NATIONAL ACADEMIES Sciences Engineering Medicine

TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: Remaining In-Service Life of Culverts and Other Geotechnical Assets

April 24, 2023

1:00 – 2:30 PM

PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact TRBwebinar@nas.edu

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.

ENGINEERING RCEP REGISTERED CONTINUING EDUCATION PROGRAM

AICP Credit Information

This webinar will focus on qualitative models to assess conditional and performance of in-service assets and forecast remaining service life for geotechnical management applications. Presenters will share current practices and gaps for assessing the condition of culverts and other geotechnical assets.

Learning Objectives

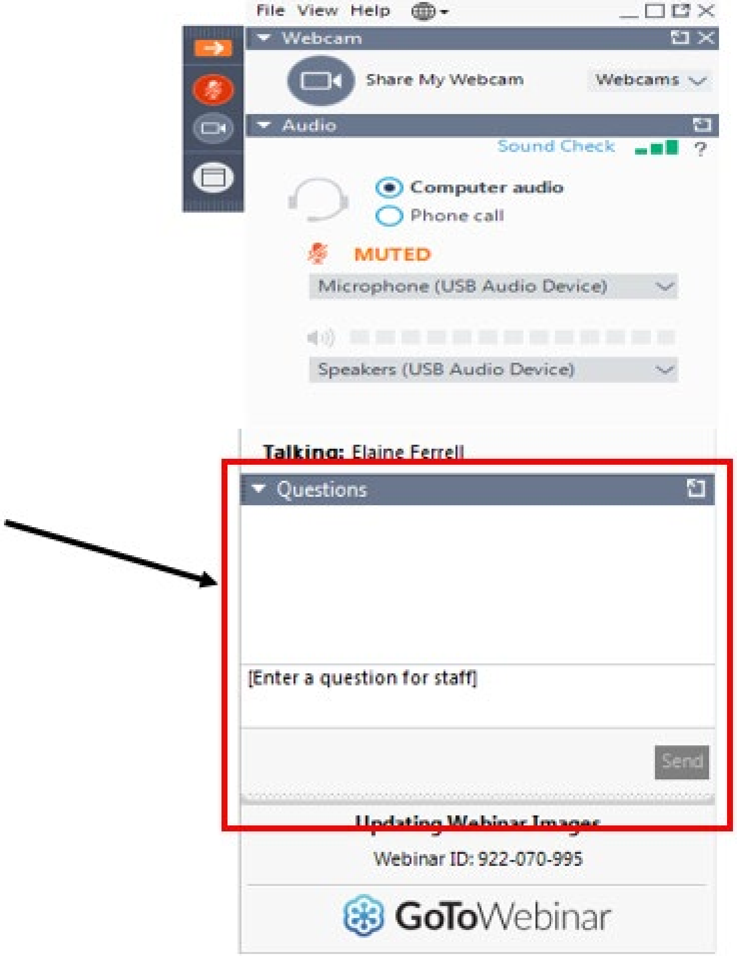
At the end of this webinar, you will be able to:

- Identify the current practices and gaps in assessing conditions of culverts and other geotechnical assets
- Evaluate the methods to develop performance models for culverts based on different condition assessment data
- Implement performance forecasting to estimate remaining service life of in-service geotechnical assets

Questions and Answers

- Please type your questions into your webinar control panel

- We will read your questions out loud, and answer as many as time allows



Today’s presenters

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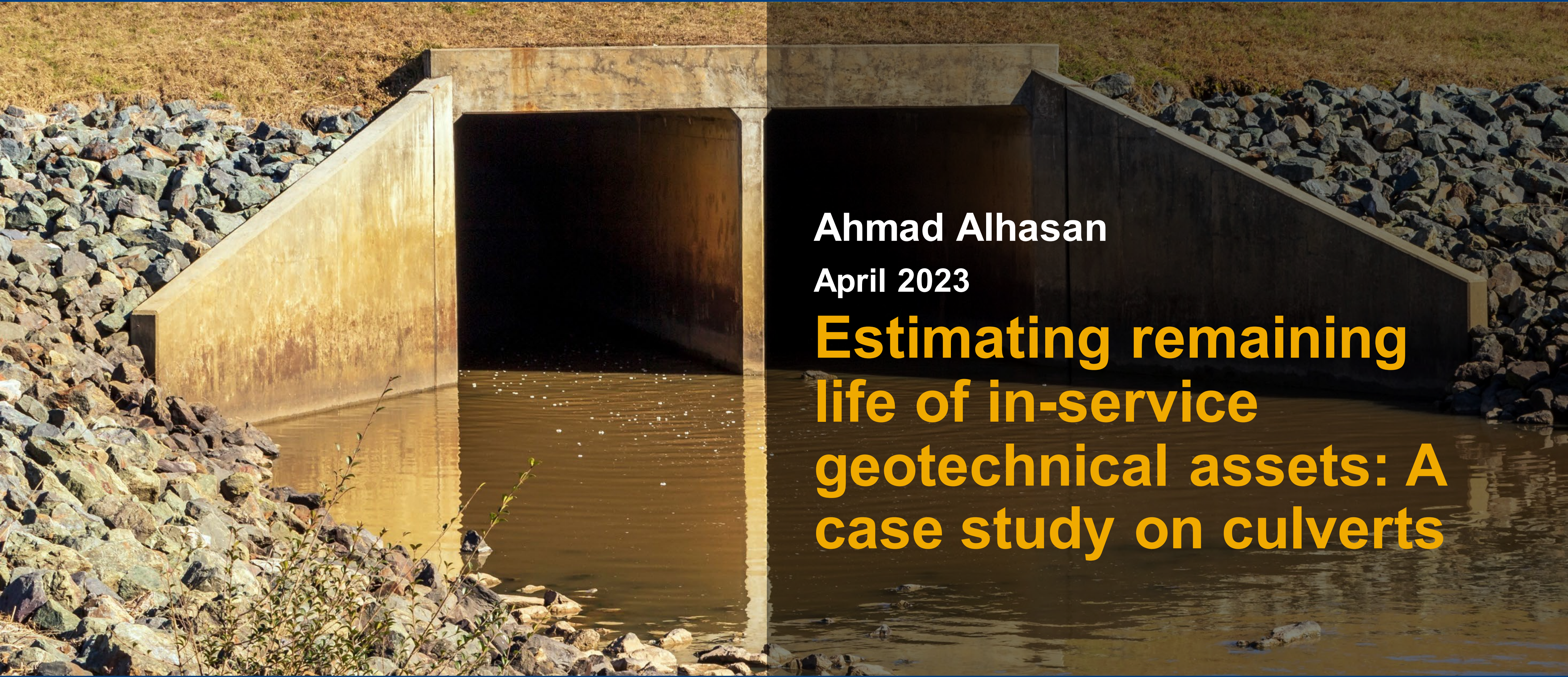


Ahmad Alhasan

April 2023

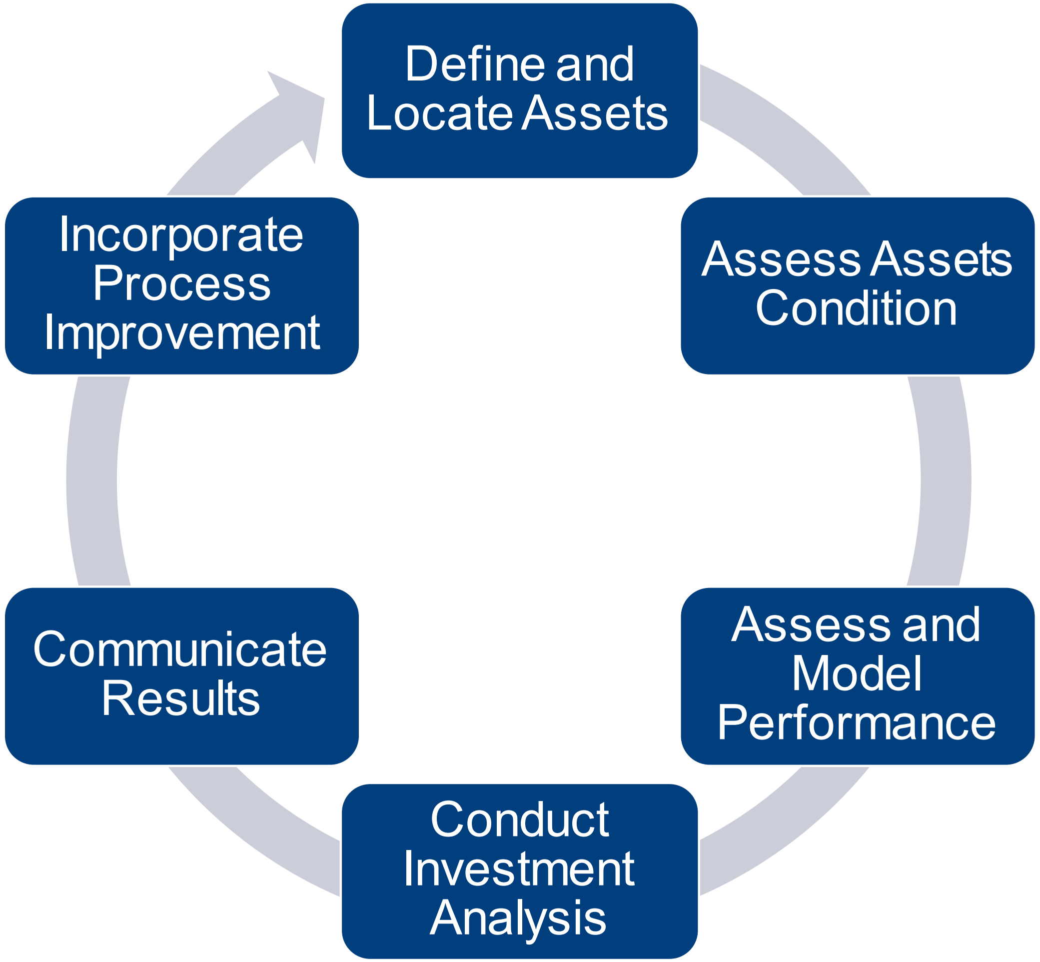
Estimating remaining life of in-service geotechnical assets: A case study on culverts

Agenda

- Geotechnical Asset Management
- Condition Assessment and Performance Modeling Concepts
- Case Study
- Model Fitting and Forecasting
- Beyond this Webinar

Geotechnical Asset Management

- GAM includes several components and the agency's focus can vary.
- Generally, a GAM program includes multiple steps and requires an iterative and cyclic to improve and refine the program throughout its implementation.



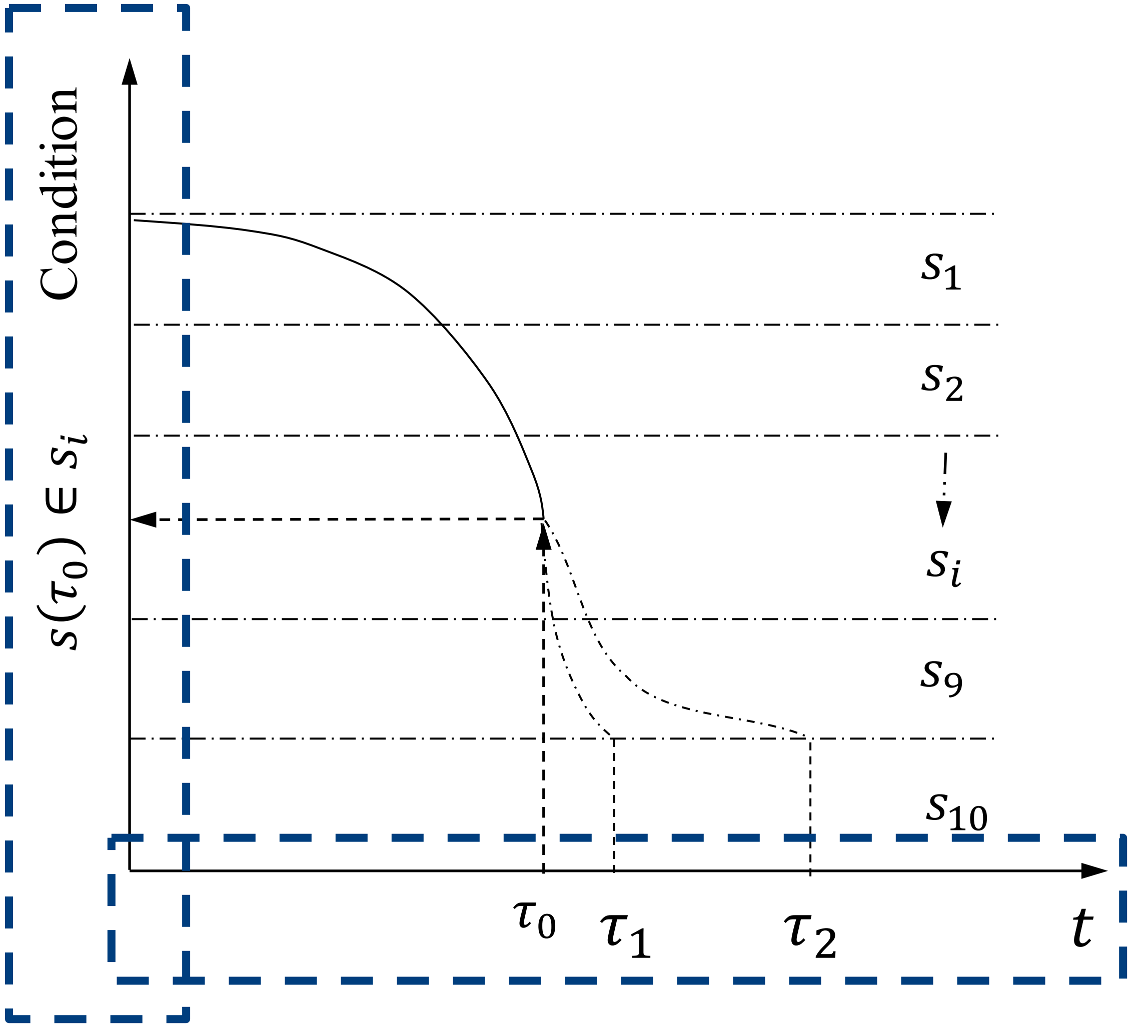
Implementation steps, modified from NCHRP Project 24-46

Design Life and Service Life

- Design life can be defined as the period on which the statistical derivation of transient loads is based.
- Service life is the forecasted time the asset will provide desired function and remains in service.
- Service life is typically modeled based on real world observations.

