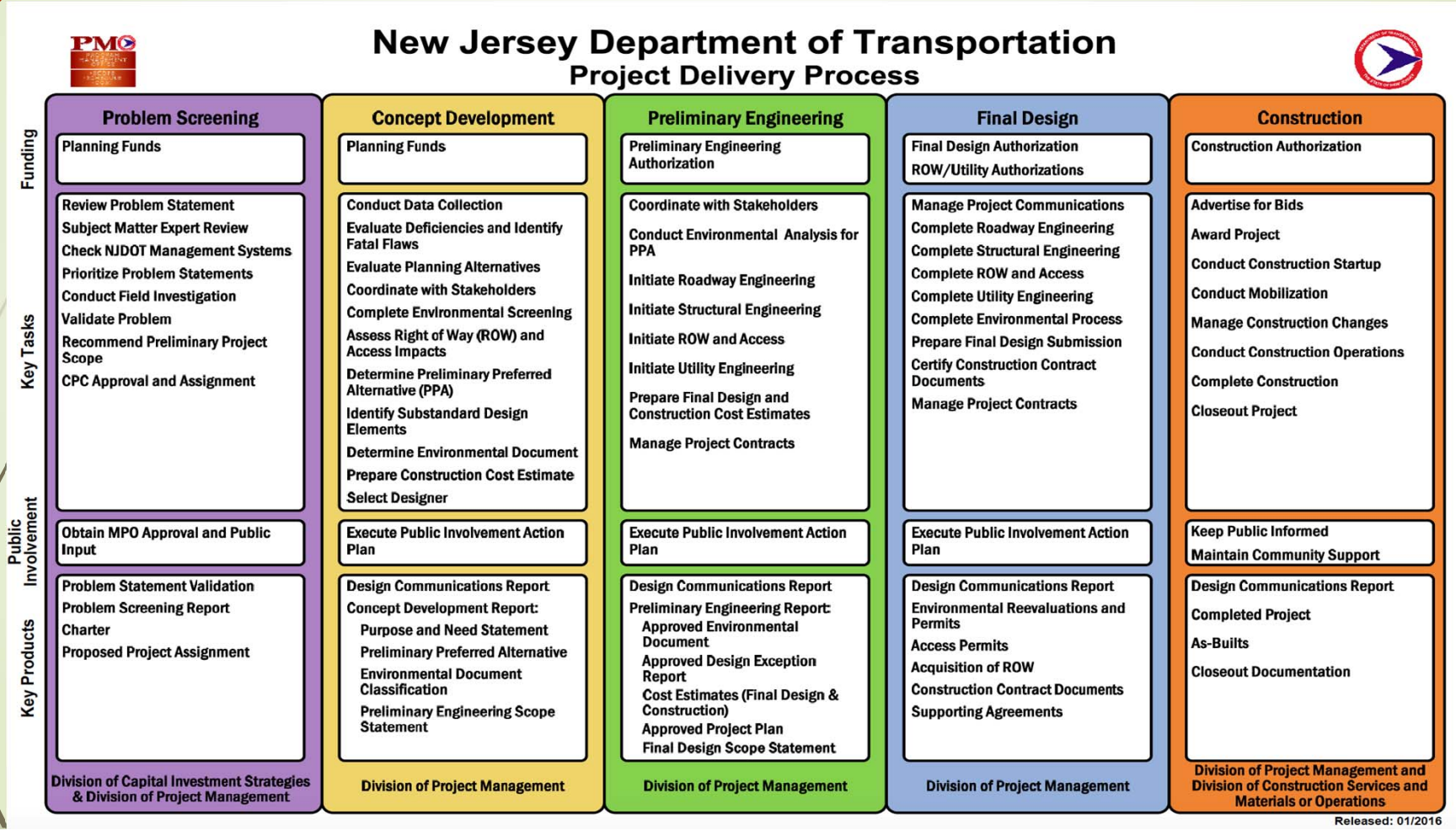
$$\text{Risk} = \sum_i P_{f,i} C_i$$

- **Refined by Graziano Fiorillo, PhD (RIME Team)**
- More aligned with BrM 5.2.3 Risk Module
- Includes Probabilistic approach rather than cumulative
- 2-Dimensional concept
- Will be used for Bridge-Bridge Risk Assessment in BrM 5.2.3
- Consequences correlates directly to BrM Risk Assessments and Risk Utility value

