Midwest Bridge Element Deterioration TPF-5(432)

Philip Meinel

Structures Asset Management Engineer

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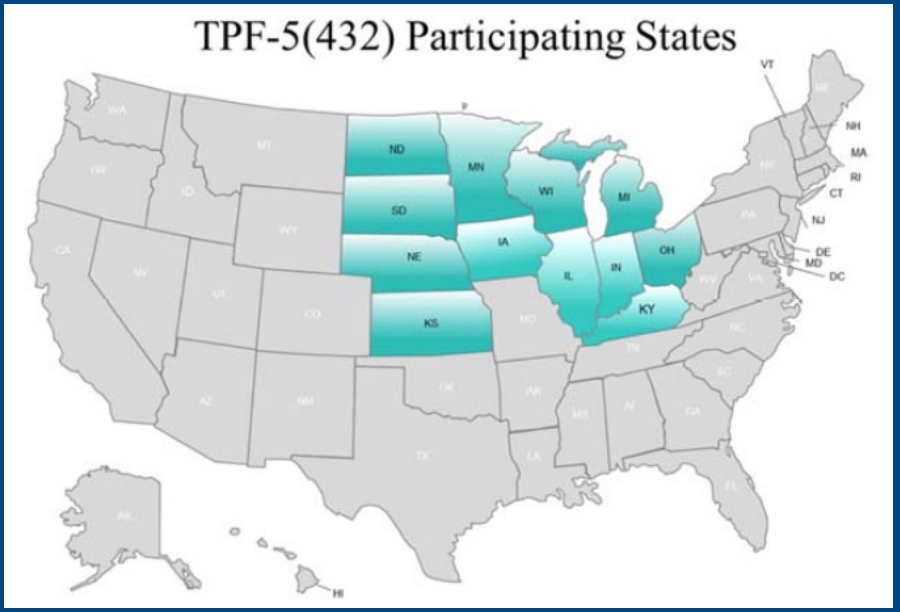
Participating State DOTs

- Twelve Midwest State DOTs
  - ND, SD, MN, NE, KS, IA, WI, IL, MI, IN,OH, KY
- Principal Investigator
  - WSP

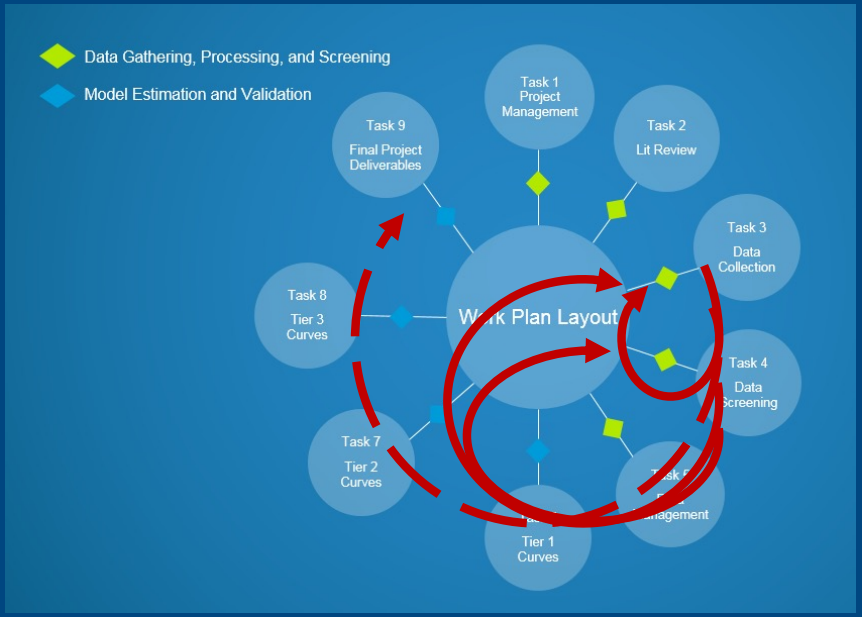


Research Objective

- DOTs pool resources and historic bridge data
- Develop reliable deterioration curves
  - Component NBI ratings
  - NBE, BME, and ADE
- Improve accuracy of various bridge management systems
  - (AASHTO BrM, Agile Assets, and in-house developed applications).

Research Approach

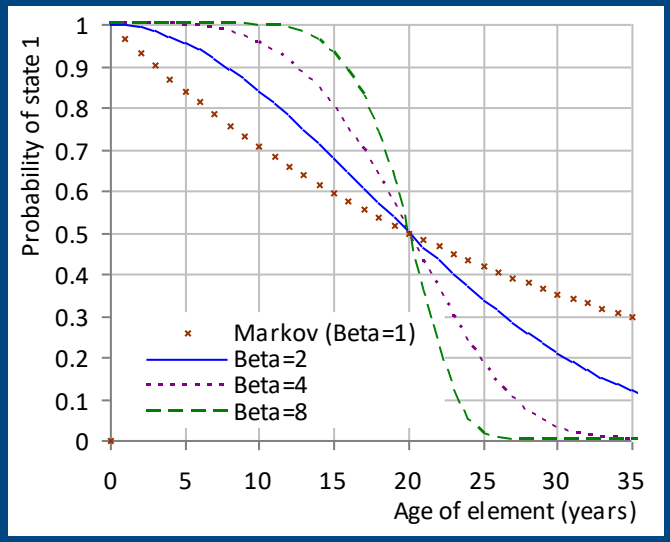
- List of tasks
  - Literature Review
    - Select Deterioration Methods
  - Raw Dataset
    - Data and Policy Gathering
  - Analysis Dataset
    - Data Processing and Screening
  - Model Estimation
    - including Statistical Validation
  - Expert Review
    - Review Models and Final Report



Literature Review

Types of forecasting models

- Onset of Deterioration
  - Markovian models have fairly rapid initial deterioration
  - Weibull curve
  - Protection factor
  - Environment Factors



Comparison of shaping parameters

Literature Review

Model estimation methods

- Linear regression
  - Estimating transition probability matrix [*P*] by: $[P] = [XX]^{-1}[XY]$
- Maximum likelihood estimation
  - Ability to estimate protection factors and Weibull model shaping parameters
  - Using statistical packages such as “R” or Excel’s Solver
- Florida one-step method
  - Estimating p_{ij} using single-year transitions and multivariate linear equations

$$y_1 = x_1 p_{11} p_{11}$$

$$y_2 = x_1 p_{11} p_{12} + x_1 p_{12} p_{22} + x_2 p_{22} p_{22}$$

$$y_3 = x_1 p_{12} p_{23} + x_2 p_{22} p_{23} + x_2 p_{23} p_{33} + x_3 p_{33} p_{33}$$

$$y_4 = x_2 p_{23} p_{34} + x_3 p_{33} p_{34} + x_3 p_{34} p_{44} + x_4 p_{44} p_{44}$$

