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TRANSPORTATION RESEARCH BOARD

Advances in Pavement Condition Surveys

April 7, 2021

@NASEMTRB
#TRBwebinar

PDH Certification Information:

- 2.0 Professional Development Hour (PDH) – see follow-up email for instructions
- You must attend the entire webinar to be eligible to receive PDH credits
- Questions? Contact Reggie Gillum at RGillum@nas.edu

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Learning Objectives

1. Identify the differences between currently-used cracking definitions and how new technologies influence choice of metrics

2. Describe and implement cracking metrics that can be measured with high repeatability

3. Apply drone and AI technology in pavement condition surveys

TRB: Advances in Pavement Condition Surveys

April 7, 2021

Andrew Mergenmeier, P.E.
Senior Pavement and Materials Engineer
U.S. Department of Transportation
Federal Highway Administration
Resource Center

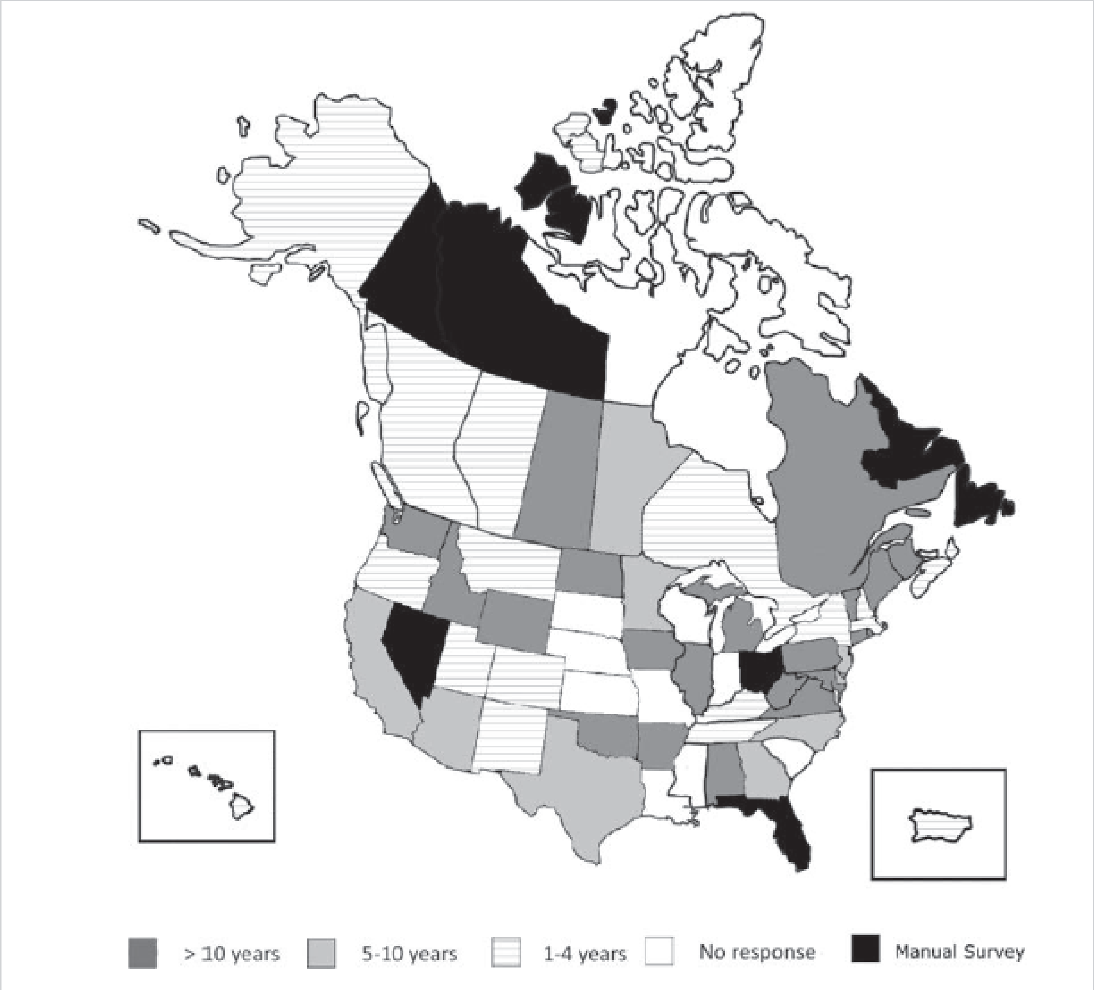
Outline – Highway Speed Pavement Condition Data Surveys

- AASHTO Standards: Ride, Rutting, Cracking, and Faulting
- Data Quality

Source: FHWA

Evolution of Pavement Surveys

Methodology	Fast	Safe	Repeatable and Objective
Walking			
Windshield	✓		
Semi-Automated	✓	✓	
Automated	✓	✓	✓



Source: NCHRP 531, 2019

Length of time conducting automated pavement condition surveys

Highway Speed Pavement Condition Surveys - Ride

- AASHTO M 328 Profiler Equipment Spec
- AASHTO R 56 Profiler System Certification
- AASHTO R 57 Operating Profilers and Evaluating Pvt Profiles
- AASHTO R 54 Pavement Ride Quality Specification

Pooled Fund Project, TPF-5(063)

Highway Speed Pavement Condition Surveys

TPF-5(299)/(399) 24 State DOT's (FHWA Administered): Improve the Quality of Pavement Surface Distress and Transverse Profile Data Collection and Analysis by assembling SHAs, the FHWA, and industry representatives to:

- Initial focus on rutting, cracking and faulting
- Identify data collection integrity and quality issues
- Identify data analysis needs
- Suggest approaches to addressing identified issues and needs

Based on this information, the SHAs and the FHWA will:

- Initiate and monitor projects intended to address identified issues and needs
- Disseminate results
- Assist in solution deployment

Highway Speed Pavement Condition Surveys – Rutting, Cracking, and Faulting

- AASHTO R 85, Quantifying Cracks in Asphalt Pavement Surfaces from Collected Images Utilizing Automated Methods
- AASHTO R 86, Collecting Images of Pavement Surfaces for Distress Detection
- AASHTO R 87, Determining Pavement Deformation Parameters and Cross-Slope from Collected Transverse Profiles
- AASHTO R 88, Collecting the Transverse Pavement Profile
- AASHTO R 36, Evaluating Faulting of Concrete Pavements

Ongoing FHWA/TPF and NCHRP activities to enhance

Quality Assessment

- Calibration and Verification of Transverse Pavement Profile Measurements
  - Standards approved for publication by AASHTO in 2021
  - Final Report published 2020
  - https://www.fhwa.dot.gov/pavement/pub_details.cfm?id=1109
- Developing Guidelines for Cracking Assessment for Use in Vendor Selection Process for Pavement Crack Data Collection/Analysis Systems and/or Services
  - Final report published 2021
  - https://www.fhwa.dot.gov/pavement/pub_details.cfm?id=1119
- Successful Practices for Quality Management of Pavement Surface Condition Data Collection and Analysis
  - Final report published in 2021
  - https://www.fhwa.dot.gov/pavement/pub_details.cfm?id=1120

Conclusion

- Many ongoing and planned national activities to support equipment/personnel certification and verification
- Stay engaged to accelerate the learning curve and implementation

Questions?

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Comparable Cracking Definitions in the Age of Artificial Intelligence

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TRB AKP10 Webinar

April 7 2021

Presentation Content

- ❑ Results from **NCHRP 01-57A**
  - ❑ Developing Standard Definitions for Comparable Pavement Cracking Data
  - ❑ Designed for Future Technology & Automation
- ❑ Can AI Help in Full Automation in Pavement Condition Survey
  - ❑ Cognition Based; Automation?
  - ❑ Repeatability, Consistency, Accuracy

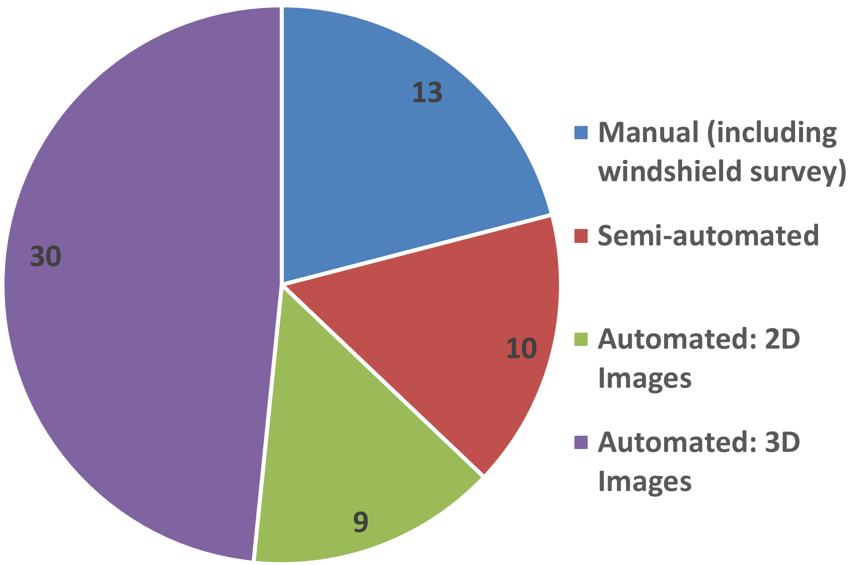
Objectives of NCHRP 01-57A

- Develop standard, discrete definitions for common cracking types for asphalt and concrete pavements
- Help service providers and SHAs conduct objective cracking measurements and encourage continuing technological innovations
- Facilitate comparable measurement and interpretation of pavement cracking
- Have sufficient details to meet requirements for developing automated cracking software, for being compatible with existing & emerging technologies
- Primarily for network level surveys and help application of new technologies at the project level

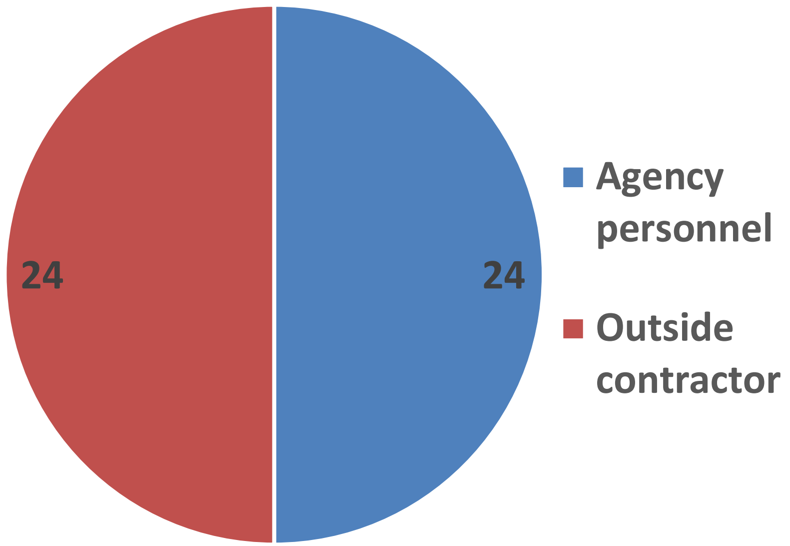
Online Survey of State Highway Agencies

- From April to May 2018
- Five Sections
  - Part I: Cracking data collection, processing, and common issues
  - Part II: Cracking definitions of transverse, longitudinal, alligator/fatigue, block, edge, durability "D" cracking, corner break, and other cracking data
  - Part III: Wheel Path Definitions
  - Part IV: AASHTO R 85-18 Applications
  - Part V: General Comments
- Responses from 38 Different SHAs

Part I: Data Collection, Processing, & Common Issues

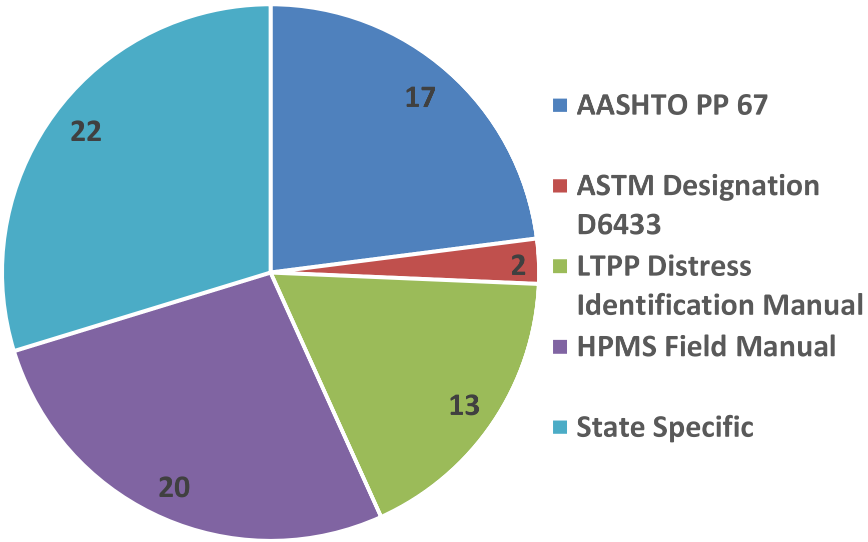


39 of SHAs Apply 2D/3D Image based Automated Technologies for Cracking Data Collection and Processing Methods