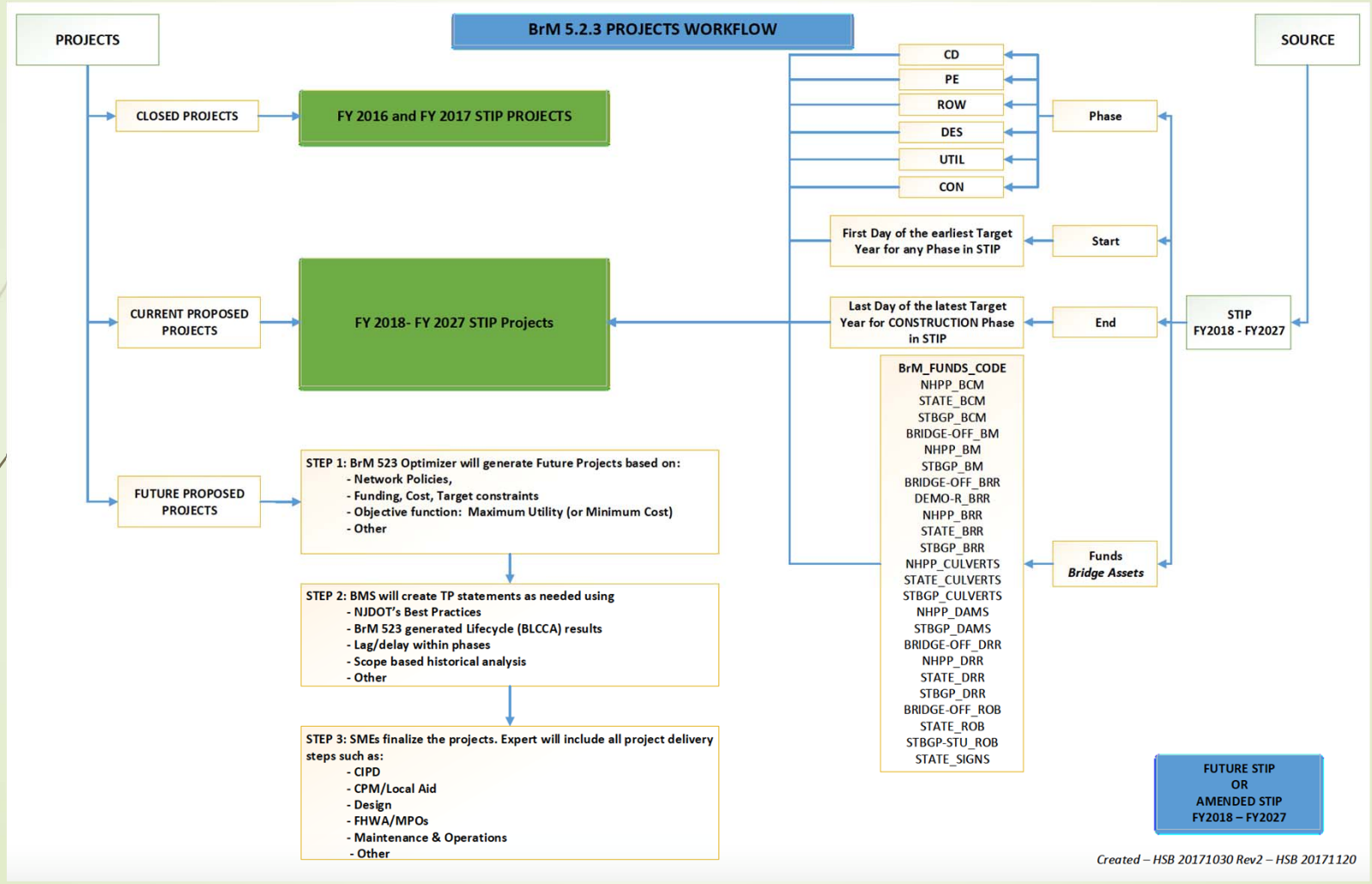
OL : Overload
FT : Fatigue
FL : Flooding/Scour
SM: Seismic
VC : Vehicle Collision
VS : Vessel Collision
VH: Vehicular Accidents