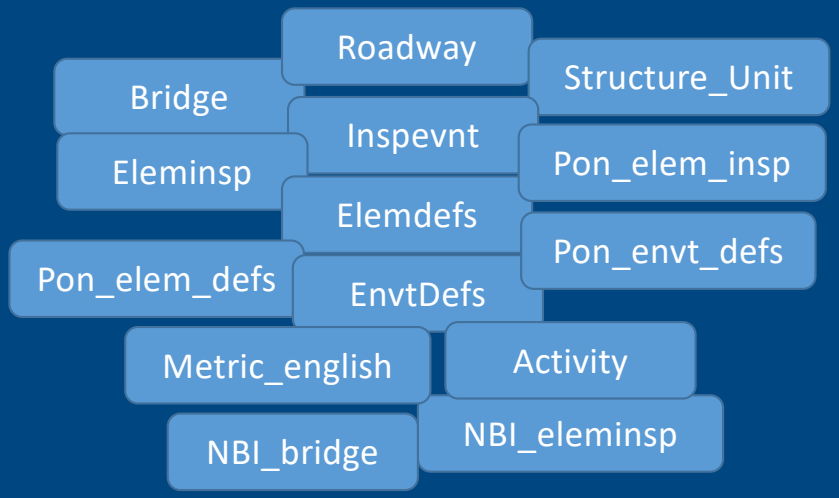
Raw Dataset
Data Gathering

- Shared Data
  - 219,383 Bridges
  - 1,778,813 Routine inspections
  - 387,248 Routine inspections with AASHTO Elements
  - 96,954 Routine inspections with AASHTO Element Defects
  - 198,341 Construction Activity entries
  - 9,112 NDE inspections
  - 399 ADEs

Analysis Database

Data Screening

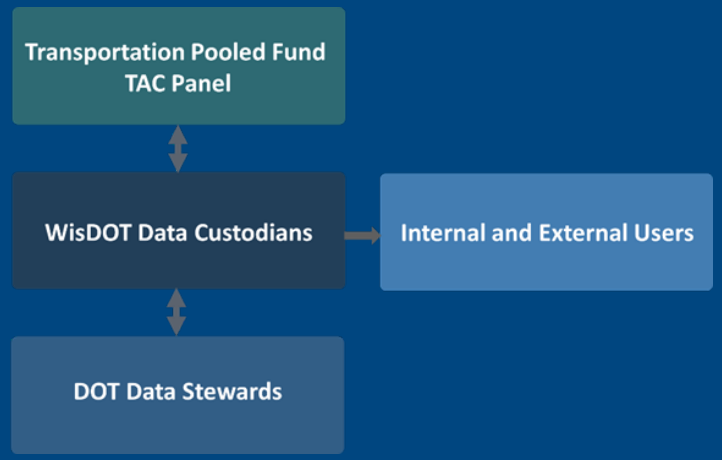
- Tables needed



- Filtering
  - A guidance to discern if inspection data is inappropriate for use in modeling
  - Adding a column in each spreadsheet to mark if a record is valid or not
  - Validation focuses on missing records, non-standard environment class, negative condition state quantities.

Analysis Database
Data Governance

- Objective
  - Create a framework to ensure the security and accessibility of analysis database
- Data Principles
  - Quality
  - Security
  - Accessibility
  - Retention



Deterioration Curves

- Three basic formats:
  - Markov – Closed-form solution, pivot tables to investigate strata
    - Estimation and validation data sets side-by-side, final result a combination
    - Graphs to compare models
  - Weibull – Maximum likelihood shape parameter
    - Onset of deterioration of newer bridges where no action is taken
    - Uses Excel Solver to find optimal parameter
  - Action effectiveness – Maximum likelihood estimation
    - Finds the transition probability matrix that best explains improvement in RC Deck condition after major preservation
- Each task has one or more separate spreadsheets

Deterioration Curves

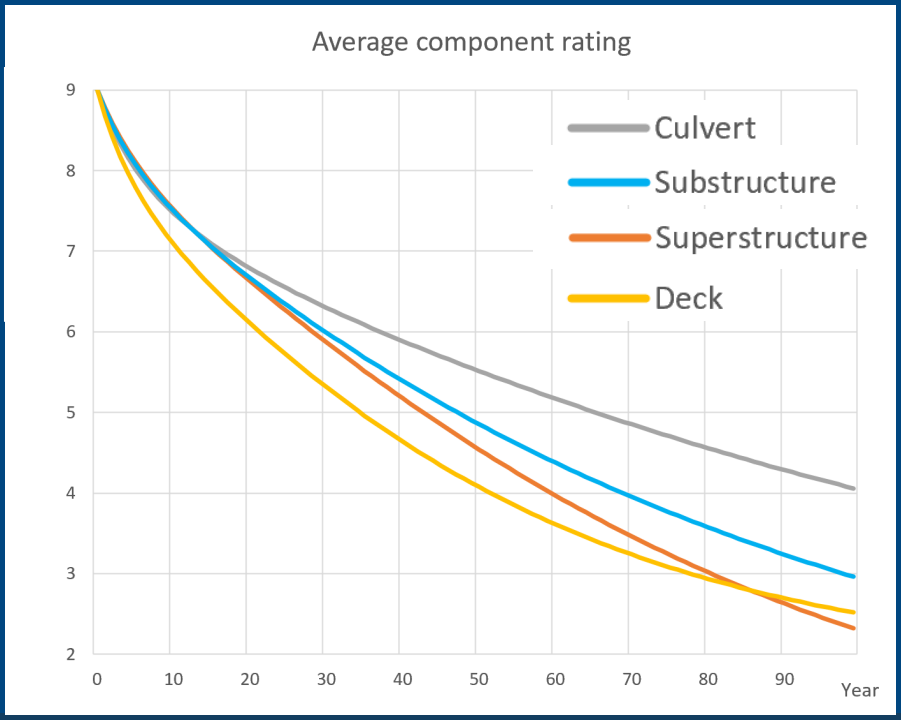
- Markov Procedure
  - Refine dataset by selecting specific element or component
  - Create tables of inspection pairs using SQL
  - Incorporate work activities
  - Stratify data set with specific inventory values
  - Create Excel spreadsheets to perform analysis and validation

Deterioration Curves

- Tier 1
  - Component NBI Ratings
  - NBE - RC Deck, RC Slab
  - RC Deck after Major Preservation
- Tier 2
  - Wearing Surfaces
  - Joints
  - Paint
  - Defect progression
  - Substructure elements

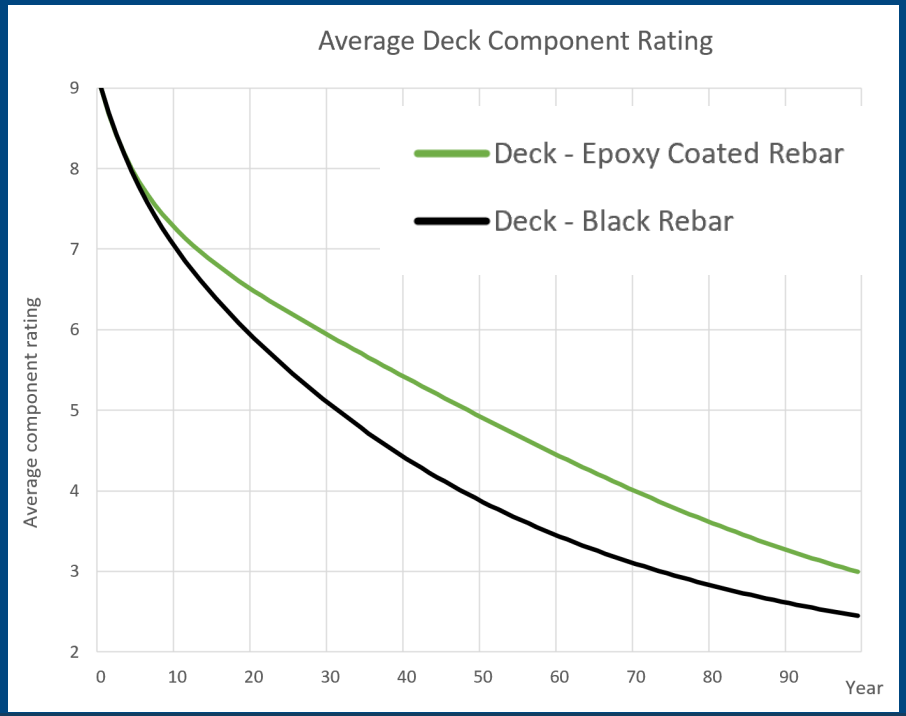
Deterioration Curves
Tier 1

- Component NBI
  - Random Sample
  - State-owned
  - Bridges with traffic
  - Non-buried structures



