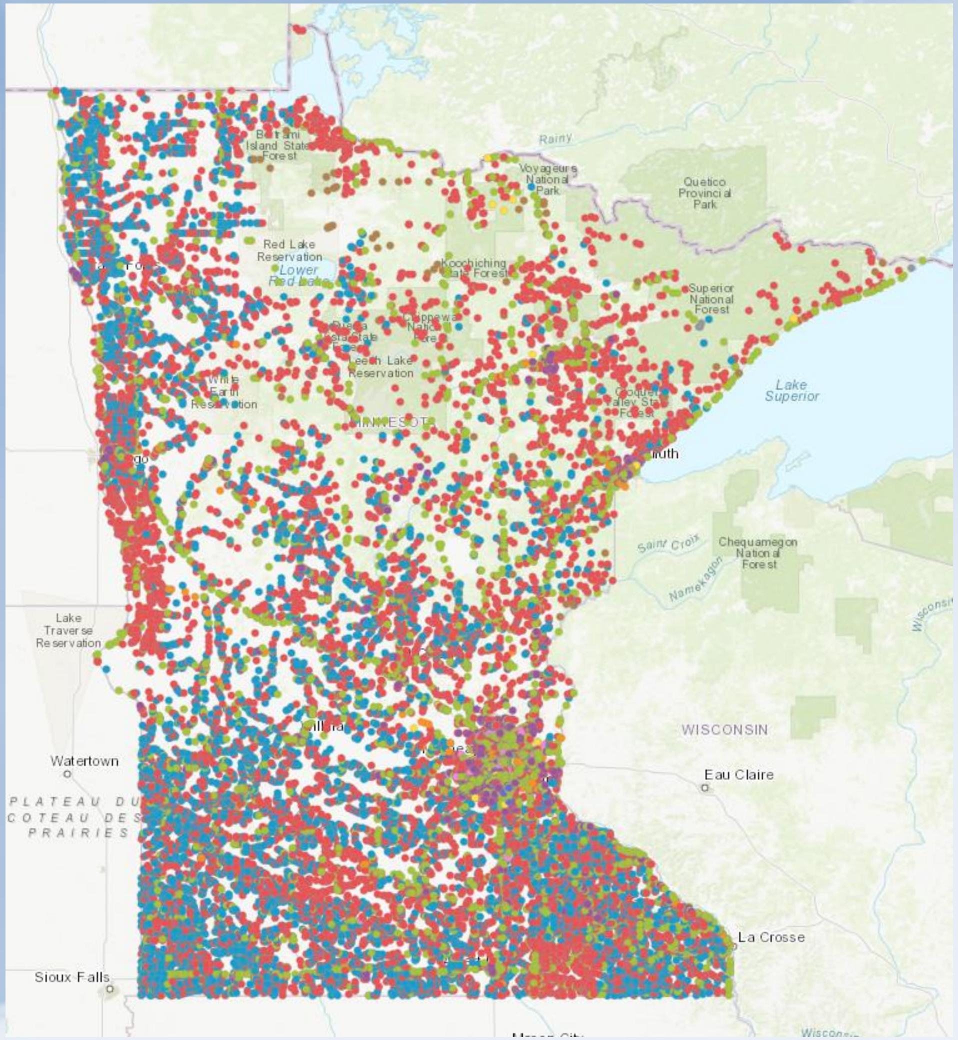
Establishing Data-Driven Life Cycle Benefits of Bridge Maintenance

Başak Bektaş
Associate Professor of Civil Engineering
Minnesota State University, Mankato, USA