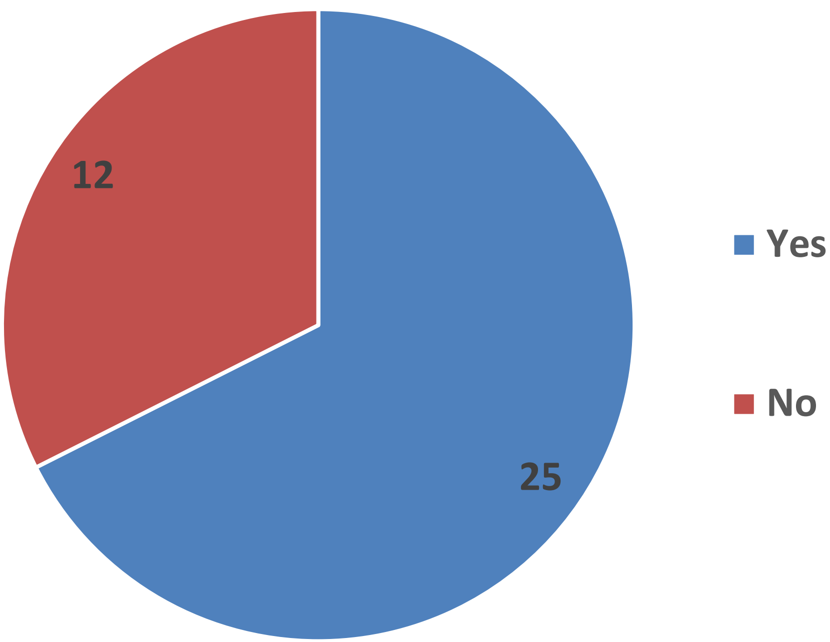


Data Collection and Processing Personnel

Part I: Data Collection, Processing, & Common Issues

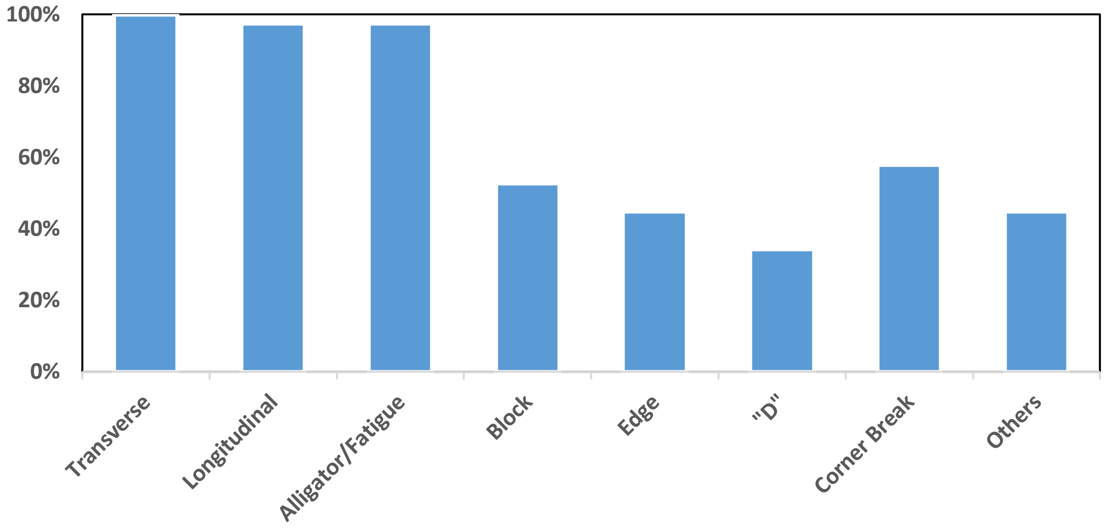


Data Collection and Processing Protocols

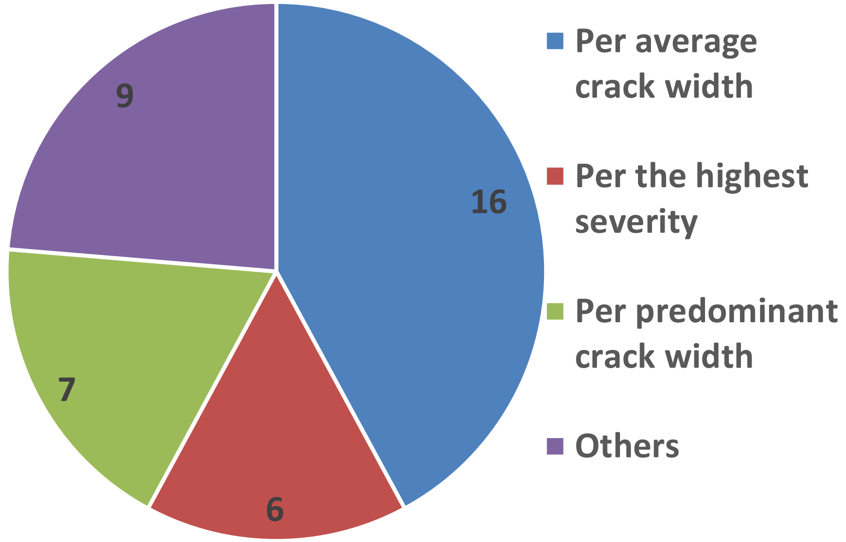


25 SHAs Conduct QA/AC on Automated Cracking Analysis Results

Part I: Data Collection, Processing, & Common Issues

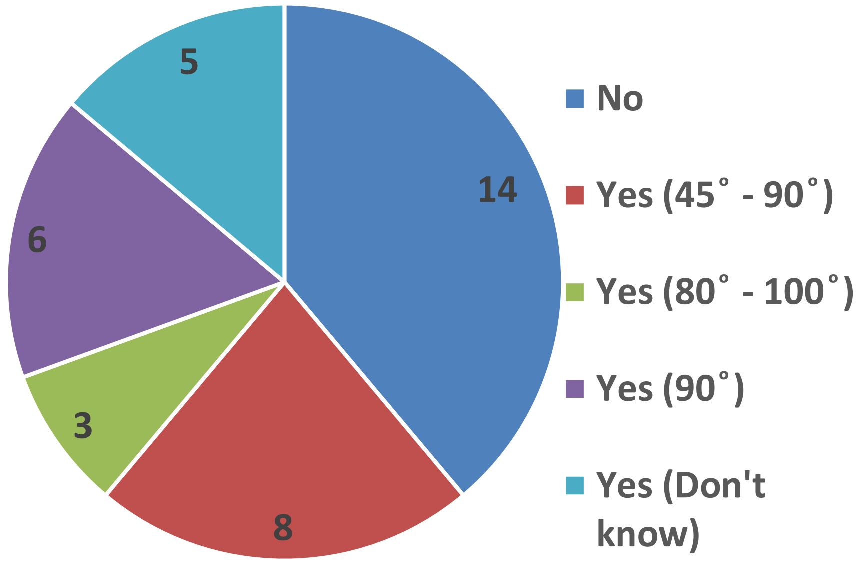


Almost All the SHAs Collect Transverse, Longitudinal, and Alligator/Fatigue Cracking

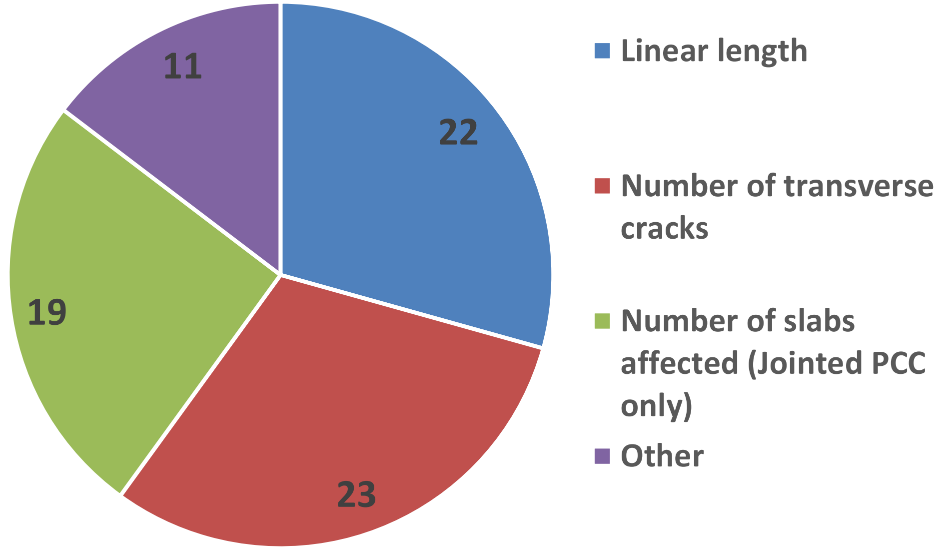


Cracking Severity Levels: 16 SHAs Use Average Crack Width

Part II: Definitions, Transverse Cracking

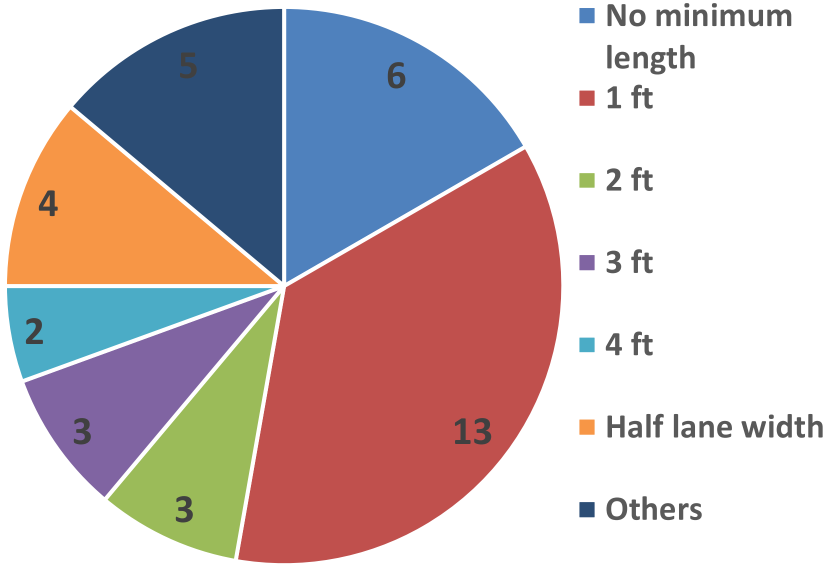


22 SHAs Use Angle Orientation To Define Transverse Cracking

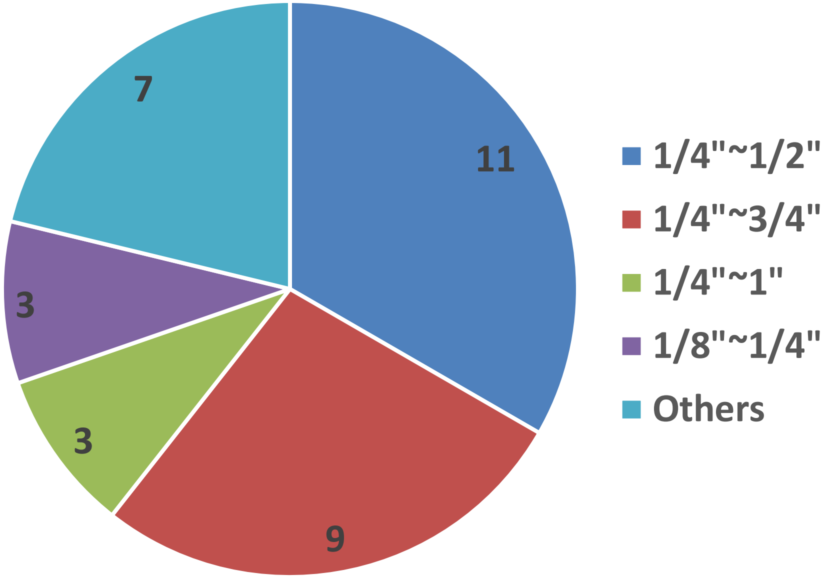


Extent Evaluation Factors:
Linear Length (22)
Number of Transverse Cracks (23)
Number of Slabs Affected (Jointed PCC only) (19)

Part II: Definitions, Transverse Cracking

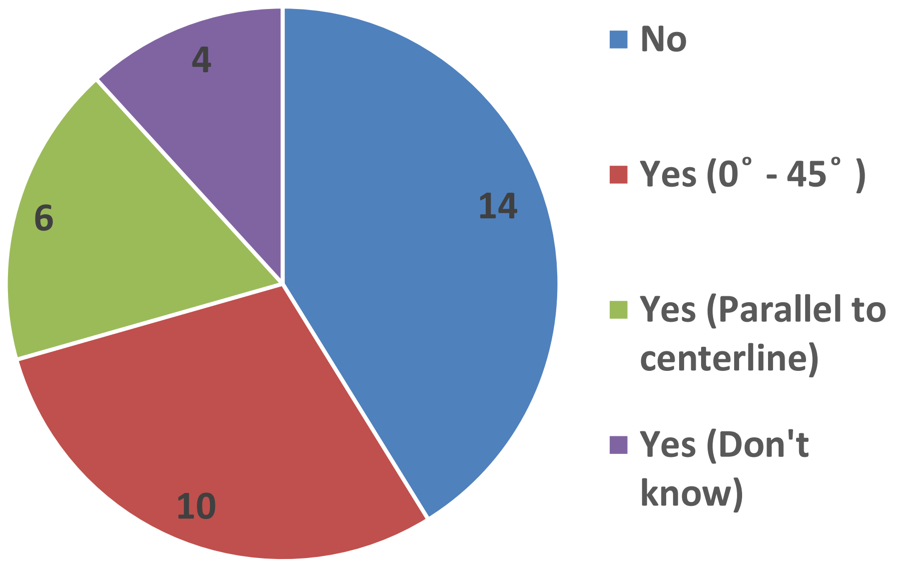


Minimum Length:
1 ft. (13)

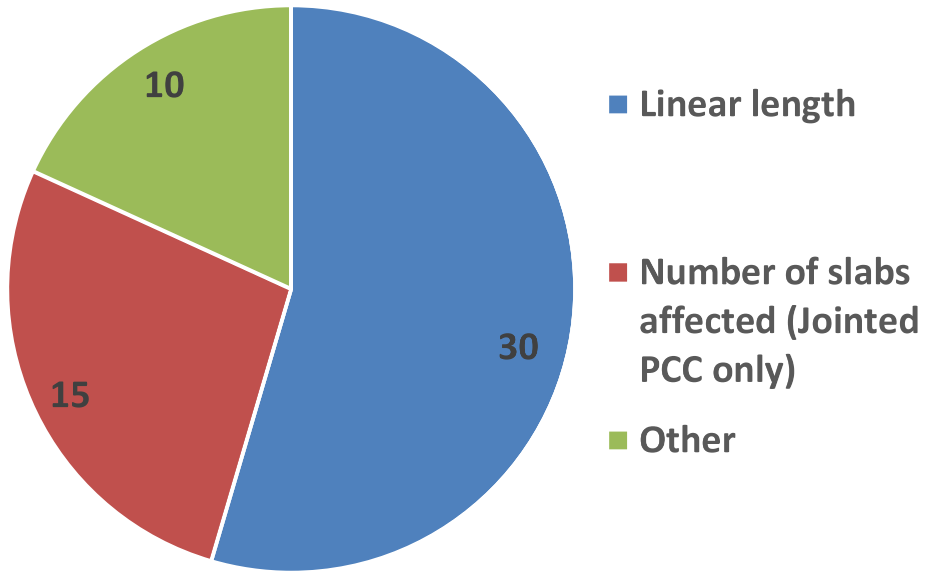


Crack Width Thresholds:
¼”~½” (11)
¼”~¾” (9)