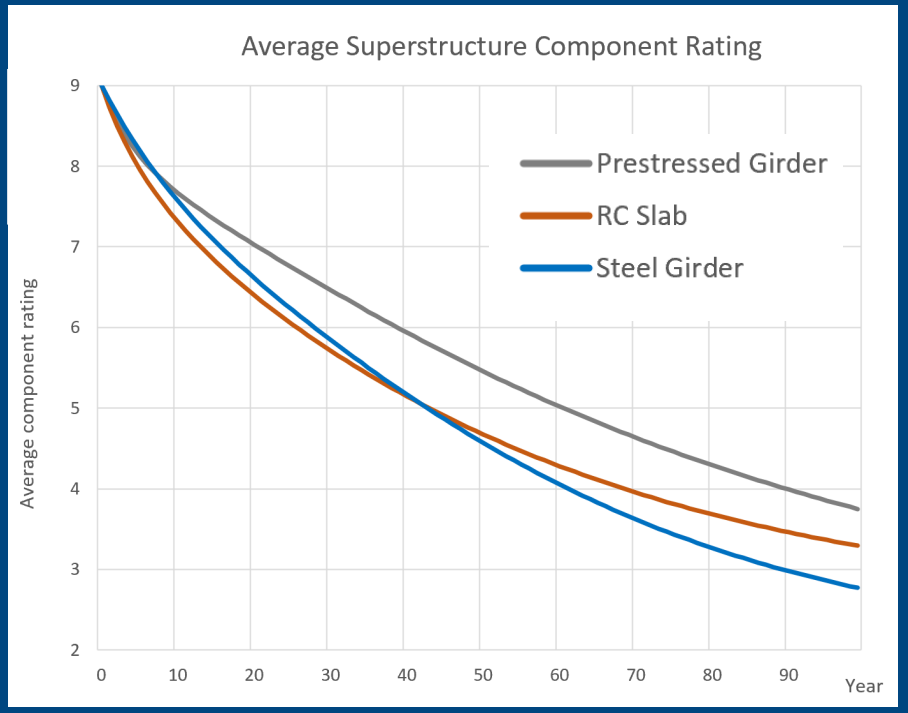
Deterioration Curves
Tier 1

- Deck NBI
  - Rebar Type



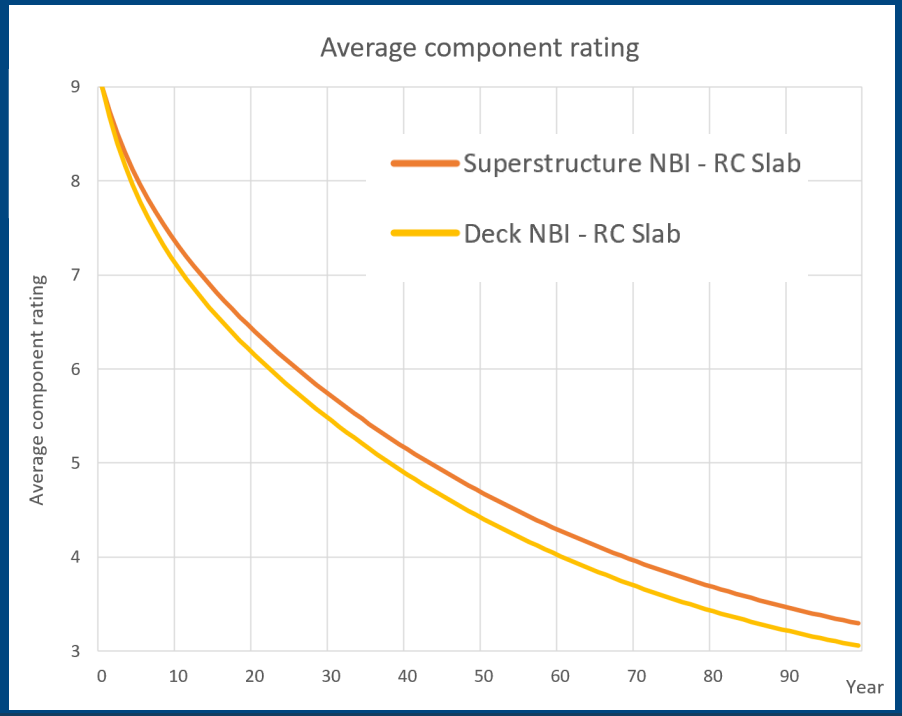
Deterioration Curves
Tier 1

- Superstructure NBI
  - Span Type



Deterioration Curves
Tier 1

- RC Slab Ratings
  - Deck NBI
  - Superstructure NBI



Deterioration Curves
Tier 1

- RC Deck Element
  - Statistical validation is strong:

Row L	Pop	Pop4	T12	T23	T34	ActHI	PreHI	r-Sq
1	12,970	593	43.2	18.9	27.9	94.87	94.98	0.7981
2	12,794	559	43.9	20.6	22.3	94.97	95.04	0.8086
Grand Tot	**25,764**	**1,152**	**43.6**	**19.7**	**24.8**	**94.92**	**95.01**	**0.8032**

  - Construction era:

ow Lab	Pop	Pop4	T12	T23	T34
<1960	4,925	258	29.4	17.5	45.6
1960-84	11,767	743	39.1	18.6	18.6
1985+	9,073	151	68.2	31.2	12.7
Grand Tot	**25,764**	**1,152**	**43.6**	**19.7**	**24.8**

  - Traffic volume:

ow Lab	Pop	Pop4	T12	T23	T34
0	51	0	47.7	21.2	999.0
1 (<1k)	6,246	186	40.8	20.0	38.5
2 (<10k)	10,918	451	50.8	19.5	30.6
3 (>=10k)	8,550	515	38.4	19.7	12.0
Grand Tot	**25,764**	**1,152**	**43.6**	**19.7**	**24.8**

- Individual states uneven, especially for condition 3->4

ow Lab	Pop	Pop4	T12	T23	T34
IA	4,073	82	247.2	39.8	61.7
IL	2,129	557	20.8	20.9	2.3
IN	244	1	187.7	101.0	999.0
KS	1,462	7	260.3	51.4	127.7
KY	878	12	13.4	19.8	33.1
MI	3,411	63	21.5	19.3	182.5
MN	2,550	97	41.4	15.3	51.8
ND	1,041	31	33.1	24.1	42.0
NE	2,236	18	78.8	14.5	999.0
OH	1,733	206	49.6	27.6	38.1
SD	1,300	15	30.8	14.4	132.4
WI	4,706	63	69.3	19.8	27.6
Grand Tot	**25,764**	**1,152**	**43.6**	**19.7**	**24.8**