basak.bektas@mnsu.edu
Webpage
LinkedIn

Sarah Sondag
Bridge Preservation Engineer
Minnesota DOT

sarah.sondag@ state.mn.us



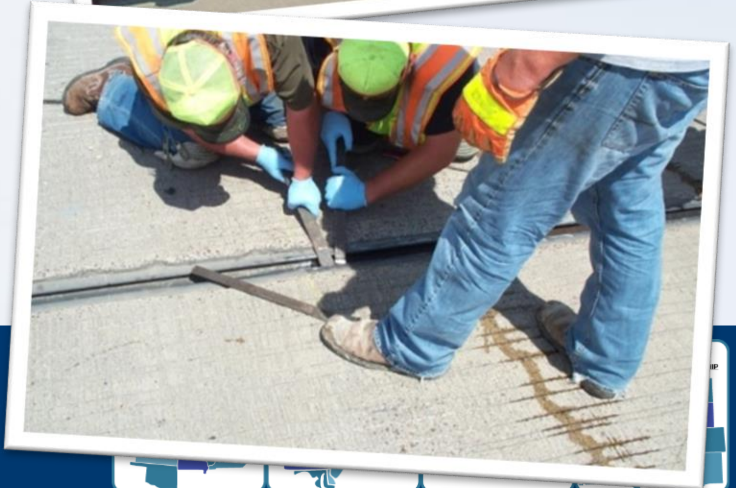
Bridge Info Interactive Map (Bridges by Owner)

20,091
4,444
46 Million SF
400,000 SF

Source: 2024 Bridge Office Annual Report
2023 Inspection Season Data

Preventive Maintenance

Activity	Recommended Frequency
Flushing	Annually
Crack Sealing (Crack Chase or Flood Seal)	Every 3-5 years
Deck Sealing (Silane or Penetrating Sealer)	Every 5-10 years
Poured Joint Sealing	Every 5-8 years
Cleaning and Lubricating Bearings	Every 4 years
Rail Sealing	Every 5-7 years
Maintenance Painting	Every 5 years
Gland Repair and Replacement	As Needed
Joint Repair and Re-establishment	As Needed



Research Objective

Demonstrate the economic benefit of maintenance

Identify high value maintenance activities

Update practice guidance and performance measures

Use results to focus limited resources

Outline

- Context
- Problem
- Approach
- Data
- Models
- Future Tasks

Context

Bridge Condition Data in the US

Rating	Description
9	EXCELLENT CONDITION
8	VERY GOOD CONDITION
7	GOOD CONDITION
6	SATISFACTORY CONDITION
5	FAIR CONDITION
4	POOR CONDITION
3	SERIOUS CONDITION
2	CRITICAL CONDITION
1	"IMMINENT" FAILURE CONDITION
0	FAILED CONDITION

Component

- Since 1970s
- 116 NBI items
  - Deck, superstructure and substructure general condition ratings (GCR)
- 9-0 scale
- SNBI, 2022