Source: Rutgers University – RIME Team

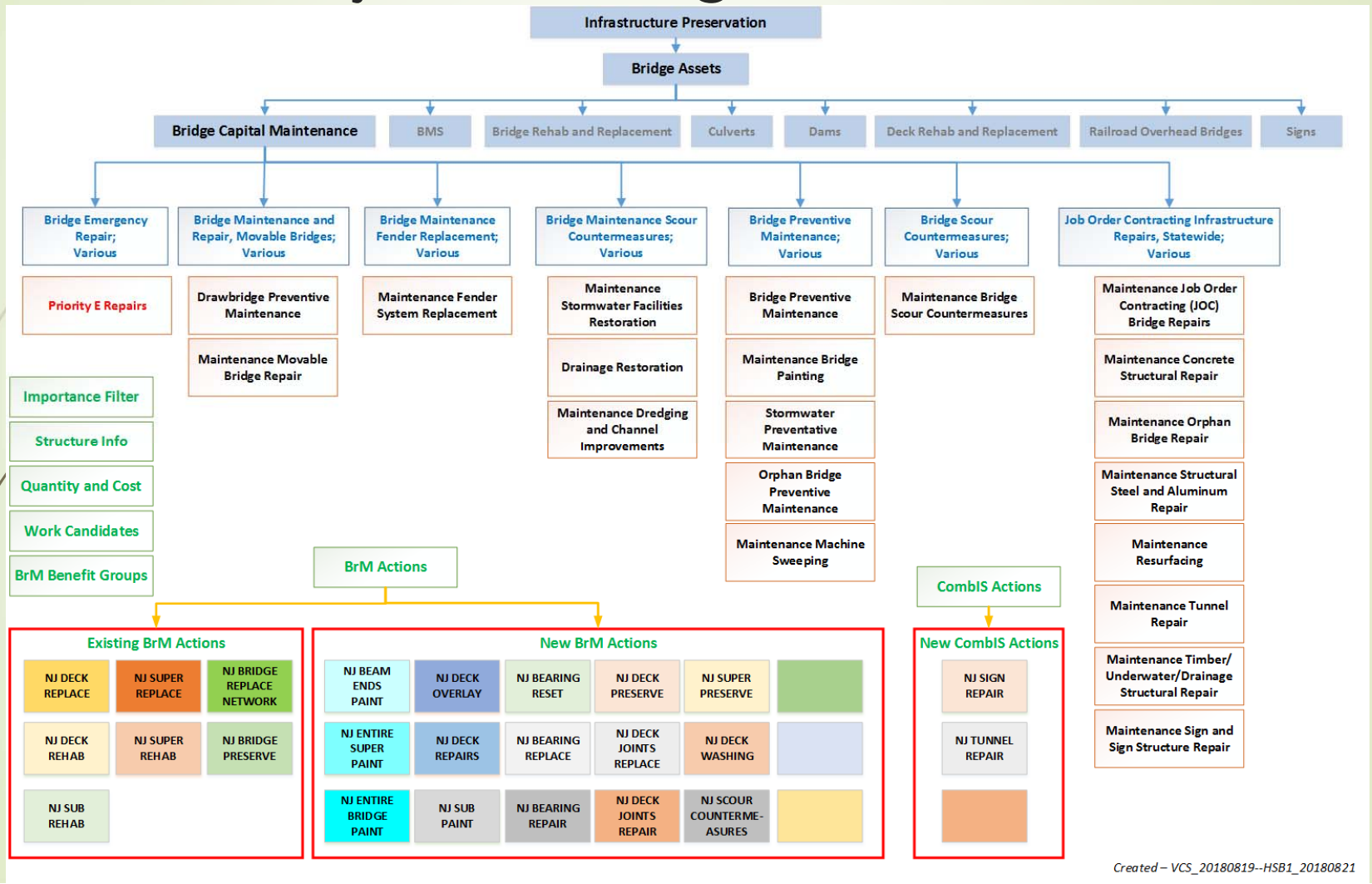
NJDOT Projects & Program Model



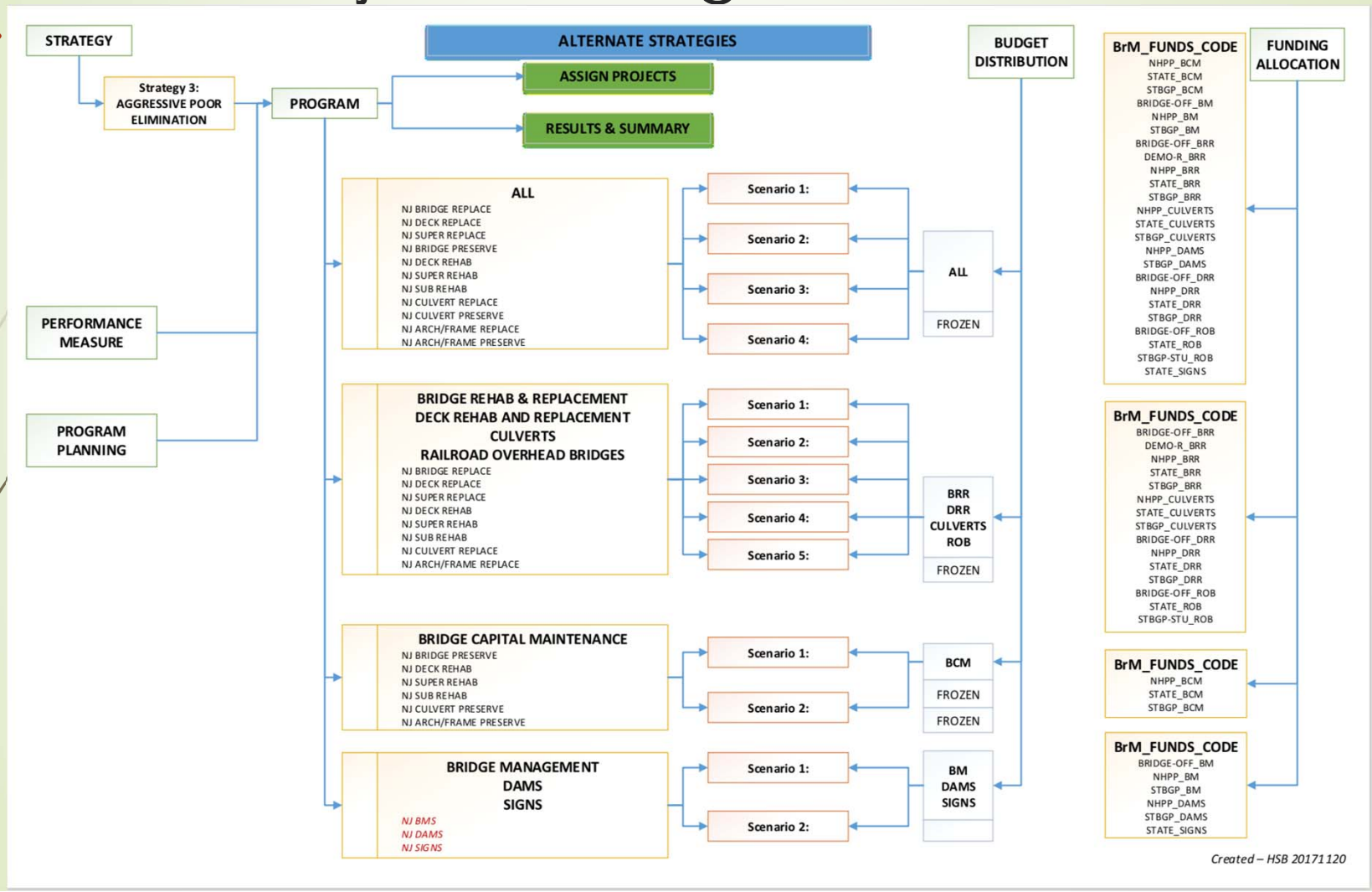
NJDOT Projects & Program Model



NJDOT Projects & Program Model



NJDOT Projects & Program Model



NJDOT Projects & Program Model

- **Program Input in BrM 5.2.3**
  - Program Name, Time period, Bridge Filter
  - Scenarios – SOGR versus Constrained
  - NBI Convertor
  - Inflation and Discount rates
  - Network Policies

Table 2A: General PROGRAM INPUTS - State Maintained NBIS Bridges

Index	Program Name	Program Status	Program Start	Program End	Program Objective	Program Bridge Filter	Total Bridges Analyzed
2A_01	NJ-Replacement-Future-Projects	Planned	2016	2027	Undefined	NJ - Highway Carrying State Maintained Non-Programmed NBIS Bridges	2484

Table 2B: PROGRAM Scenarios - State Maintained NBIS Bridges

Index	Scenarios Used
2B_01	CON1-AVAIL-FUNDS
2B_02	CON2-AVAIL-FUNDS-PLUS-100M
2B_03	CON3-AVAIL-FUNDS-PLUS-25PER-OF-BUDGET
2B_04	CON4-AVAIL-FUNDS-MINUS-25PER-OF-BUDGET
2B_05	CON5-AVAIL-FUNDS-PLUS-200M
2B_06	DEFAULT
2B_07	SGR1-610M-PER-YEAR
2B_08	SGR2-720M-PER-YEAR
2B_09	SGR3-1220M-PER-YEAR

