RAVELING DETERIORATION ANALYSIS USING MACROTEXTURE AND AGGREGATE LOSS INDICATORS FROM MULTI-TIMESTAMP 3D PAVEMENT SURFACE DATA

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RPUG
Road Profile Users' Group

Pavement Raveling Distress

- **Raveling distress, also known as aggregate loss or surface disintegration**
  - Wearing away of the pavement surface caused by the dislodging of aggregate particles and loss of asphalt binder [1].
  - Most common distress affecting asphalt pavements with open-graded friction course (OGFC) surfaces [2, 3].

Severity Level 1

Severity Level 2

Severity Level 3

GDOT Distress Manual Examples on OGFC

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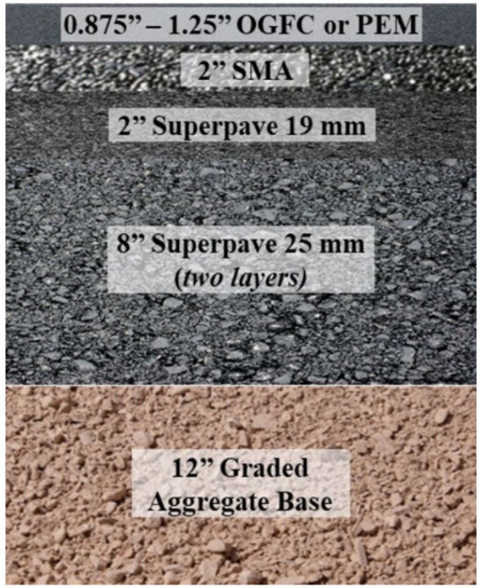
Raveling Distress on OGFC Surfaces

- **Open Graded Friction Course (OGFC) surfaces have an open-graded aggregate skeleton with interconnecting voids** to provide a fast, vertical drainage of rainfall down to an impermeable underlying layer, and eventually to the pavement edge [4].
  - Safety and environmental benefits

- **OGFC surfaces are constructed on most of Georgia's interstate highways with asphalt pavements.**

- **Raveling is the predominant distress type that makes those pavements deficient and requiring maintenance**

Fast Water Drainage of OGFC surface



Typical OGFC pavement design on Georgia's interstate highways

Impact of Raveling Distress

Excessive pavement raveling impacts 1) the serviceability and lifespan of the pavement, and 2) the safety and comfort of drivers.

- Increased Road Tire Noise
- Poor Ride Quality

Shorter Pavement Life

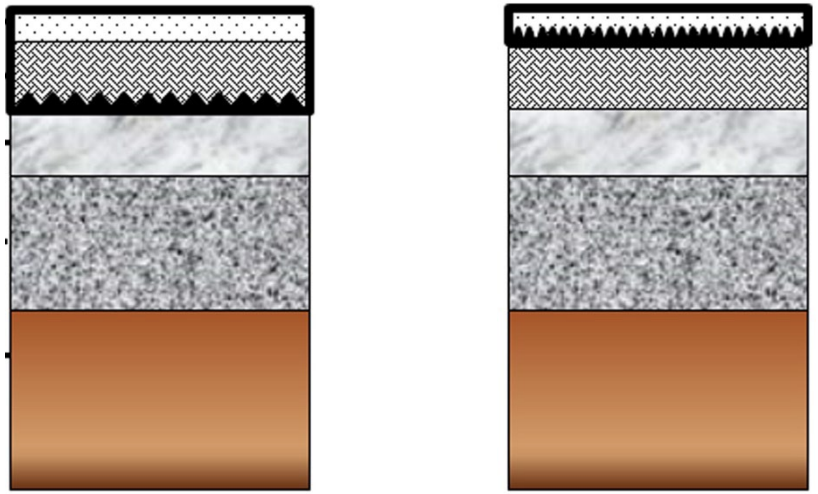
Flying Stones

Ponding and Hydroplaning

Importance of Monitoring and Understanding Raveling Deterioration

- **Raveling on OGFC pavements progresses rapidly [5]**
  - Accelerates the appearance of other distresses
  - Damages the underlying pavement layers

- **Understanding raveling deterioration behavior allows for**
  - Accurate prediction of its condition
  - Optimized predictive maintenance and rehabilitation decision-making (3R: Right treatment, Right timing, Right location)



Conventional milling and resurfacing **Micro-milling and thin overlay**

53% lifecycle cost saving
(If applied at the right timing) [18]

Traditional Raveling Condition Assessment

- **Visual rating survey protocol to classify pavement segments** (e.g., 1 mile) **into different severity levels** (e.g. low, moderate, severe) **based on qualitative definitions**
  - E.g., 30% SL1, 60% SL2, 10% SL3 in a 1-mile segment
- These survey practices are **1) Time-consuming and labor-intensive, and 2) Subjective and error-prone**
- **Condition rating data limitations**
  - **Cannot support deterioration analysis** due to unreliability and being mostly qualitative
  - **Severity levels defined lack the granularity** to capture the optimal timing of treatments (e.g., micromilling)
  - **Aggregated measures over a segment cannot be used to support localized treatment decision-making**

Raveling Rating Definition in GDOT Distress Manual

Severity Level 1
Loss of substantial number of stones

Severity Level 2
Loss of most surface

Severity Level 3
Loss of substantial portion of surface layer (>1/2 depth)

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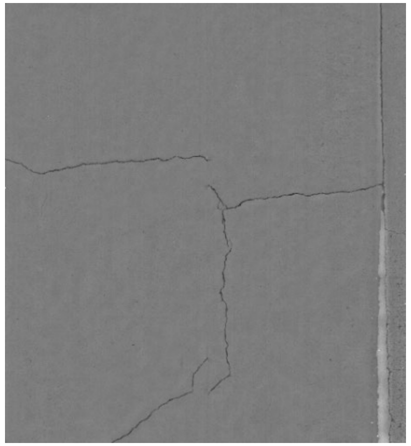
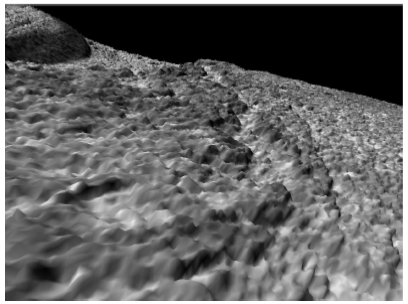
Adoption of 3D laser imaging systems

- **Mainstream technology among state DOTs for automated pavement surveying and condition assessment**
- System of 3D laser sensors capturing the high-resolution 3D pavement surface data with full lane coverage at highway speed
- Extract pavement surface indicators and distresses (cracking, rutting, faulting, IRI, macrotexture, etc.)

Georgia Tech Sensing Van with an installed 3D laser imaging system



Sample pavement range (3D) image with cracking distress



3D pavement surface texture data visualization

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Raveling Condition Assessment Using 3D Pavement Surface Data

Macrotexture Indicators

- Mean Profile Depth (MPD) [7]
- Root Mean Square Texture (RMST) [8, 9].

Aggregate Loss Quantification

- Pavemetrics LCMS Raveling Index (RI)
- Stoneway algorithm
- Yu and Tsai [13] aggregate loss depth, loss area percentage, and loss volume percentage

Raveling detection & severity level classification

- Mathavan et al. [14] detection method using signal processing
- Tsai & Wang [6] ML-based detection method
- Hsieh & Tsai [15] DL-based detection and severity level classification method using pavement image with macrotexture analysis

Research Need

- **No study has analyzed the individual raveling distress field deterioration behavior using multi-timestamp 3D pavement surface data.**

- **Need to leverage the high-quality 3D pavement surface data** to study and better understand the raveling deterioration behavior quantitatively

Research Objective

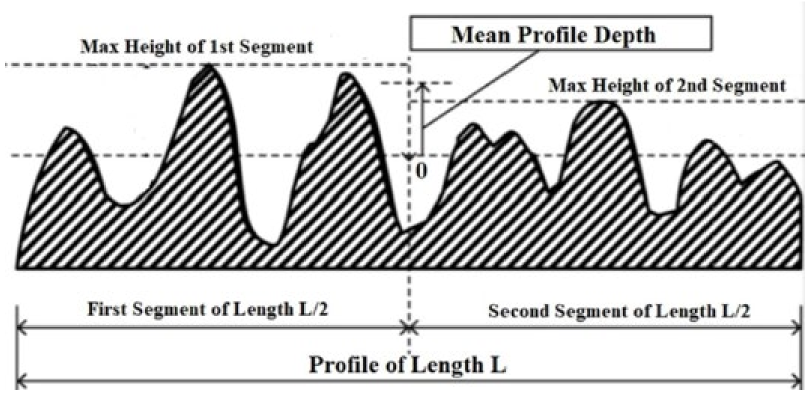
- **Evaluate the feasibility of using selected macrotexture indicators and aggregate loss indicators extracted from real-world, large-scale 3D pavement surface dataset to study the long-term pavement raveling deterioration behavior.**
  - The performance of the selected indicators will be evaluated in monitoring the raveling condition progression over time.