Element

- Late 1990s, BMS
- 1997, AASHTO CoRe Elements
- AASHTO, 2011, 2013

3.1.1—Element 12—Reinforced Concrete Deck

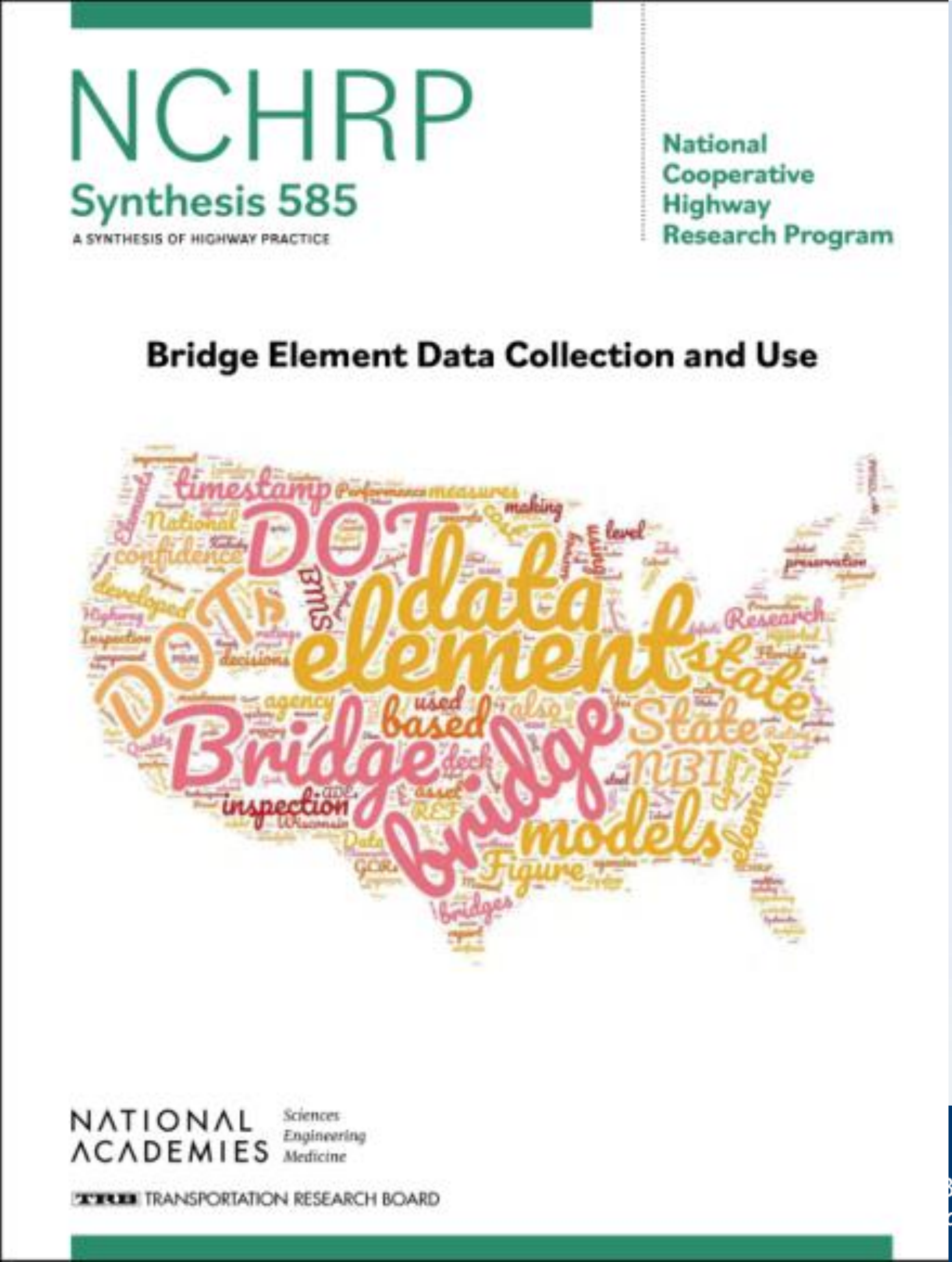
Description: All reinforced concrete bridge decks regardless of the wearing surface or protection systems used.

Classification: NBE **Units of Measurement**: ft^2

Quantity Calculation: Area of the deck from edge to edge, including any median areas and accounting for any flares or ramps present.

Condition State Definitions

	Condition States			
	1	2	3	4
Defects	GOOD	FAIR	POOR	SEVERE
Delamination/Spall/ Patched Area (1080)	None.	Delaminated. Spall 1 in. or less deep or 6 in. or less in diameter. Patched area that is sound.	Spall greater than 1 in. deep or greater than 6 in. diameter. Patched area that is unsound or showing distress. Does not warrant 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.
Exposed Rebar (1090)	None.	Present without measurable section loss.	Present with measurable section loss but does not warrant structural review.	
Efflorescence/Rust Staining (1120)	None.	Surface white without build-up or leaching without rust staining.	Heavy build-up with rust staining.	
Cracking (RC and Other) (1130)	Width less than 0.012 in. or spacing greater than 3.0 ft.	Width 0.012–0.05 in. or spacing of 1.0–3.0 ft.	Width greater than 0.05 in. or spacing of less than 1 ft.	
Abrasion/Wear (PSC/RC) (1190)	No abrasion or wearing.	Abrasion or wearing 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 or wear.	
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.



Context

- Bektas, B. (2022), Bridge Element Data Collection and Use
- Less than half of the state DOTs have established project decision rules, decision trees or performance measures based on bridge element data.
- One fourth of the state DOTs have element cost and deterioration models that they are confident in.
- Reported confidence in decision-making based on component data or models is relatively higher, compared to decision-making based on element data or models.

Problem

For owners, confidence in models is essential for sustained and successful BMS implementation and data-driven decision making.

Limited research quantifying the benefits of bridge maintenance through historic bridge condition and life cycle cost.

Imminent research need to quantify the impact of bridge maintenance and preservation based on data.

Problem

Bridge maintenance and preservation activities are widely accepted to slow bridge deterioration rates and extend service life.