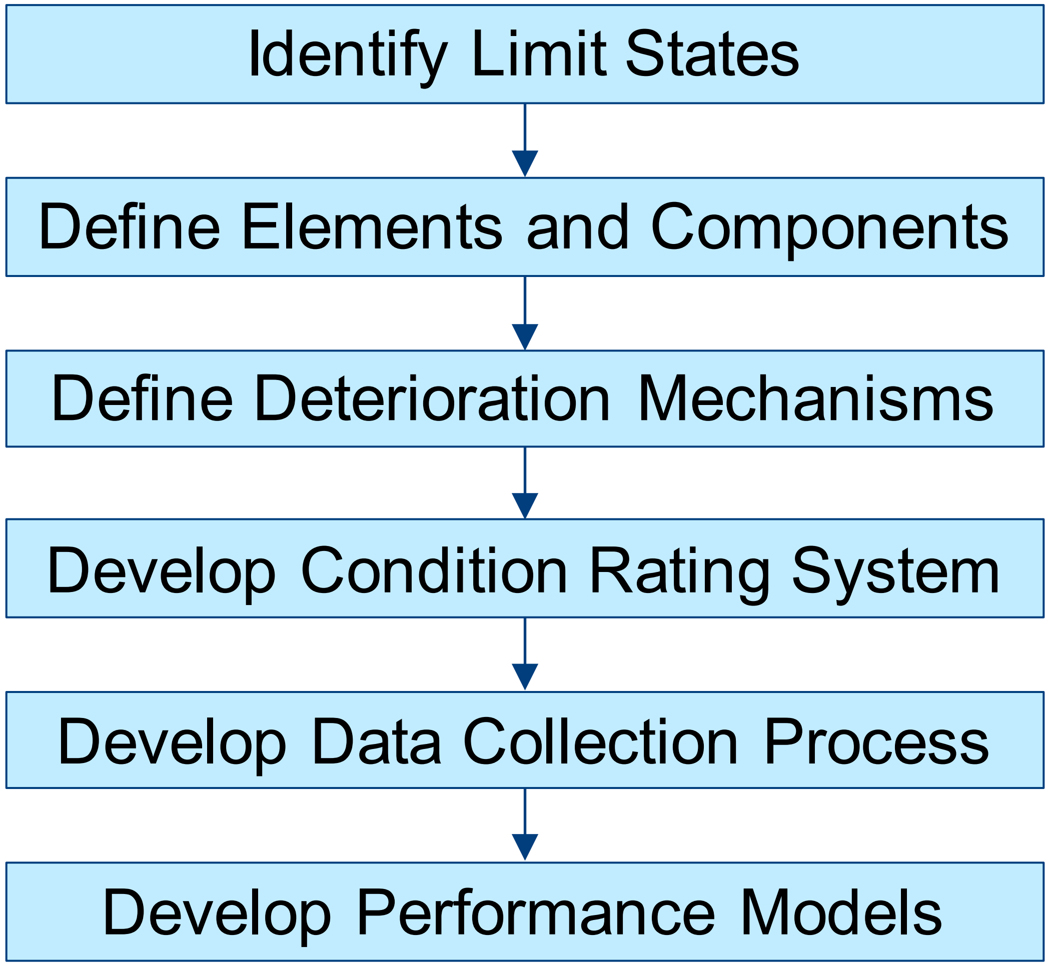
Role of Performance Models

- Performance models can be used to estimate remaining service life.
- Performance models are the quantitative tool to forecast the future and manage the assets.
- Performance models are used to estimate the benefits and control the risks.



Performance Modeling Process

- Understanding deterioration mechanisms is important to select the representative model.
- It is critical use the proper statistical assumptions and the forecasting with interpretation techniques



Types of Deterioration and Performance Models

Physical Model
- Mechanistic
- Empirical
- Mechanistic-Empirical

Process
- Continuous
- Discrete

Inference
- Deterministic
- Probabilistic

Case Study: Ohio Culverts

ODOT Manual of Bridge Inspection 2014 v8

Condition Rating Inspection

Field Manual (Chapters 7 & 8)

Culvert Seams – "ded" CONDITION RATING

Item - 47. Seams

Type – Concrete

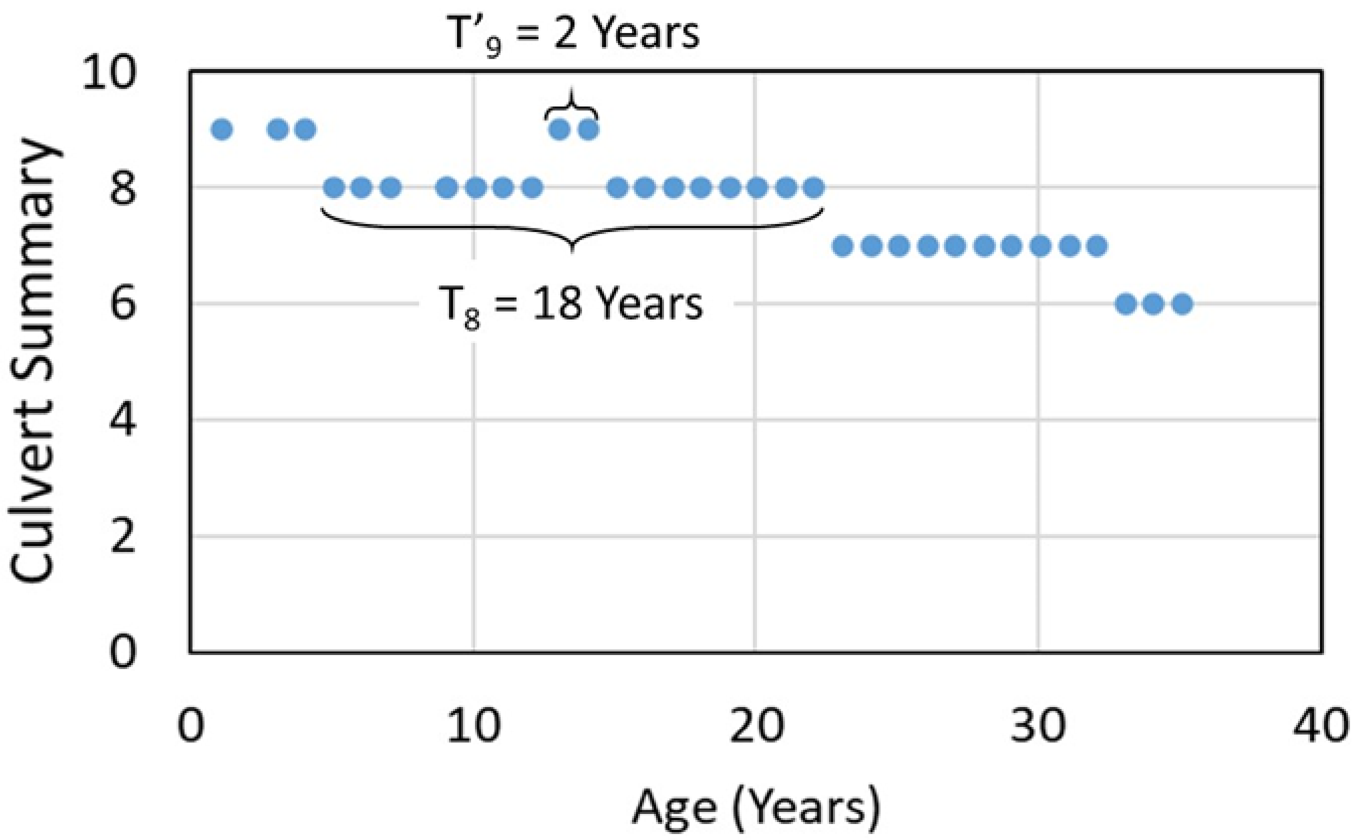
1-4	9-0 Summary	General	Alignment	Backfill
1-Good	9-Excellent	Straight line between sections.		
	8-Very Good	No settlement or misalignment; Tight with no defects apparent.		
	7-Good	Minor distress to pipe material adjacent to joint. Shallow mortar deterioration at isolated locations.	Minor misalignment at joints; off sets less than 1/2 inch.	Possible minor infiltration of fills no settlement.
2-Fair	6-Satisfactory	Extensive areas of shallow deterioration; missing mortar at isolated locations; possible infiltration or exfiltration; minor cracking.	Dislocated end section.	Minor backfill infiltration due to slight opening at joints; minor cracking or spalling at joints allowing exfiltration.
	5-Fair	Significant cracking, spalling, buckling of pipe material, loose or missing mortar at isolated locations.	Joint offset less than 3 inches. End sections dislocated about to drop off mortar generally deteriorated.	Joint open and allowing backfill to infiltrate, infiltration staining apparent.
3-Poor	4-Poor	Voids seen in fill through offset joints. End sections dropped off at inlet. Mortar severely deteriorated, significant loss of mortar.	Differential movement and separation of joints. Joint offset less than 4 inches.	Significant infiltration or exfiltration between masonry units.
	3-Serious	Large voids seen in fill through offset joints. Extensive areas of missing mortar.	Significant openings, dislocated joints in several locations exposing fill material with joint offsets greater than 4 inches.	Infiltration or exfiltration causing misalignment of pipe and settlement or depressions in roadway.
4-Critical	2-Critical	Culvert not functioning due to alignment problems throughout. Large voids seen in fill through offset joints.		
	1-Imminent Failure	Pipe partially collapsed or collapse is imminent.		

Table 57 - Condition Rating: Culvert Concrete Seams

Condition Data

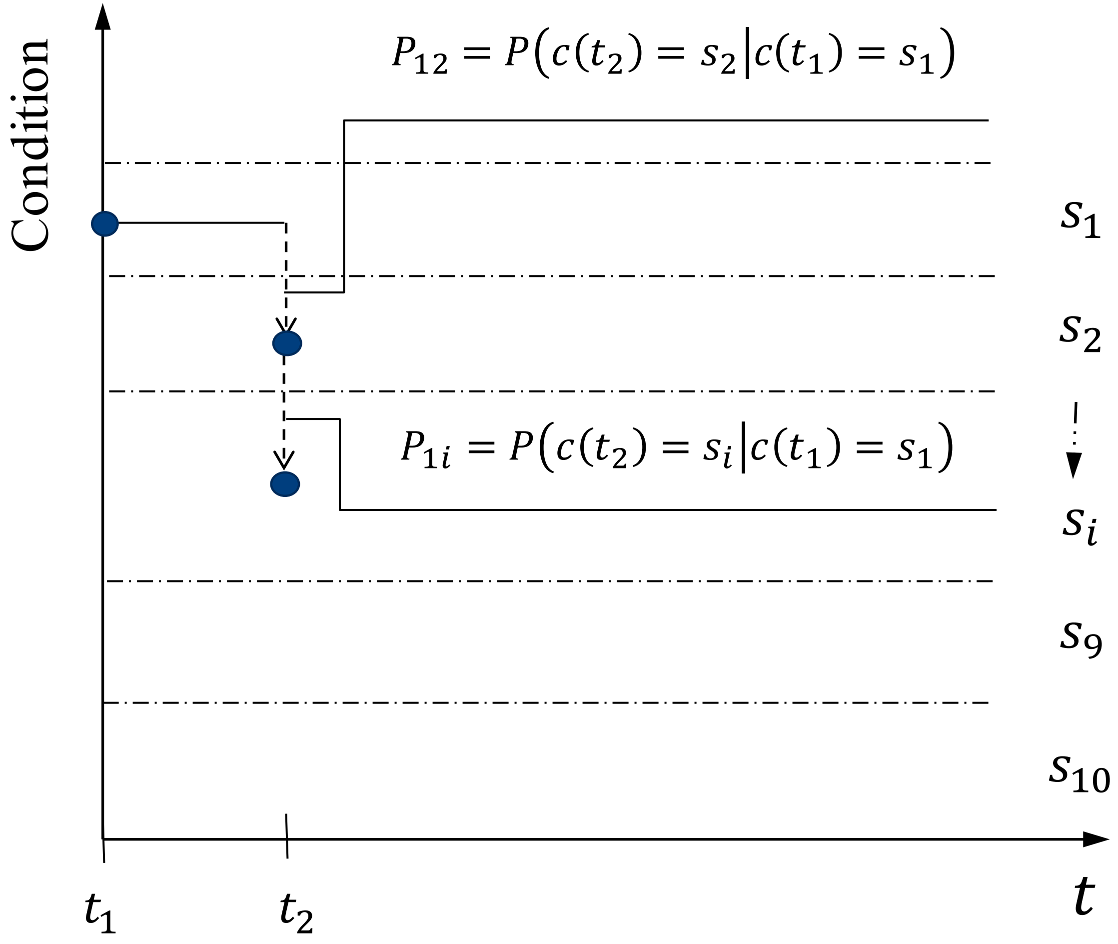
Common data issues:

- Sudden data drop due to performance rating variability
- Significant condition improvement without recorded reconstruction or preservation interventions
- Missing performance rating data within evaluation period



Condition Data as a Markov Chain Processes

$$P = \begin{matrix} 9 \\ \vdots \\ 0 \end{matrix} \begin{bmatrix} p_{11} & \cdots & p_{1\,10} \\ \vdots & \ddots & \vdots \\ p_{10\,1} & \cdots & p_{10\,10} \end{bmatrix}$$