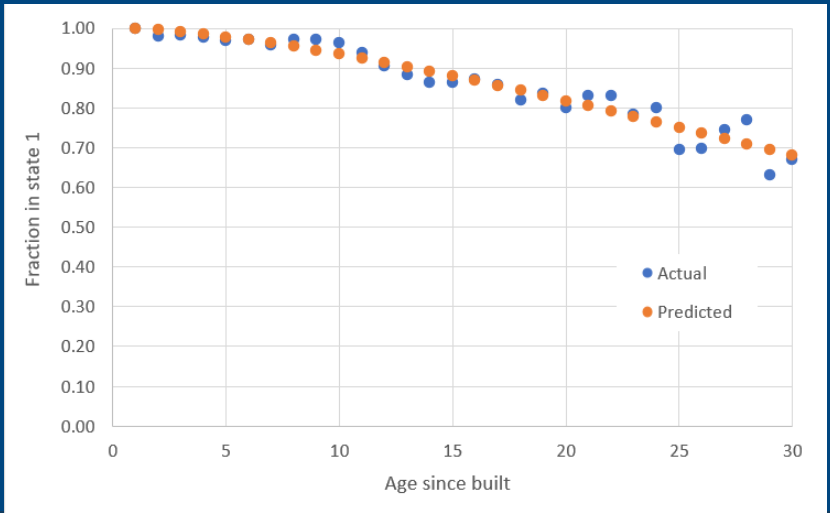
Recommended model

	T12	T23	T34	r-Sq
Overall avg:	43.6	19.7	24.8	0.8032
Uprotected:	38.3	24.5	13.8	

Deterioration Curves
Tier 1

- RC Deck Element
  - Weibull factor = 1.58

Recommended model				
	T12	T23	T34	r-Sq
Overall avg:	43.6	19.7	24.8	0.8032
Uprotected:	38.3	24.5	13.8	



Markov model transition times		
1->2	2->3	3->4
43.6	19.7	24.8

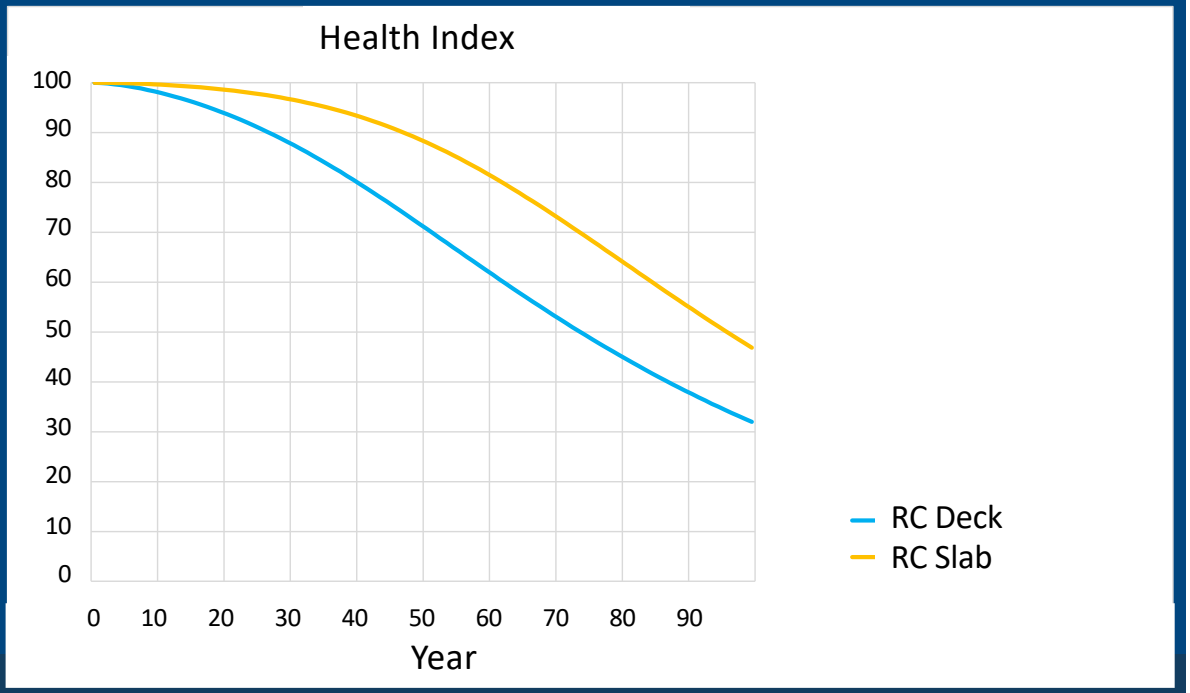
Weibull model	
Scale parameter	54.97
Shape parameter	1.58

Model diagnostics	
Total log likelihood	-569
Min log likelihood	-640
p-Stat	0.0000
Mean of actual	0.93
Mean of predicted	0.93
R-squared	0.3777

Deterioration Curves
Tier 1

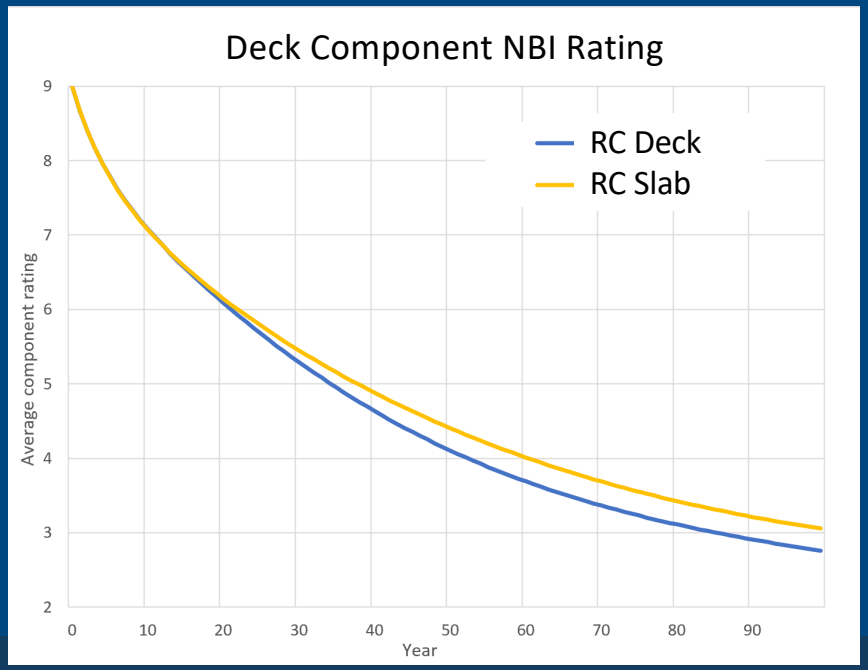
- RC Slab Element

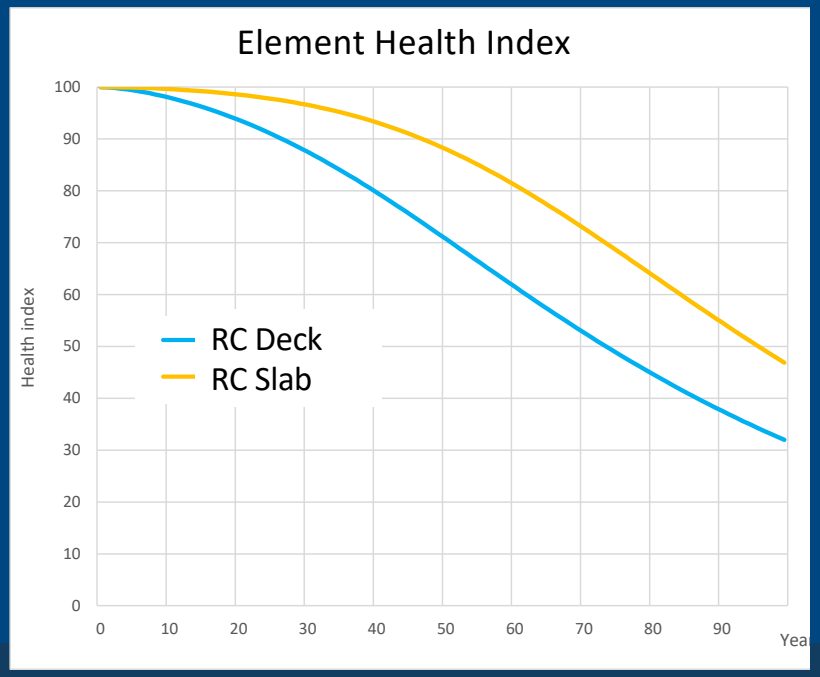
Recommended model				
	T12	T23	T34	r-Sq
Overall avg:	66.8	17.6	49.3	0.8781
Uprotected:	43.7	21.5	28.3	