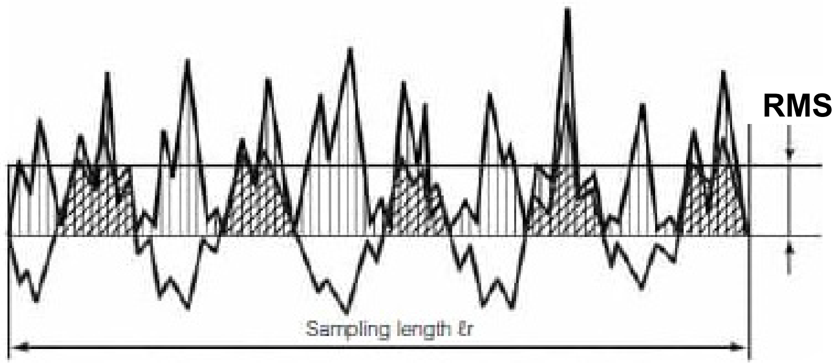
- Findings will support the development of an accurate raveling condition prediction model.
  - Support predictive and cost-effective maintenance decision-making

Selected Raveling Indicators

Macrotexture Based Indicators

- Mean Profile Depth (MPD) [7]
- Root Mean Square Texture (RMST) [8, 9].





Aggregate Loss Based Indicators

- Pavemetrics LCMS Raveling Index (RI)
- Aggregate loss indicator proposed by Yu and Tsai [13] that quantifies aggregate loss depth, percent loss area and volume

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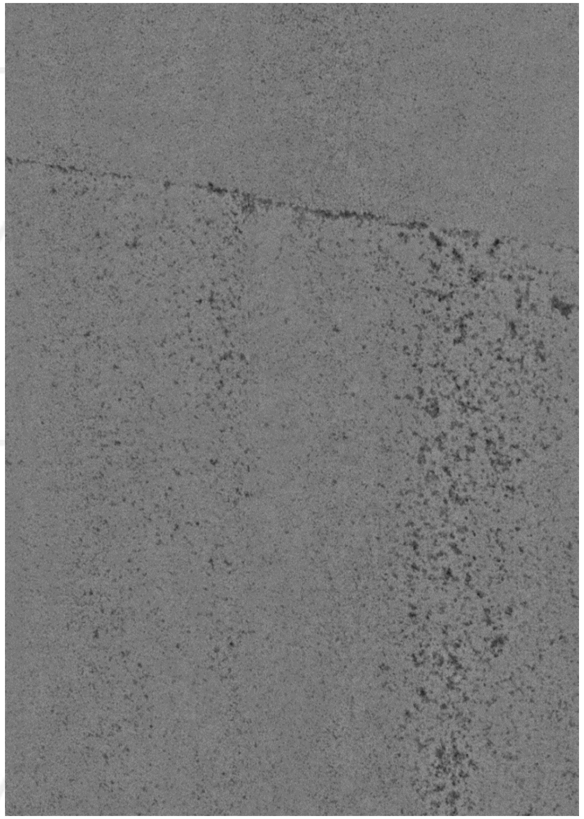
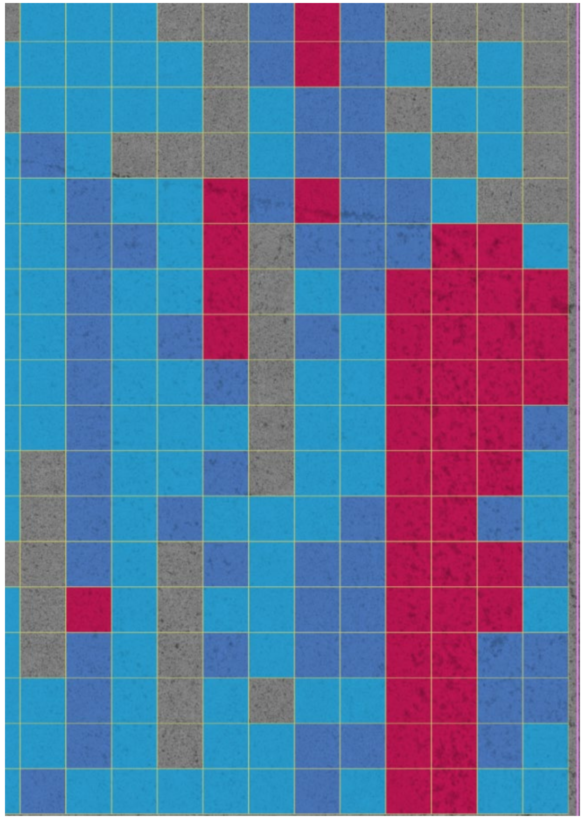
Selected Raveling Indicators - Raveling Index

- Algorithm implemented by Pavemetrics LCMS RoadInspect software
- Quantifies raveling by measuring the volume voids per unit area (cm^3/m^2) due to missing aggregates [10, 11]



Rectified Range Image

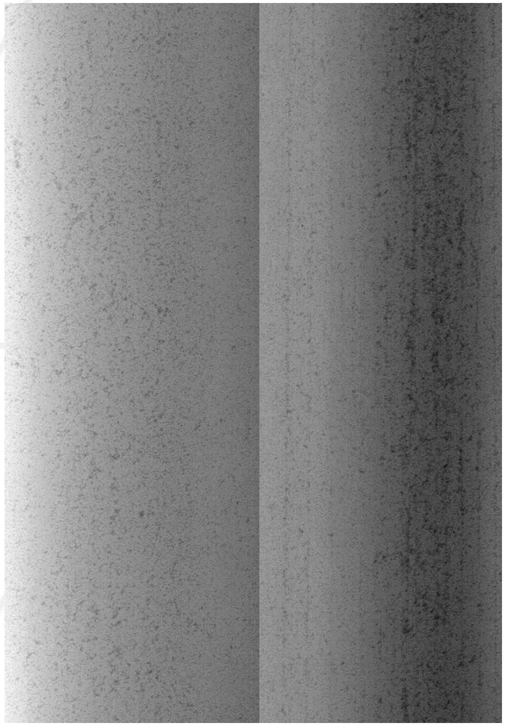


Color Coded Raveling Severity

Quantified Aggregate Volume Loss

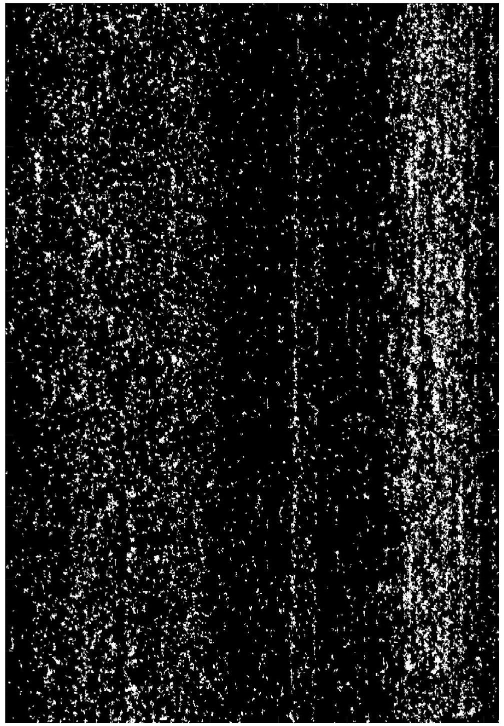
Selected Raveling Indicators - Aggregate Loss Indicator

- Method developed by Yu&Tsai [13]
- Estimates a reference surface that represent original surface with no raveling
- Quantifies raveling by identifying areas with significant depth difference with the reference surface
- Represented as **%Area_Loss, %Volume_Loss, and Avg_Loss_Depth**.