Part II: Definitions, Longitudinal Cracking

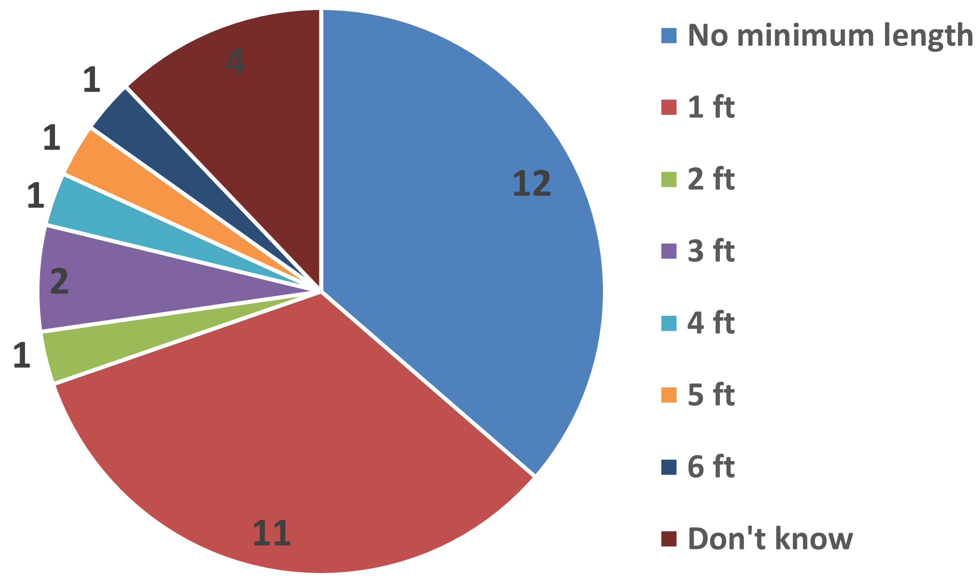


20 SHAs Use Angle Orientation To Define Longitudinal Cracking

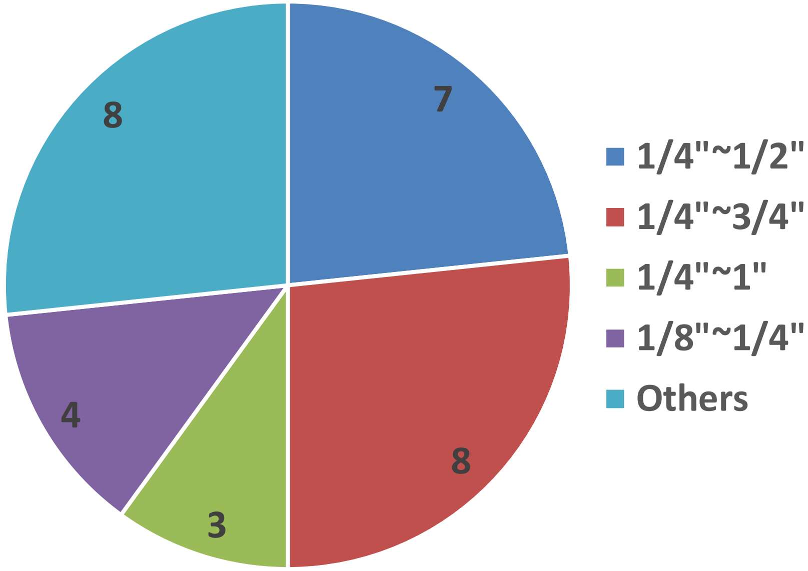


Extent Evaluation Factors: Linear Length (30)

Part II: Definitions, Longitudinal Cracking

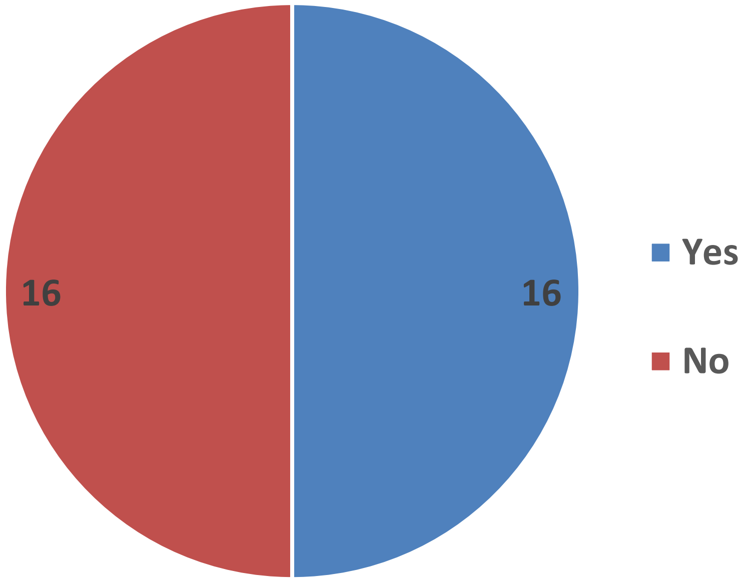


Minimum Length:
1 ft. (11)

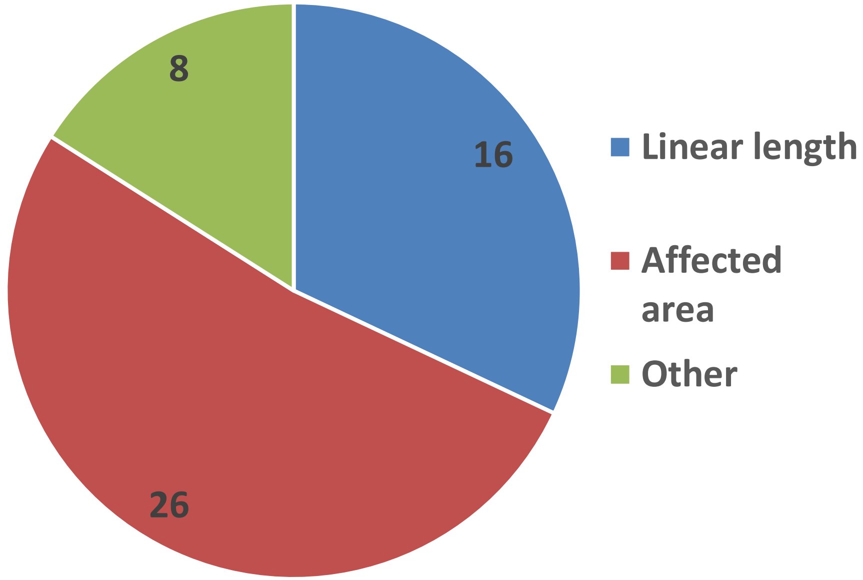


Crack Width Thresholds:
¼”~½” (7)
¼”~¾” (8)

Part II: Definitions, Alligator/Fatigue Cracking

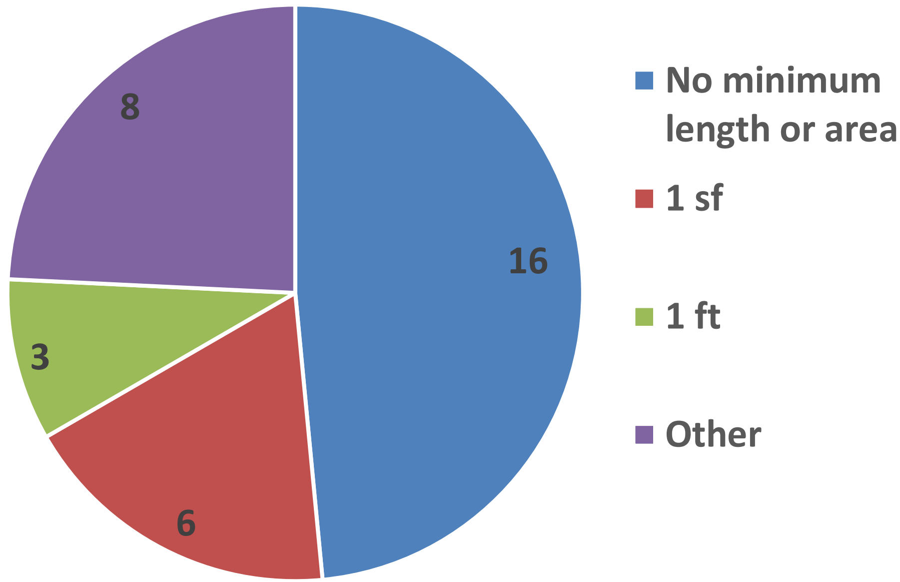


16 of SHAs Count The Portion of Cracking in Wheel Path As Alligator/Fatigue Cracking

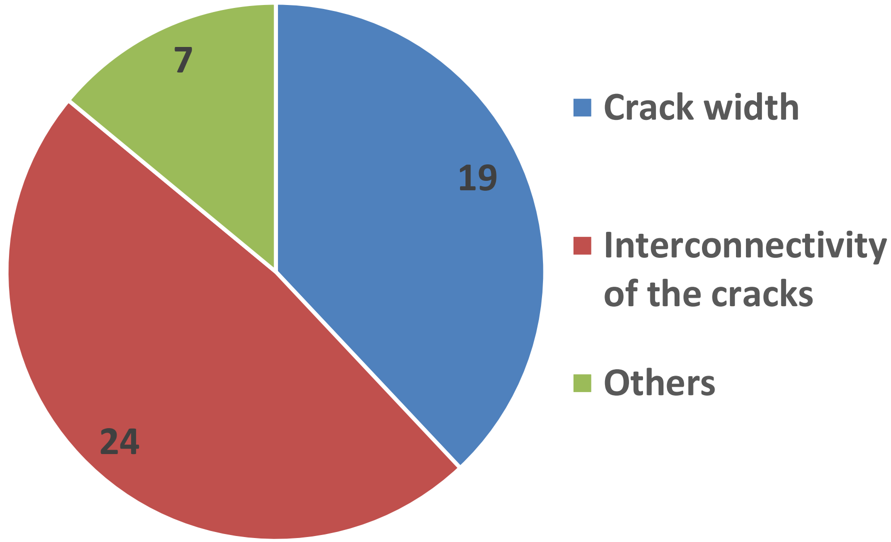


Extent Evaluation Factors: Affected Area (26)

Part II: Definitions, Alligator/Fatigue Cracking

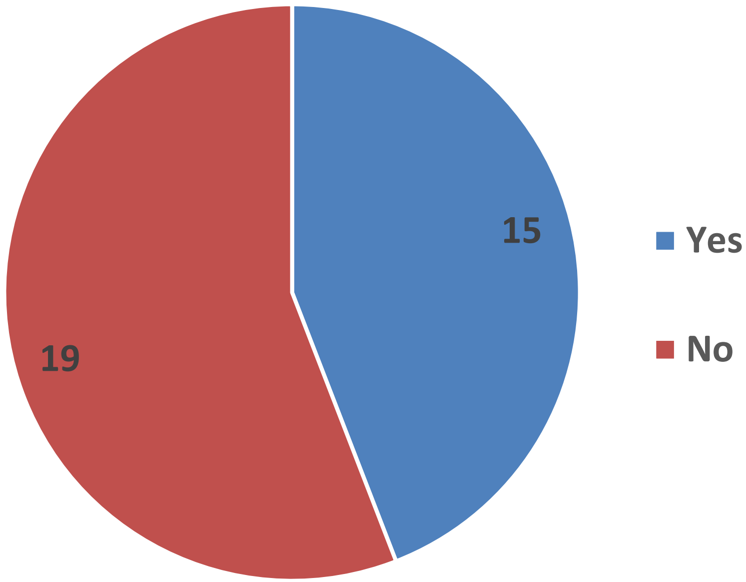


Minimum Length or Area:
No Requirement (16)

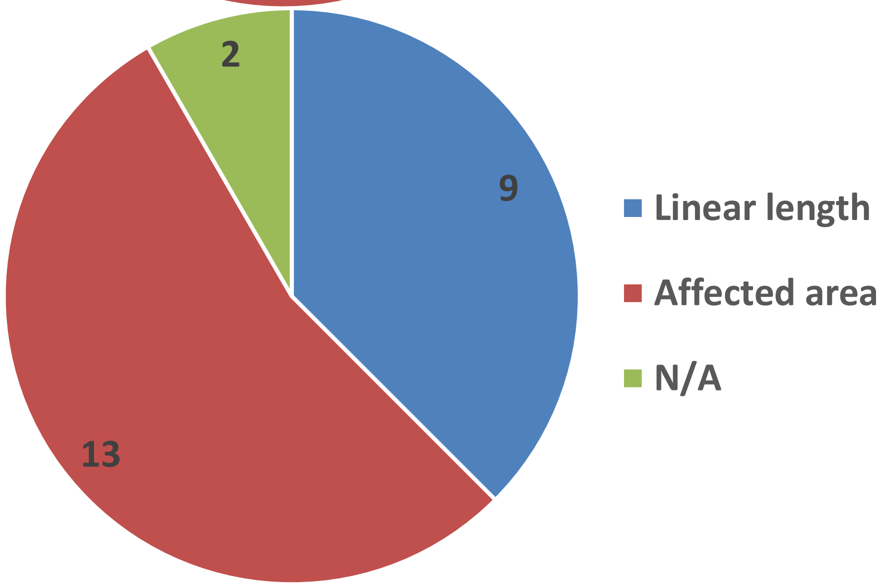


Severity Evaluation Factors:
Crack Width (19)
Interconnectivity of Cracks (24)

Part II: Definitions, Block Cracking

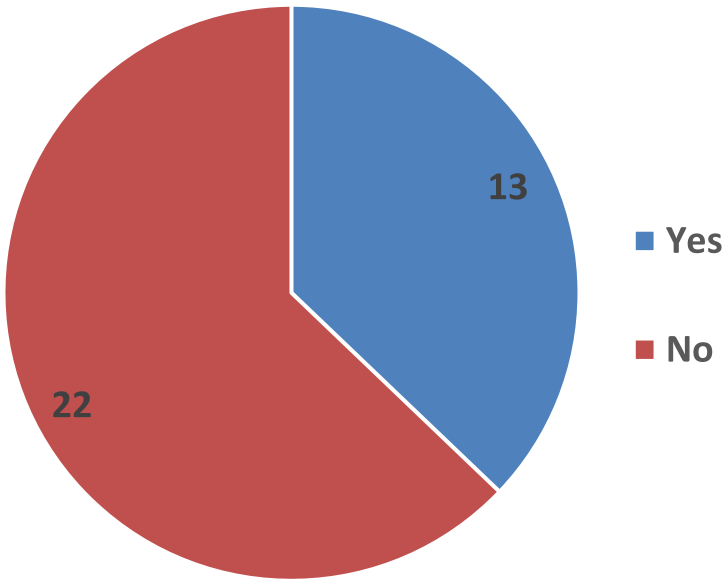


15 of SHAs Collect Block Cracking

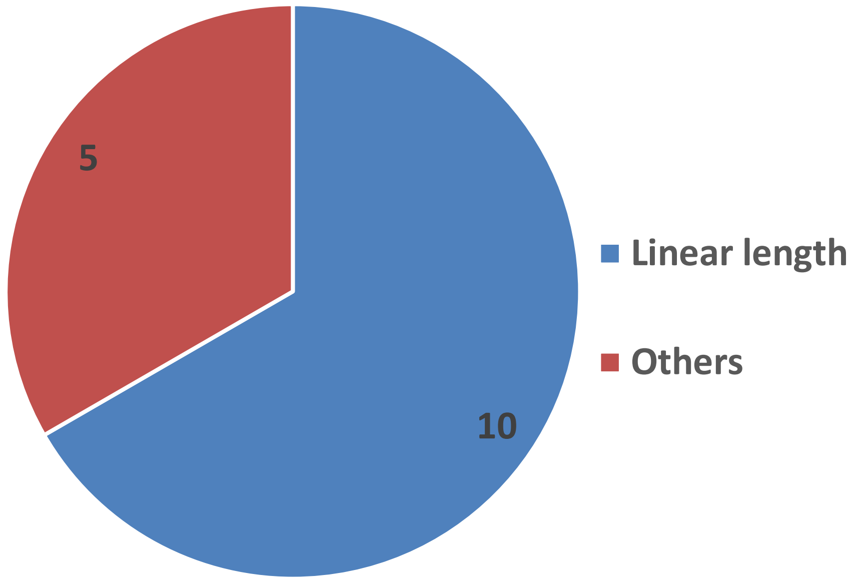


Extent Evaluation Factors:
Linear Length (9)
Affected Area (13)