Expected Future Condition

Expected Value of the **Condition Distribution** after n years is:

$$E(C|T = n, P) = M_r R$$

$$R = \begin{bmatrix} 9 \\ 8 \\ \vdots \end{bmatrix}$$

$$M_r = C_0 P^n$$

Transition Probability Matrix										
States	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
9	0.28365	0.60806	0.06557	0.01994	0.01863	0.00307	0.00097	9.7E-05	1.8E-05	1.3E-06
8	0.06639	0.92769	0.00471	0.00063	0.00053	4.4E-05	1.2E-05	5.8E-07	8.6E-08	1.9E-09
7	0	0	0.33531	0.26446	0.27891	0.08378	0.03086	0.00534	0.00117	0.00019
6	0	0	0	0.48884	0.2596	0.18069	0.05227	0.01496	0.0029	0.00074
5	0	0	0	0	0.51384	0.2649	0.16056	0.04366	0.01339	0.00365

$$\boldsymbol{E(C|T = 5, P) = 8.1}$$

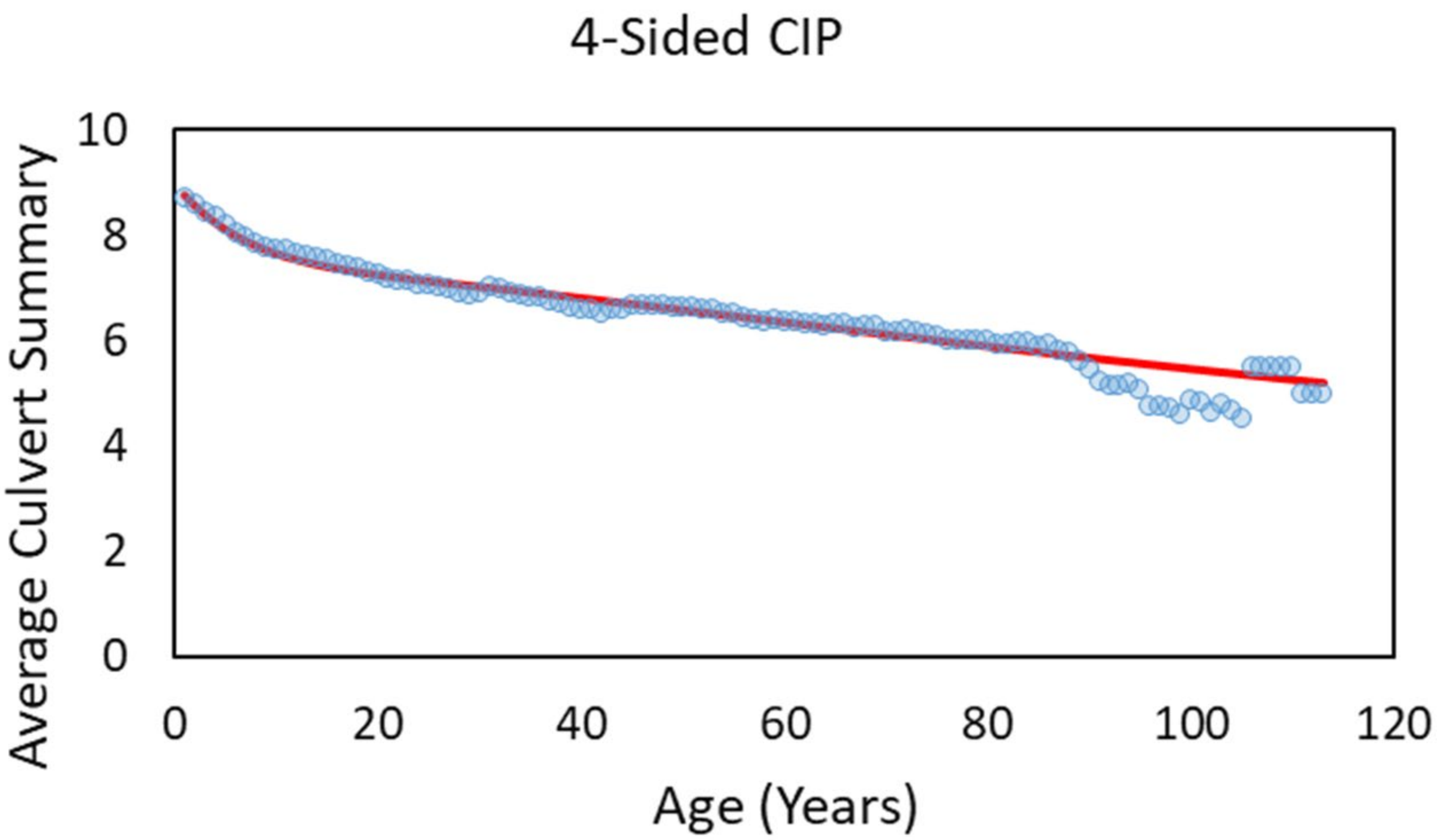
Estimating Transition Probabilities

Minimize the absolute difference between the average condition at age *t* and the expected value from Markov chain by changing the probabilities:

$$\min_{p_{ij}} \sum_{t=1}^{n} W_t$$

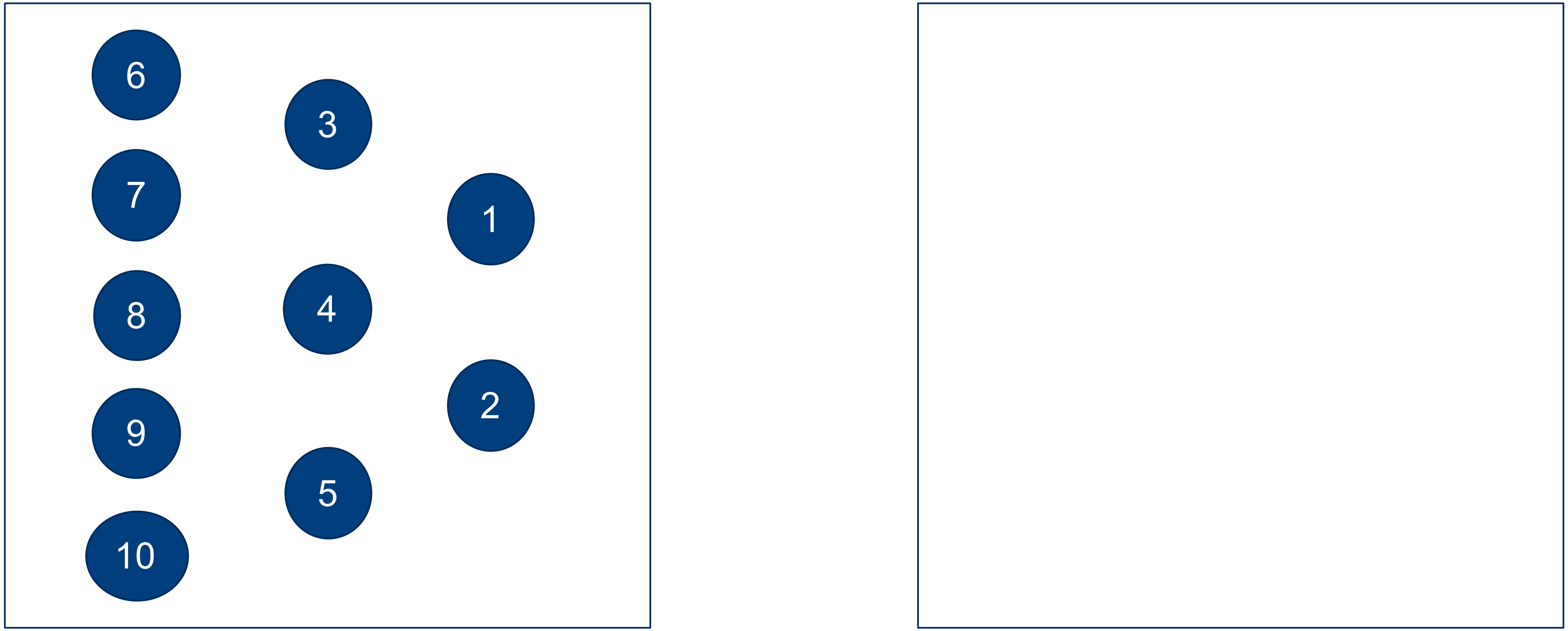
$$W_t = \left| \frac{\sum_{k=1}^{L} C_{k,t}}{L} \right| - C_0 \begin{bmatrix} p_{11} & \cdots & p_{1\,10} \\ \vdots & \ddots & \vdots \\ p_{10\,1} & \cdots & p_{10\,10} \end{bmatrix} . \begin{bmatrix} p_{11} & \cdots & p_{1\,10} \\ \vdots & \ddots & \vdots \\ p_{10\,1} & \cdots & p_{10\,10} \end{bmatrix} \ldots .R$$

Ignoring Variability Reduces Accuracy



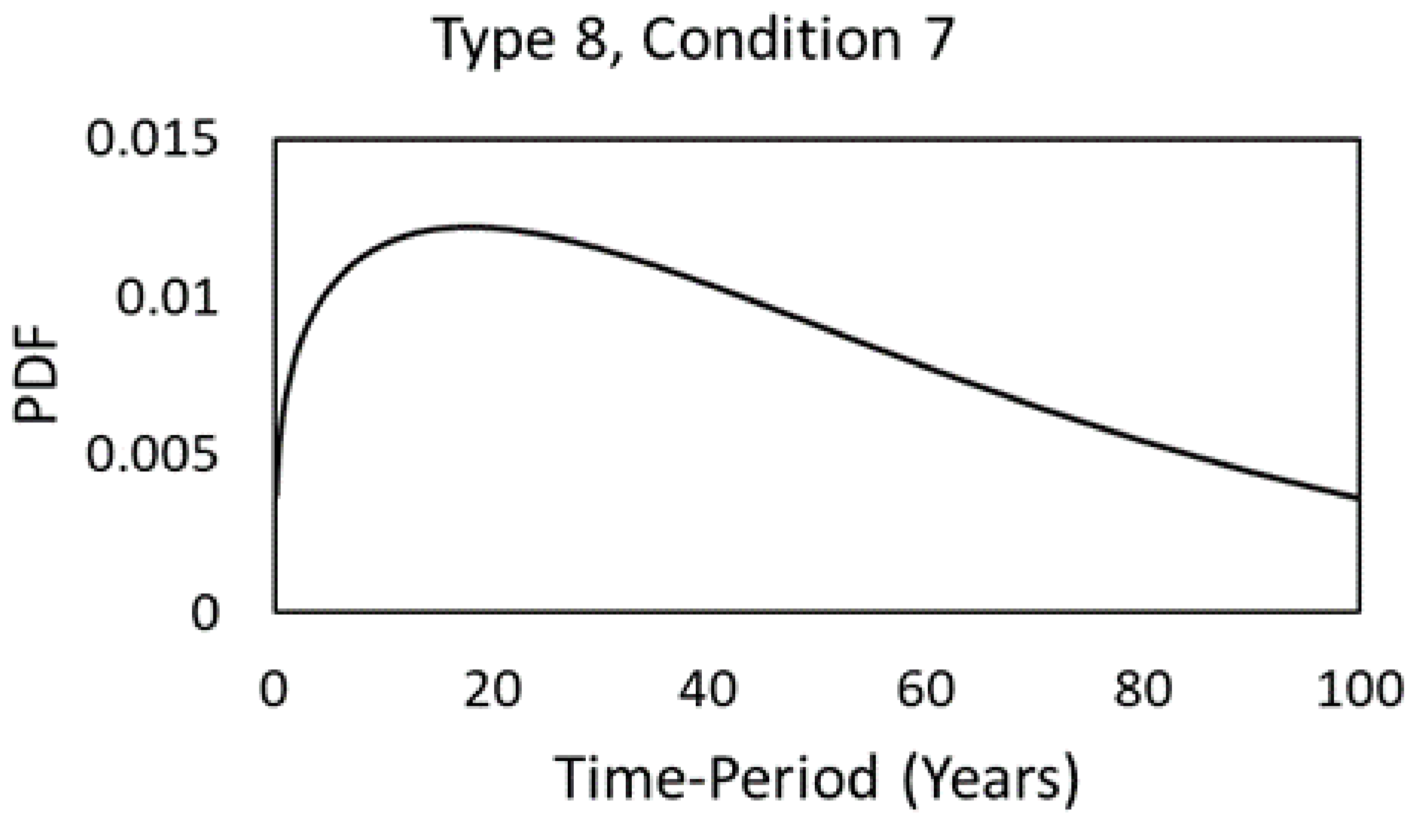
Survival Models

P (T≤ [illegible]) ≈ [illegible]