Raw Range Image

Rectified Range Image



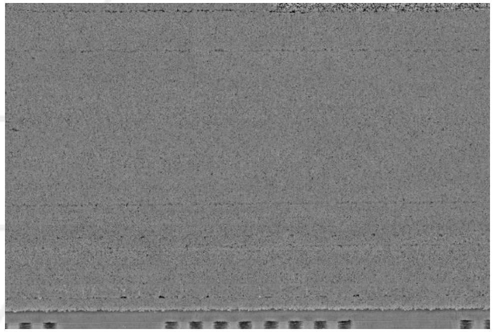
Detected Raveling Area

Data Preparation and Processing

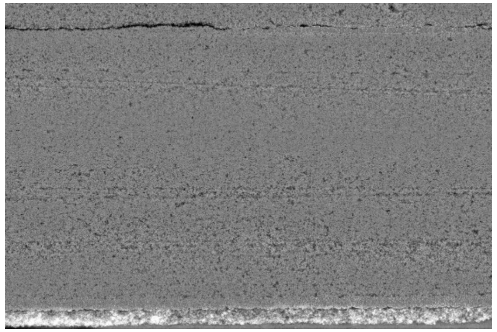
Collected 3D Pavement Range Images

16.5 ft

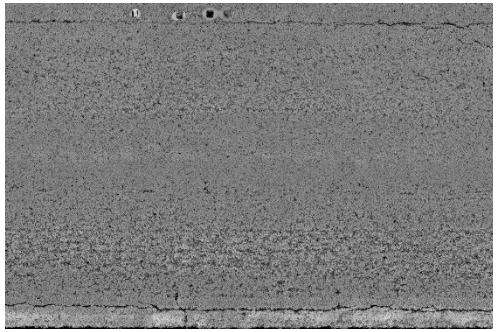
13 ft



Range Image 1
MP: 0.003



Range Image 2
MP: 0.006



Range Image 3
MP: 0.009

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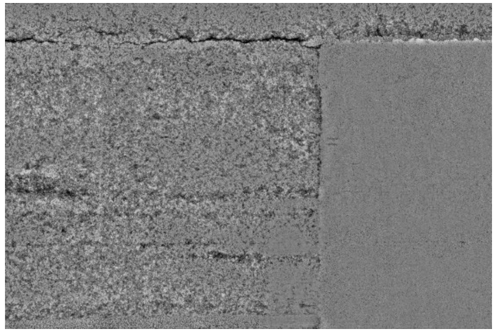

Range Image X
MP: Y

Raveling Indicator Computation

Indicator 1 Value Indicator 2 Value Indicator 3 Value Indicator 4 Value	Indicator 1 Value Indicator 2 Value Indicator 3 Value Indicator 4 Value	Indicator 1 Value Indicator 2 Value Indicator 3 Value Indicator 4 Value	…	Indicator 1 Value Indicator 2 Value Indicator 3 Value Indicator 4 Value

Aggregate each indicator over 100-ft and 0.1-mile intervals

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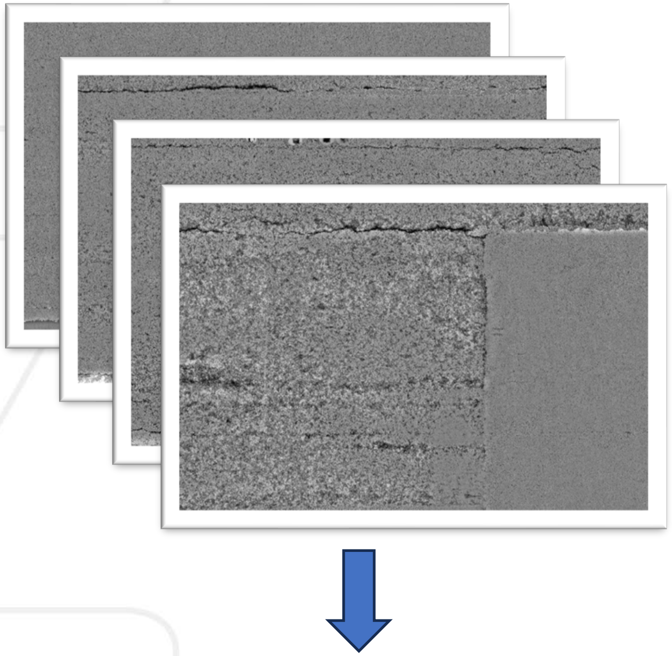
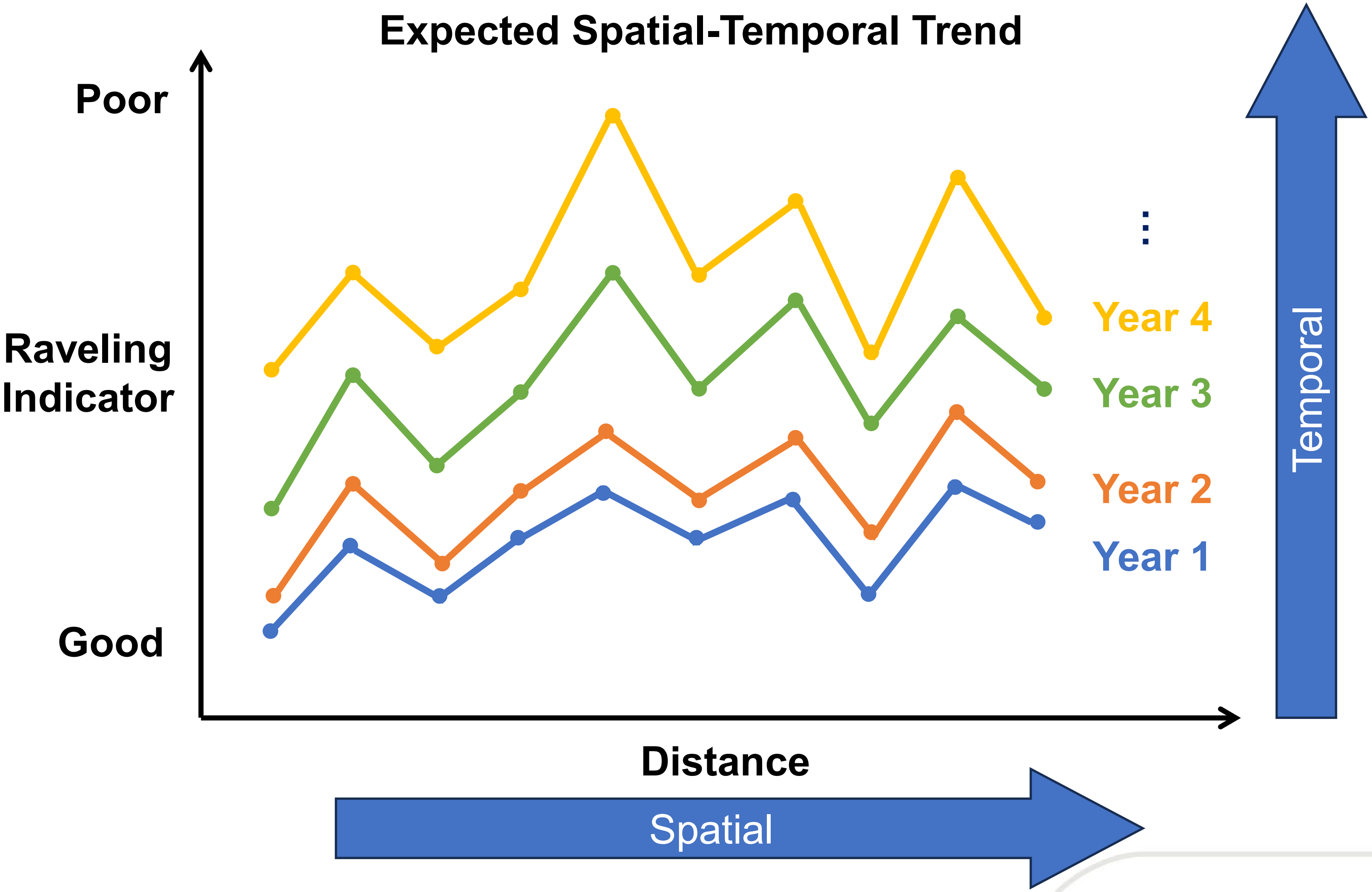
Spatial-Temporal Analysis of Raveling Condition