Part II: Definitions, Edge Cracking

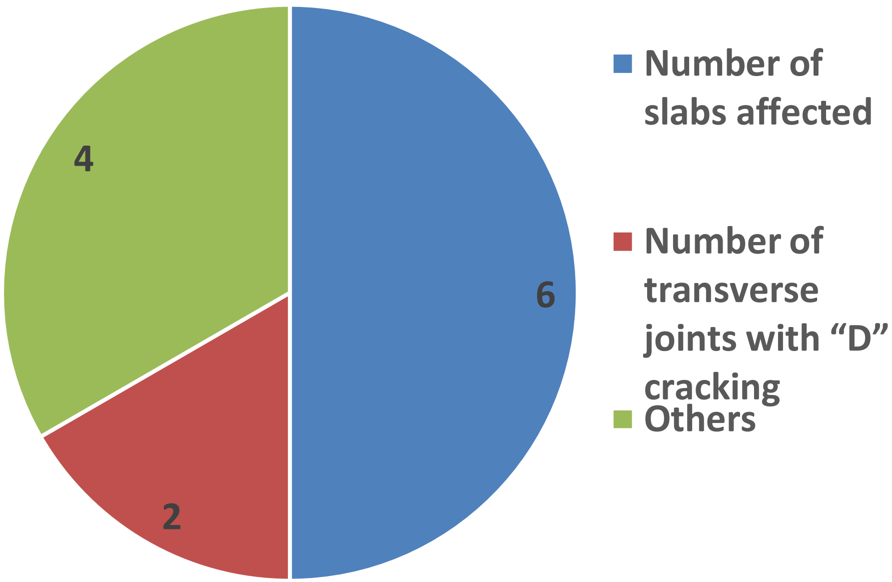


13 of SHAs Collect Edge Cracking

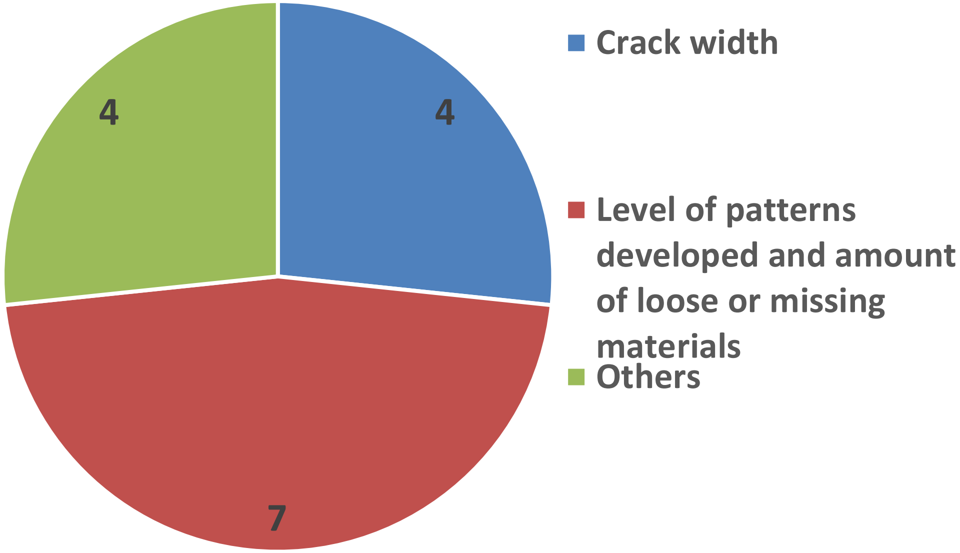


Extent Evaluation Factors: Linear Length (10)

Part II: Definitions, Durability ("D") Cracking

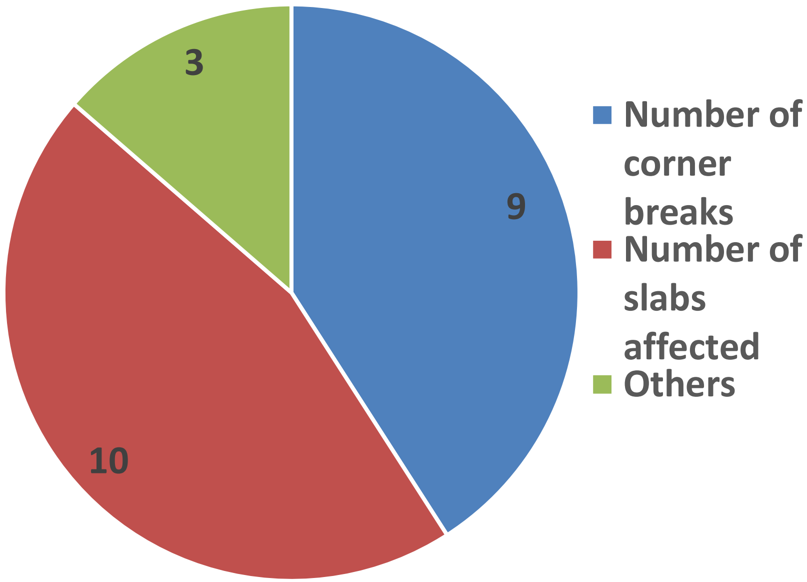


Extent Evaluation Factor: Number of Slabs Affected (6)

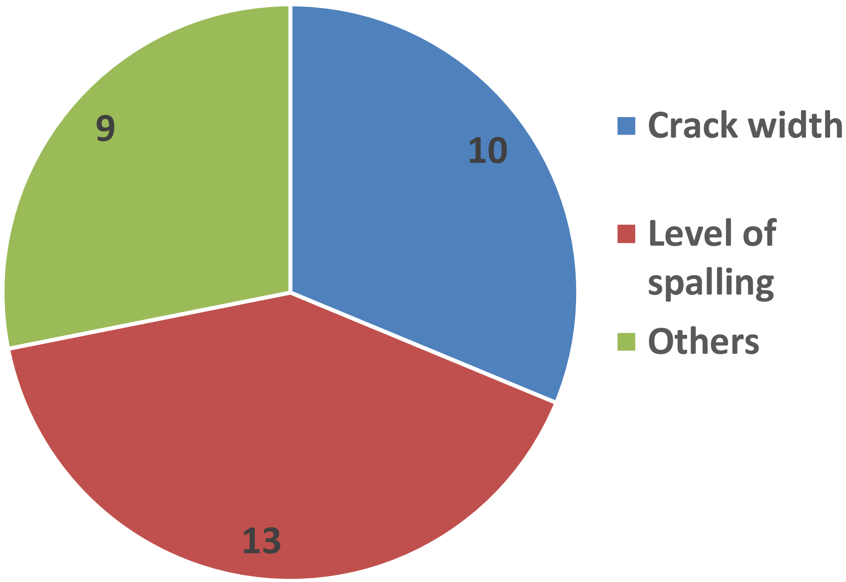


Severity Evaluation Factors: Level of Patterns Developed and Amount of Loose or Missing Materials (7)

Part II: Definitions, Corner Break

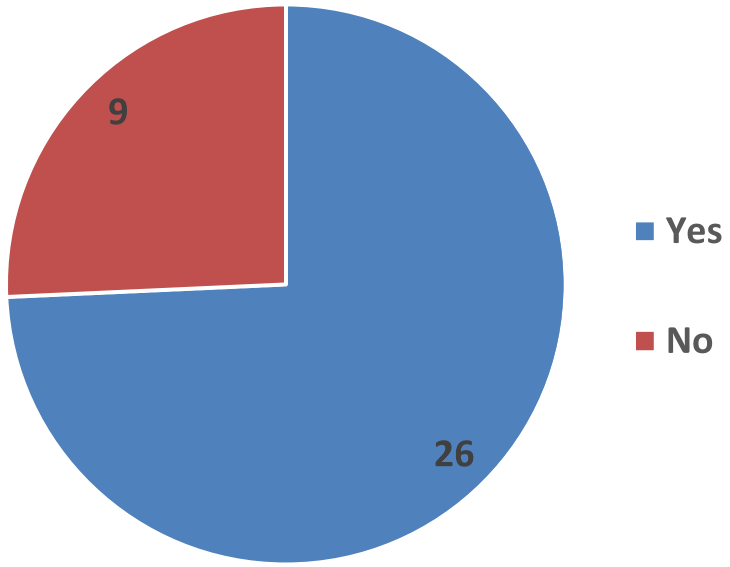


Extent Evaluation Factor:
Number of Corner Breaks (9)
Number of Slabs Affected (10)

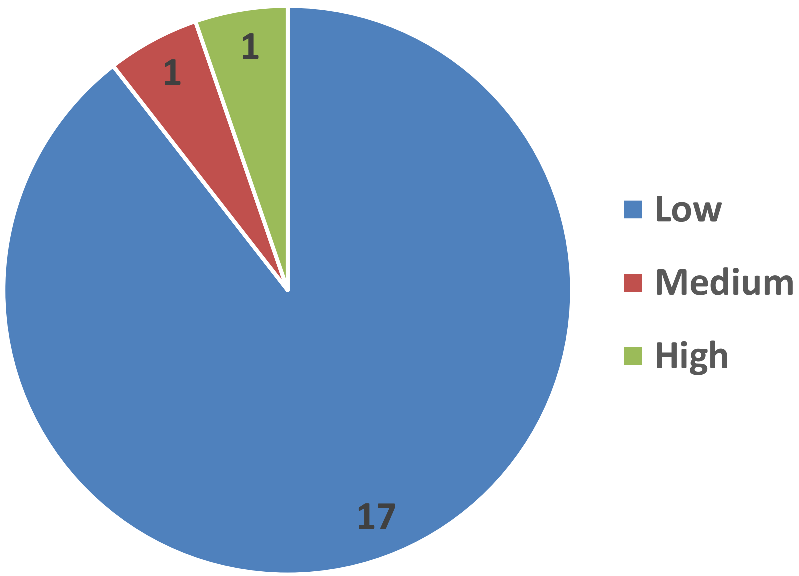


Severity Evaluation Factors:
Crack Width (10)
Level of Spalling (13)