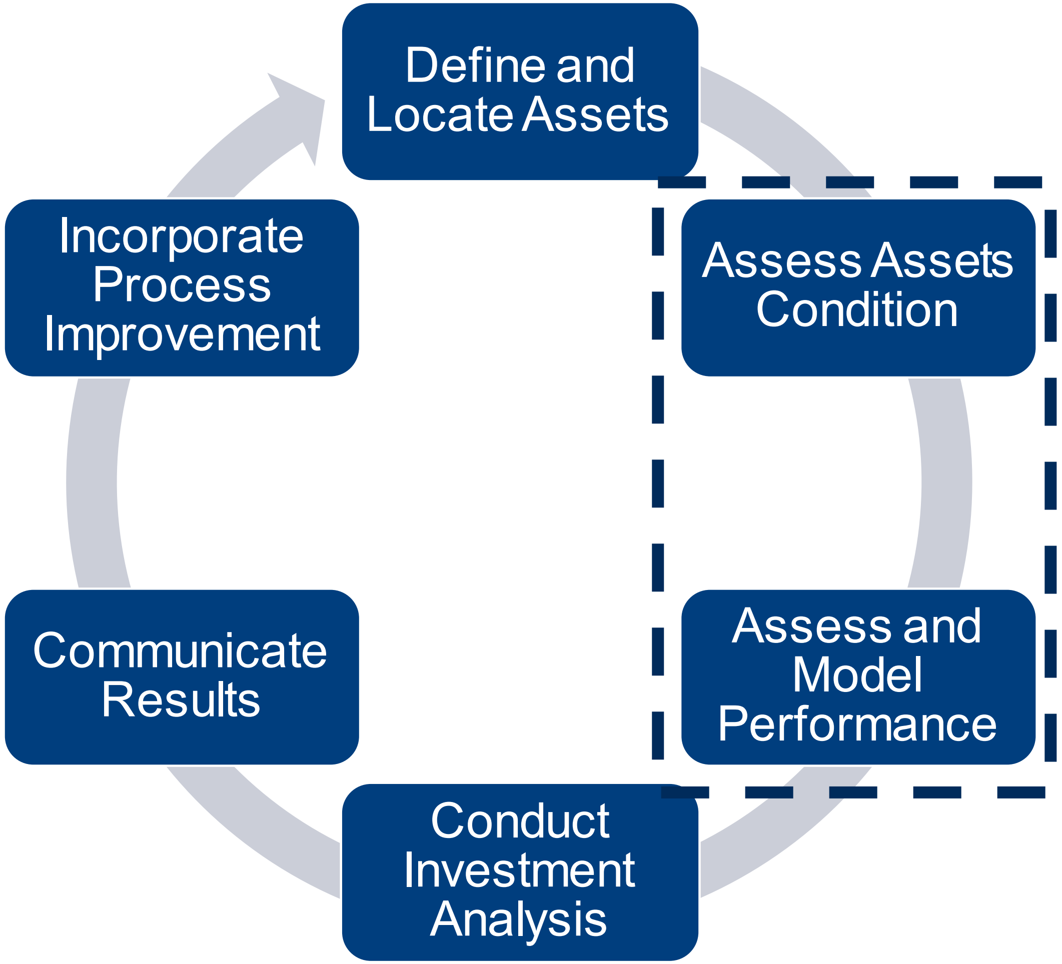


State A State B

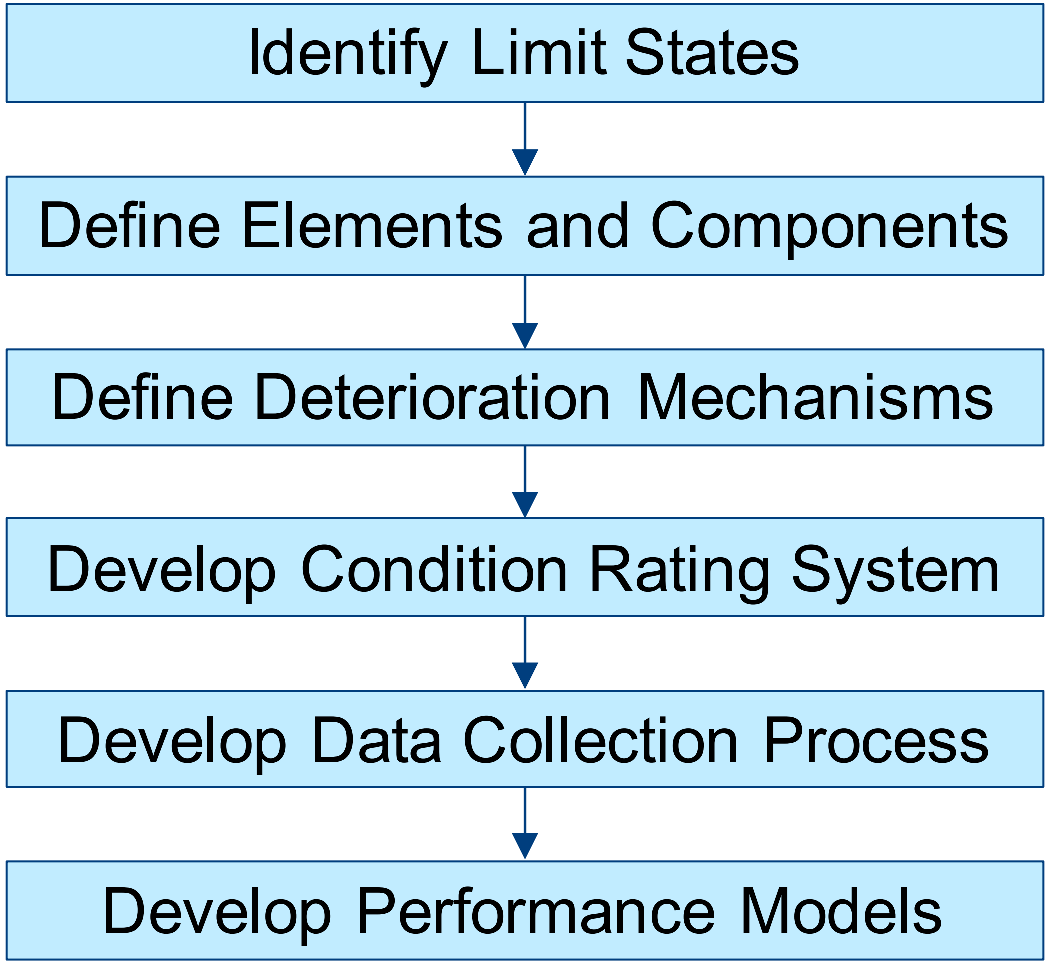
Forecasting and Interpretation



Summary



Define and Locate Assets
Assess Assets Condition
Assess and Model Performance
Conduct Investment Analysis
Communicate Results
Incorporate Process Improvement



Identify Limit States
Define Elements and Components
Define Deterioration Mechanisms
Develop Condition Rating System
Develop Data Collection Process
Develop Performance Models

Beyond this Webinar?

1. Develop procedures to infer performance of individual assets.
2. Use of physics (or engineering) based AI to develop better modeling and optimization techniques.
3. Incorporate uncertain extreme events in performance modeling and planning.
4. Quantify the resiliency of assets' performance.
5. Geotechnical assets are heterogeneous, can we develop a more homogeneous condition and performance scheme to incorporate multiple assets?

Corridor Health
A Case Study

TRB Webinar

Remaining In-Service Life of Culverts and Other Geotechnical Assets

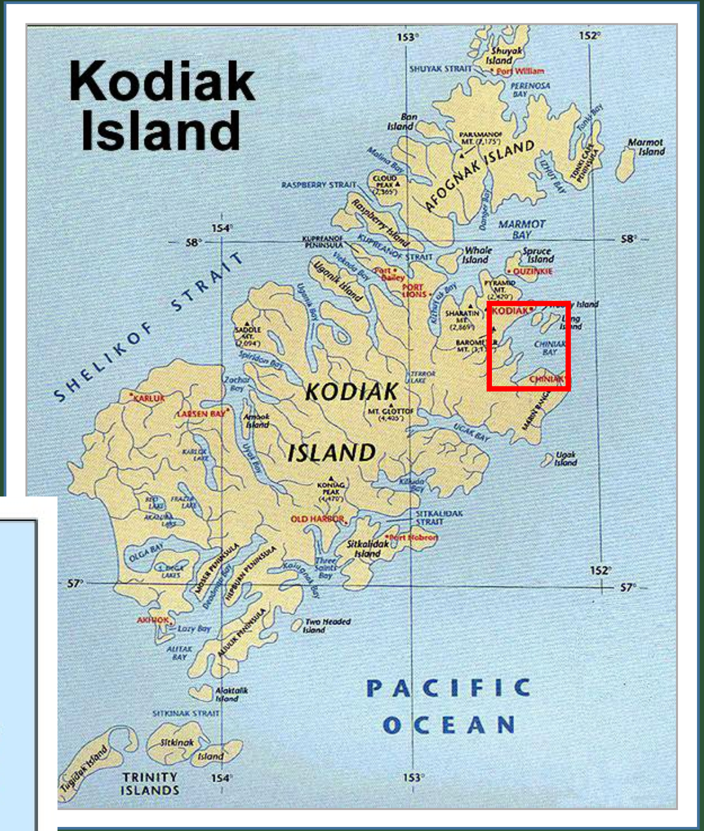
April 24, 2023

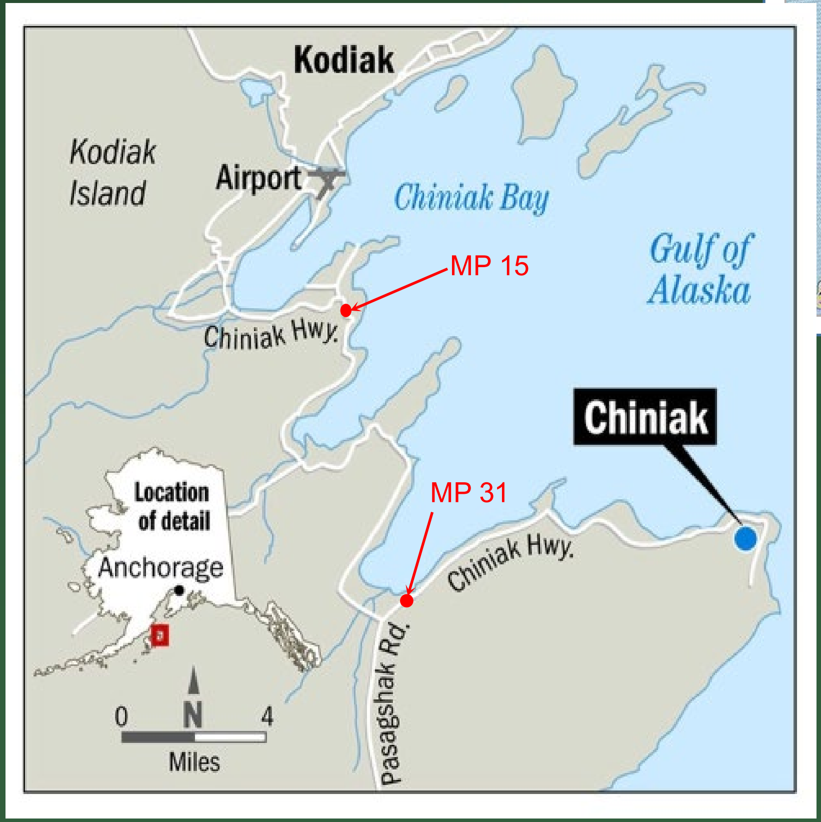
Ben George, P.E., C.E.G.

Trevor Strait, P.E., PTOE

Project Location and Approach

- Chiniak Highway, MP 15 – 31
  - Two lane roadway constructed in 50s, paved circa 90s
- STIP (3R) Rehabilitation Project
  - Mitigate Safety Concerns
    - Reduce Crashes
    - Improve Sight distance
  - Improve Roadway
    - Subgrade and surface
    - Vertical/horizontal curves
    - Guardrails
    - Drainage/culverts
- Limited $ for $$$$ work





Scope the Project

Where is poor performance occurring?

What is contributing to performance?

Inventory and Rate Assets


Soil Slopes


Culverts


Pavements


Rock Slopes


Bridges


M&O

Variable Data, Many Sources, Non-Standardized

Critical Assets

- Identify which assets drive Scope
  - Pavement
  - Bridges
  - Culverts
  - Roadway Geometry
  - Geotechnical (slopes, retaining walls)
- Develop method to evaluate each asset within a Good/Fair/Poor, 0-100 scoring framework

- Ratings considered:
  - Safety
  - Reliability
  - General Fund Costs
  - Other impacts and considerations

Asset – Culverts

- Existing method of analysis
  - Non-Standardized
  - Based on Inspections

- Culvert Material
- Culvert Shape
- Culvert Rise
- Culvert Span
- Culvert Length
- Pipe Physical Condition
- Pipe Structural Condition
- Flow Condition
- Embedment Depth
- Baffles Present
- Height of Cover
- Roadway Deflection
- Inlet Type
- Inlet Structural Condition
- Inlet Embankment Condition
- Inlet Channel Condition
- Outlet Type
- Outlet Structural Condition
- Outlet Embankment Condition
- Outlet Channel Condition
- ADF&G Fish Passage Rating

Asset – Culverts

- Rating Method
  1. Fail Condition Screening
  2. Calculate worst of Physical Condition, Structural Condition, and Flow Condition
  3. Calculate worst of Inlet/Outlet Embankment Condition
  4. Average these values
  5. Adjust for Fish Passage Rating

Attribute	Description	Rating Value
Pipe Physical Condition	Like new, no defects	100
	Cracked, spalled, light rust	75
	Broken, rust pitted, weathered joints	50
	Deteriorated, rotted, bottom out	25
	Unknown	-
Pipe Structural Condition	Good, no sags or deflection	100
	Fair, minor sags with no ponding, minor deflection that would inhibit the installation of a liner pipe	50
	Poor, major sag with ponding, major deflection that would inhibit the installation of a liner pipe	25
	Pipe collapsed	0
	Unknown	-
Flow Condition	Open	100
	< 1/2 clogged	50
	1/2 or more clogged	25
	Unknown	-
Inlet Embankment Condition	Good, no slope failure	100
	Fair, eroded slopes are localized and easily repairable	50
	Poor, eroded slopes have potential to impact roadway	25
	Unknown	-
Outlet Embankment Condition	Good, no slope failure	100
	Fair, eroded slopes are localized and easily repairable	50
	Poor, eroded slopes have potential to impact roadway	25
	Unknown	-
Fish Passage Rating	Green	100
	Gray	50
	Red	25
	Black	-

Asset – Culverts

- Rating Method compared to Inspection Photos

Good Rating

Fair Rating

Asset – Geotechnical Elements

- Existing method of analysis
  - Significant existing methodology for assessing geotechnical conditions
    - Geotechnical Asset Management (GAM) elements
  - Existing Alaska inventory
  - Documents retaining walls, rock slopes, and soil slopes that are impacting the roadway
  - Location and Condition of Material Sources

Asset – GAM Elements

Alaska DOT&PF Rock Slope Rating Calculator

Ver. 1.1 Dec 2017

Rated By	B. George, A. Mines
Rating Date	5/14/2019 7:52:53 PM
Site ID	0674000018382019