Impact of Maintenance and Preservation

Defining the impact for decision making

- Expert Elicitation
- Quantification / Modeling of Preservation Impact

Limitations

- A starting point
- Based on data addressing variability of structures, environment and history

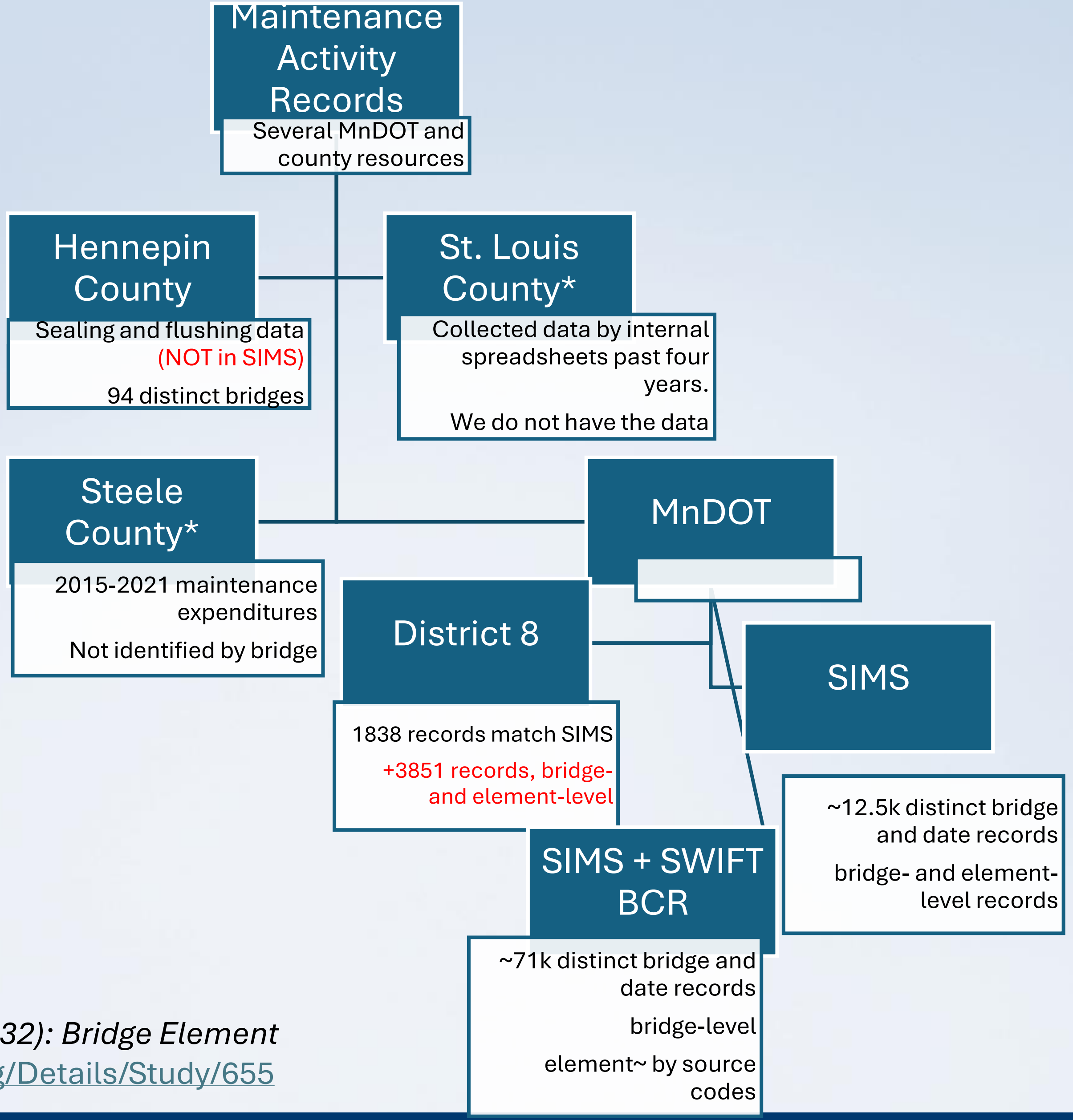
Approach


Condition History
Bridge Maintenance Data
Work History
Impact
Decision Trees
Bridge Characteristics
Environment

Data

- Majority of the maintenance records cover 2011-2023 period.