Table 2C: PROGRAM Configuration Data - State Maintained NBIS Bridges

Index	NBI Deterioration Method	NBI Converter Profile	Long-Term Analysis Period	Discount Rate	Inflation Rate	Inflation Estimation method	Used Residual HiX Approximation
2C_01	NBI Converter	NJ Default	50	0.00%	3.00%	Fixed Inflation Rate	Yes

Table 2D: PROGRAM Network Policies - State Maintained NBIS Bridges

Index	Network Policies Used
2D_01	NJ Deck Replace
2D_02	NJ Super Replace
2D_03	NJ Bridge Replace
2D_04	NJ Bridge Preserve

Table 2E: PROGRAM Utility Weight Profile - State Maintained NBIS Bridges

Index	Utility Profile Used	Condition	LifeCycle	Mobility	Risk
2E_01	NJDOT Weight Profile 1	91	3	3	3

NJDOT Projects & Program Model

- **Program Input in BrM 5.2.3 cont..**
  - Utility Tree Weight Profiles
    - Condition
    - Life Cycle
    - Mobility
    - Risk
  - Subdivisions
    - NHS
    - Non-NHS

Table 2F: PROGRAM Utility Weight Condition Profile - State Maintained NBIS Bridges

Index	Utility Condition Profile	Element Ratings	NBI Ratings
2F_01	NJDOT Weight Profile 1	90	10

Table 2G: PROGRAM Utility Weight Element Condition Profile - State Maintained NBIS Bridges

Index	Utility Element Condition Profile	Bearing Elements	Culvert Elements	Deck/Slabs Elements	Joints Elements	Substructure Elements	Superstructure Elements
2G_01	NJDOT Weight Profile 1	15	25	25	15	25	25

Table 2H: PROGRAM Utility Weight NBI Condition Profile - State Maintained NBIS Bridges

Index	Utility NBI Condition Profile	Culverts	Deck	Substructure	Superstructure
2H_01	NJDOT Weight Profile 1	33	33	33	33

Table 2I: PROGRAM Utility Weight Mobility Profile - State Maintained NBIS Bridges

Index	Utility Mobility Profile	NBI 72 Approach Roadway Alignment	NBI 68 Deck Geometry	NBI 19 Detour Length	NBI 70 Posting	NBI 69 Underclearances
2I_01	NJDOT Weight Profile 1	15	25	15	25	20

Table 2J: PROGRAM Subdivision Profile - State Maintained NBIS Bridges

Index	Utility Risk Profile	NBI 61 Channel and Channel Protection	NBI 92a Fracture Critical	NBI 70 Posting	NBI 113 Scour Critical	NBI 69 Underclearances	NBI 71 Waterway Adequacy
2J_01	NJDOT Weight Profile 1	10	20	20	30	20	10

Table 2K: PROGRAM Utility Weight Risk Profile - State Maintained NBIS Bridges

Index	Subdivision Profile	Segment	Count of Bridges	Sum of Deck Area	% By Count	% By Deck Area
2K_01	NJ-Subdivision_01	Not On NHS	749	6,654,386	30.15%	19.37%
2K_02	NJ-Subdivision_01	On NHS	1,735	27,693,389	69.85%	80.63%
Total			2,484	34,347,775		

Source: FACTSHEET 2017 (Data Ending 2016) - Final Data As of 4/18/2017

NJDOT Projects & Program Model

- **Desired Performance Measure/Target Settings in BrM 5.2.3**
  - Built-in Performance Measures such as
    - Percent POOR by Deck Area
    - Percent GOOD by Deck Area
  - Best and Worst Value settings
  - Separate settings by subdivisions - NHS and Non-NHS

Program	Scenario	Utility BEST Value	Utility WORST Value	% POOR BEST Value	% POOR WORST Value	% GOOD BEST Value	% GOOD WORST Value	NHS Utility MIN Goal	NHS Utility MAX Goal	NHS % POOR Goal by Deck Area	NHS % GOOD Goal by Deck Area
NJ-Replacement-Future-Projects	CON1-AVAIL-FUNDS	100	0	0	100	100	0	40	60	6	45
NJ-Replacement-Future-Projects	CON2-AVAIL-FUNDS-PLUS-100M	100	0	0	100	100	0	40	60	6	45
NJ-Replacement-Future-Projects	CON3-AVAIL-FUNDS-PLUS-25PER-OF-BUDGET	100	0	0	100	100	0	40	60	6	45
NJ-Replacement-Future-Projects	CON4-AVAIL-FUNDS-MINUS-25PER-OF-BUDGET	100	0	0	100	100	0	40	60	6	45
NJ-Replacement-Future-Projects	CON5-AVAIL-FUNDS-PLUS-200M	100	0	0	100	100	0	40	60	6	45
NJ-Replacement-Future-Projects	DEFAULT	100	0	0	100	100	0	40	60	6	45
NJ-Replacement-Future-Projects	SGR1-610M-PER-YEAR	100	0	0	100	100	0	40	60	6	45
NJ-Replacement-Future-Projects	SGR2-720M-PER-YEAR	100	0	0	100	100	0	40	60	6	45
NJ-Replacement-Future-Projects	SGR3-1220M-PER-YEAR	100	0	0	100	100	0	40	60	6	45

NJDOT Projects & Program Model

- *Source: BrM Technical Manual (NJDOT BMS Manual development is in progress)*
- **Purpose of Optimization** under Program Planning Module in BrM 5.2.3
  - Automatically Generates Project Recommendation by Programs
  - **Maximize Utility and Performance Benefits under specific constraints**
- Project Selection Framework during BrM 5.2.3 Optimization
  - Divide available funding for each year by Subdivisions & estimate initial scores
    - UTILITY Value for current conditions
    - PERFORMANCE Measure for current conditions
  - Determine Allowable ACTIONS based on
    - Network Policies