Range Images

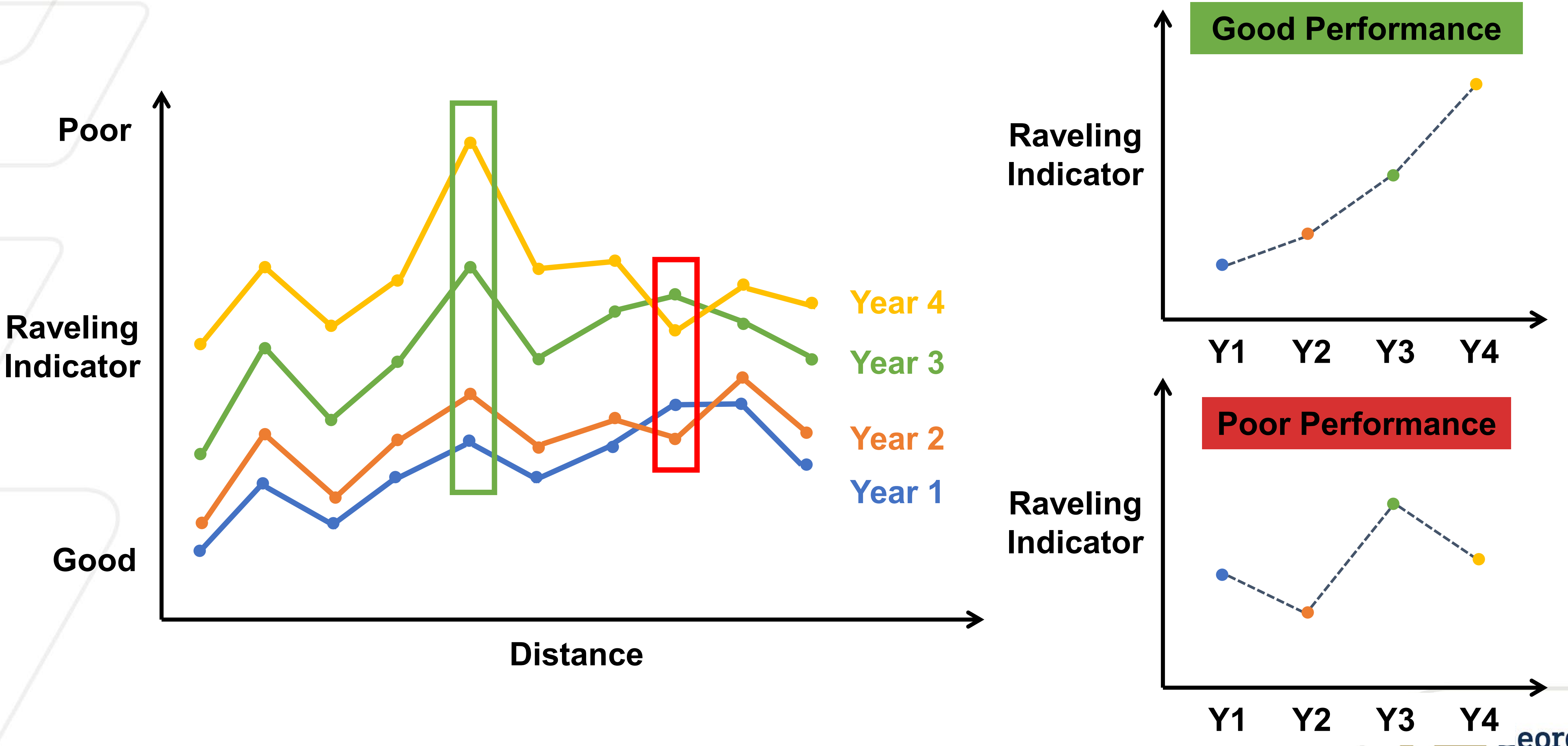


Aggregated Raveling Indicator Values

Expected Spatial-Temporal Trend



Spatial-Temporal Analysis of Raveling Condition



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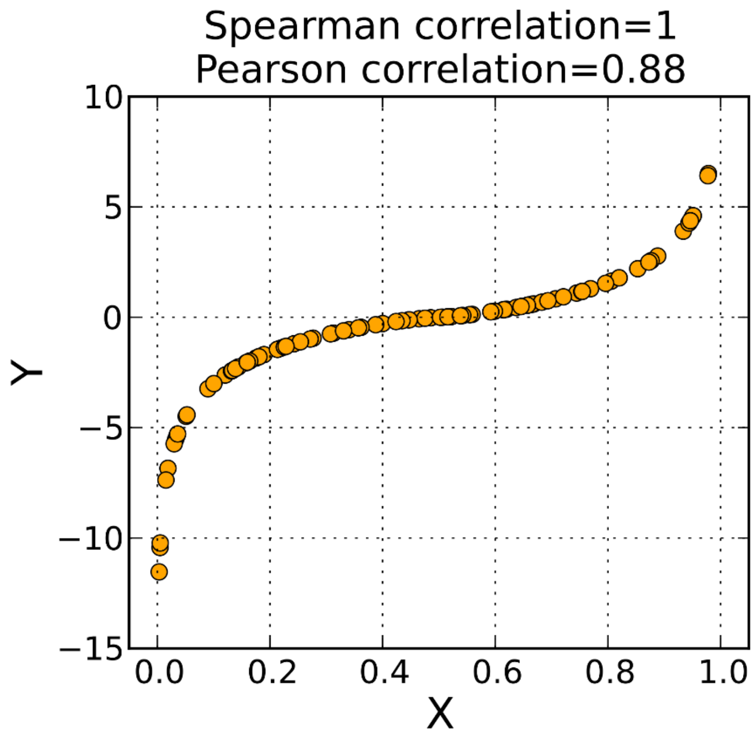
Performance Evaluation: SROCC

To quantitatively assess the performance of the indicators in showing an increasing deterioration trend with time.