- TPF-5(432): Bridge Element Deterioration for Midwest States
  - DOTs pool resources and historic bridge data
  - Participating states: ND, SD, MN, NE, KS, IA, WI, IL, MI, IN, OH, KY
  - Develop reliable deterioration curves
    - Markov transition times
  - Custom MN models for this project
    - Now includes 2021-2023 data



Boadi, R., Thompson, P. D., Serigos, P., Bektas, B., & Xu, G. (2022). *TPF-5(432): Bridge Element Deterioration for Midwest States, Final Report* https://www.pooledfund.org/Details/Study/655

		Element Number																
Work Code	empty	810	301	331	321	815	899	300	892	510	895	12	215	816	894	893	330	311
Clean							384	48							72			
Clean and Lubricate																		9
Crack Seal	2	852	2	1	14						15			2				
Expansion Joint Plate				11		12	5	32			31						1	
Fall Clean								105										
Fill Void				1	61		4		106		12		2	1	8	1		
Flood Seal		56																
Flush	12,971																	
GelSeal		49																
Gunite																		
Joint Seal			4	7	47													
Rail Seal	2			344														
Repair	4	1	130	240	781	2	170	37	102	521	300	401	202	5	58	125	120	
Repair Gland			5					153						3				
Repair Joint			58					24						39				
Replace	2		5	22	20	753	71	84	22	8	54	1	5	2	8	26	18	
Replace Gland								40						12				
Reset																		1
Seal		1,402	1,015	604	65		14	8	342	2	14	1	52	73	4			
Seal Joint	1		610	3										63				
Silane		40									1							
Steel Repair				1		69		43			11							
Grand Total	12,982	2,400	1,829	1,234	988	836	649	575	572	533	447	408	286	237	150	152	139	11

A select number of elements receive frequent maintenance treatments.

The maintenance records were examined to develop a list of potential models.

Models

Mining the data to identify the most frequent maintenance work items that could lead to statistically valid models.

Grouping the bridges, components and elements with respect to maintenance level.

Hierarchical & K-Means Clustering

Contrasting component and element deterioration models for different maintenance levels

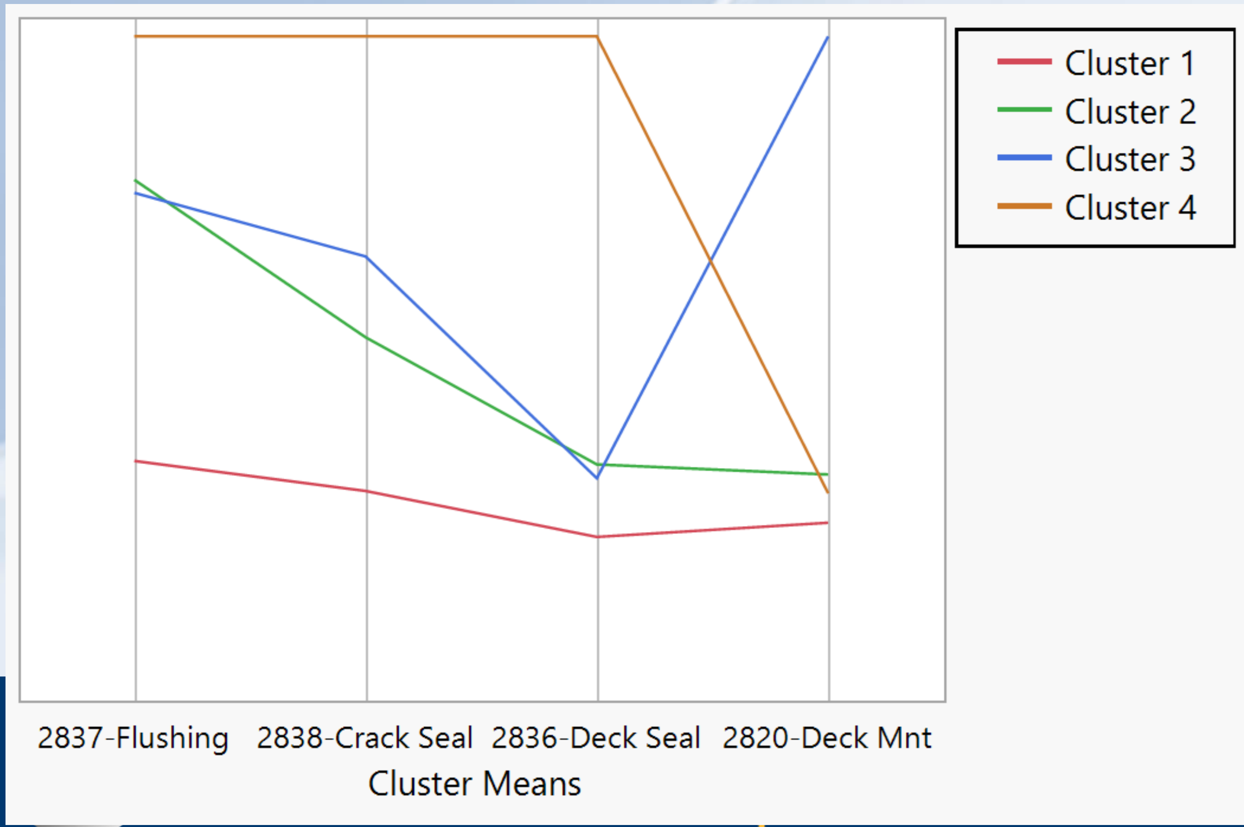
Methodology used in TPF-5(432): Bridge Element Deterioration for Midwest States for Markovian deterioration models