Site Information

Region	SR	Community		**Rockfall Type**	
Highway Name	CHINIAK HIGHWAY	Maint. District	Kodiak	Rock Avalanche	NO
		Maint. Station	Kalisen Bay	Planar Failure	NO
CDS Route Number	67400			Wedge Failure	NO
Highway Milepost	28.7	Common Name		Toppling Failure	NO
CDS Milepoint	18.38	B-Slope	NO	Raveling/Undermining	YES
Latitude	57.598915	Mitigation Present	NO	Block Failure	YES
Longitude	-152.474077	Site Rating Status	ACTIVE		

Comments: Split 2010 site 0674000018142010 in 2 based on activity and presence of drainage channel. Frequent maintenance issue, jointed rock under glacial till slope. Rockfall frequently crosses road. 12 ft ditch. Activity increasing towards N end of slope

Site Measurements

Slope Height (ft)	100	Roadway Width (ft)	26	Sight Distance	430
Slope Length (ft)	375	Speed Limit (mph)	55	AASHTO DSD (ft)	
Block Size (ft)	4	Annual Precipitation (in)			
Event Volume (cy)	10	AADT (count)	529		

GIS Alaska Precipitation Map – https://arcg.is/1kmhCUN

GIS 2012/2013 AADT Map – https://arcg.is/1MnAI6W

Site Summary

Condition Index	36	Total USMP Rating	562	Programmatic Improvement Cost to CS1	533813
Condition State	4	Hazard Rating	443		
Condition State text	POOR	Risk Rating	119		

Calculation is programmatic and does not reflect site-specific needs. Actual costs may differ significantly

Slope Hazard Rating

			Highest of size of volume scores	81
			Slope Height Score	81
Case 1 Structure Score	9	*Discon. Fav, discon rand, discon adverse, cont. adverse*		
Case 1 Joint Friction Score	27	*Rough Irreg, undulating, planar, clay filled/slickensides*		
Case 2 Features Score	27	*Few features, Occ, Many, Major*		
Case 2 Diff Erosion Score	50	*Small diff, mod, Large w/fave, Large w/Unfave*		
			Geologic Character Score (Highest sum of Case 1 or Case 2 Scores)	77
Ditch Effectiveness Score	50	*Good, Moderate, Limited, None*	*Ditch Effectiveness Score*	50
Maintenance Freq. Score	50	*Sched. Ditch maint, patrols after storms, daily seasonal patrols, daily patrols*	*Maint. Freq. Score*	50
Rockfall History Score	50	*Few, Occ, Many, Constant*	*Rockfall History Score*	50
Annual Precip. Score	81		*Annual Precip Score*	81
Slope Drainage Score	27	*Dry or well drained, intermittent water, usually wet, always wet*	*Water on Slope Score*	54
			Hazard Subtotal	443

Slope Risk Rating

			Decision Sight Distance Score	49.019902
			Roadway Width Score	35.533997
			AADT Score	3
% Time Car Within Site	1.133238		*Average Vehicle Risk Score*	1.133238
Impact on Traffic Score	9	*Minor Delay, One Lane Open, 100 mi or 1 day closure, no detour or 3 days+*	*Traffic Impact Score*	9
ROW Impact Score	3	*None, Minor, Private property-no structures, structures/roads/RR/util/parks*	*ROW Impacts Score*	3
Environ. Impacts Score	0	*Zero points if no environmental impacts are likely, 50 pts if some possible*	*Environ. Impacts Score*	0
Maint. Complexity Score	9	*Routine, Specialized Equip, Difficult effort/location, Complex/dangerous*	*Maint. Complexity Score*	9
Maintenance Freq. Score	50	*Sched. Ditch maint, patrols after storms, daily seasonal patrols, daily patrols*	*Maint. Freq. Score*	50
Event Cost Score	9	*$10k, $50k, $100k, $250k in reasonable worst case*	*Event Cost Score*	9
			Risk Subtotal	119

Asset – GAM Elements

- Supplemental Rating – Threatening Slopes

Asset – GAM Elements

- Supplemental Rating – Threatening Slopes

Threatening Slopes Rating Categories
Potential Roadway Impacts
Potential Traffic Impacts
Potential Level of Maintenance Effort Required
Potential Length of Roadway Affected
Slope Condition
Distance from EOP to Feature

Compile Data

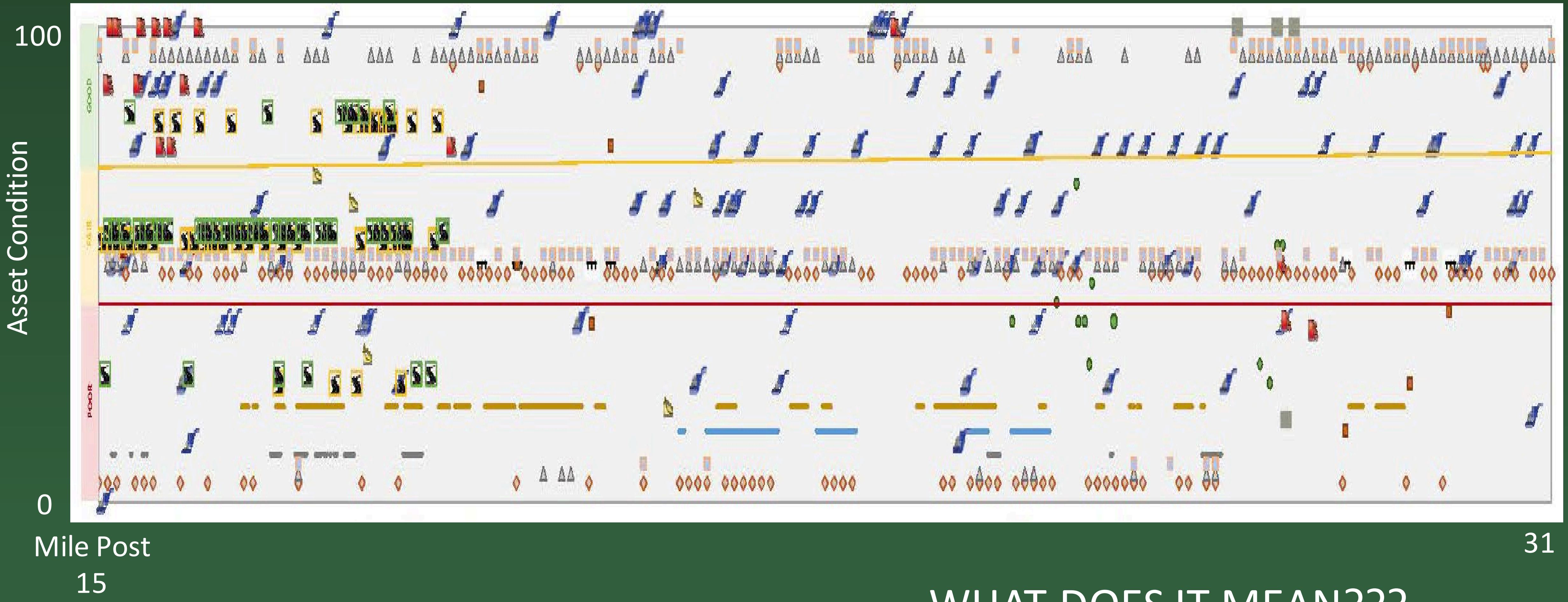
- 8 bridges
  - Including 8 river banks and 8 supplemental bridge ratings
- 16 miles of pavement
- 17 rock slopes & 5 soil slopes
  - Including 12 threatening slopes
- 5 retaining walls
- 107 culverts
- 150 horizontal curves & 400 vertical curves

Compile Data

- Combining dissimilar asset types
  - Asset Rating Systems give a 0-100 value for each asset
  - Weighting system
    - Needs to be adjustable based on project requirements

Asset Type	Asset Weight
Bridges	3
Culverts	1
Pavement	2
GAM Elements	2
Roadway Geometry	2

Compile Data

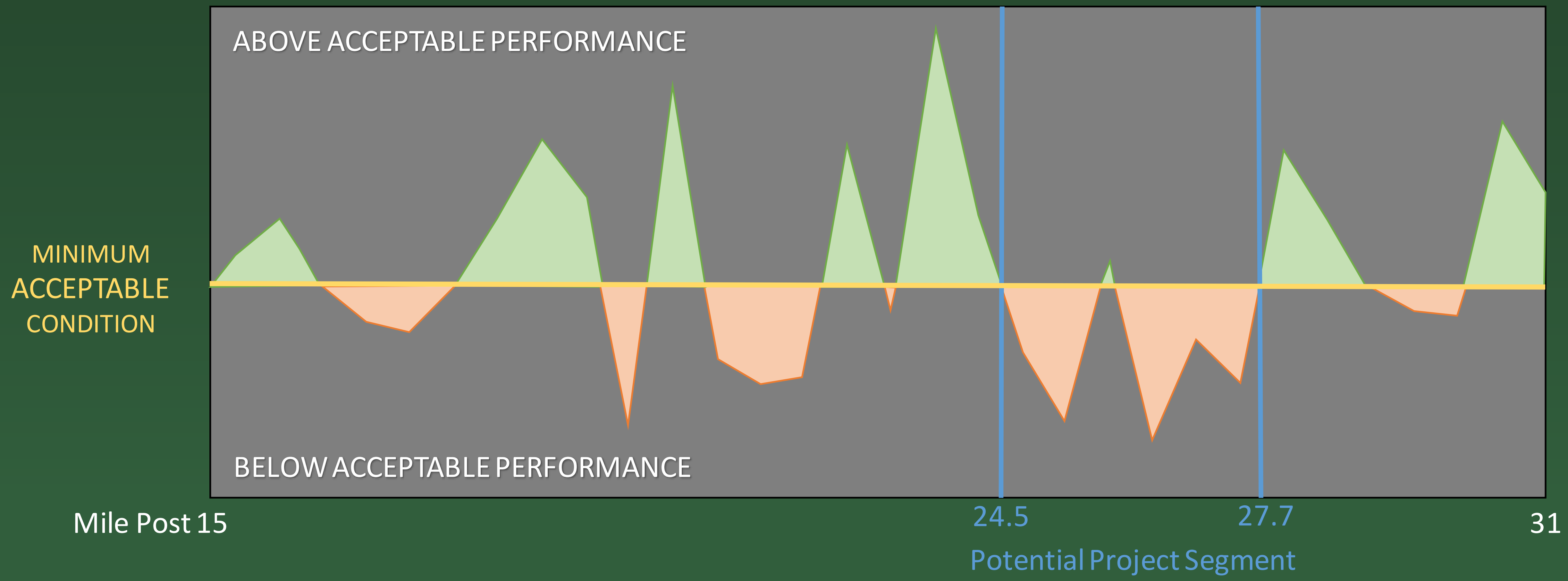


WHAT DOES IT MEAN???

Corridor Level (For Segmenting)

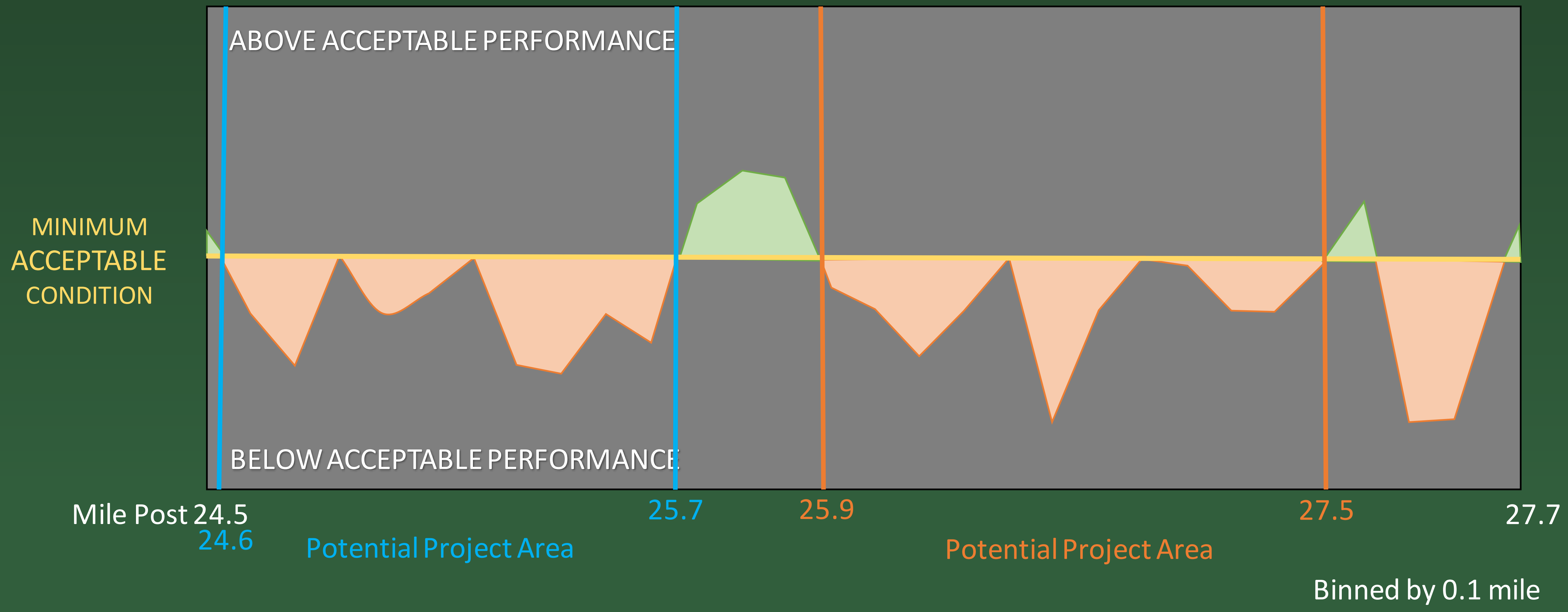
$$Corridor\ Health\ Score = \sum[(Si - MAC) \times Wi]$$