Deterioration Curves
Tier 1

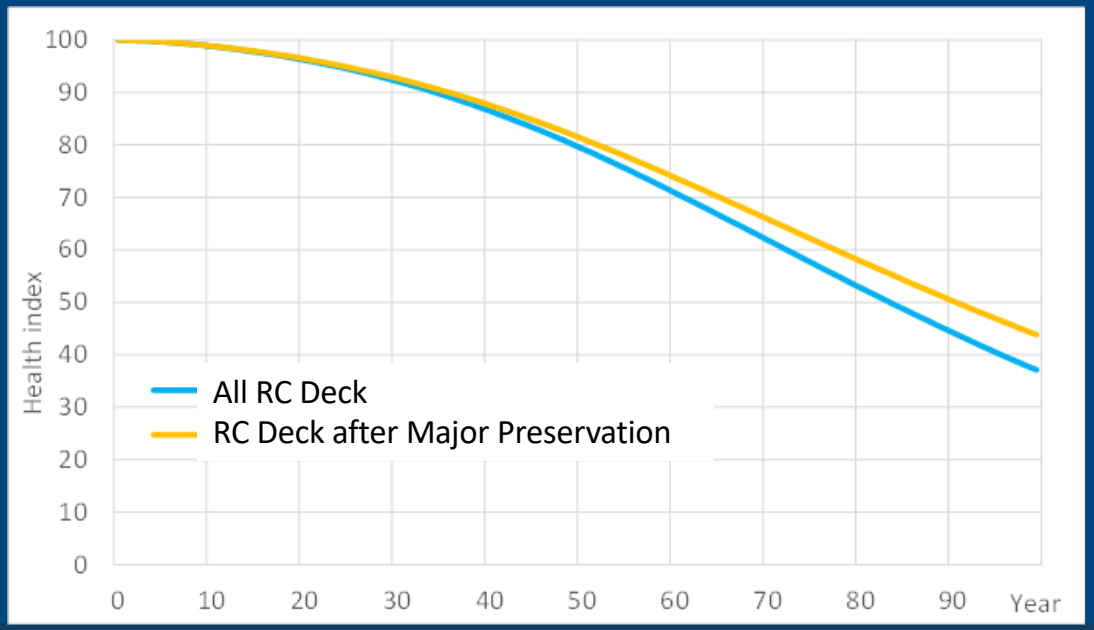
- Compare Deck NBI Rating and Element Deterioration





Deterioration Curves
Tier 1

- RC Deck Element after major preservation



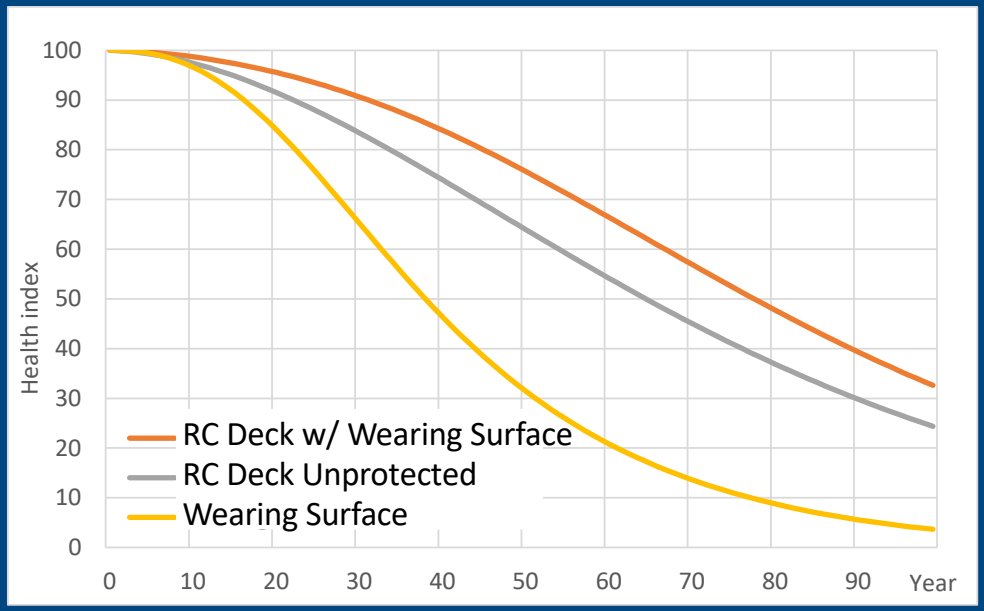
Deterioration Curves
Tier 2 – Mentality – Diving Deeper

- Bridge Components help us with a vague idea of structure condition
  - Focus has been on communication and funding
- Bridge Elements help us understand **where** we need to work
- Element Defects help us understand **what** work needs to be done
  - Specific defects are the key to an automated BMS optimizer that is focused on **bridge preservation**

	NBI Item 58	Top Deck Element Distress Area (%)	Bottom Deck Element Distress Area (%)	Preservation Activity
Concrete Deck/Slab	6	8513 CS3 + CS4 > 15% (reapplication)	1080 < 1%	Thin Polymer Overlay
		>20% (3220 OR 8911 CS3 + CS4) OR >15% 3210 (applied to bare deck)	1080 < 5% OR 1130 CS3 + CS4 < 25%	Concrete Overlay
		>20% (3210 OR 8911 CS3 + CS4) OR >50% 3220 (reapplication)		

Deterioration Curves
Tier 2

- Effect of wearing surfaces on deck element deterioration



Deterioration Curves
Tier 2

- Wearing surface types
  - Research Groupings from ADEs and…

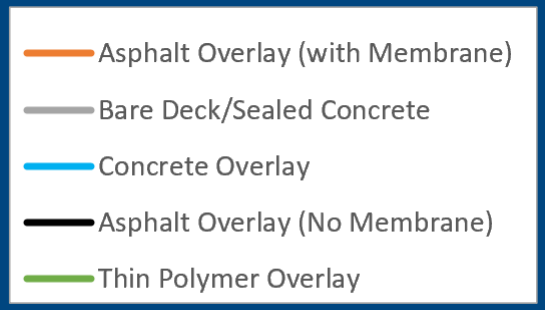
Row Labels	Pop	Pop4	T12	T23	T34
Asphalt Overlay (No Membrane)	2,585	213	11.6	7.8	14.1
Asphalt Overlay (with Membrane)	367	13	17.4	5.7	143.1
Bare Deck/Sealed Concrete	5,605	91	38.4	31.5	71.0
Concrete Overlay (Latex Modified)	348	8	28.3	15.1	559.0
Concrete Overlay (Low Slump)	3,847	94	22.7	11.7	130.9
Concrete Overlay (Silica Fume)	1,157	7	89.6	20.2	264.3
Gravel Overlay	546	23	12.2	3.8	1.9
Not Applicable	33	1	38.3	999.0	999.0
Other Wearing Surface	18	2	77.4	42.5	285.2
Polyester Polymer Overlay (PPC)	365	74	56.8	2.0	0.5
Thin Polymer Overlay (2 Layer Epoxy)	838	322	30.5	6.6	3.2
Timber	44	5	33.0	51.7	8.2
Grand Total	**15,753**	**853**	**24.6**	**11.1**	**13.0**