Models

Work Description	Potential Element Models	Potential NBI GCR Models
BRDG POURED/ RELIEF JOINT SEAL	Poured Seal Joint 301, Approach Relief Joint 816	
BRIDGE APPROACH PANEL	Concrete Approach Slab 321*	
BRIDGE BEARING ASSEMBLIES	Elastomeric Bearing 310, Expansion Bearing 311*	Superstructure?
BRIDGE CONC BARRIER/RAIL SEAL	Concrete Bridge Railing 331*	
BRIDGE CULVERT MAINTENANCE	Concrete Culvert 241*	Culvert
BRIDGE DECK	**Reinforced Concrete Deck 12 *, Wearing Surface 510**	**Deck**
BRIDGE DECK CRACK SEALING	**Concrete Wearing Surface - Cracking and Sealing 810 & RC Deck 12, 510, 521**	**Deck**
BRIDGE DECK SEALING FIXED	**Concrete Deck Cracking Element 810*, & RC Deck 12, 510**	**Deck**
BRIDGE EXPANSION, RELIEF JNTS	Strip Seal Joint 300*, Approach Relief Joint 816	Super/Sub? See comment.
BRIDGE FLUSHING	**One to two bridge flushing records. 762 structures that were not flushed. Decks? Joints? Bearings (under joints)?**	**Deck, Superstructure, Substructure**
BRIDGE PREP & PAINTING	Steel Protective Coatings 515, steel elements (frequent super elements)?	Superstructure
BRIDGE SLOPE PROTECTION	Scour 885, Slopes & Slope Protection 892, Deck & Approach Drainage 894	Substructure
BRIDGE SUBSTRUCTURE**	Most frequent substructure elements (Concrete Column 205, Reinforced Concrete Abutment 215)	Substructure
BRIDGE SUPERSTRUCTURE	Most frequent superstructure elements (Prestressed Concrete Girder or Beam 109) Steel Girder	Superstructure
JOINT REESTABLISHMENT	Strip Seal Expansion Joint 300, Poured Seal Joint 301*, Approach Relief Joint 816 underlying super/sub? Deck?	
PROTECTION STRAPS/CURB PLATES	Plow Fingers 815, Strip Seal Expansion Joint 300	
WATERWAY MAINTENANCE	Deck & Approach Drainage 894 might fit better with element 899, 885, or 892. In a lot of cases, this is removing debris from the channel for flow or rip rap placement.	Channel

Deck Maintenance Clusters

	Cluster	Count	Flushing	Crack Seal	Deck Seal	Deck Mnt
Minimal Maintenance	1	10,379	0.03	0.02	0.00	0.00
Moderate Maintenance	2	2,184	6.13	1.37	0.47	0.41
Focused Deck Maintenance	3	288	5.85	2.08	0.38	4.14
Flush&Seal (High Mnt)	4	216	9.24	4.01	3.26	0.25



- For clustering analysis, the number of maintenance activities by bridge, component, and element during the study period, were used as variables.
- Hierarchical and K-means clustering were used together to identify maintenance levels.
- The objective is to create groups as different as possible in terms of the variables, frequency of select maintenance activities in this case.
- Too many clusters would preclude valid deterioration models.