NJDOT Projects & Program Model

- For each Combination, calculate
  - PROJECT Score

$$S_{PROJ} = W_S \times \frac{\Delta U}{Cost}$$

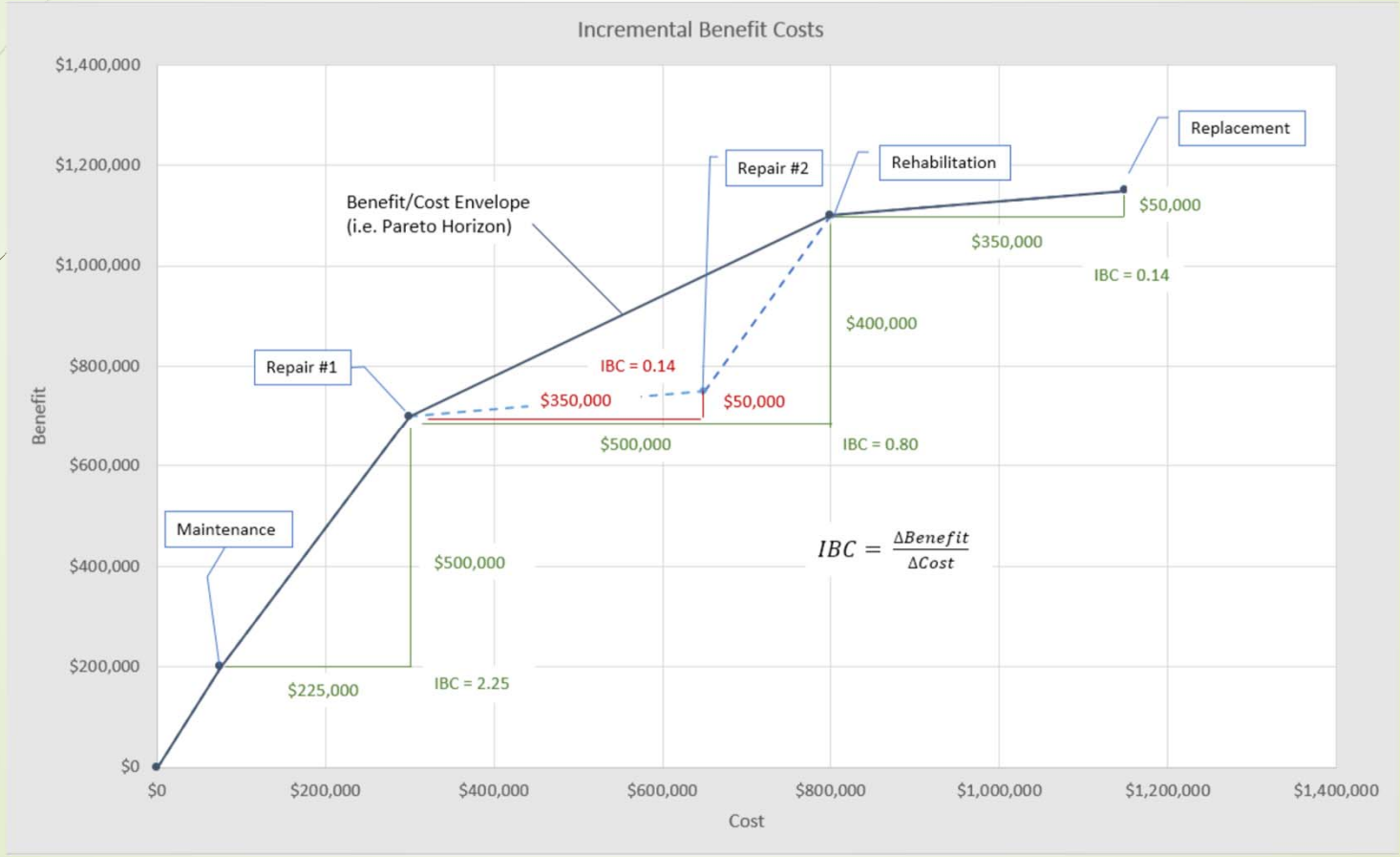
  - PERFORMANCE MEASURE Score

$$S_{PM} = W_S \times \frac{\Delta PM}{Cost}$$

- Structure Weights
  - play a significant role in the scoring of projects and the related performance measures
  - to help determine the relative importance between bridges
  - NJDOT is currently developing factors for Structure Weight based on Importance, Size, Location

NJDOT Projects & Program Model

- PICK Preferred Project Alternatives for each bridge based on **Incremental Benefit Costs**



JJ14

Slide 66

JJ14 remove entire 7 step approach

Joshua Johnson, 7/15/2018

NJDOT Projects & Program Model

- Selection
  - SORT Preferred Project Alternatives for each bridge by $\mathbf{S_{PROJ}}$
  - APPLY Funding Constraints
  - SELECT project from sorted list with HIGHEST Incremental Benefit Cost
- Performance Check
  - CHECK for Performance Measure Constraint are met
  - If not met, SORT by $\mathbf{S_{PM}}$ and EXCHANGE lower $\mathbf{S_{PM}}$ score with higher $\mathbf{S_{PM}}$ score
  - Repeat until Performance Constraint is met
- REPEAT above EACH YEAR within a program

NJDOT Projects & Program Model

- Limitations of BrM Optimizer 5.2.3 (Validation using RIME Team)
  - Inconsistent and Unexpected Results While Using "Structure Weight Formula"
  - Unexpected Results While Using "Keep Assigned Projects"
  - Inconsistent Results between a Project in the Results List of "Program Planning" and the Same Project in the "Project List" Section
  - A Utility Value for a Bridge in "Life Cycle Cost Analysis (LCCA)" Section

NJDOT Projects & Program Model

- **Frozen (or already programmed in STIP) Projects**

NBIS Bridges	NHS % Deck Area		
Year	POOR	FAIR	GOOD
2017	72.50%	17.76%	9.75%
2018	55.39%	17.76%	26.85%
2019	54.00%	17.76%	28.24%
2020	49.02%	13.22%	37.76%
2021	48.09%	11.22%	40.70%
2022	47.01%	1.62%	51.37%
2023	18.02%	1.07%	80.91%
2024	15.66%	0.68%	83.66%
2025	14.01%	0.00%	85.99%
2026	1.60%	0.00%	98.40%
2027	0.00%	0.00%	100.00%