Part II: Definitions, Sealed Cracking

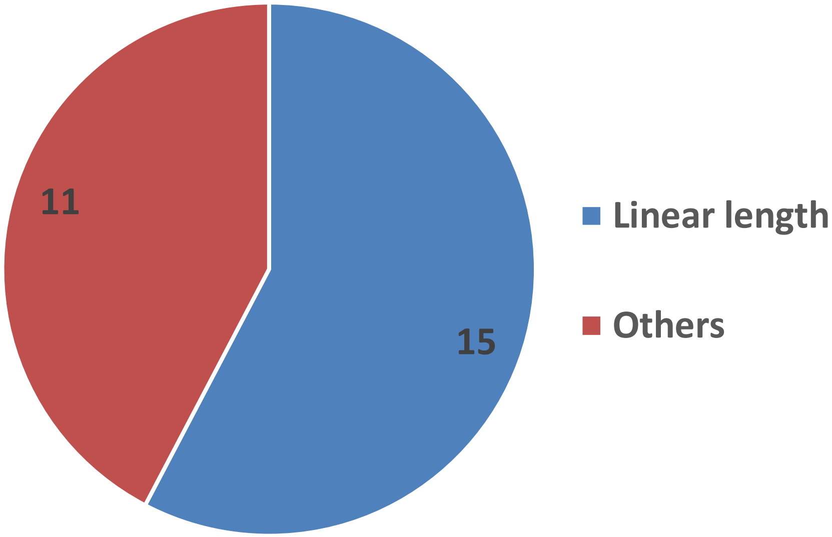


26 of SHAs Collect Sealed Cracking

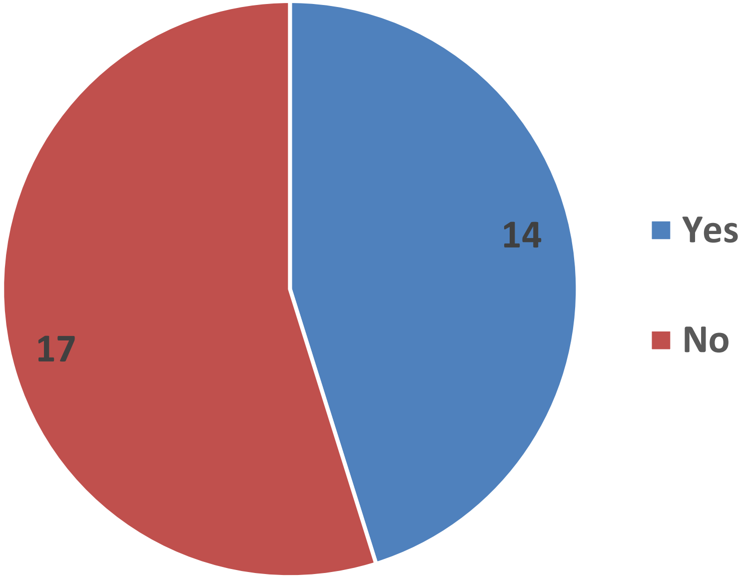


17 of SHAs Rate Sealed Cracking as "Low" Severity Level

Part II: Definitions, Sealed Cracking

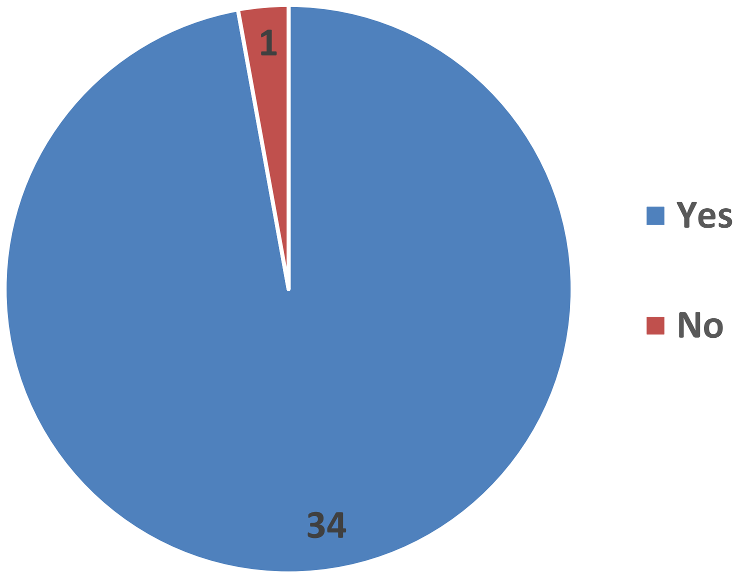


15 of SHAs Report “Linear Length” for Sealed Cracking

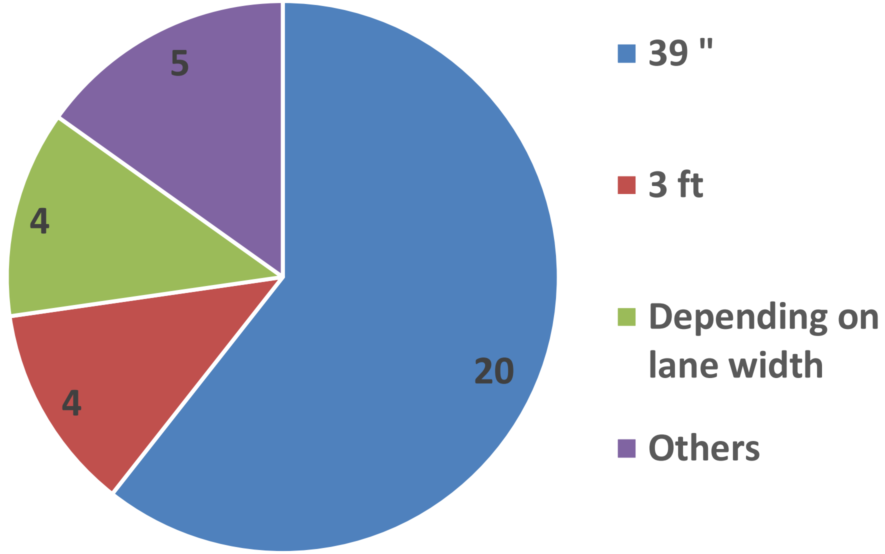


17 of SHAs Do Not Collect and Report Other Cracking Data

Part III: Wheel Path Definitions

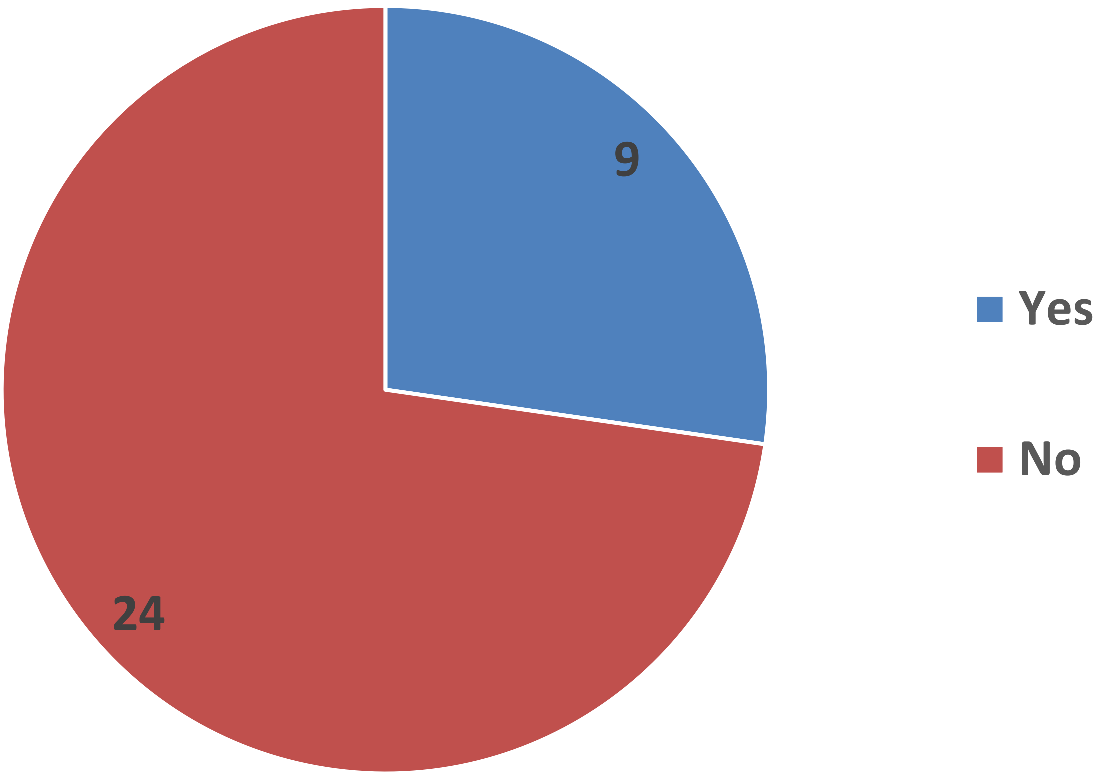


34 of SHAs Differentiate Wheel Path and Non-Wheel Path Zones



20 of SHAs Use 39” (1m) as Wheel Path Width

Part IV: AASHTO R 85-18 Application



24 of SHAs Have Not Implemented AASHTO R 85-18

Part IV: AASHTO R 85-18 Application

- Among the 14 SHA respondents:
  - 6 indicated concerns on whether AASHTO R 85-18 will meet the data needs for HPMS reporting, PMS, and Pavement ME Design™
  - 4 would like to distinguish alligator cracking and block cracking rather than simply use pattern cracking
  - 2 recommended using severity levels for pavement cracking data and calculating cracking density as additional indicators for pavement condition evaluation
  - 1 indicated possible inconsistency with the historical data collected using agency protocols for pavement management and the impact on performance prediction

Part V: General Comments

- 23 SHAs provide opinions and comments for a new cracking protocol for fully automated system in next 10 years. Typically:
  - ✓ Development of cracking certification standard or practice similar to that for ride quality
  - ✓ Improved crack detection accuracy, especially on concrete pavements
  - ✓ Provide a protocol that can keep up with the evolution of automated cracking data collection technology
  - ✓ Real-time cracking detection and reporting

Role of Cracking Data in Decision-Making

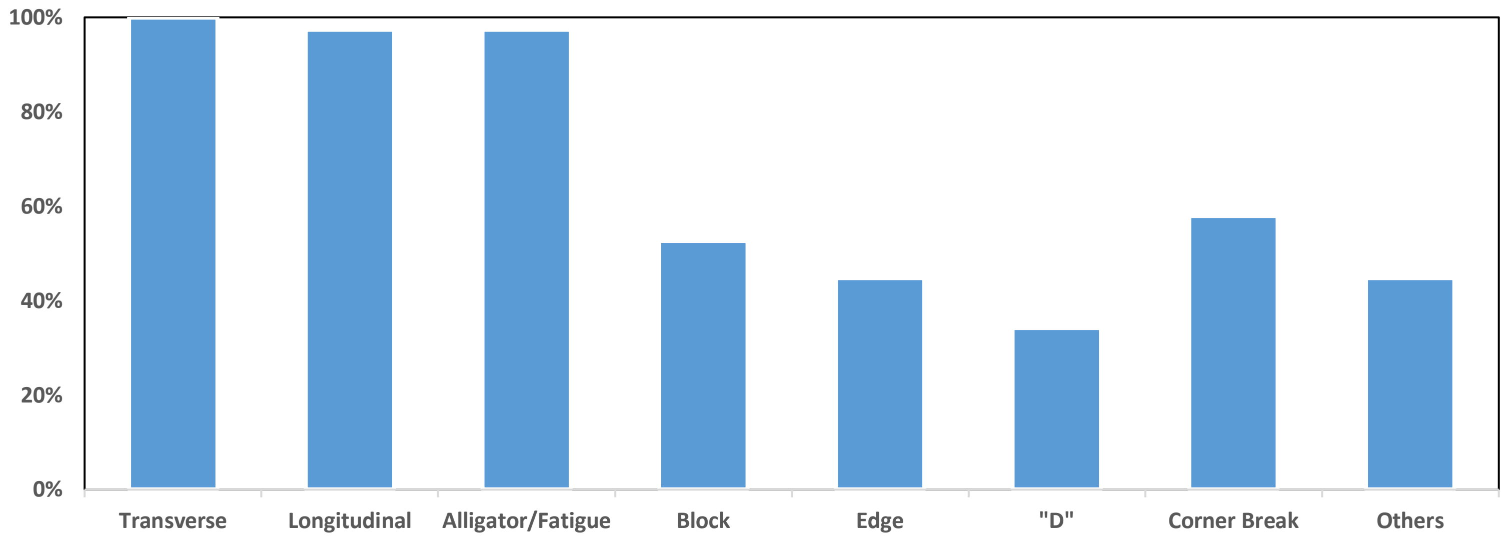
- Network Level
  - Composite indices: Pavement Condition Index (PCI) or Present Serviceability Index (PSI)
  - Individual indices: structure index or non-structural cracking index
  - Represent overall pavement condition
- Project Level
  - Determine the most cost-effective and feasible treatment based upon pavement distress data
  - Severity and percentage of cracking: relate to pavement treatment selection
  - Support planning & programming of pavement management activities

Summary of Cracking Data in Decision-Making

- Cracking data: important to calculate pavement condition indices for network level decision-making
- Pavement cracking condition affects the selection of maintenance and rehabilitation treatments and strategies at project level
- SHAs develop procedures and guidelines to ensure collected cracking data meets acceptance criteria

Cracking Data Desired by SHAs, Overall

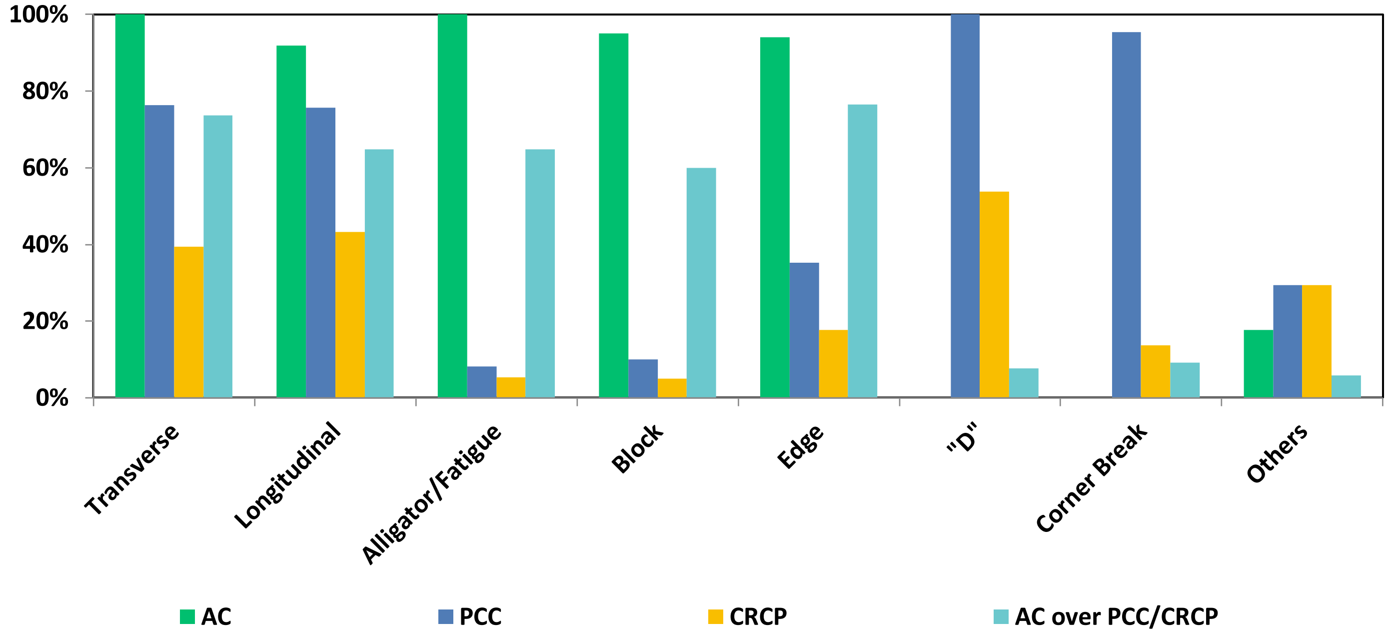
- Pavement Management



Nearly all SHAs collect transverse, longitudinal, and alligator/fatigue cracking

Cracking Data Desired by SHAs, Surface Types

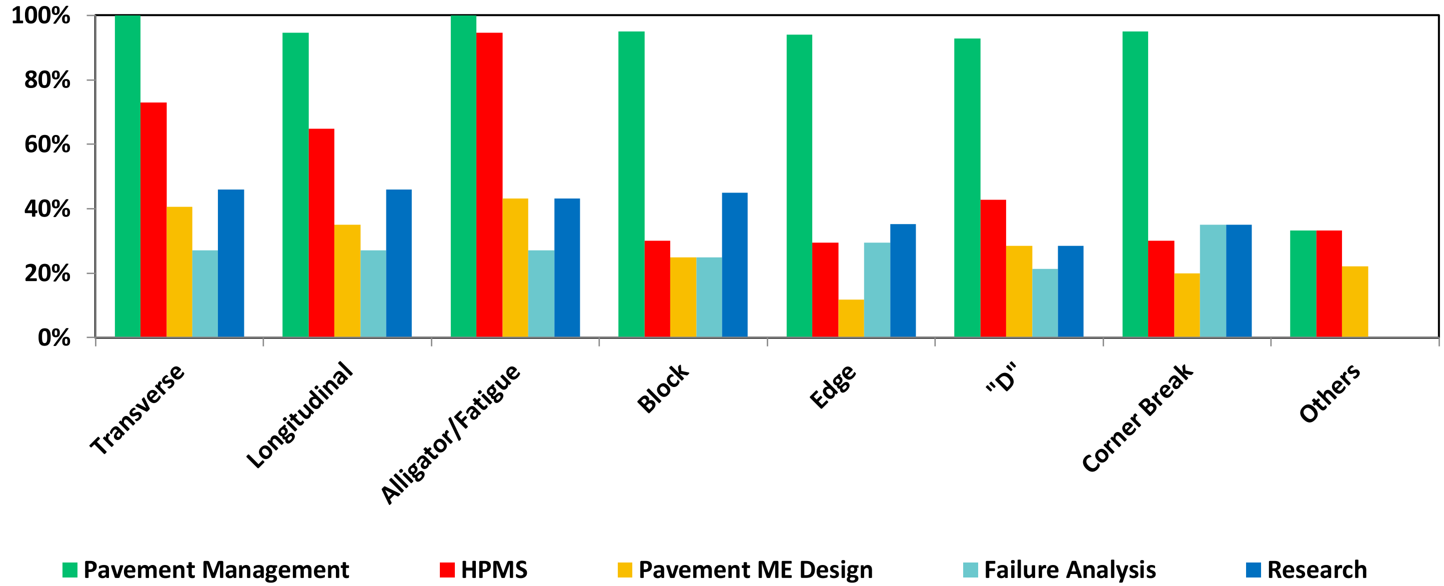
- Pavement Management



Typically collected cracking by SHAs
For AC: transverse, longitudinal, alligator/fatigue, block, and edge cracking;
For JPCP: transverse, longitudinal, “D” cracking, corner break, and shattered slabs;
For CRCP: transverse, longitudinal, “D” cracking, and shattered slabs.

Cracking Data Desired by SHAs, Applications

- Pavement Management



Usage of collected cracking data by SHAs
Pavement management: transverse, longitudinal, alligator/fatigue, block, edge, “D” cracking, and corner break;
HPMS reporting: transverse, longitudinal, and alligator cracking.