- **Spearman rank-order correlation coefficient (SROCC) was used as a performance metric.**
- Nonparametric measure of rank correlation assessing how well the relationship between two variables can be described as strictly increasing or decreasing, regardless of the change rate.
- Deterioration is expected to be strictly increasing, but not necessarily at a constant rate



Case Study on Georgia Interstate Highways

- Eight 1-mile segments with OGFC surface selected on I-59 and I-575 in Georgia
- Typical 2-lane divided interstate highways with truck-lane surveyed consistently
- Analysis period: 2014 to 2019 (6 years)
- Diverse raveling condition
- None or minimal maintenance repairs (e.g., patching)

Northbound Direction

MP 14 to MP 19

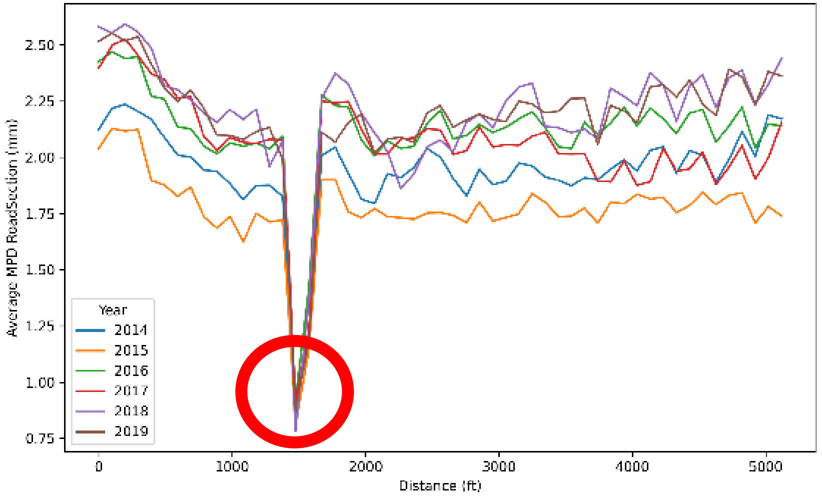
2014 – 2019

Northbound Direction

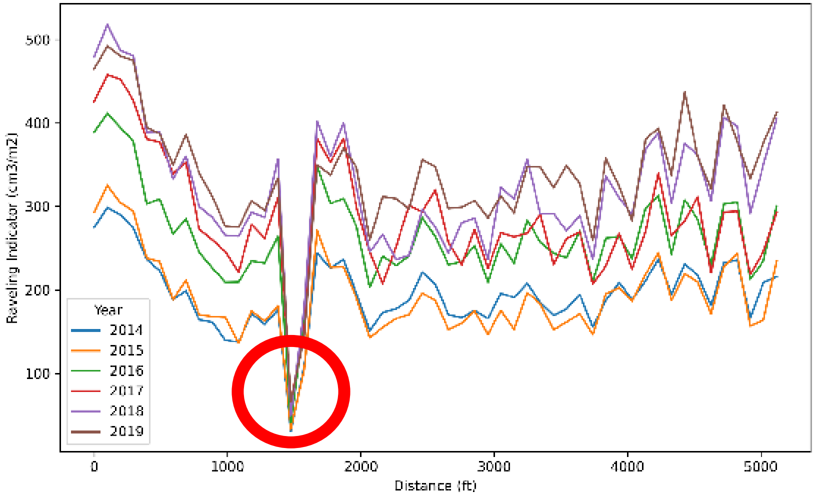
MP 1 to MP 3; MP 6 to MP 8

2014 – 2018

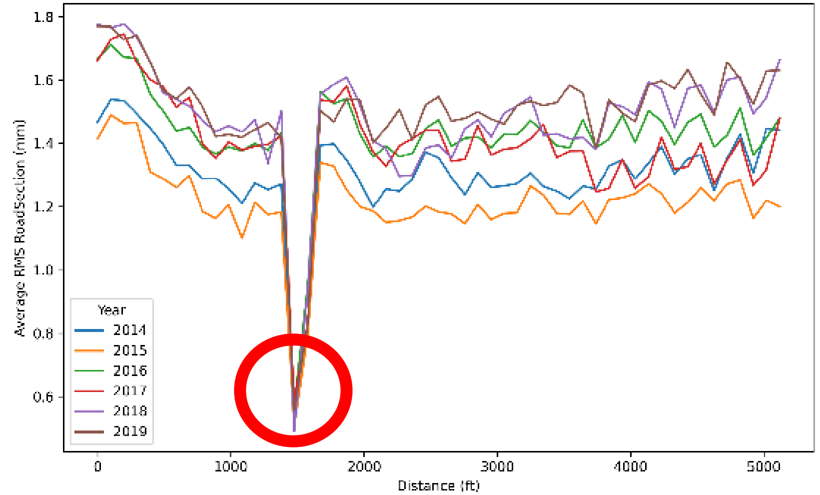
Spatial-temporal deterioration: 100-ft aggregation interval



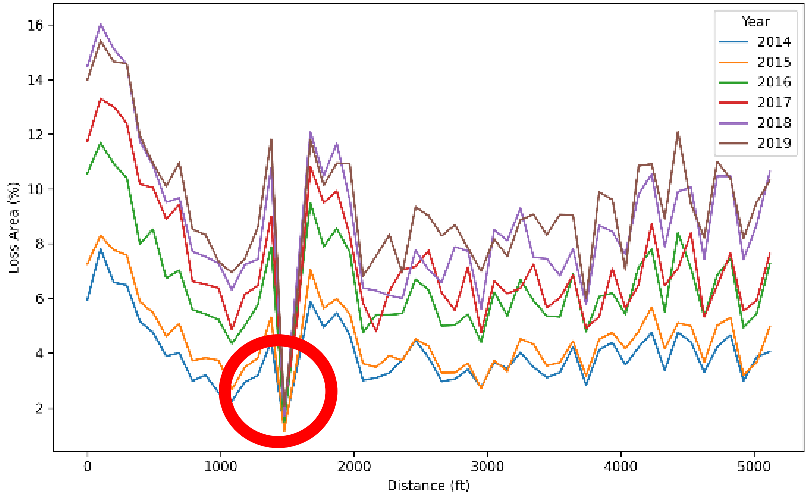
Average MPD (mm)



LCMS Raveling Index (cm^3/m^2)



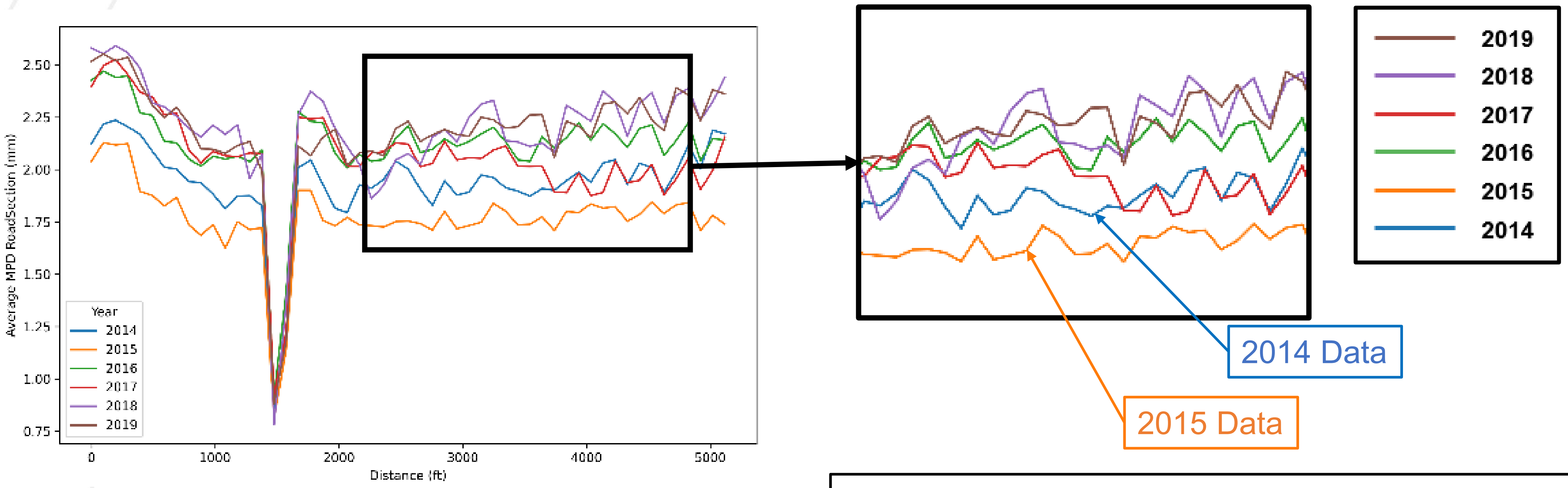
Average RMS (mm)



Aggregate Loss Area (%)