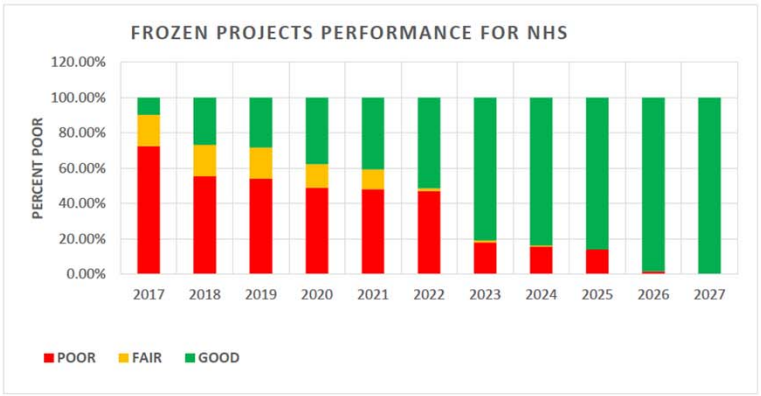
NBIS Bridges	Non-NHS % Deck Area		
Year	POOR	FAIR	GOOD
2017	91.11%	8.89%	0.00%
2018	85.72%	8.89%	5.39%
2019	83.29%	8.52%	8.19%
2020	83.29%	8.52%	8.19%
2021	67.64%	6.02%	26.34%
2022	38.67%	0.00%	61.33%
2023	38.67%	0.00%	61.33%
2024	27.95%	0.00%	72.05%
2025	0.00%	0.00%	100.00%
2026	0.00%	0.00%	100.00%
2027	0.00%	0.00%	100.00%

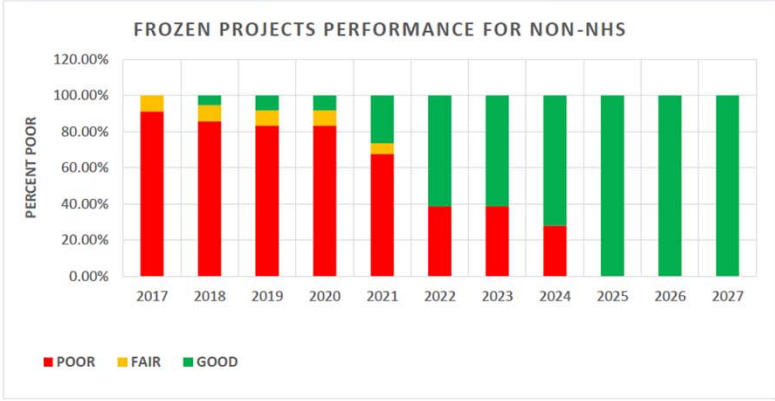
NBIS Bridges	NHS Deck Area					
Year Construction Completed	POOR	FAIR	GOOD	Grand Total	FROZEN PROJECT DECK AREA POOR	FROZEN PROJECT DECK AREA GOOD
2017	-	-	-	-	942,438	126,683
2018	222,396	-	-	222,396	720,042	349,079
2019	18,019	-	-	18,019	702,023	367,098
2020	64,820	58,944	126,683	250,447	637,203	490,862
2021	12,098	26,070	-	38,168	625,105	529,030
2022	14,060	124,732	-	138,792	611,045	667,822
2023	376,772	7,189	-	383,961	234,273	1,051,783
2024	30,657	5,076	-	35,733	203,616	1,087,516
2025	21,432	8,807	-	30,239	182,184	1,117,755
2026	161,364	-	-	161,364	20,820	1,279,119
2027	20,820	-	-	20,820	-	1,299,939
Grand Total	942,438	230,818	126,683	1,299,939		

DO NOT MOVE

NBIS Bridges	Non-NHS Deck Area					
Year Construction Completed	POOR	FAIR	GOOD	Grand Total	FROZEN PROJECT DECK AREA POOR	FROZEN PROJECT DECK AREA GOOD
2017	-	-	-	-	135,968	-
2018	8,040	-	-	8,040	127,928	8,040
2019	3,640	543	-	4,183	124,288	12,223
2020	-	-	-	-	124,288	12,223
2021	23,342	3,739	-	27,081	100,946	39,304
2022	43,243	8,981	-	52,224	57,703	91,528
2023	-	-	-	-	57,703	91,528
2024	15,987	-	-	15,987	41,716	107,515
2025	41,716	-	-	41,716	-	149,231
2026	-	-	-	-	-	149,231
2027	-	-	-	-	-	149,231
Grand Total	135,968	13,263	-	149,231		