Cracking Data Desired by SHAs, HPMS

- Asphalt: % of total wheel path area exhibiting visible fatigue type cracking at all severity levels
- JPCP: % of slabs with transverse cracking
- CRCP: % of the area exhibiting longitudinal cracking, punchouts, and patching

Cracking Data Desired by SHAs, MEPDG

HMA Distress Data

IRI[1]	in/mile
Alligator cracking	% cracked per section length
Transverse cracking	ft/mile
Asphalt rutting[2] (permanent deformation)	in.

JPCP Distress Data

IRI[1]	in/mile
Transverse slab cracking	%
Mean joint faulting[2]	in.

CRCP Distress Data

IRI[1]	in/mile
Number of punchouts	per/mile

[1] International Roughness Index, typical measured every tenth of a mile
[2] Average, standard deviation, COV, maximum, minimum

Cracking Data Desired for MEPDG Local Calibration (AASHTO 2020)

Cracking Data Desired by SHAs, MAP-21

- Support the use of performance measures to drive investment decision-making
- Develop a risk-based asset management plan to improve the asset condition

Surface Type	Metric	Measure Range	Rating
Asphalt Pavement	Cracking_Percent	<5% 5-20% >20%	Good Fair Poor
JPCP	Cracking_Percent	<5% 5-15% >15%	Good Fair Poor
CRCP	Cracking_Percent	<5% 5-10% >10%	Good Fair Poor

Final Rulemaking for Cracking (FHWA 2016)

Core Thinking of New Cracking Definitions

- Cracking definitions are defined with mathematical clarity for automatic computer processing
- Objective quantification of cracking is more desired in automatic processing
- Locating cracks is more feasible than identifying the causes of cracks
- Clear and quantitative criteria are needed for cracking classification and measurement
- Cracking definitions eliminate or reduce the impact of non-critical influencing factors
- Cracking definitions support different levels of pavement management activities

Three Levels of Cracking Definitions

- Level 3 cracking data: primarily used for vendor technology verification and qualification
- Level 2 data: used for network level pavement management
- Level 1 data: used for project level pavement engineering
- Data analysis for cracking definitions begins with Level 3, followed by Level 2, and then Level 1

Level 3: Cracking Percent for Extent

- Level 3: Percent of cracking (baseline performance);

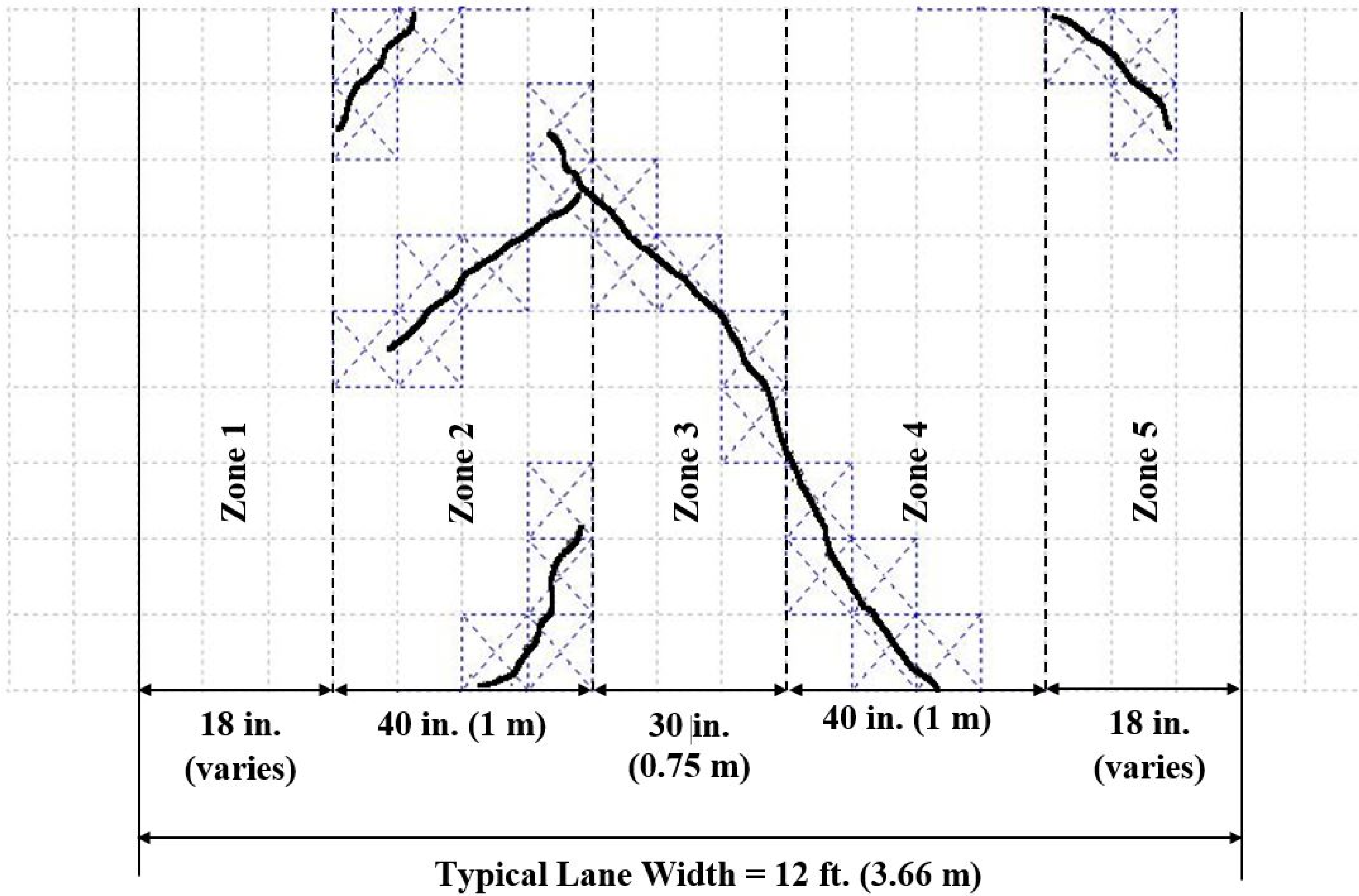
$$Level\ 3\ Index = \frac{n_c}{N} \times 100\%$$

Where:

n_c: Number of 10 in. × 10 in. (250 mm × 250 mm) grids containing cracks of 528 ft. (161 m) roadway section

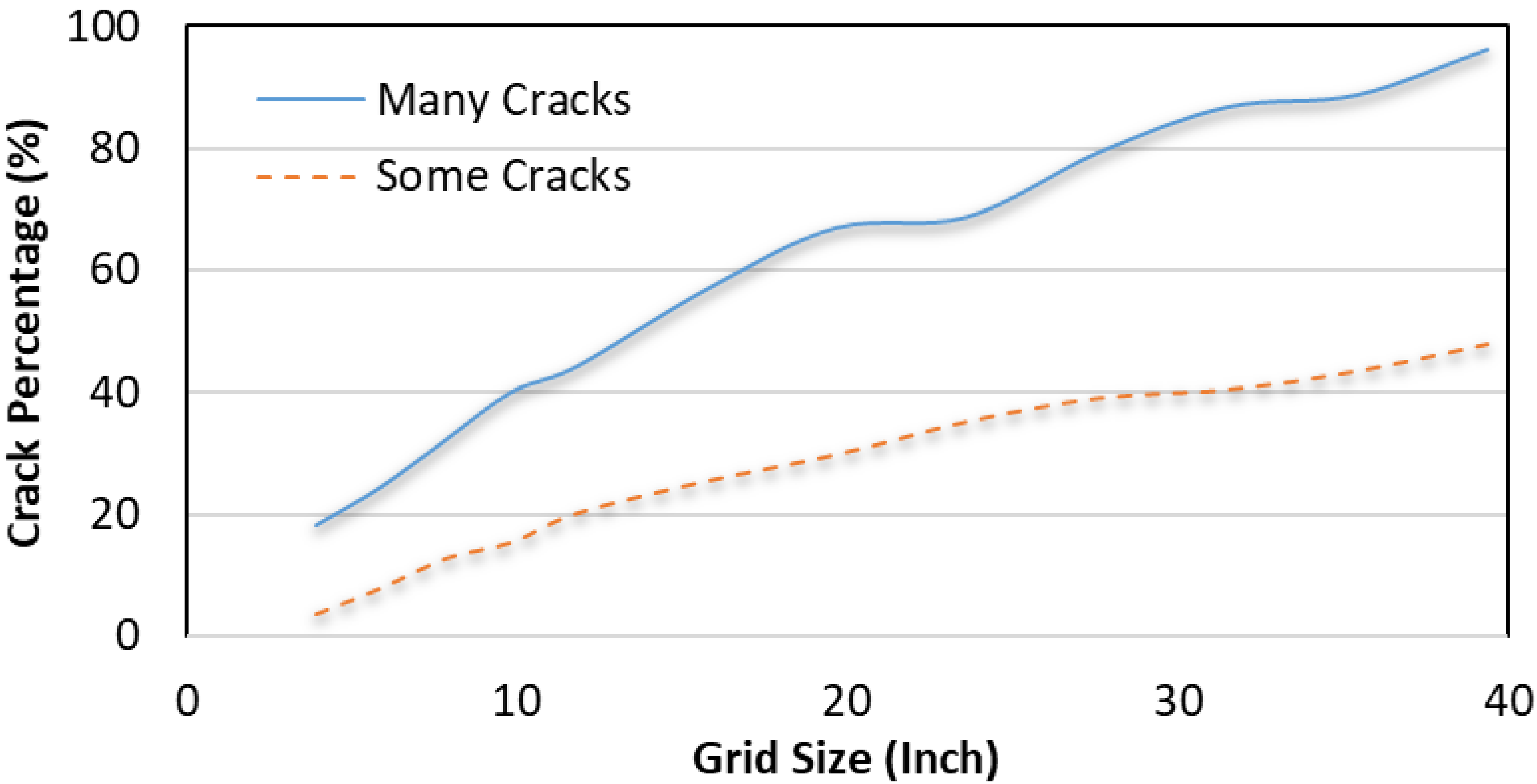
N: Total number of 10 in. × 10 in. (250 mm × 250 mm) grids of 528 ft. (161 m) roadway section

Percent of Cracking Illustration



Level 3 with 10 in. 10 in.
(250 mm x 250 mm) Grids with Wheel Paths

Level 3: Cracking Percent for Extent



Sensitivity of Cracking Percent at Level 3 to Grid Size

Level 2: Cracking Width for Severity

- Level 2: Cracking percent within each of the three severity levels for the 528 ft. (161 m) lane section
  - Low severity: average crack width ≤ 1/4 in. (6 mm)
  - Medium severity: average crack width > 1/4 in. (6 mm) and ≤ 1/2 in. (12 mm)
  - High severity: average crack width > 1/2 in. (12 mm)
- Level 2: also calculates the percent cracking, by severity level, for each of the five zones on asphalt pavement

Level 1: Cracking Positions and Orientations for Project Level Analysis (Asphalt Pavement)

- Crack types: wheel path crack, longitudinal crack, transverse crack, sealed crack, and other cracks
- Quantification procedure
  - Longitudinal and transverse crack: linear length
  - Wheel path crack: linear length and percent of wheel path crack
  - Sealed crack: linear length (without consideration of severity levels)
- Severity levels: low, medium, and high

Level 1: Cracking Positions and Orientations for Project Level Analysis (Asphalt Pavement)

- Applications
  - HPMS and MAP-21 reporting: percent wheel path cracking
  - MEPDG calibration: length of transverse cracking can be associated with MEPDG transverse cracking (ft/mi), and the percent of wheel path cracking can be associated with MEPDG alligator cracking (% lane area)
  - PMS: the severity, extent, and cracking percentage for all the defined cracks will be used for PMS including cracking performance prediction and treatment timing

Level 1: Cracking Positions and Orientations for Project Level Analysis (JPCP/JRCP)

- Crack types: longitudinal crack, transverse crack, corner break, and other cracks
- Quantification procedure
  - Longitudinal, transverse, and other crack: linear length
  - Record the number of corner break
  - Record the number of slabs with transverse cracks
- Severity levels: low, medium, and high

Level 1: Cracking Positions and Orientations for Project Level Analysis (JPCP/JRCP)

- Applications
  - HPMS and MAP-21 reporting: percent of transverse cracked slabs
  - MEPDG calibration: percent of transverse cracked slabs
  - PMS: the severity, extent, cracking percentage, and percent of slabs for all the defined cracks will be used for PMS

Level 1: Cracking Positions and Orientations for Project Level Analysis (CRCP)

- Crack types: longitudinal crack, transverse crack, punchouts, and other cracks
- Quantification procedure
  - Longitudinal, transverse, and other crack: linear length
  - Record the number of punchouts
- Severity levels: low, medium, and high

Level 1: Cracking Positions and Orientations for Project Level Analysis (CRCP)

- Applications
  - HPMS and MAP-21 reporting: percent area of longitudinal cracking and punchouts
  - MEPDG calibration: number of punchouts
  - PMS: the severity, extent, and cracking percentage for all the defined cracks will be used for PMS

AASHTO R85 and Proposed Definitions

- Similarities
  - Crack, crack orientation, crack width, and crack length
  - Wheel path definition
  - The minimum crack length is 12 in. (0.3 m)
  - The angles between crack and lane centerline
    - +20 and -20 degrees for longitudinal crack
    - 70 and 110 degrees for transverse crack