Deck Deterioration by Cluster

	TTime	Deck GCR					
	Cluster	**9**	**8**	**7**	**6**	**5**	**TTime 9-5**
Minimal Maintenance	1	2.4	4.6	6.8	6.6	9.4	29.8
Moderate Maintenance	2	1.1	2.9	11.8	16.4	14.7	46.9
Focused Deck Maintenance	3	1.2	2.5	8.3	18.7	21.6	52.3
Flush&Seal (High Mnt)	4	2.0	5.0	12.1	14.8	28.3	62.1

- Except GCR (General Condition Rating) 9&8, **clusters with higher levels of maintenance consistently have higher transition times** (time spent in each GCR), indicating service life extension.
- Increased maintenance typically correlated to higher transition times.

Deck Deterioration by Cluster and Construction Era

	TTime	Deck GCR					
	Era	9	8	7	6	5	TTime 9-5
	<1960						
Minimal Maintenance	1	2.0	3.4	4.2	5.4	8.8	23.7
Moderate Maintenance	2	0.8	2.4	5.8	8.4	11.0	28.3
Focused Deck Maintenance	3	1.2	3.0	5.4	11.1	56.0	76.7
Flush&Seal (High Mnt)	4		4.0	11.1	10.5	19.1	44.7
	1960-84						
Minimal Maintenance	1	2.3	4.2	7.3	8.1	11.3	33.2
Moderate Maintenance	2	0.9	3.1	9.2	19.6	17.9	50.7
Focused Deck Maintenance	3	1.7	2.3	7.7	22.2	21.1	54.9
Flush&Seal (High Mnt)	4	1.6	4.8	9.1	13.4	35.6	64.6
	1985+						TTime 9-7
Minimal Maintenance	1	2.4	6.7	20.1			29.2
Moderate Maintenance	2	1.2	2.8	30.5			34.4
Focused Deck Maintenance	3	0.9	3.1	14.2			18.3
Flush&Seal (High Mnt)	4	2.0	5.3	27.1			34.5

- Increased transition time by maintenance, especially for GCRs 7-5.

Deck Deterioration by Cluster and Traffic Level

	TTime	Deck GCR					
	Row Labels	9	8	7	6	5	TTime 9-5
	00-01k						
Minimal Maintenance	1	2.7	4.9	6.1	6.4	9.2	29.3
Moderate Maintenance	2	1.3	4.0	8.3	11.7	12.0	37.2
Focused Deck Maintenance	3	1.4	3.0	6.5	26.7	17.2	54.8
Flush&Seal (High Mnt)	4	1.9	7.3	9.7	27.2	9.2	55.3
	01-10k						
Minimal Maintenance	1	1.6	4.3	8.7	7.2	10.5	32.3
Moderate Maintenance	2	1.2	3.1	12.2	17.4	15.8	49.7
Focused Deck Maintenance	3	1.1	3.0	8.1	14.8	35.4	62.3
Flush&Seal (High Mnt)	4	2.1	4.6	13.1	12.4	25.4	57.6
	10k+						
Minimal Maintenance	1	1.4	2.1	9.7	7.6	9.1	29.9
Moderate Maintenance	2	1.0	2.0	12.6	17.3	14.9	47.8
Focused Deck Maintenance	3	1.3	1.9	8.6	22.2	13.5	47.5
Flush&Seal (High Mnt)	4	1.4	4.1	6.9	27.4	9.1	48.9

- Red transition times for Flush & Seal cluster could not be computed due to limited number of inspection pairs. The transition times for minimal maintenance were noted to compare TTime 9-5.
- Increased transition times are again observed for GCRs 7-5.

Preliminary Findings

Deck component models indicate increased service lives with maintenance activity.

While there are some exceptions for higher GCRs (9&8), transition times for GCRs 7-5 are consistently higher.

Future Tasks

Expansion of the data set to include 2022-2023 maintenance data.

This was done for the deck models presented today.

GCR models

Superstructure and substructure models

Element models

Life cycle cost analysis

Decision trees

Questions?