DO NOT MOVE





NJDOT Projects & Program Model

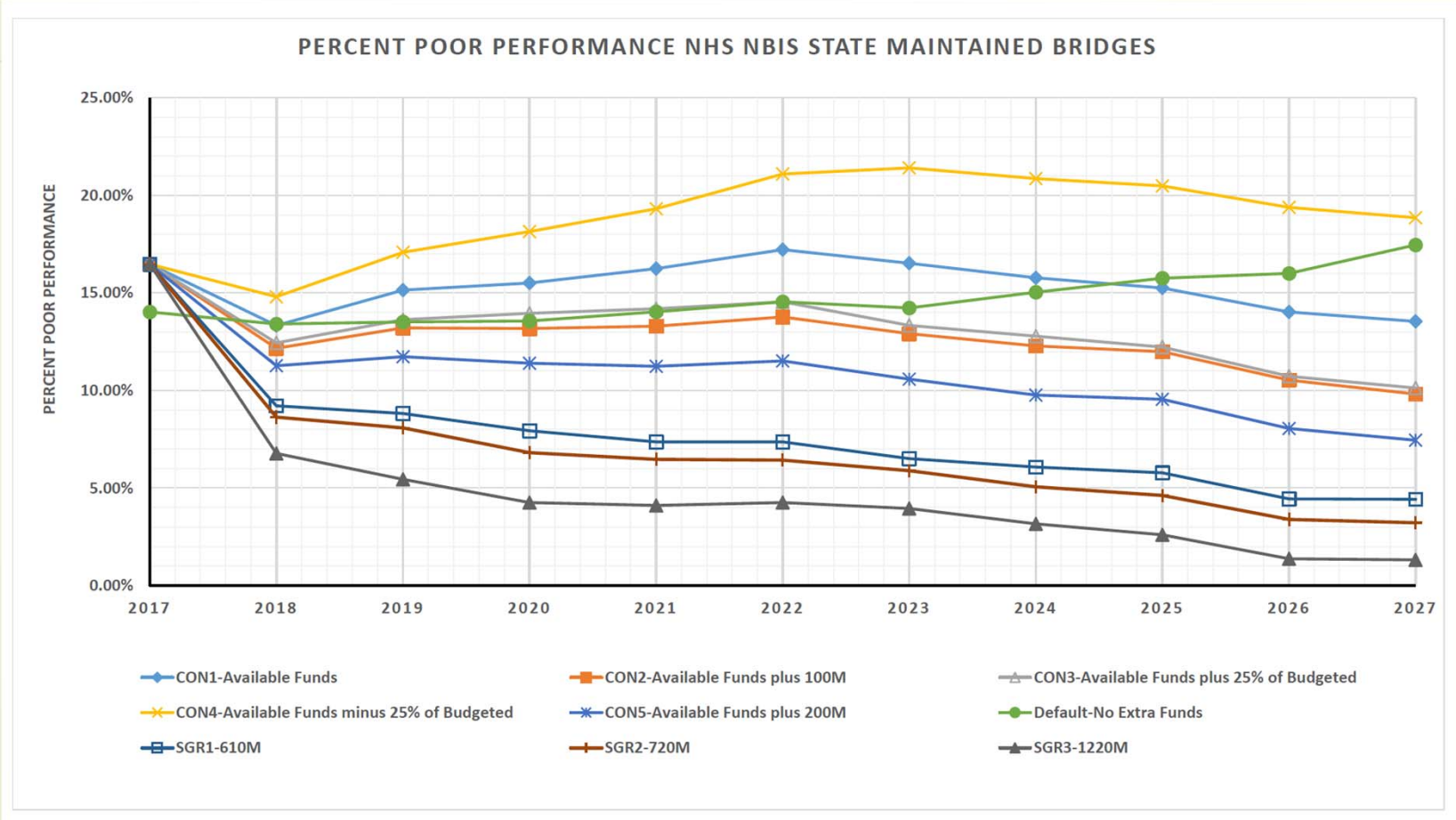
- **Program Results after Optimization**
  - Manual adjustment needed to incorporate Frozen Projects
    - Bug Fix in BrM 5.2.3, Structure Weight Formula, Large Deck Area Bridge issue
  - Currently using Updated/Patched version
  - Currently validating the results with real world projects

POOR PERFORMANCE BY DECK AREA
NHS NBIS STATE MAINTAINED BRIDGES

Year	CON1 FUTURE POOR DECK AREA	CON2 FUTURE POOR DECK AREA	CON3 FUTURE POOR DECK AREA	CON4 FUTURE POOR DECK AREA	CON5 FUTURE POOR DECK AREA	DEFAULT FUTURE POOR DECK	SGR1 FUTURE POOR DECK AREA	SGR2 FUTURE POOR DECK AREA	SGR3 FUTURE POOR DECK AREA	CON1 COMBINED POOR	CON2 COMBINED POOR	CON3 COMBINED POOR	CON4 COMBINED POOR	CON5 COMBINED POOR	DEFAULT COMBINED POOR	SGR1 COMBINED POOR	SGR2 COMBINED POOR	SGR3 COMBINED POOR
2017	4,985,101	4,985,101	4,985,101	4,985,101	4,985,101	4,105,377	4,985,101	4,985,101	4,985,101	5,927,539	5,927,539	5,927,539	5,927,539	5,927,539	5,047,815	5,927,539	5,927,539	5,927,539
2018	4,077,449	3,658,533	3,756,280	4,608,076	3,337,364	4,105,377	2,597,279	2,387,821	1,717,555	4,797,491	4,378,575	4,476,322	5,328,118	4,057,406	4,825,419	3,317,321	3,107,863	2,437,597
2019	4,747,715	4,049,521	4,203,124	5,445,908	3,518,894	4,161,233	2,471,604	2,206,291	1,256,748	5,449,738	4,751,544	4,905,147	6,147,931	4,220,917	4,863,256	3,173,627	2,908,314	1,958,771
2020	4,943,209	4,105,377	4,384,654	5,892,752	3,463,039	4,245,016	2,220,254	1,815,302	893,687	5,580,412	4,742,580	5,021,857	6,529,955	4,100,242	4,882,219	2,857,457	2,452,505	1,530,890
2021	5,222,486	4,161,232	4,482,401	6,325,632	3,421,147	4,426,546	2,024,760	1,703,591	851,796	5,847,591	4,786,337	5,107,506	6,950,737	4,046,252	5,051,651	2,649,865	2,328,696	1,476,901
2022	5,585,546	4,342,762	4,622,040	6,981,933	3,532,858	4,622,040	2,038,724	1,703,591	921,615	6,196,591	4,953,807	5,233,085	7,592,978	4,143,903	5,233,085	2,649,769	2,314,636	1,532,660
2023	5,711,221	4,412,581	4,566,184	7,470,669	3,574,750	4,887,354	2,108,544	1,885,122	1,186,929	5,945,494	4,646,854	4,800,457	7,704,942	3,809,023	5,121,627	2,342,817	2,119,395	1,421,202
2024	5,473,835	4,217,087	4,398,618	7,303,102	3,309,436	5,208,523	1,982,869	1,619,808	935,579	5,677,451	4,420,703	4,602,234	7,506,718	3,513,052	5,412,139	2,186,485	1,823,424	1,139,195
2025	5,306,269	4,133,304	4,217,087	7,191,391	3,253,580	5,487,800	1,899,086	1,480,170	754,049	5,488,453	4,315,488	4,399,271	7,373,575	3,435,764	5,669,984	2,081,270	1,662,354	936,233
2026	5,026,991	3,770,243	3,840,063	6,954,005	2,876,556	5,739,150	1,577,917	1,200,892	474,771	5,047,811	3,791,063	3,860,883	6,974,825	2,897,376	5,759,970	1,598,737	1,221,712	495,591
2027	4,873,389	3,532,858	3,644,569	6,786,439	2,681,062	6,283,740	1,591,881	1,159,001	474,771	4,873,389	3,532,858	3,644,569	6,786,439	2,681,062	6,283,740	1,591,881	1,159,001	474,771