AASHTO R85 and Proposed Definitions

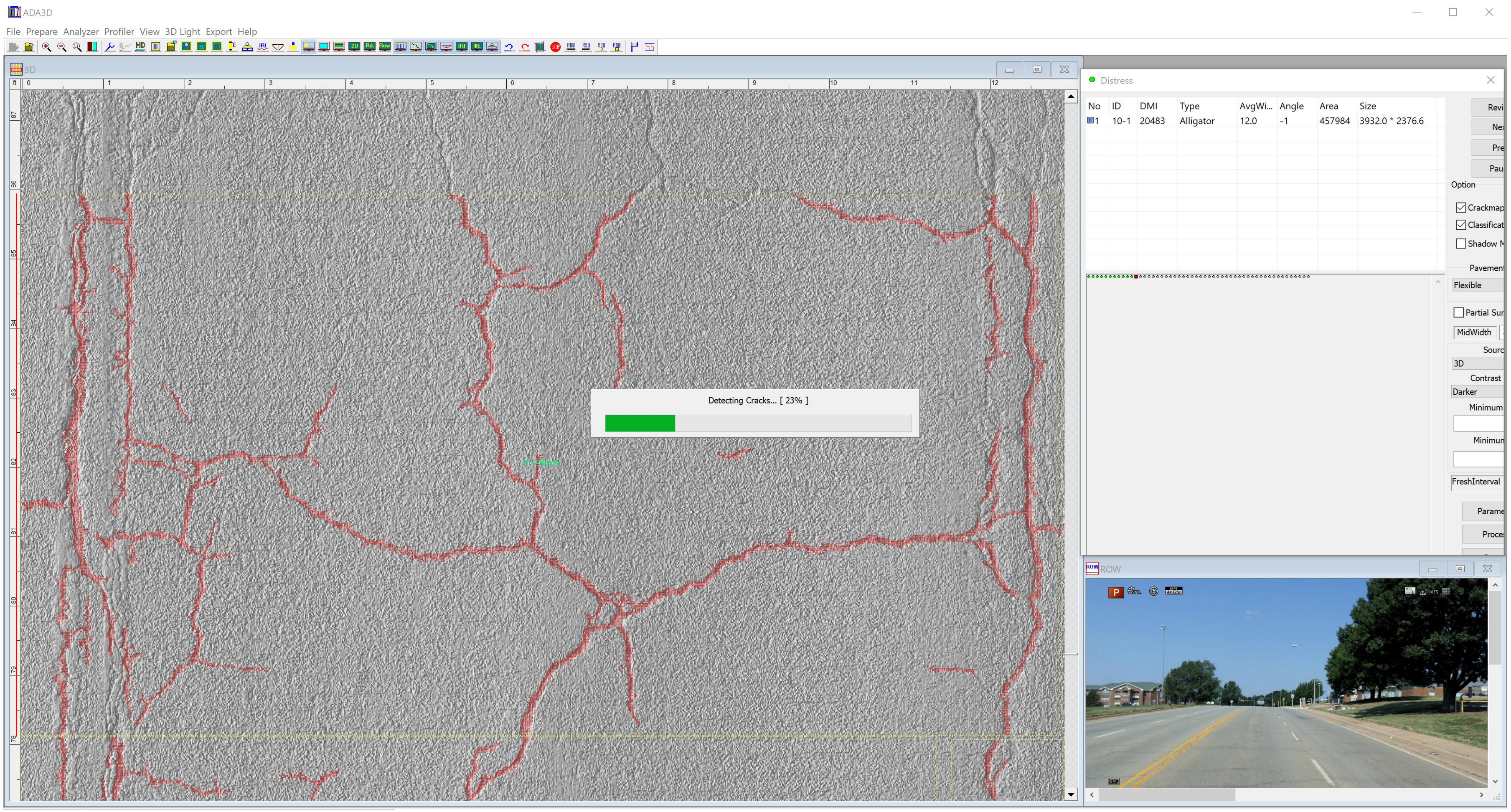
- Deviations
  - Three levels of cracking data are proposed
  - Image area outside of and under lane markings is excluded from the cracking definitions
  - Propose wheel path crack and sealed crack
  - Consider crack severity levels
  - Propose cracking definitions for JPCP/JRCP and CRCP pavements

Summary of Field Data Collection

- 12 selected sites: 0.2 miles long for each site
- 5 runs on each site for repeatability: 60 data collections in total

Site ID	Pavement Type	Beginning GPS Coordinate		Visual Inspection
		Longitude	Latitude	
1	Asphalt	-97.08737	36.1183	With many wide cracks.
2		-97.08447	36.126	With many wide cracks.
3		-97.11255	36.1158	With some cracks.
4		-97.10567	36.1161	With some cracks.
5		-97.13946	36.1159	With few small cracks.
6		-97.13002	36.1161	With few small cracks.
7	JPCP	-97.42505	35.6147	With some cracks.
8		-97.42509	35.6102	With some cracks.
9		-97.42496	35.6336	With some cracks.
10		-97.42502	35.6207	With some cracks.
11		-97.34529	36.0846	With few small cracks.
12		-97.3453	36.0718	With few small cracks.

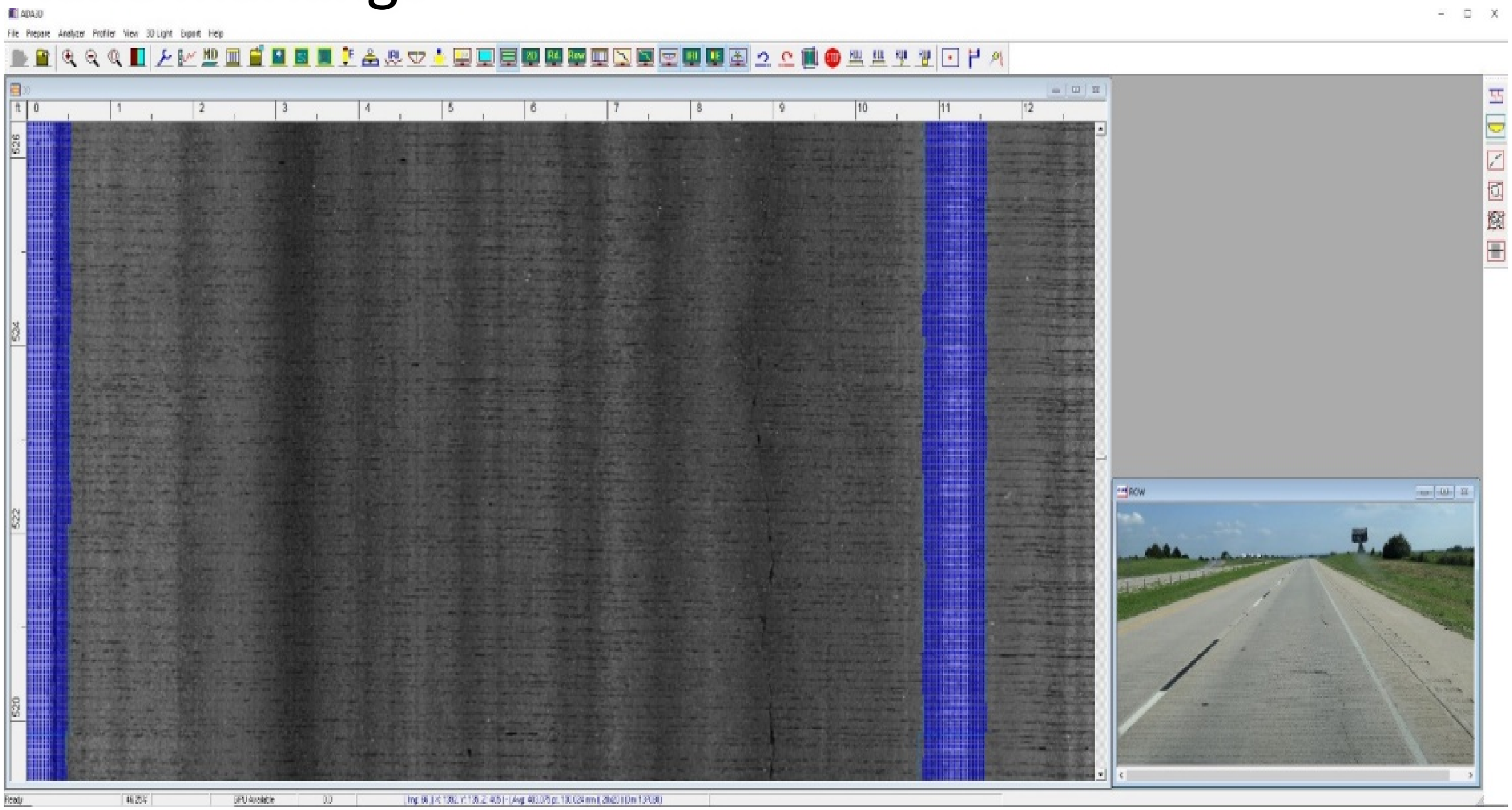
CrackNet thru Deep-Learning



Interface of ADA3D (courtesy of WayLink Systems Corporation)

Lane Marking Detection

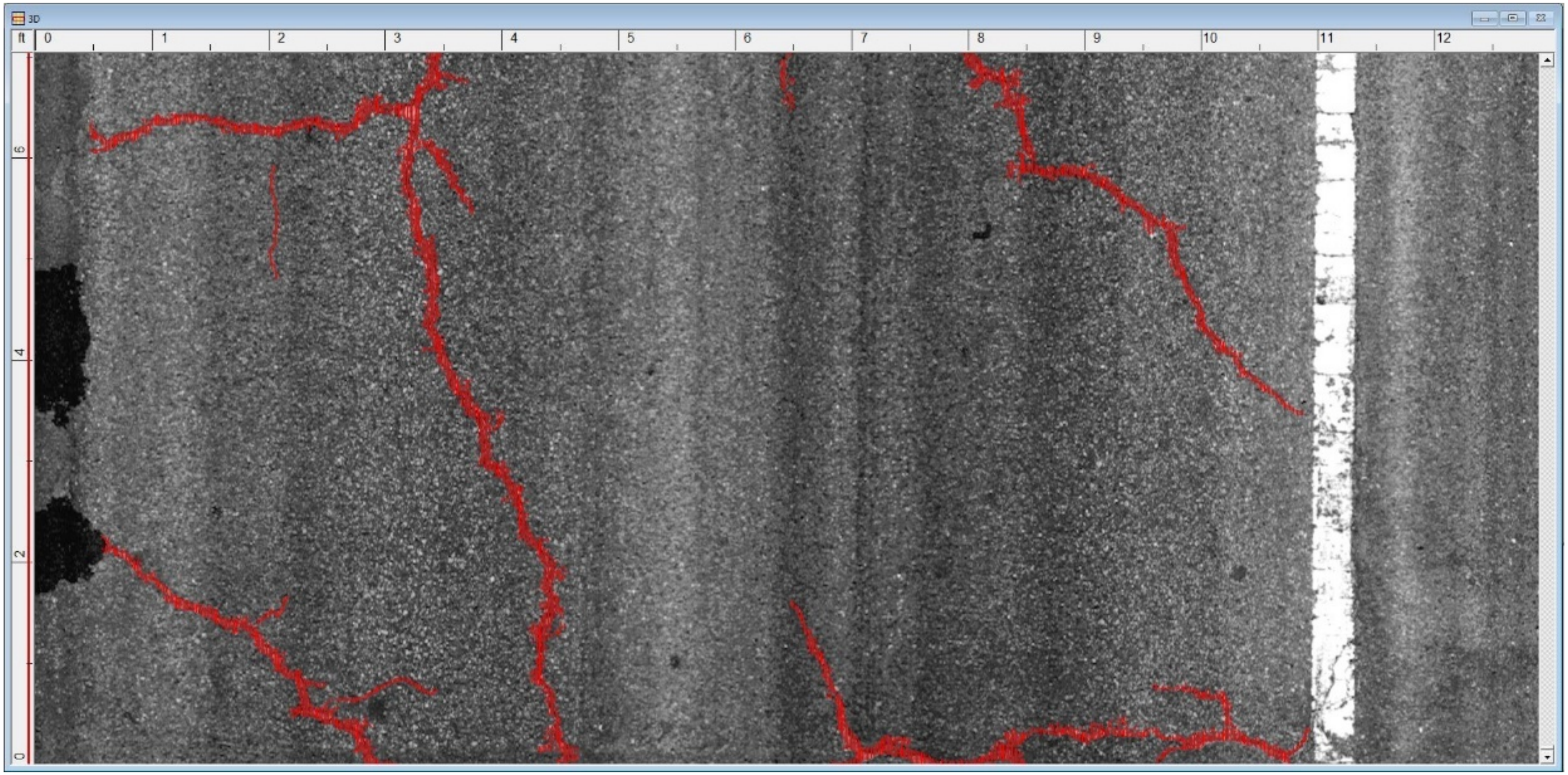
- Cracking analysis: image area within the identified lane markings



ADA3D for Lane Marking Detection (courtesy of WayLink Systems Corporation)