Si = Average Asset Condition Score per Milepoint Bin
MAC = Minimum Acceptable Condition (per asset)
Wi = Asset Weighting

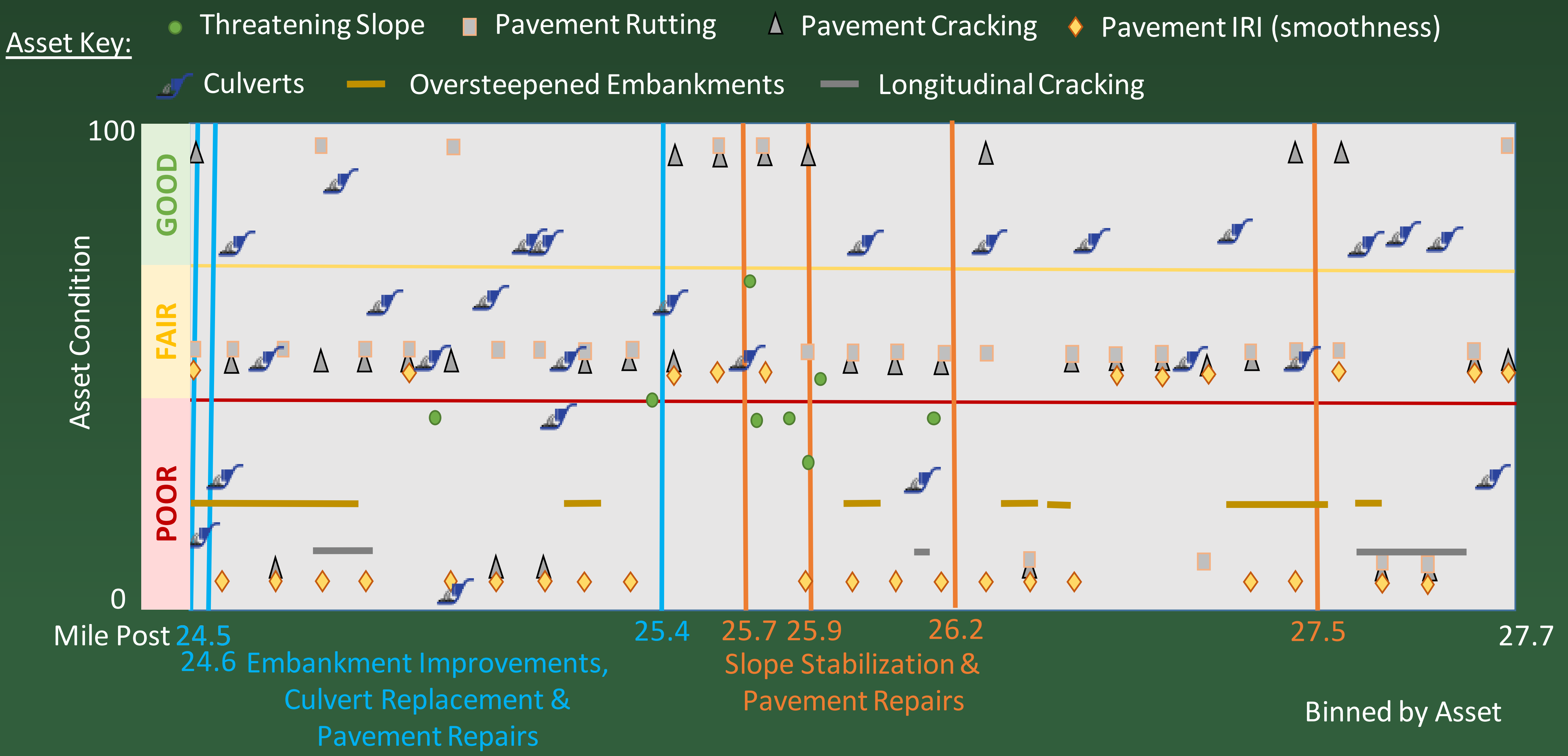


Binned by 0.5 mile

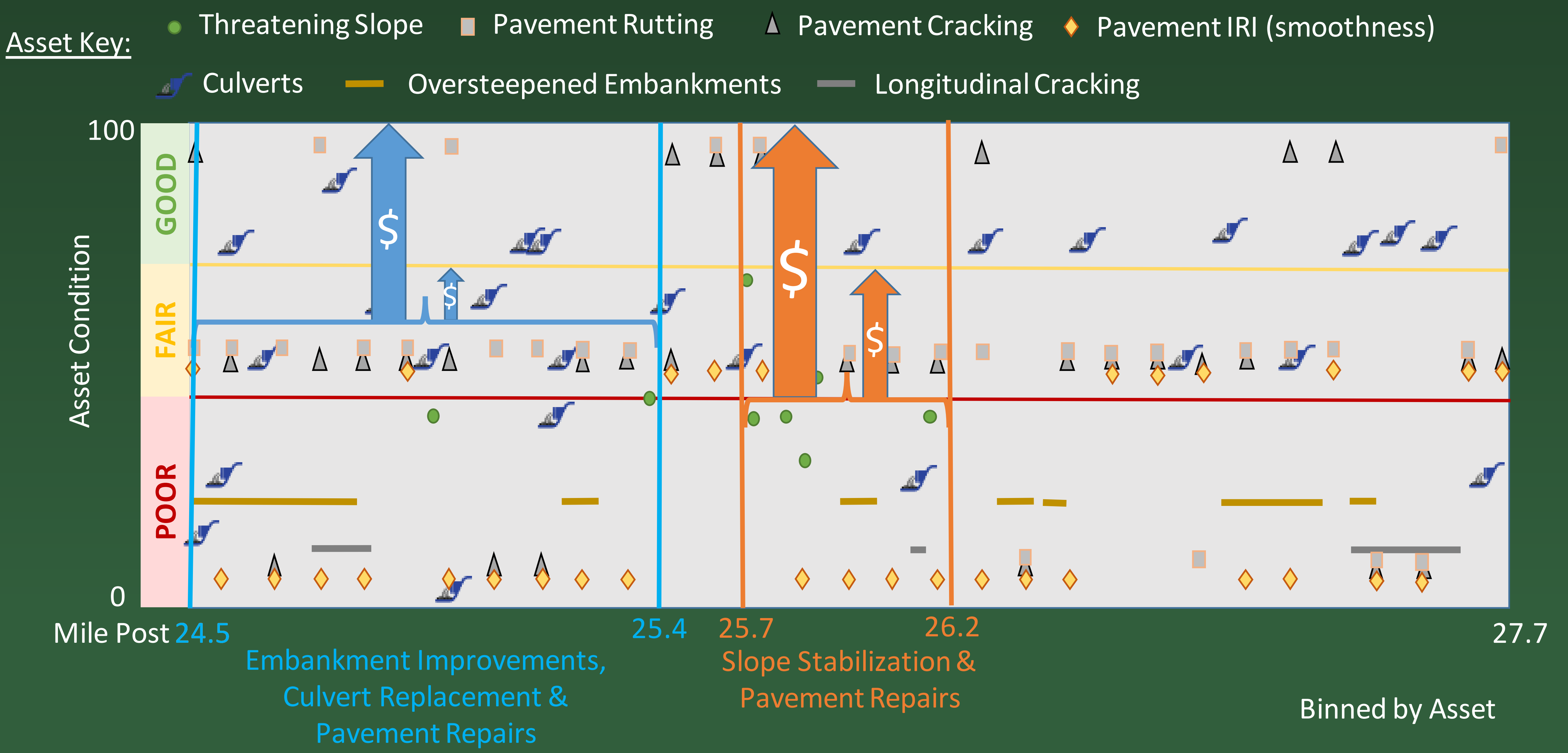
Segment Level (For Projects)



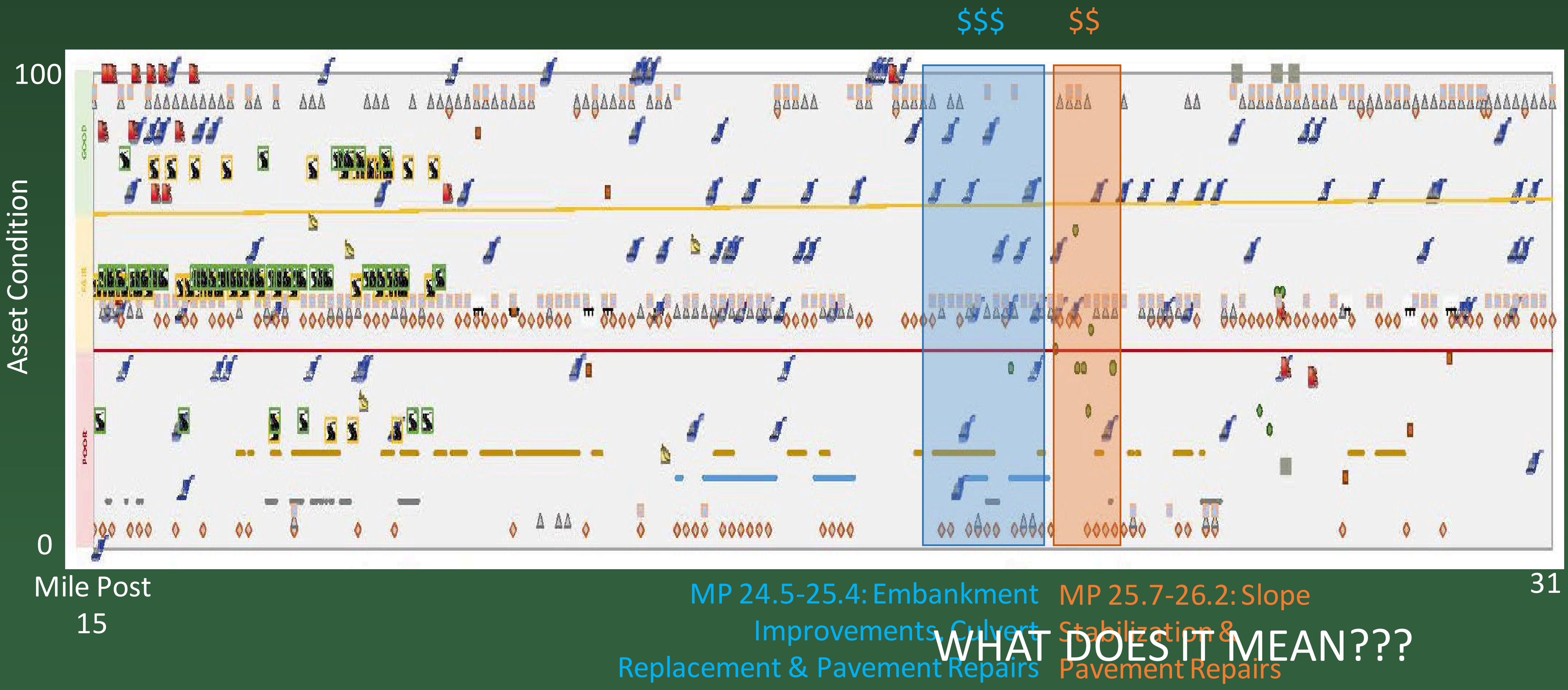
Asset Level (For Scoping)



Asset Level (For Costing)



Selected Project Areas with Estimated Costs



WHAT DOES IT MEAN???

Corridor Segmentation

- Total Corridor Needed Cost = $58 M
- Project 1 Cost (Seg 2*, 5) = $18 M
  - Soldier Pile Spot Repair, Rehab, Resurfacing
- Project 2 Cost (Seg 2.4, 3, 6) = $17 M
  - Rehab and Resurfacing
- Project 3 Cost (Seg 2.1, 2.2) = $13 M
  - Rehab and Resurfacing
- Construction Total = $48 M
- Remaining Project Costs = $10 M

Segment	Mile Post Start	End	Primary Work Type	Estimated Construction Costs	Project #
1	31.22	29.00	Resurfacing	$2,557,000	
2*	28.12	27.85	Soldier Pile Spot Repair	$5,128,000	1
2.1	29.00	28.00	Resurfacing	$3,785,000	3
2.2	28.00	25.88	Rehabilitation & Resurfacing	$9,248,000	3
2.3	25.88	25.52	None		
2.4	25.52	24.50	Rehabilitation	$6,865,000	2
3	24.50	24.00	Rehabilitation & Resurfacing	$2,504,000	2
4	24.00	23.50	Resurfacing	$805,000	
5.1	23.50	22.87	Rehabilitation	$3,074,000	1
5.2	22.87	21.00	Rehabilitation & Resurfacing	$9,764,000	1
6	21.00	19.25	Rehabilitation & Resurfacing	$7,270,000	2
7	19.25	18.75	Resurfacing	$783,000	
8	18.75	18.20	Resurfacing	$580,000	
9	18.20	17.20	Resurfacing	$1,644,000	
10	17.20	15.00	Resurfacing	$3,701,000	

Next Steps

- Chiniak Highway
  - Developed a Pre-Environmental Review package for the entire corridor
  - Develop designs and construction documents for the identified projects
- Corridor Health Index
  - Implement the process on additional corridors
  - Adjust process as more is learned
  - Increase usability of data analysis

Acknowledgements

- Alaska DOT&PF Southcoast Region
  - Jim Brown, Project Manager
  - Mitch McDonald, Regional Engineering Geologist
  - Mort Larsen, Engineering Geologist
- HDL Engineering Consultants
  - Jeff Fuglestad, Project Manager
  - Doug Simon, Geotechnical Engineer
  - Kelsey Means, Civil Engineer
- Landslide Technology
  - Aine Mines, Project Engineer

Questions?

ODOT CULVERT DURABILITY AND SERVICE LIFE METHODOLOGY

Kyle Brandon, P.E.