Low Texture/Aggregate Loss Caused by Concrete Bridge

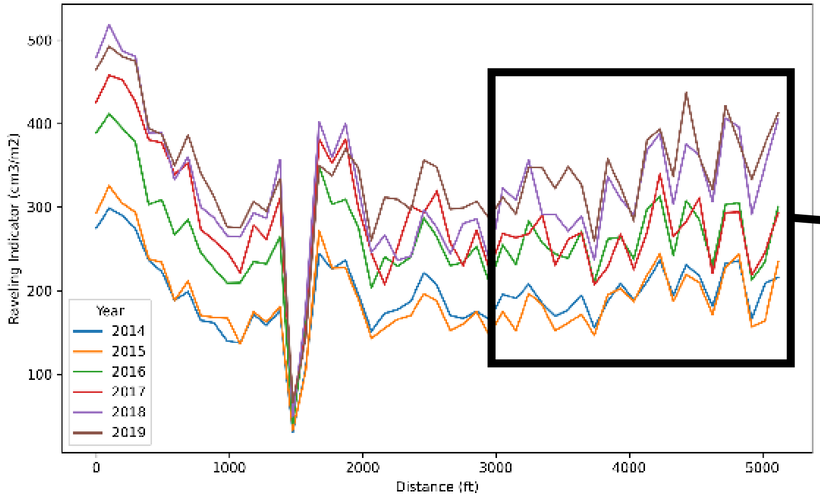
Spatial-temporal deterioration: 100-ft aggregation interval

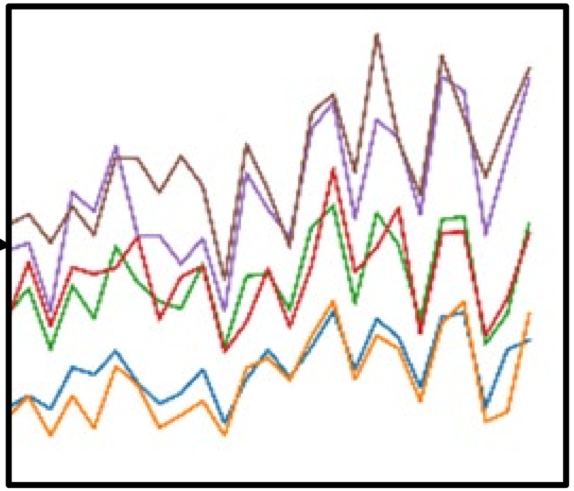


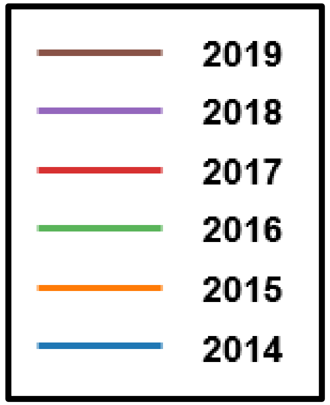
Average MPD (mm)

Macrotexture Indicator showed illogical trend:
Does not reflect year-to-year increase as expected.

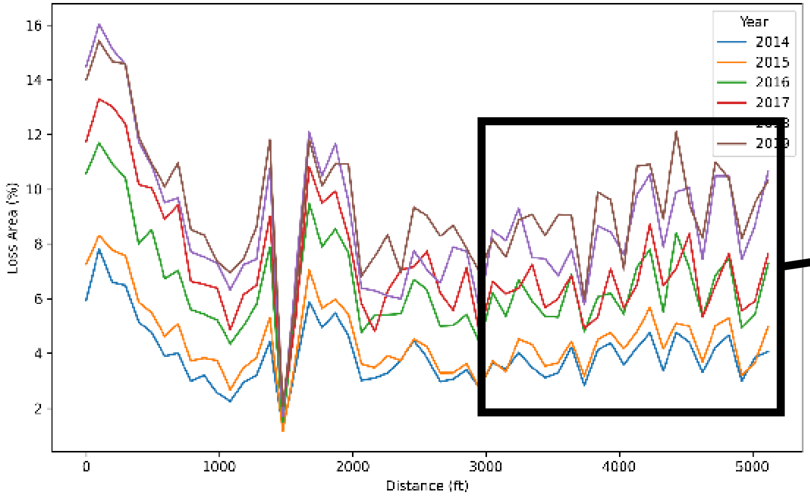
Spatial-temporal deterioration: 100-ft aggregation interval

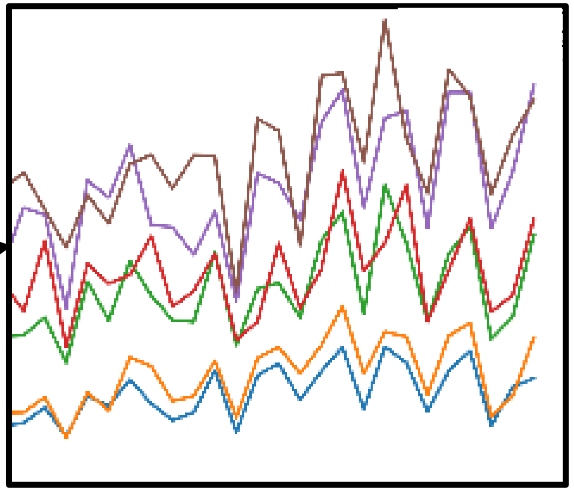






LCMS Raveling Index (cm^3/m^2)





Aggregate Loss Area (%)

Aggregate Loss Indicator showed more logical trend:
More consistent year-to-year increase in raveling.

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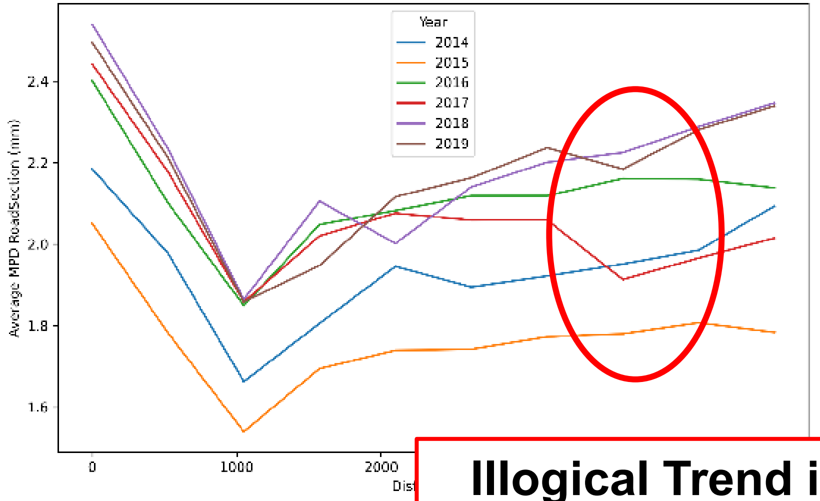
Spatial-temporal deterioration: 0.1-mile aggregation interval