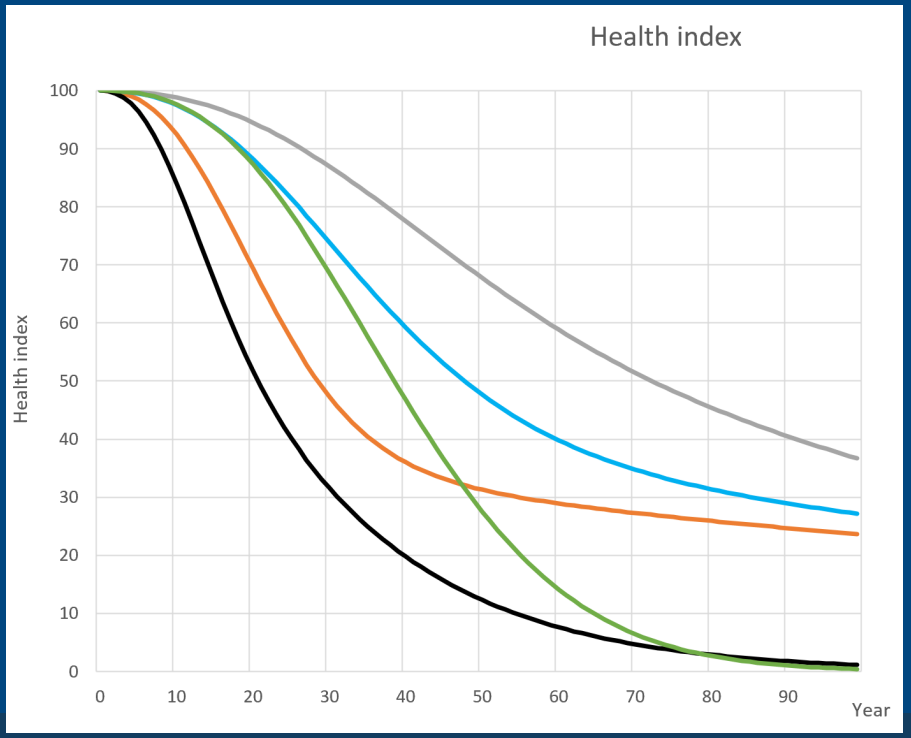
Translated from NBI item 108

Type of wearing surface	Pop	Pop4	T12	T23	T34
0 None	105	3	57.1	30.7	135.8
1 Monolithic Concrete	5,900	105	35.2	27.6	46.2
2 Integral Concrete	270	9	18.2	7.7	282.9
3 Latex Concrete or similar	352	8	27.2	15.4	559.9
4 Low Slump Concrete	4,516	103	31.2	11.7	107.9
5 Epoxy Overlay	1,091	369	36.2	6.0	2.4
6 Bituminous	2,810	221	11.7	7.7	15.0
7 Wood or Timber	63	8	30.8	56.1	16.6
8 Gravel	562	23	12.4	4.0	1.9
9 Other	51	3	31.7	12.2	999.0
N Not Applicable	33	1	38.3	999.0	999.0
Grand Total	**15,753**	**853**	**24.6**	**11.1**	**13.0**

Deterioration Curves
Tier 2

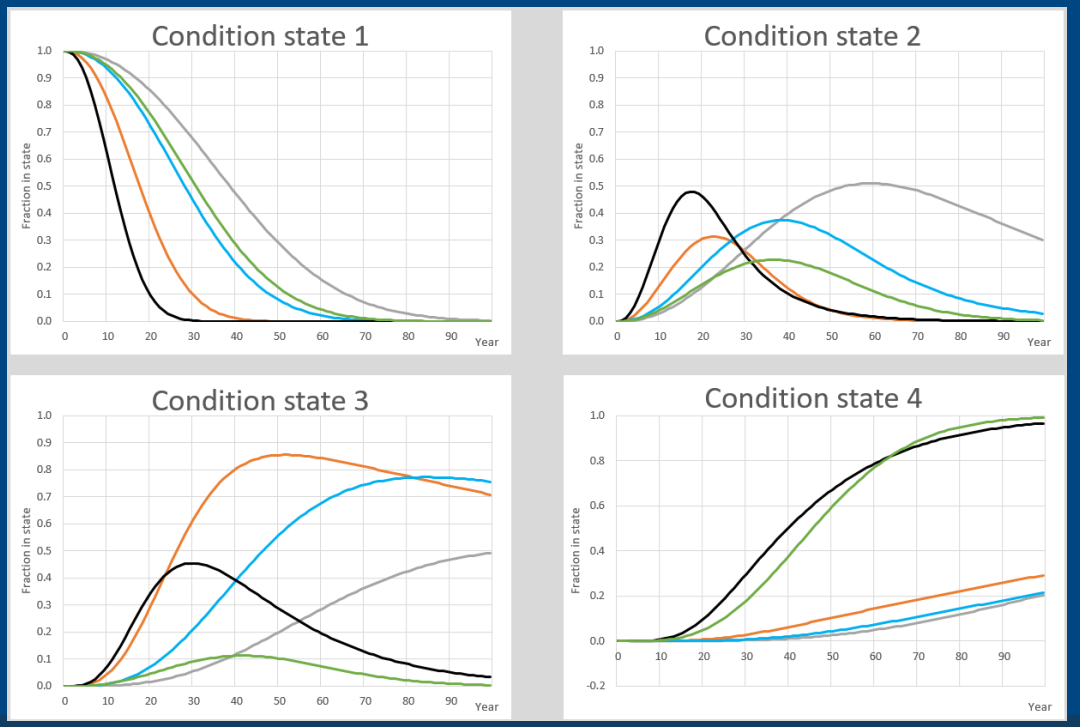
- Wearing surface types
  - One Weibull factor for all types
    - 2.24





Deterioration Curves
Tier 2

- Wearing surface types
  - One Weibull factor for all types
    - 2.24



Deterioration Curves
Tier 2

- Joint deterioration is faster than expected

Joint type	Population	1->2	2->3	3->4
300 Strip Seal Expansion Joint	9,896	4.8	11.5	4.8
301 Pourable Joint Seal	8,797	5.2	3.4	6.7
302 Compression Joint Seal	3,250	10.2	4.3	5.3
303 Assembly Joint With Seal	565	8.5	6.9	6.8
304 Open Expansion Joint	949	8.3	10.6	8.3
305 Assembly Joint Without Seal	859	9.4	5.7	4.9
306 Other Joint	462	15.6	5.2	4.4
All	24,778	5.8	5.9	6.0

Deterioration Curves
Tier 2

- Delamination defect development
  - Use “Health Index” to stratify effect of cracking defect 1130
    - Index = CS1 + (2/3)CS2 + (1/3)CS3
  - Vast majority of decks without delaminations stayed in that condition
    - Slow development
  - Relationship with deck cracking behaved as expected
    - As cracking increases, likelihood of delamination increases

Transition times for defect 1080, as affected by the status of defect 1130 (years)

Defect 1130	Population	1->2	2->3	3->4
Up to 0.80	545	12.3	35.8	80.2
Up to 0.98	2,509	15.1	29.4	66.9
Up to 1.00	5,425	30.9	16.5	52.6
No defect record	1,498	17.1	17.0	35.1
All	9,980	25.6	23.2	59.8