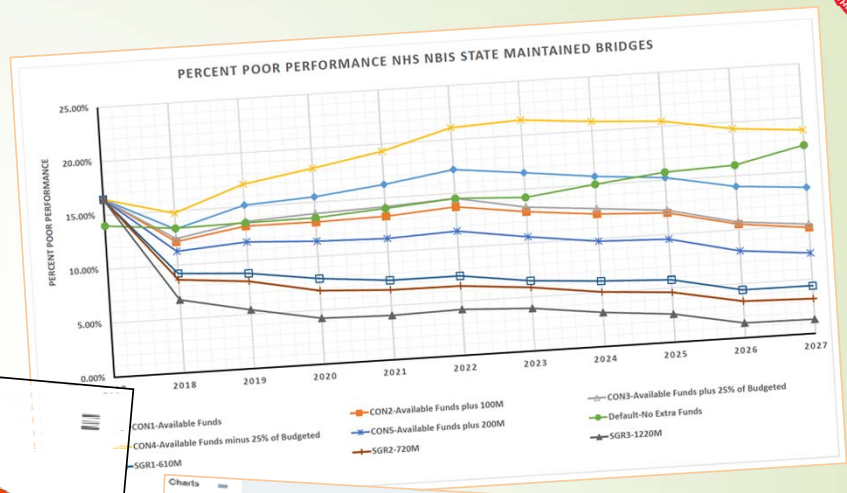
NJDOT Projects & Program Model

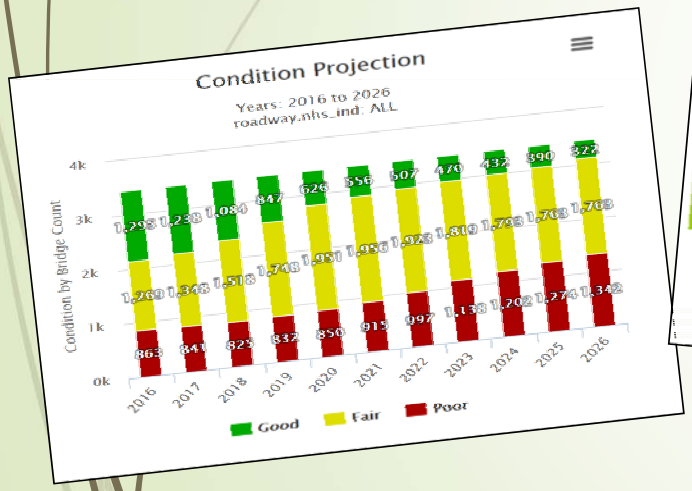
- **Example of Scenario Explorer**
  - SAMPLE only

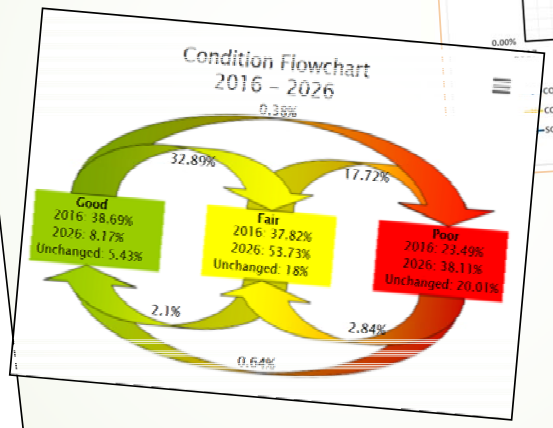


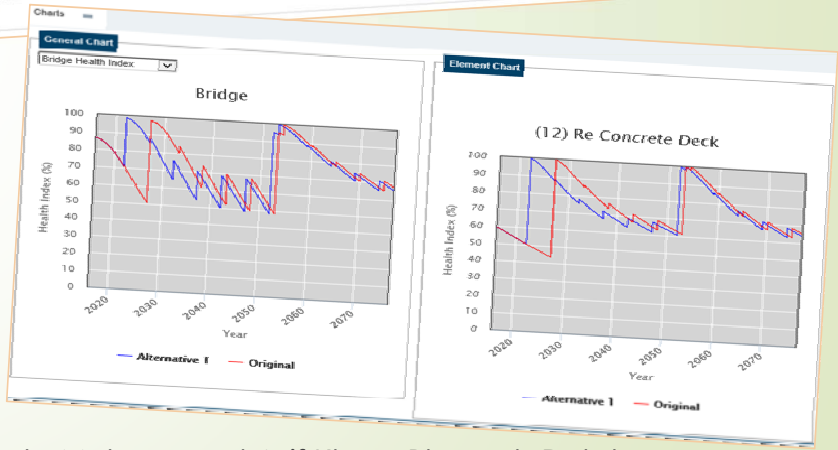
Questions

- Thankyou all
- Any questions
- Demo









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  - Josh Johnson and Zac Boyle from Bentley Systems
  - Derek Constable from FHWA