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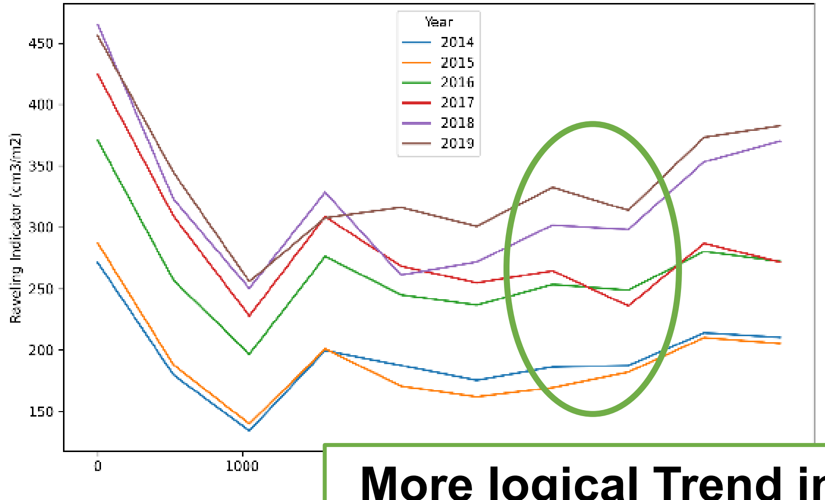
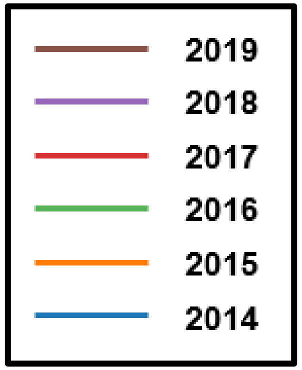
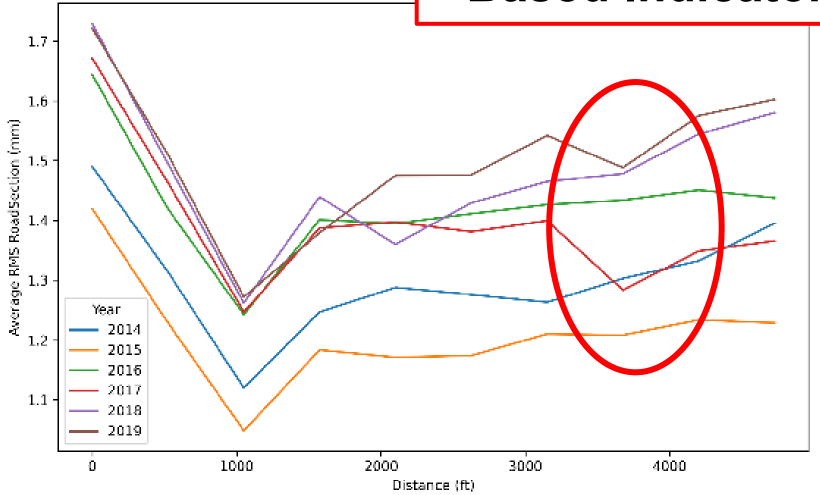
Illogical Trend in Macrotexture-Based Indicators



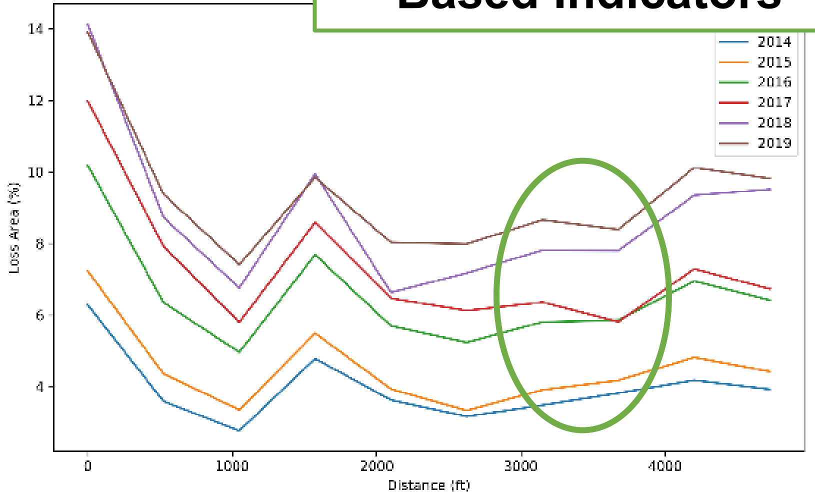
LCMS Rave

More logical Trend in Aggregate Loss-Based Indicators





Average RMS (mm)



Aggregate Loss Area (%)

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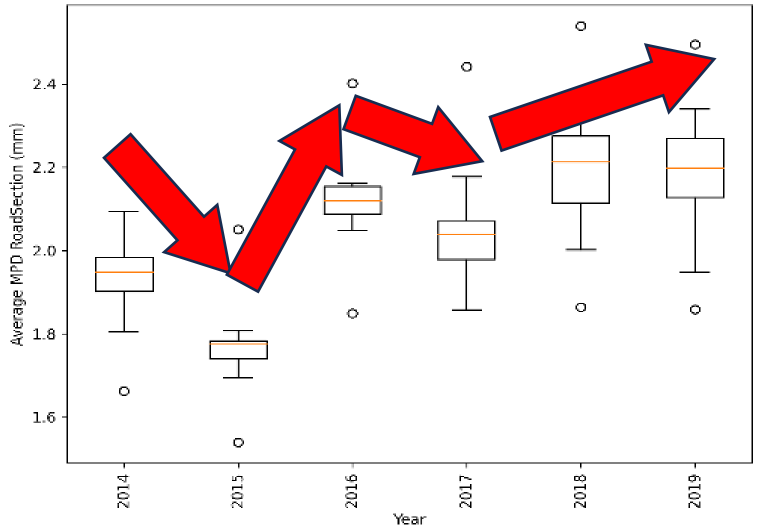
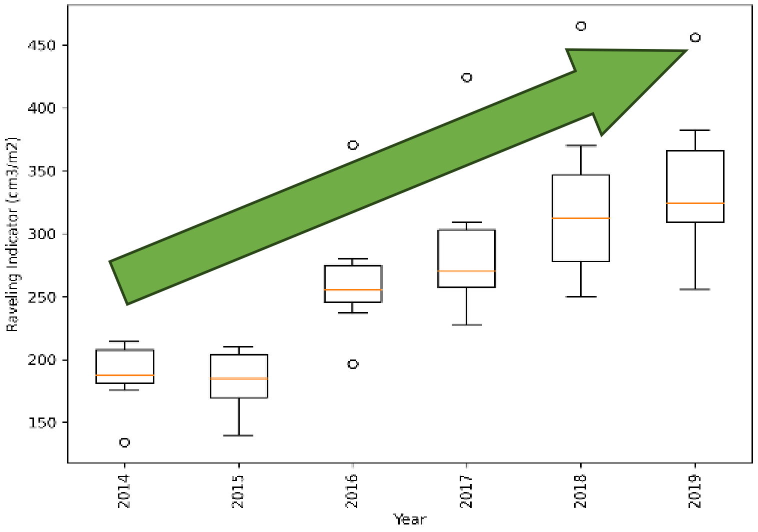
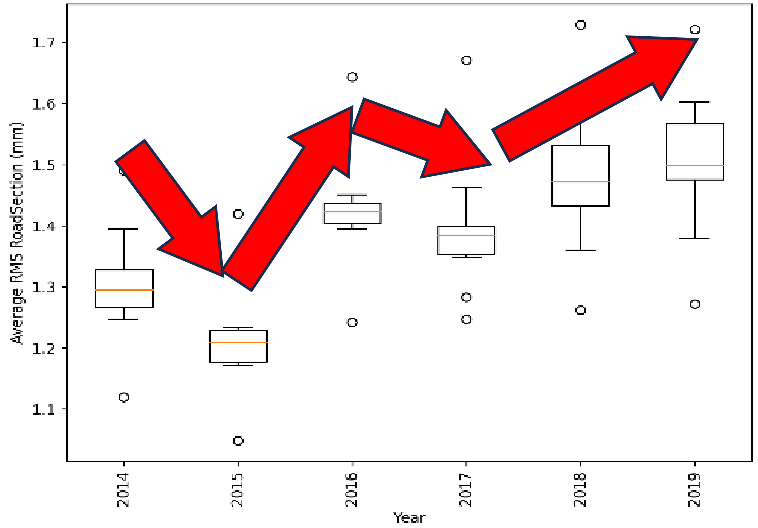
Temporal deterioration trend in 0.1-mile segments



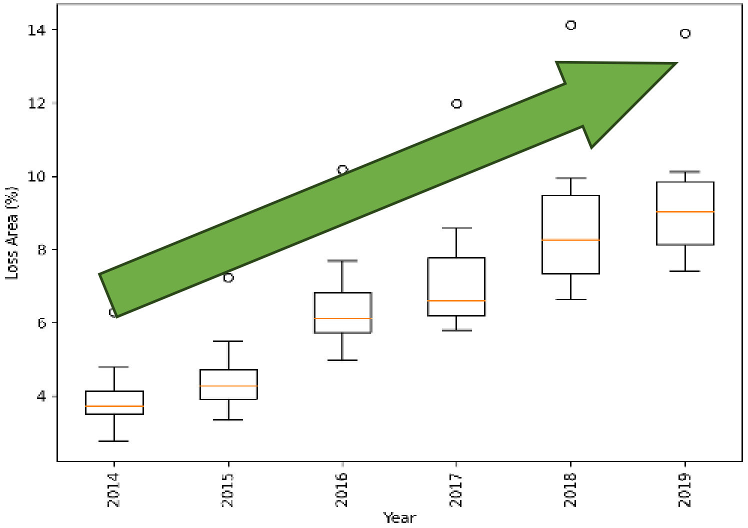
Average MPD (mm)