Deterioration Curves
Tier 2

- Delamination defect development
  - Example using CS2 Cracking (Defect 1130)

Up to 1.00 = 0 - 6 % of element has CS2 cracking

  - Least likely to develop delamination (Defect 1080)

Up to 0.98 = 6 – 60% of element has CS2 cracking

  - 2 times more likely to develop delamination (Defect 1080)

Transition times for defect 1080, as affected by the status of defect 1130 (years)

Defect 1130	Population	1->2	2->3	3->4
Up to 0.80	545	12.3	35.8	80.2
Up to 0.98	2,509	15.1	29.4	66.9
Up to 1.00	5,425	30.9	16.5	52.6
No defect record	1,498	17.1	17.0	35.1
All	9,980	25.6	23.2	59.8

Deterioration Curves
Tier 2

- Paint system defects
  - Paint has big effect on steel deterioration

Coating condition index	Population	1->2	2->3	3->4
0.00	592	6.8	19.9	53.5
up to 0.80	3,355	15.6	26.7	98.7
up to 0.98	1,864	24.2	21.6	23.0
up to 1.00	4,169	33.8	17.4	49.2
All	9,980	25.6	23.2	59.8

- Steel girder corrosion
  - Paint has big effect on steel deterioration

Defect 1000	Population	1->2	2->3	3->4
up to 0.80	545	12.3	35.8	80.2
up to 0.98	2,509	15.1	29.4	66.9
up to 1.00	5,425	30.9	16.5	52.6
No defect record	1,498	17.1	17.0	35.1
All	9,980	25.6	23.2	59.8

Deterioration Curves
Tier 2

- RC Substructures
  - Transition times by element

Element type	Population	1->2	2->3	3->4
Pier caps	25,320	69.4	12.4	68.0
Abutments	33,799	40.9	16.6	47.6
Pier walls	8,172	50.3	15.6	25.4
Columns	19,334	23.8	11.3	80.5

  - Column data collected by “each”

  - ADT under is a significant factor for Pier Caps

Row L	Pop	Pop4	T12	T23	T34
0	16,939	173	92.8	15.7	72.3
1 (<1k)	1,032	25	86.3	9.1	71.9
2 (<10k)	2,225	39	67.4	10.4	89.4
3 (>=10k)	5,125	87	37.1	7.8	52.4
Grand Tot	25,320	324	69.4	12.4	68.0

  - ADT > 10,000 could be considered a “harsh” environment

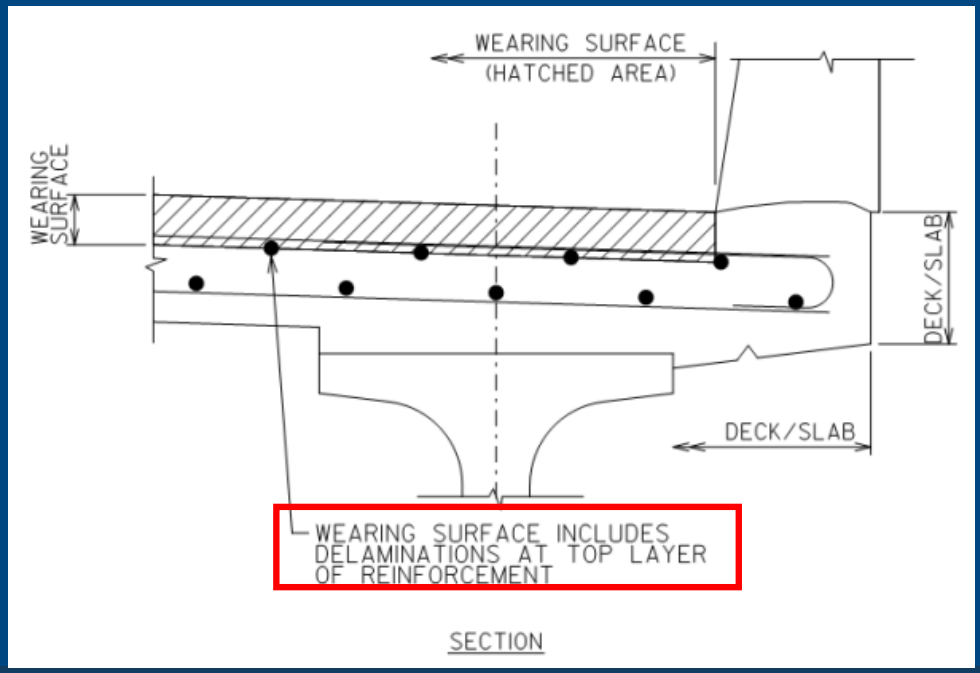
Deterioration Curves
Tier 3

- Scope
  - Identify useful agency-defined elements (ADE)
  - Determine which elements to advance further
  - Provide guidance on data collection, gathering, and formatting
  - Determine the status of NDE efforts/programs
  - NDE translation to concrete bridge deck inspections

Deterioration Curves
Tier 3

- Wearing Surface ADEs were very helpful for this research

Wearing Surface ADEs	No Wearing Surface ADEs
• Kentucky	• Indiana
• Nebraska	• Kansas
• South Dakota	• Minnesota
• Wisconsin	• North Dakota
• Illinois	• Ohio
• Michigan	• Iowa



Deterioration Curves
Tier 3 - Inspection Practice

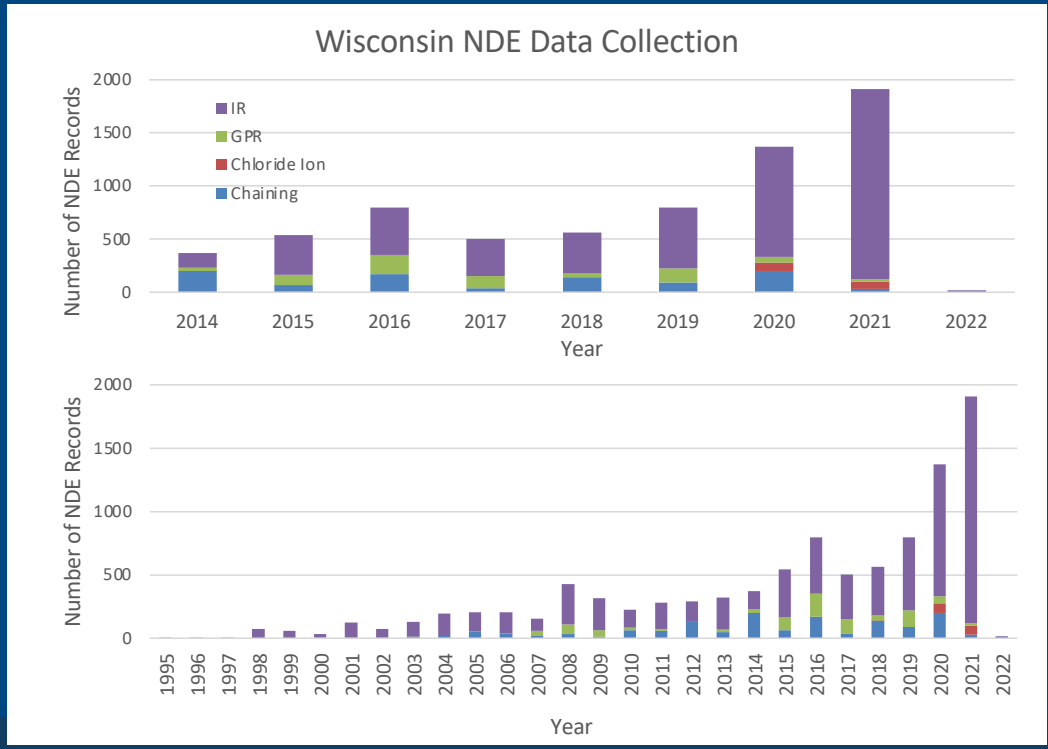
- Element-Level Defect Data by Midwest State DOTs