April 24, 2023

BASICS OF CULVERT DURABILITY

- Durability Concepts
- ODOT Durability Design Methodology
  - Durability Research
  - ODOT Durability Spreadsheet
- Future of Service Life Estimation

DURABILITY CONCEPTS

- Culvert Durability
  - Resistance to environmental degradation
    - Corrosion
    - Abrasion
    - Thermoplastic degradation?
    - Other factors not considered herein
      - Joints
      - Structural
      - Freeze-thaw
      - Installation

DURABILITY CONCEPTS

- Combined Abrasion and Corrosion
  - Corrosive layer formed and then abraded away
  - Resultant section loss can be many times greater than addition of each individual processes

DURABILITY CONCEPTS

- Abrasion
  - Progressive section loss
    - Almost always evidenced in culvert invert
    - High stream velocities
    - High bedload
  - CalTrans has extensive information on abrasion
    - Used as a resource for ODOT Design and Inspection

DURABILITY CONCEPTS

- ODOT Abrasion

Abrasion Levels and Materials

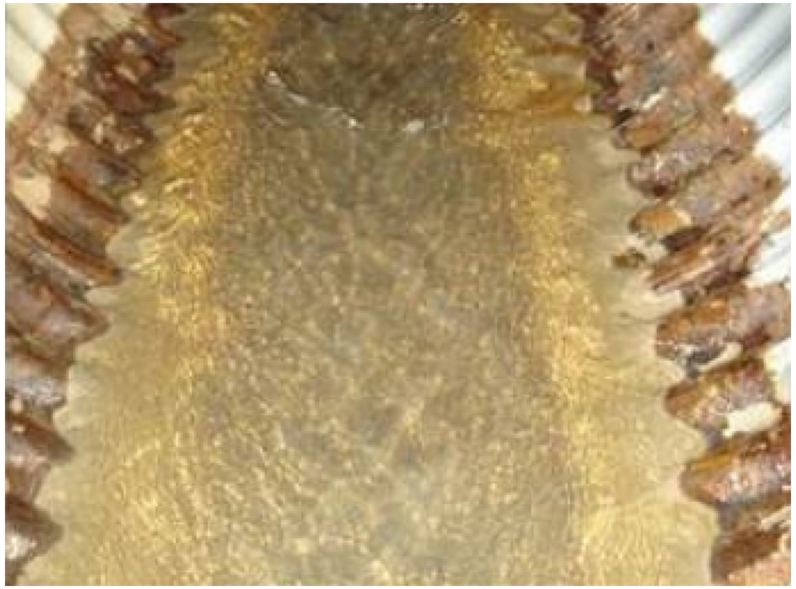
Abrasion Level	General Site Characteristics	Abrasion Level	General Site Characteristics
Level 1	Bedloads of silts and clays or clean water with virtually no abrasive bed load. Non-Abrasive Material	**Level 5**	Moderate bed load volumes of angular sands and gravel or rock.
Level 2	Moderate bed loads of sand or gravel.	**Level 6**	Moderate bed load volumes of angular sands and gravel or rock. OR Heavy bed load volumes of angular sands and gravel or rock.
Level 3	Moderate bed load volumes of sand, gravels, and small cobbles.		
Level 4	Moderate bed load volumes of angular sands, gravels, and cobbles/rocks		

Sand	0.002	inches – 0.08 inches
Gravel	0.08	inches – 0.16 inches
Pebbles	0.16	inches – 2.5 inches
Cobbles	2.5	inches – 10 inches
Boulders	10	inches or greater

DURABILITY CONCEPTS

DURABILITY CONCEPTS

- Corrosion
  - Acids
    - Less than 5.5 is strongly acidic
    - Greater than 8.5 strongly alkaline



METAL CULVERTS

- Steel
  - Protective Coatings
    - Galvanizing
    - Aluminizing
    - Bituminous coating
    - Polymer coating
    - Invert paving
- Aluminum

METAL CULVERTS

- Steel
  - pH between 5.5 – 8.5
  - Not recommended for highly abrasive sites unless protective coating provided
- Aluminum
  - pH between 5.5 – 8.5
  - Not recommended for highly abrasive sites

CONCRETE CULVERTS

- pH < 5
  - Use special concrete mix with high alkalinity
  - Add sacrificial concrete cover
  - Coatings
- Generally abrasion resistant
- Sulfates > 0.5%
  - Use special cements (Type V cement)

PLASTIC CULVERTS

- Generally inert to corrosion
- Resistance to very high abrasion is not well documented
- Oxidation
  - Currently handled through material standards
- Slow-crack growth
  - Currently handled through material standards
- UV Degradation

ODOT METHODOLOGY

- Conduit Inspection Program
- Durability Study
- Durability Design Methodology
  - Service Life Prediction
  - Durability Spreadsheet

CONDUIT MANAGEMENT

OHIO DEPARTMENT OF TRANSPORTATION

CULVERT MANAGEMENT MANUAL

VERSION: JULY 2016

Material- Concrete Culvert

Material Code	Category	Description
9	Excellent	New Condition; superficial and isolated damage from construction.
8	Very Good	Hairline cracking without rust staining or delamination(s). Surface in good condition. Isolated damage from construction.
7	Good	Hairline cracking; no single crack >$^{1}/_{16}$ inch without rust staining parallel to the direction of traffic. Light scaling on < 10% of exposed area < 1/8 inch deep. Delaminated/Spalled area < 1% of surface area. Note: cast-in-place box culverts may have a single large crack (<$^{3}/_{16}$ inch) on each surface parallel traffic direction
6	Satisfactory	Hairline map cracking with molted areas; cracks <⅛ in. parallel to traffic with minor efflorescence or minor amts of leakage. Scaling on <20% of exposed area <¼ inch deep. Spalled areas with exposed reinforcing <5%. Delaminated/spalled areas <5% of SA
5	Fair	Map cracking; cracks <⅛ in parallel to traffic or <$^{1}/_{16}$ in transverse to traffic with efflorescence and/or rust stains, leakage and molted areas. Scaling on < 30% of exposed area $^{3}/_{16}$ inch deep. Spalled areas with exposed reinforcing < 10%. Total delaminated/spalled areas < 15% of surface area.
4	Poor	Transverse cracks open >⅛ inch with efflorescence and rust staining. Spalling at numerous locations; extensive surface scaling on invert >½ inch. Extensive cracking with cracks open more than ⅛ inch with efflorescence. Spalling has caused exposure of heavily corroded reinforcing steel on bottom or top slab; extensive surface scaling on invert >¾ inch (approximately 50% of culvert is affected).
3	Serious	Extensive cracking with spalling, delamination(s), and slight differential movement; scaling has exposed all surfaces of the reinforcing steel in bottom to top slab or invert (approx all exposed surfaces are 50% loss of wall thickness at invert; concrete very soft.
2	Critical	Full depth holes; extensive cracking >½ inch. Spalled areas with exposed reinforcing > 25%; total delaminated/spalled/punky concrete areas >50% of surface area. Reinforcing steel bars have extensive section loss and bar perimeter is completely exposed.
1	Imminent Failure	Culvert partially collapsed or collapse is imminent.
0	Failed	The culvert is collapsed

GENERAL

General Appraisal and Operational Status
This is a two-part item. The first box is for coding the general, overall condition of the culvert. The second box is for coding the operational status of the culvert.

R - General Appraisal (GA)
The General Appraisal (GA) is the lowest rating of the bold box items on the CR-86 form. The Headwall and Scour ratings are only considered bold for those structures deemed Scour or Headwall Critical by the inspector.

Code	Description
9	As built condition
8	Very good condition - no problems noted
7	Good condition - some minor problems
6	Satisfactory condition - structural elements show some deterioration
5	Fair condition - all primary structural elements are sound, but may have minor section loss
4	Poor condition - advanced section loss, deterioration, or spalling
3	Serious condition - loss of section, deterioration, or spalling have seriously affected primary structural components
2	Critical condition - advanced deterioration of primary structural elements. Culvert should be closed or closely monitored, until corrective action is taken
1	"Imminent" failure condition -major deterioration/section loss present on structural components. Culvert closed to traffic.
0	Failed condition - out of service - beyond corrective action

CONDUIT MANAGEMENT

STATE OF OHIO DEPARTMENT OF TRANSPORTATION
CULVERT INVENTORY REPORT

CR-87 07-16

CULVERT FILE NUMBER

	1. Entry Class
LOCATION AND ROUTE INFORMATION	
2. District	3. County
4. Route	5. Straight Line Mileage
6. Latitude	7. Longitude
8. Special Designation	9. Culvert Owner
10. Maintenance Responsibility	
11. Feature Intersection	
CULVERT	
12. Year built	13. Number of Cells
14. Broken Back	15. Culvert Shape
16. Culvert Material	17. Span (Inches)
18. Rise (Inches)	19. Length (Feet)
20. Metal Gage Thickness 1	21. Metal Gage Thickness 2
22. Type of Pipe Protection	23. Slope of Pipe (Percent)
24. Slope Direction	25. Skew (Degrees)
26. Skew Direction	27. Inlet End Treatment
28. Outlet End Treatment	29. Maximum Height of Cover (Feet)
30. Height of Inlet Headwall (Feet)	31. Inlet Headwall to EOP Distance (Feet)
32. Height of Outlet Headwall (Feet)	33. Outlet Headwall to EOP Distance (Feet)
34. Drainage Area (Acres)	35. Drainage Discharge (CFS)
36. Abrasive Conditions	37. Abrasion Level
38. pH	39. Channel Protection (Inlet)
40. Channel Protection (Outlet)	
Inventory Modifications	
41. Modification Type	42. Year Modified
43. Modification Material	44. Modification Size (Inches)
45. Inlet Extension Year	46. Inlet Extension Shape
47. Inlet Extension Material	48. Inlet Extension Span (Inches)
49. Inlet Extension Rise (Inches)	50. Metal Inlet Gage Thickness 1
51. Metal Inlet Gage Thickness 2	52. Inlet Extension Length (Feet)
53. Outlet Extension Year	54. Outlet Extension Shape
55. Outlet Extension Material	56. Outlet Extension Span (Inches)
57. Outlet Extension Rise (Inches)	58. Metal Outlet Gage Thickness 1
59. Metal Outlet Gage Thickness 2	60. Outlet Extension Length (Feet)

COMMENTS (use back of form if additional space is needed):

INVENTORIED BY: ______________________ DATE: ___________

July 2016 74 | Page

STATE OF OHIO DEPARTMENT OF TRANSPORTATION
CULVERT INSPECTION REPORT

CR-86 07-16

CULVERT FILE NUMBER CULVERT NUMBER ____ CO ____ ROUTE ____ ID - ____ SLM DISTRICT ____

SPAN ____ SHAPE ____ MATERIAL ____________ LENGTH ________

ROADWAY ID ______________ ENTRY CLASS ____ NUMBER OF CELLS ____

LATITUDE ______________ LONGITUDE ______________

FEATURE INTERSECTION: ______________________

CULVERT			
1. Level of Inspection			
2. General		3. Culvert Alignment	
4. Shape		5. Seams or Joints	
6. Slab		7. Abutments	
8. Headwalls*		9. End Structure	
CHANNEL			
10. Channel Alignment		11. Protection	
12. Culvert Waterway Blockage		13. Scour*	
APPROACHES			
14. Pavement		15. Guardrail	
16. Embankment			
		GENERAL APPRAISAL & OPERATIONAL STATUS	

*Only a bold box for structures that are Headwall or Scour critical. These items should not govern the GA if they are not determined to be critical upon the judgment of the inspector.

INSPECTED BY: ______________________ DATE: ___________

July 2016 75 | Page

CONDUIT			
1. Level of Inspection	M	2. Material	6
3. Conduit Alignment	7	4. Shape	8
5. Seams or Joints	7	6. Slab	
7. Abutments		8. Headwalls *	5
9. End Structure			
CHANNEL			
10. Channel Alignment	5	11. Protection	5
12. Conduit Waterway Blockage	7	13. Scour **	7
APPROACHES			
14. Pavement	7	15. Guardrail	5
16. Embankment	7		
		GENERAL APPRAISAL & OPERATIONAL STATUS	6 A

DURABILITY STUDY

Assessment of ODOT's Conduit Service Life Prediction Methodology

Prepared by Shad Sargand, John Hurd, Kevin White, Teruhisa Masada, Johnnatan Garcia-Ruiz, and Gabriel Colorado-Urrea

Prepared for the Ohio Department of Transportation
Office of Statewide Planning and Research

State Job Number 134725

September 2016

Final Report

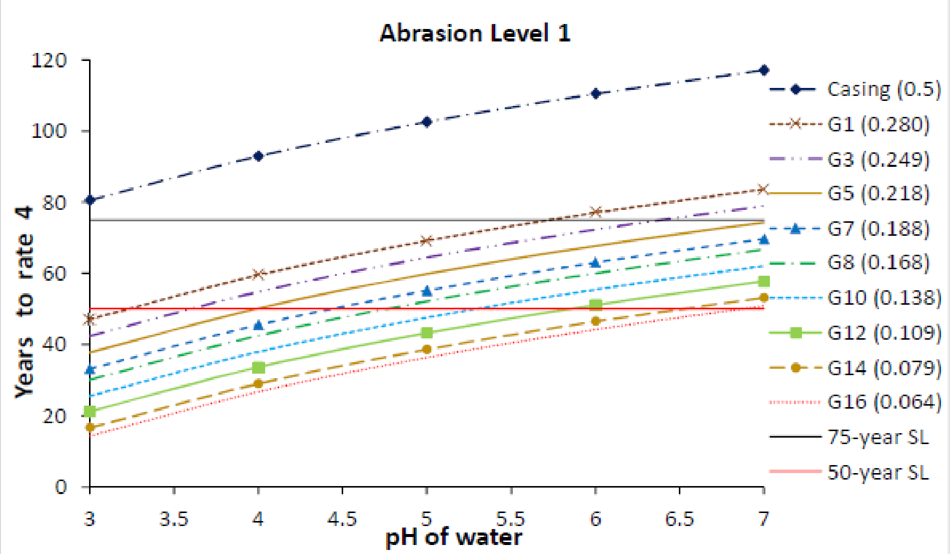


Figure 59. Estimated service life of corrugated steel pipe of varying gauges (G values) in flow at abrasion level 1, assuming an average soil pH value of 7.6. Numerals in parentheses are pipe wall thicknesses in inches (1 in = 25.4 mm).