LCMS Raveling Index (cm^3/m^2)



Average RMS (mm)



Aggregate Loss Area (%)

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Potential Factors Causing Imperfect Trends

Not all aggregated segments show consistently increasing trends due to the following potential factors:

- Data quality of 3D pavement surface data (i.e., accuracy)
- Data registration between multiple timestamps (misalignment)
  - Vehicle wandering
  - Segments termini not precisely aligned
- Localized resurfacing for severe raveling spots

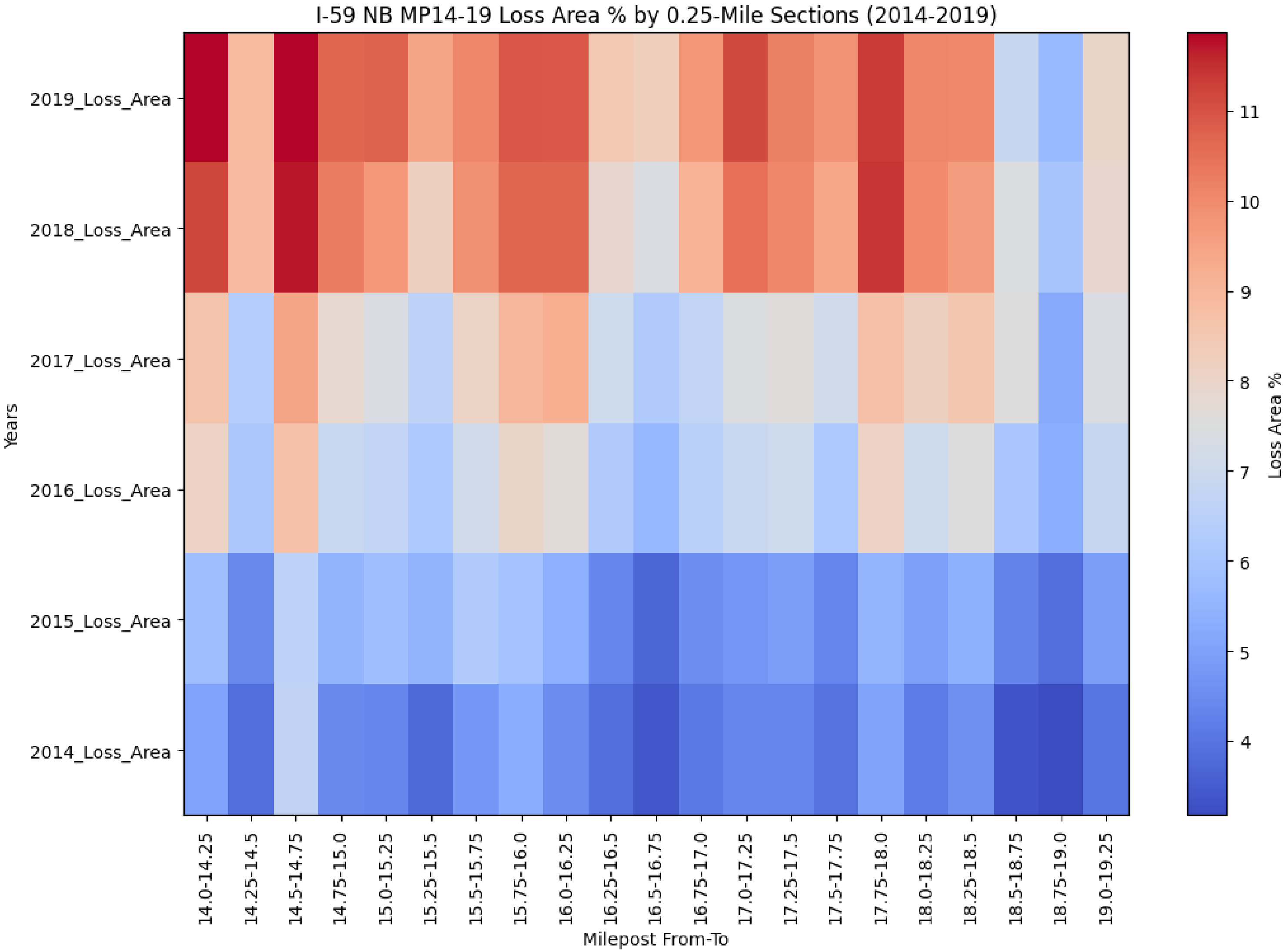
SROCC for 100-ft aggregation interval

Indicator		SROCC								Overall SROCC
		I-59 Northbound				I-575 Northbound				
		MP 14-15	MP 16-17	MP 17-18	MP 18-19	MP 1-2	MP 2-3	MP 6-7	MP 7-8	
Macrotexture-Based Indicators	Average MPD	0.81	0.71	0.79	0.70	0.53	0.59	0.62	0.53	0.66
	Average RMS	0.83	0.76	0.83	0.69	0.49	0.46	0.65	0.55	0.66
Aggregate Loss-Based Indicators	Raveling Index (LCMS)	0.88	0.91	0.89	0.77	0.79	**0.85**	0.84	**0.74**	0.83
	Loss Depth	0.68	0.78	0.57	0.22	0.64	0.51	0.54	0.43	0.55
	Loss Area	**0.92**	**0.96**	**0.93**	**0.83**	0.82	**0.84**	**0.88**	**0.73**	**0.86**
	Loss Volume	**0.92**	0.95	**0.93**	**0.83**	**0.83**	0.82	0.85	**0.73**	**0.86**

SROCC for 0.1-mile aggregation interval

Indicator		SROCC								Overall SROCC
		I-59 Northbound				I-575 Northbound				
		MP 14-15	MP 16-17	MP 17-18	MP 18-19	MP 1-2	MP 2-3	MP 6-7	MP 7-8	
Macrotexture-Based Indicators	Average MPD	0.85	0.76	0.82	0.71	0.58	0.62	0.69	0.59	0.70
	Average RMS	0.82	0.80	0.90	0.71	0.55	0.53	0.68	0.65	0.70
Aggregate Loss-Based Indicators	Raveling Index (LCMS)	0.92	0.92	0.94	0.75	**0.86**	**0.91**	0.83	0.80	0.87
	Loss Depth	0.79	0.78	0.45	0.25	0.68	0.59	0.65	0.57	0.59
	Loss Area	**0.97**	**0.98**	**0.97**	**0.85**	0.83	0.85	**0.88**	**0.85**	**0.90**
	Loss Volume	0.96	**0.98**	0.96	**0.85**	0.81	0.85	0.85	0.84	0.89

I-59 NB MP14 to MP19: Loss Area % (2014-2019)



Findings

- Aggregate loss-based indicators show a better performance in monitoring raveling condition deterioration compared to macrotexture-based indicators.
- The selected aggregate loss-based indicators (LCMS Raveling Index and Yu&Tsai aggregate loss quantification) show a promising performance.

→ This study proves the feasibility of using quantitative raveling indicators extracted from 3D pavement surface data to adequately monitor the raveling deterioration.

→ This was previously infeasible using existing qualitative rating measures.

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Recommendations for future research

- **Performing a comprehensive raveling deterioration analysis:** Effects of various environmental, traffic, and design factors on raveling deterioration.
- **Developing an accurate raveling condition forecasting model**
- **Determining the optimal timing of raveling treatment options associated with the quantitative raveling indicators.**
- **Exploring a standardized raveling quantification indicator** that agencies can adopt to support condition assessment, forecasting, and treatment selection.

Acknowledgement

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Q/A

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