Element-Level Defect Data	No Element-Level Defect Data
• Kentucky • Nebraska • South Dakota • Wisconsin • Iowa	• Indiana • Kansas • Minnesota • North Dakota • Ohio • Illinois • Michigan

Defect	CS 1 Good	CS 2 Fair	CS 3 Poor
Material Defects			
Delaminations/ Spalls/Patch Areas/Exposed Rebar (1080)	None.	Delaminated. Spalls 1 in. or less deep or less than 6 in. diameter. Reinforcement may be exposed. Corrosion may be present, but without section loss. Patched area that is sound.	Spalls greater than 1 in. deep or greater than 6 in. diameter. Patched area that is unsound or showing distress. Reinforcement present with measurable section loss. Does not warrant structural review.
Cracking (RC)/ Efflorescence (1130)	No cracks. Hairline cracks not requiring sealing, or cracks that have been sealed. No efflorescence present.	Unsealed cracks of narrow width, or unsealed minor to moderate pattern/map cracking. Efflorescence is present; it's minor with no evidence of rust staining.	Unsealed cracks of medium to wide width, or extensive pattern map cracking. Efflorescence is present; there is heavy build-up and/or rust staining.
Abrasion/Wear (PSC/RC) (1190)	No abrasion.	Abrasion has exposed coarse aggregate but the aggregate remains secure in the concrete.	Coarse aggregate is loose or has popped out of the concrete matrix due to abrasion.

Deterioration Curves
Tier 3

- Most NDE use is limited to
  - As-needed
  - Research
- Not many network-level NDE programs for bridge deck evaluation



Deterioration Curves

Tier 3

- NDE defects related to Bridge Element Condition States

Table 40. Wisconsin DOT NDE Data Items for Deck Evaluation

NDE Method	NDE Defect Quantities*	NDE to Element Condition Mapping
Visual	Spall	Defect 3210, CS3
	Asphalt Patching	Defect 3210, CS3
	Concrete Patching	Defect 3210, CS2
IR or Sounding	Delamination	Defect 3210, CS2
IR or Sounding	Debonding	Defect 3210, CS2
GPR	Contamination/Deterioration	NA**
Chloride Ion Testing	Avg Chloride Concentration (per wt of concrete) at rebar level	Defect 8905***

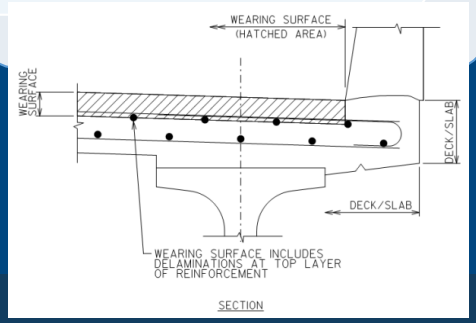
*Additional NDE data is recorded in the WI Highway Structures Information System (HSIS) according to the Deck Scanning Policy located in Appendix A of the WI Structures Inspection Manual.
**GPR results have no direct correlation to AASHTO element defects. WI is evaluating results for predictive ability of future defects.
***Even though defect 8905 is available for use in the Field Inspection Manual, but it is not actively being used and not typically recorded. Chloride ion test results are stored in HSIS by other means.

Deterioration Curves
Tier 3

- Main Recommendations

Defect
Delaminations/ Spalls/Patch Areas/Exposed Rebar (1080)
Cracking (RC)/ Efflorescence (1130)
Abrasion/Wear (PSC/RC) (1190)

Uniform way of assessing deck condition



Format of treatment/work history

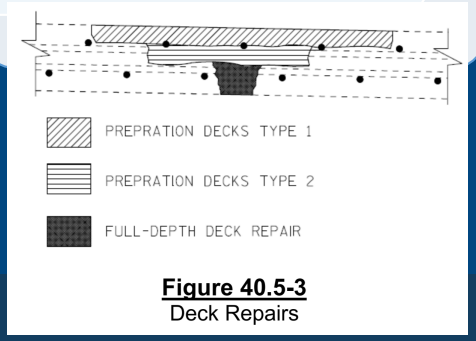
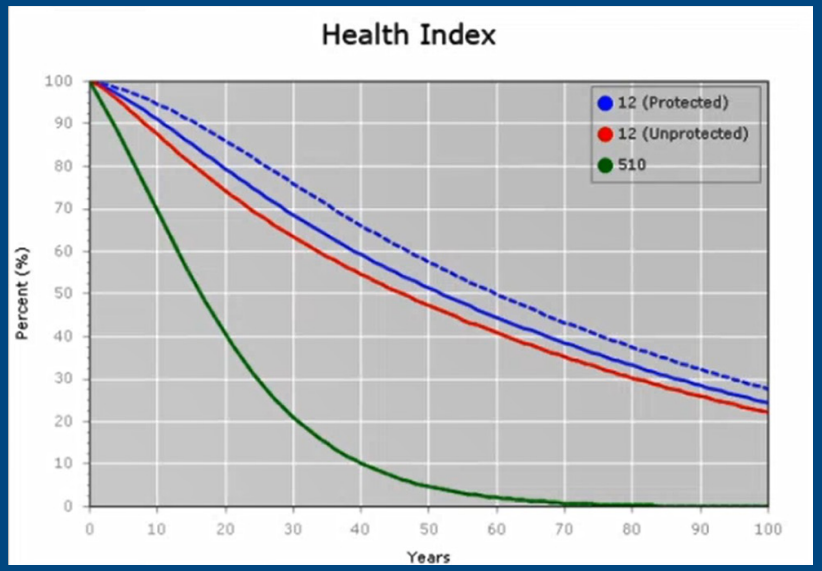


Figure 40.5-3
Deck Repairs

Implementation

- Mainly geared towards BrM users, but compatible with other BMS software
- Some results too advanced for current BMS software
- Models may be stratified with care
- Model data can be updated
- Additional element models can be generated
- Compare to existing BMS settings



Implementation: BrM Specific

- Create separate TPF deterioration profile to compare against existing results
- GCR deterioration rates assigned to each individual structure based on inventory filtering
- Element deterioration rates can be set for all structures based on overall average deterioration
- Element deterioration rates need to utilize a formula factor if tailored to a specific subset of the inventory
- Can create separate protective wearing surface elements for deck/slab

Implementation: Proposed Enhancements

- Allow element deterioration by inventory data
  - Example: RC Cap deterioration varies by ADT under
- Automatically assign initial deterioration curve based on inventory data
  - Example: A redeck is performed on a structure, which updates the rebar type from black steel to epoxy coated. BrM automatically selects the correct Deck NBI deterioration based on rebar type.

Implementation: Proposed Enhancements

- Update inventory data (and deterioration curve) based on recommended treatments within an optimization run
  - Example: Concrete overlay recommended
    - Replace original wearing surface (WS) with Conc Ovly WS element
    - Utilize Conc Ovly deterioration for WS and deck protection

Future Research

- Updating data and refine deterioration models.
- Additional data cleaning efforts and alignment of data collection practices.
- Improved understanding of the differences among the twelve agencies in their element deterioration rates.
- Improvements in the quality and consistency of construction activity data collected by agencies.
- Further development of defect data and associated models.
- Best practice guidance and implementation.

THANK YOU!

Philip Meinel

Structures Asset Management Engineer

Philip.Meinel@dot.wi.gov

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