9.1.1 Sites with pH < 7.0

Data used: Field inspections performed for this study augmented with data from Hurd [1985] and some additional parameters from Meacham, Hurd, and Shisler [1982]

Model 1: Using ODOT Rating system, R^2=0.648

$$CODOT = 10.689Log(pH_w) - 0.026Age - 0.389Abrasion - 4.445\left(1 - \frac{Sed}{Rise}\right) + 4.169$$

Model 2: Using ORITE Rating system, R^2=0.643

$$CORITE = 11.605Log(pH_w) - 0.027Age - 0.391Abrasion - 4.839\left(1 - \frac{Sed}{Rise}\right) + 3.685$$

Model 3: Using Hurd Rating system, R^2=0.602

$$CHurd = -151.934Log(pH_w) + 0.319Age + 5.083Abrasion + 72.199\left(1 - \frac{Sed}{Rise}\right) + 49.559$$

DURABILITY SPREADSHEET

Example -Conduit Type: Type A Culvert; Conduit Shape: Circular; Hydraulic Requirements: 66 inch smooth or corrugated; Stream Information

County	Knox	Route	4	Section	14.36	PID	99999	Shape	Circular
Station	16+00	Station	16+00					Span x Rise	66

User Input		Constants and Calculated Values			
pH_w	Abrasion Level	pHs	Sediment/Rise	End of Service Life GA	Service Life Required
7.8	2.0	7.6	0	4	75

Metal Con

Material		707.01 , 707.02, or 707.03 Metallic coated (galvanized)	707.01 or 707.02 or 707.03 Metallic coated (galvanized) with Concrete Field Paving	707.01 or 707.02 Metallic coated (Aluminized)	***707.01 or 707.02 Metallic coated (aluminized) with Concrete Field Paving	707.04 Polymeric Coated over galvanized steel	***707.04 Polymeric Coated with Concrete Field Paving	707.05 or 707.07 (707.01 or 707.02 galvanized) 1/2 Bituminous coated with Bituminous paved invert	***707.05 or 707.07 (707.01 or 707.02 aluminized) 1/2 Bituminous coated with Bituminous paved invert	**707.11 Polymer Precoated spiral rib steel
Conduit Use and Shape		Culvert or Liner Pipe - Round or Pipe Arch	Culvert-Round, Pipe Arch, and Arch	Culvert or Liner Pipe -Round or Pipe Arch	Culvert -Round or Pipe Arch	Culvert or Liner Pipe - Round or Pipe Arch	Culvert-Round or Pipe Arch	Culvert -Round or Pipe Arch	Culvert -Round or Pipe Arch	Storm Sewer or Liner Pipe- Round
	Corr. Depth (inches)									
min gauge or thickness	1/4 or 1/2	10	10	10	10	10	10	10	10	N/A
	1	12	12	12	12	12	12	12	12	N/A
	2	12	12	N/A	N/A	N/A	N/A	12	N/A	N/A
	3/4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12
	1/4 or 1/2	8	8	10	10	10	10	8	10	N/A

Metal Options: 66" Type A Conduit, 707.02 (0.109) with CFP, 707.02 (0.064) aluminized, 707.04 (0.064)

DURABILITY SPREADSHEET

Concrete Conduit Durability Results						
Material	**706.01 Non-reinforced Concrete Pipe	**706.02 Reinforced Concrete Circular Pipe	**706.03 Reinforced Concrete Pipe, Epoxy Coated	**706.04 Reinforced Concrete Elliptical Culvert, Storm Drain, and Sewer Pipe	**706.05 Precast Reinforced Concrete Box Sections	706.08 Clay Drain Tile
Conduit Use and Shape	Culvert or Storm Sewer - Round	Culvet or Storm Sewer - Round	Culvert or Storm Sewer - Round or Elliptical	Culvert or Storm Sewer - Elliptical	Culvert or Storm Sewer - Box	Culvert or Storm Sewer - Round

Plastic Conduit Durability Results										
Material	707.33 Corrugated Polyethylene Smooth Lined Pipe	707.34 Polyethylene Plastic Pipe Based on Outside Diameter (OD)	707.35 Polyethylene Profile Wall Pipe	707.42 Polyvinyl Chloride Corrugated Smooth Interior Pipe	707.43 Polyvinyl Chloride Profile Wall Pipe	707.45 Polyvinyl Chloride Solid Wall Pipe	707.46 Polyvinyl Chloride Drain Waste and Vent Pipe	707.47 ABS and Polyvinyl Chloride Composite Pipe	707.48 Polyvinyl Chloride Large-Diameter Solid Wall Pipe	707.65 Polypropylene corrugated Double Wall Pipe	707.69 Polypr Triple Wall
Conduit Use and Shape	Culvert, Storm Sewer, or Liner Pipe - Round	Culvert, Storm Sewer, or Liner Pipe - Round	Culvert, Storm Sewer, or Liner Pipe - Round	Storm Sewer or Liner Pipe - Round	Storm Sewer or Liner Pipe - Round	Storm Sewer - Round	Storm Sewer - Round	Storm Sewer - Round	Storm Sewer - Round	Culvert or Storm Sewer - Round	Culvert or Stor - Roun

Constants	
Protective Coating Constants-Initial Service Life (years)	
Concrete Invert Paving=	20
Aluminized=	35
Aluminized Spiral Rib=	35
Polymeric=	50
Bituminous coated w/ bitum. paved invert=	10
Bituminous lined =	25
Galvanized=	0

Plastic Options: 66" Type A Conduit, 707.35, 707.75, SS938

Concrete Options: 66" Type A Conduit, 706.02

FUTURE OF SERVICE LIFE ESTIMATION

- Goal for the future is to develop degradation models in order to estimate remaining service life
  - "Evaluation of Degradation of Concrete Box Culverts and 3-Sided Culverts" completed 2021 for bridge sized culverts 10' and greater in Ohio
- Continued Collection of Inspection Data
- Enough current data for conduits 48" and greater?
  - More frequent inspection cycle
  - Currently evaluating
- 50 years from now?

FUTURE OF SERVICE LIFE ESTIMATION

Division of Engineering Research on Call Agreement 34652

Task 2 – Evaluation of Degradation of Concrete Box Culverts and 3-Sided Culverts

Ahmad Alhasan, Kevin White, Jerry DiMaggio,

for the Ohio Department of Transportation
Office of Statewide Planning and Research

and the
United States Department of Transportation
Federal Highway Administration

November 2021

Final Report

		Future Condition State (1-Year Step)									
		9	8	7	6	5	4	3	2	1	0
Current Condition State	9	0.7924	0.2076	0	0	0	0	0	0	0	0
	8	0	0.9163	0.0837	0	0	0	0	0	0	0
	7	0	0	0.9900	0.0100	0	0	0	0	0	0
	6	0	0	0	0.9770	0.0230	0	0	0	0	0
	5	0	0	0	0	0.9570	0.0430	0	0	0	0
	4	0	0	0	0	0	0.9248	0.0752	0	0	0
	3	0	0	0	0	0	0	0.9258	0.0742	0	0
	2	0	0	0	0	0	0	0	0.9040	0.0960	0
	1	0	0	0	0	0	0	0	0	0.7718	0.2282
	0	0	0	0	0	0	0	0	0	0	1

(a)

		Future Condition State (1-Year Step)									
		9	8	7	6	5	4	3	2	1	0
Current Condition State	9	0.8482	0.0981	0.0537	0	0	0	0	0	0	0
	8	0.0126	0.8534	0.1051	0.0290	0	0	0	0	0	0
	7	0	0.1115	0.8293	0.0587	0.0005	0	0	0	0	0
	6	0	0	0.1644	0.8192	0.0164	0.0000	0	0	0	0
	5	0	0	0	0	0.8670	0.0943	0.0387	0	0	0
	4	0	0	0	0	0	0.8662	0.0940	0.0398	0	0
	3	0	0	0	0	0	0	0.8631	0.0949	0.0420	0
	2	0	0	0	0	0	0	0	0.8589	0.0963	0.0448
	1	0	0	0	0	0	0	0	0	0.8396	0.1604
	0	0	0	0	0	0	0	0	0	0	1

(b)

Figure 8. Transition probability matrices of (a) the Standard Model and (b) the Modified Model with more possible transitions for Type 2 culverts.

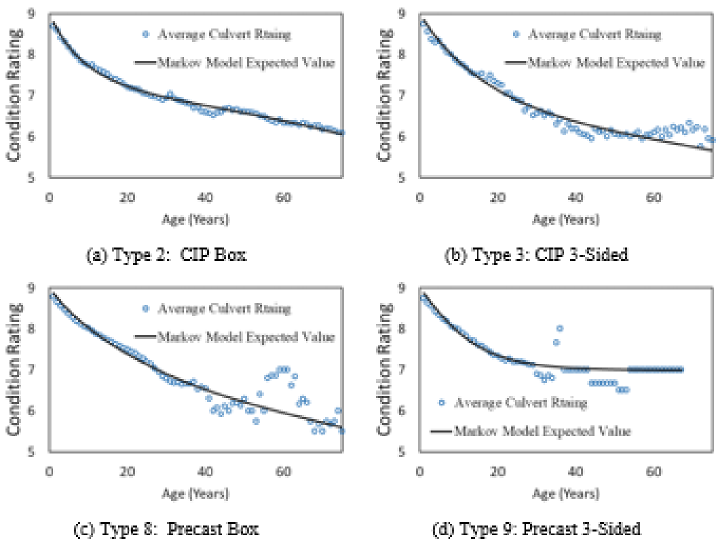


Figure 9. Scatter plots of average culvert rating versus time with the expected value curve estimated using the Standard Markovian model for all culvert types.

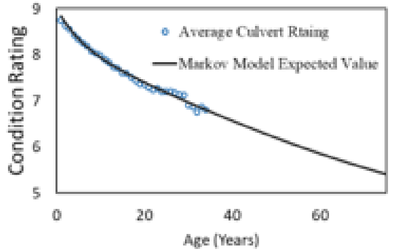


Figure 10. Scatter plot of average culvert rating versus time with the expected value curve of the Standard Markovian model revaluated using data for ages less than 34 years for Type 9 culverts.

QUESTIONS

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May 17

TRB Webinar: Risk-targeted Ground Motions for Bridge Design

July 8-11

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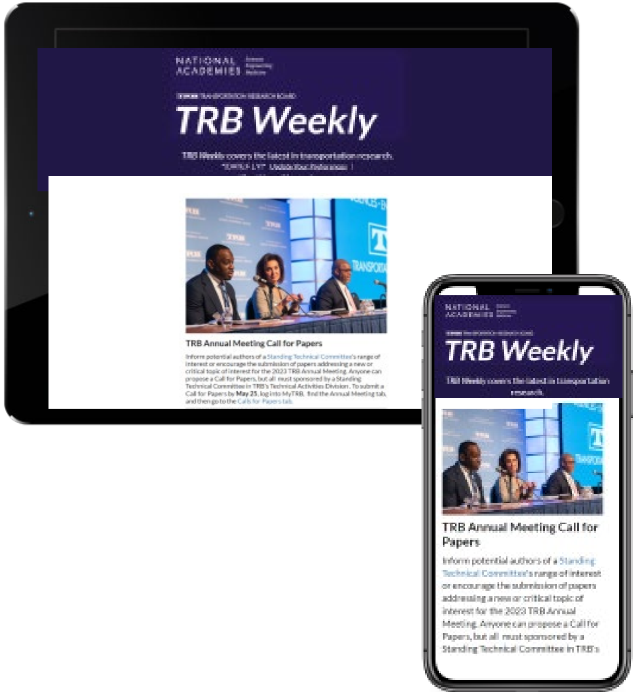

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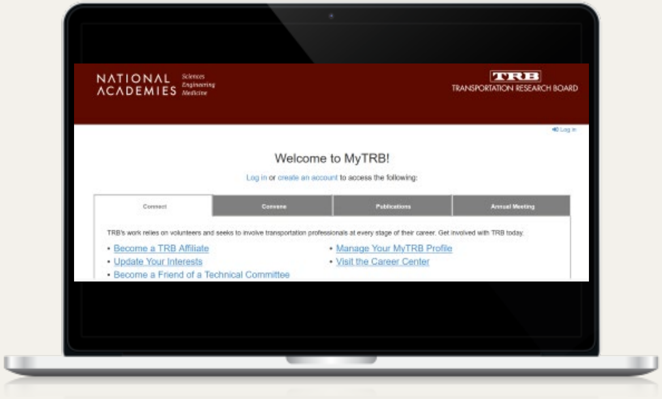

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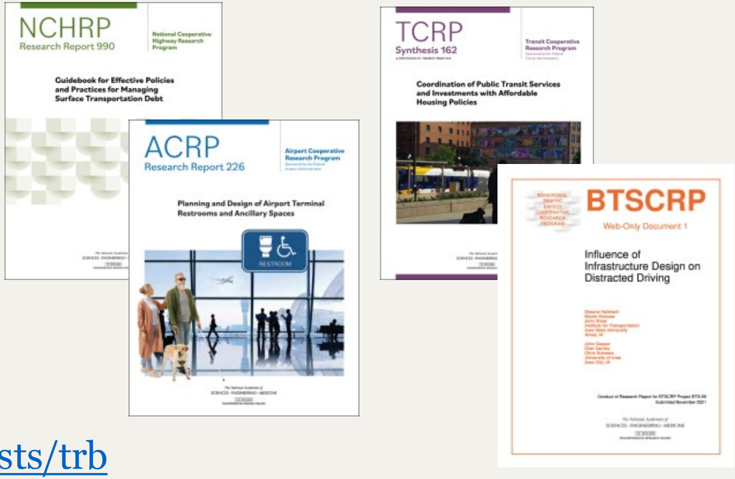

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