Wheel Paths and Grid Generation

- Summarize cracking data per the proposed definitions



Original Image

Wheel Paths and Grid Generation

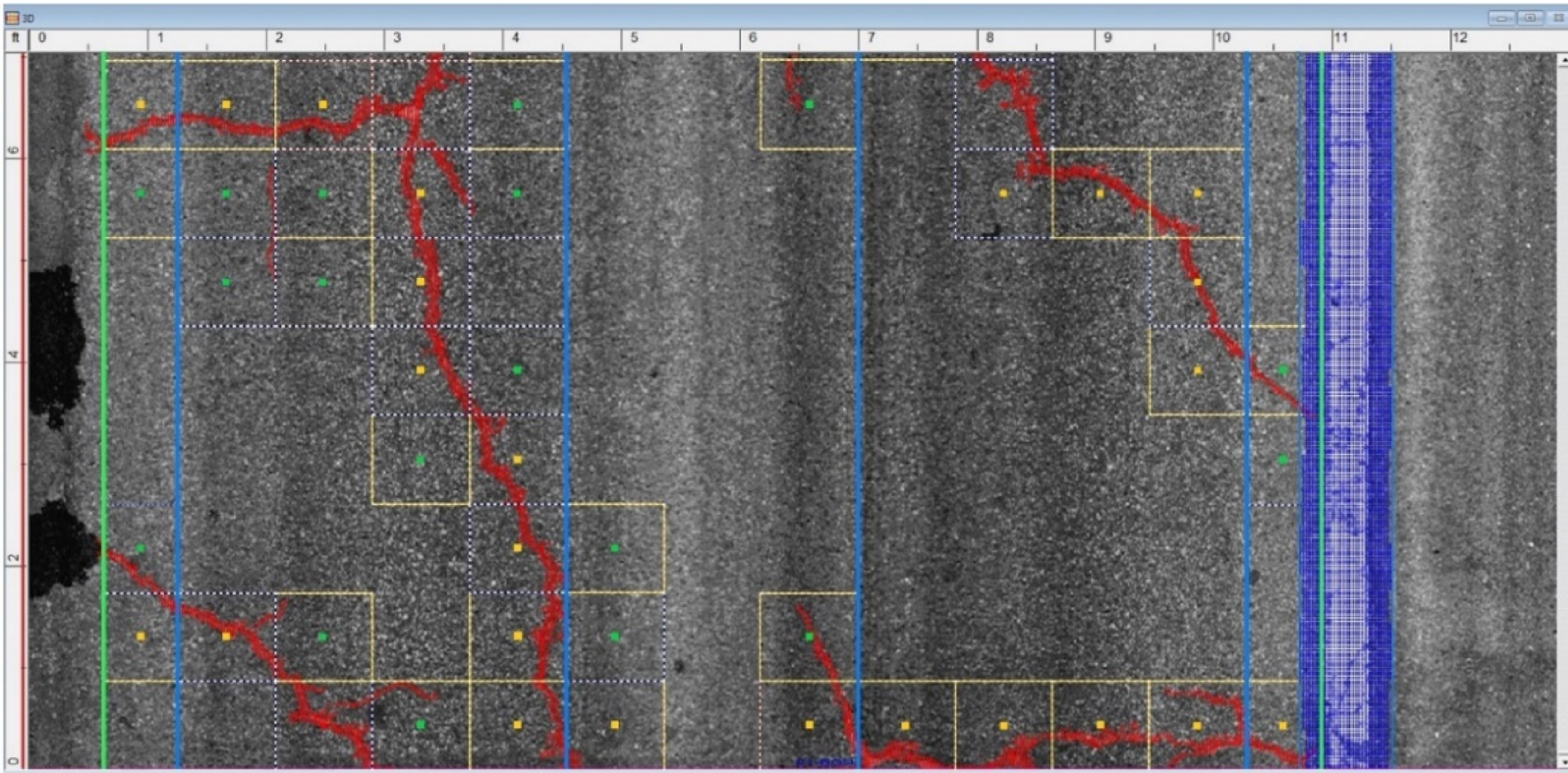
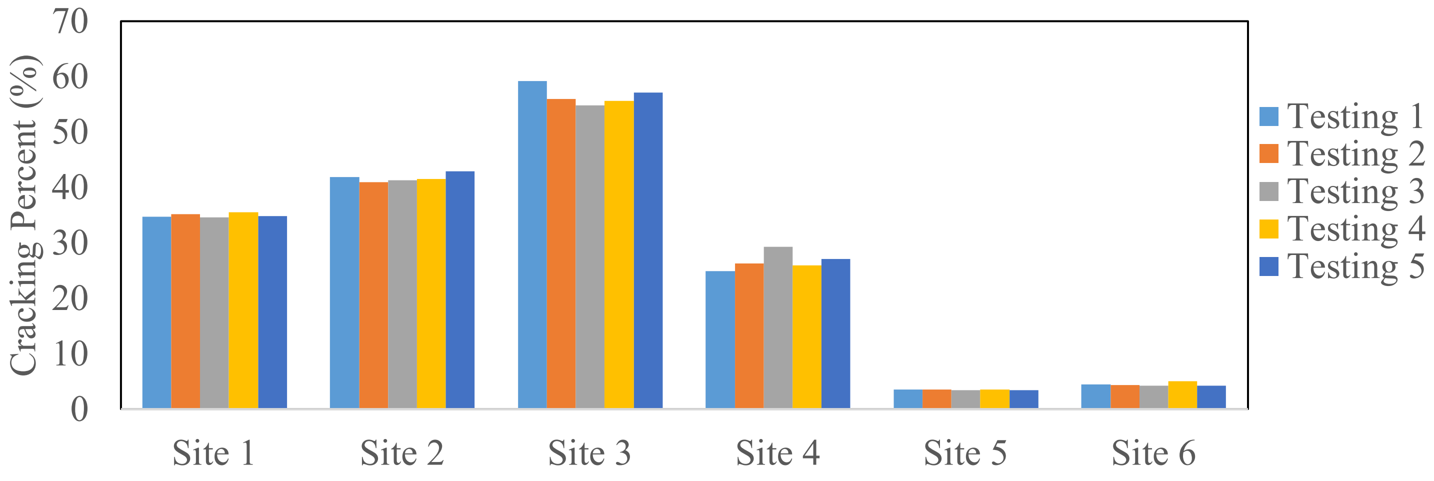
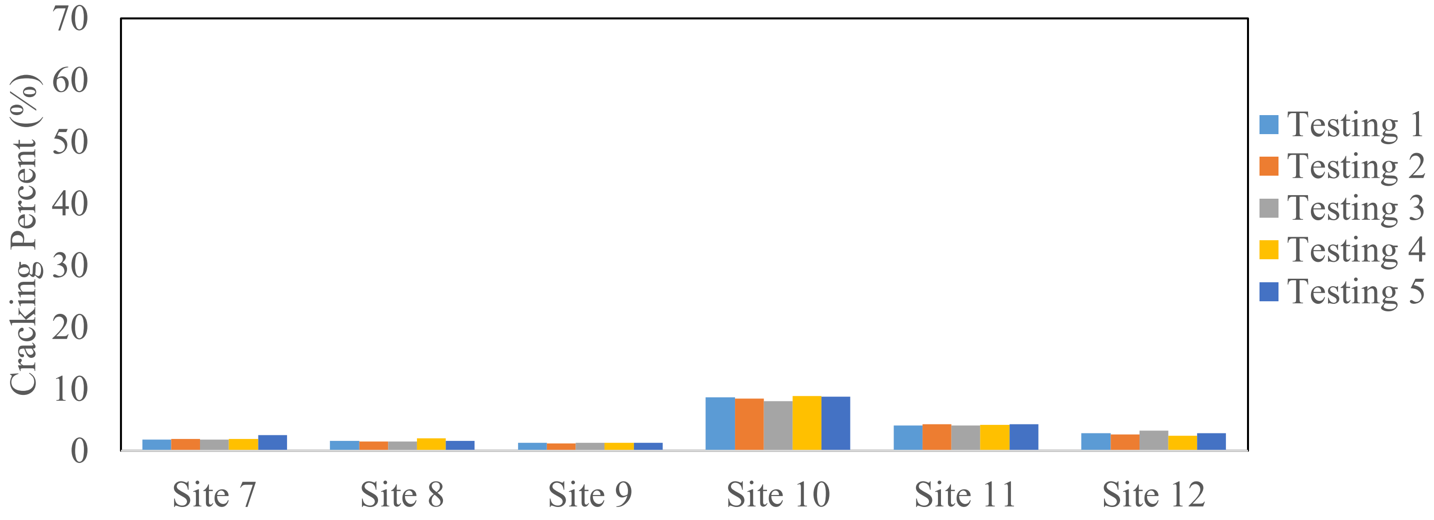


Image with Wheel Paths and Grids

Summary of Level 3 Cracking Data

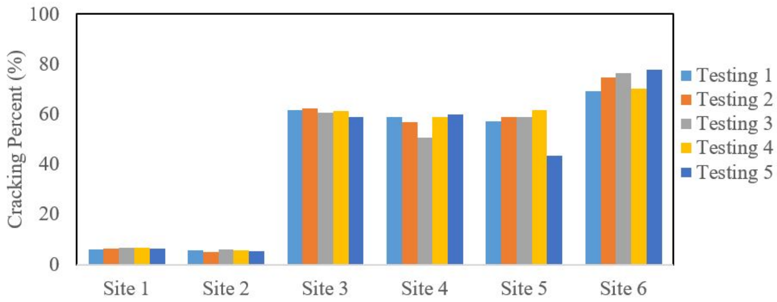


Asphalt Sites

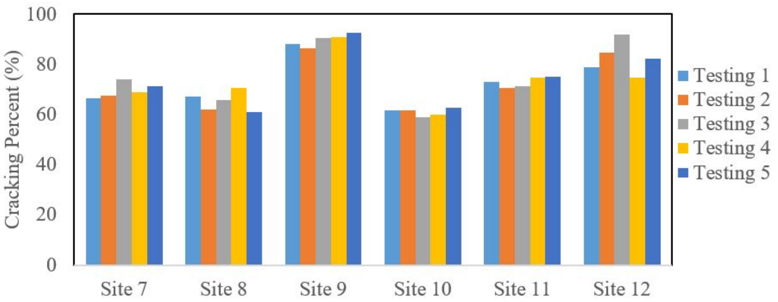


JPCP Sites

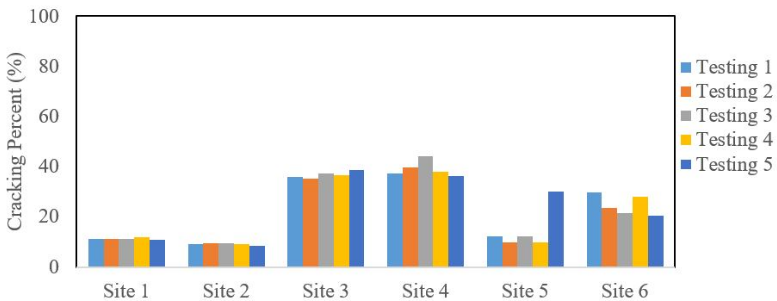
Summary of Level 2 Cracking Data



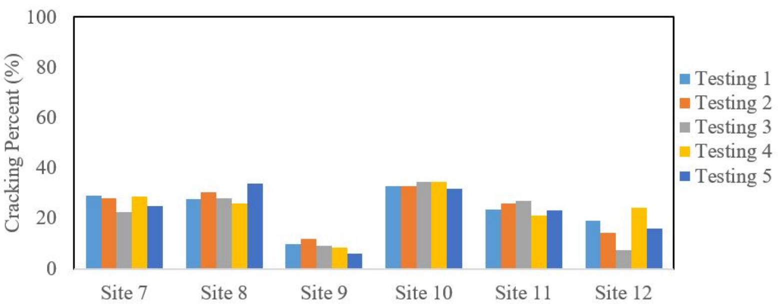
(a) Low severity cracking percent.



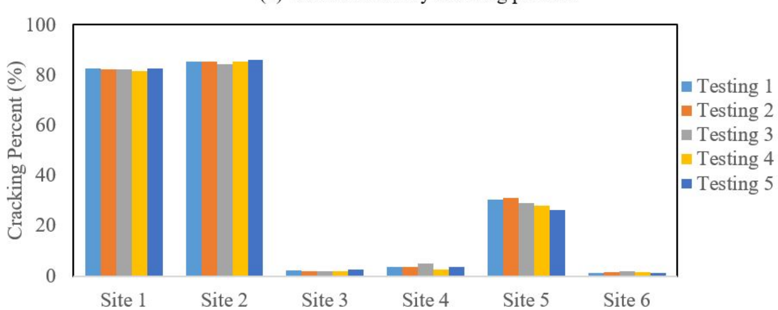
(a) Low severity cracking percent.



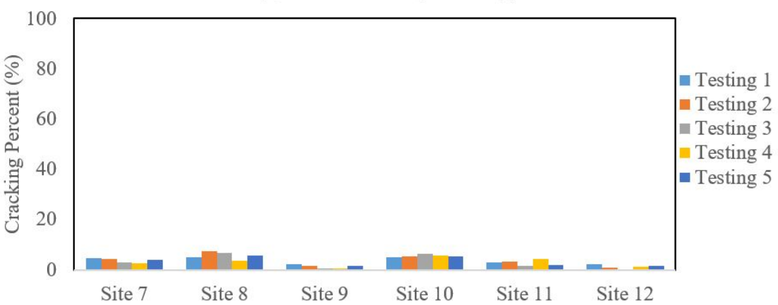
(b) Medium severity cracking percent.



(b) Medium severity cracking percent.



(c) High severity cracking percent.

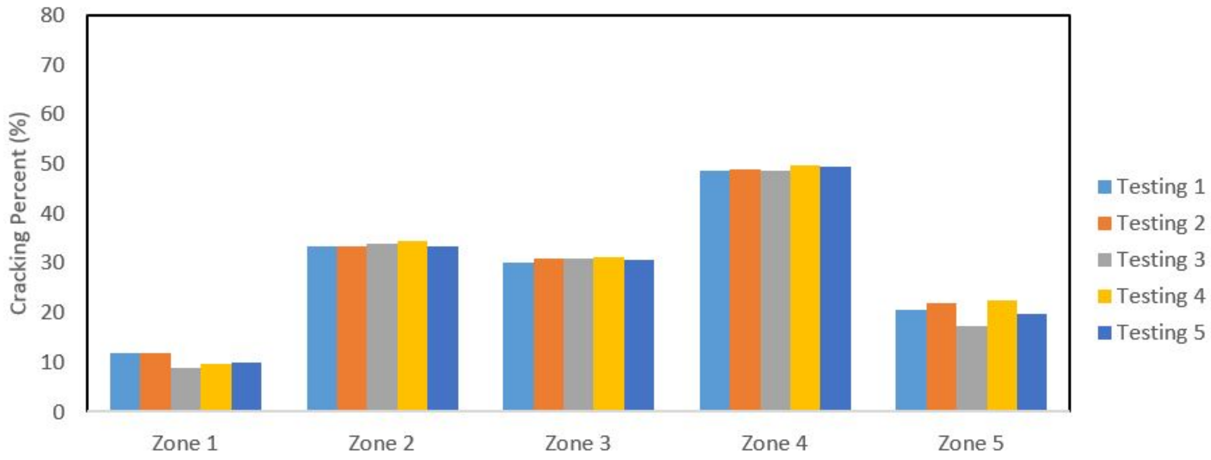


(c) High severity cracking percent.

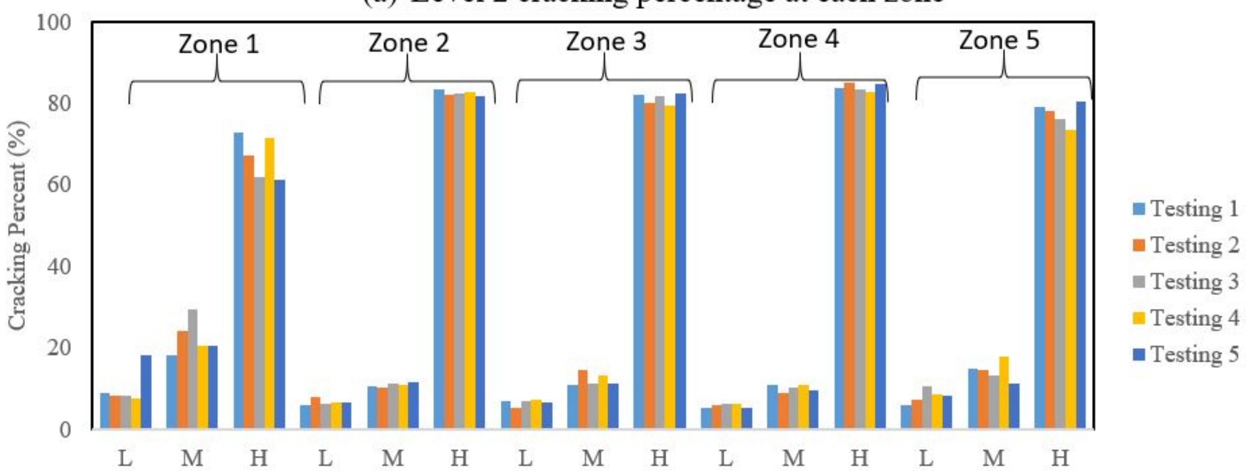
Asphalt Sites

JPCP Sites

Cracking Information of Each Zone (Level 2)



(a) Level 2 cracking percentage at each zone



(b) Level 2 cracking percent for each severity level at each zone

Summary of Level 2 Cracking Data at Site 1

Summary of Level 1 Cracking Data

Site ID	Statistical Result	Longitudinal Crack (ft)	Transverse Crack (ft)	Wheel Path Crack (ft)	Wheel Path Crack Percentage (%)
1	Mean	417.8	503.0	3767.1	15.2
	SD	19.3	10.0	86.3	0.2
	CV	4.6	2.0	2.3	1.5
2	Mean	1393.4	650.8	3114.1	14.6
	SD	21.0	21.8	25.3	0.1
	CV	1.5	3.4	0.8	0.9
3	Mean	734.2	1084.2	5982.5	17.2
	SD	45.9	35.5	122.3	0.5
	CV	6.2	3.3	2.0	2.9
4	Mean	523.5	377.0	2614.8	7.4
	SD	111.3	11.6	124.7	0.5
	CV	21.3	3.1	4.8	6.4
5	Mean	104.2	155.8	306.8	0.5
	SD	81.7	2.8	14.4	0.1
	CV	78.4	1.8	4.7	10.1
6	Mean	313.2	146.7	378.8	0.8
	SD	79.0	8.9	10.6	0.1
	CV	25.2	6.1	2.8	7.2

Asphalt Sites

Level 1 Cracking Data with Severity Levels

Site ID	Statistical Results	Longitudinal Crack (ft)			Transverse Crack (ft)			Wheel Path Crack (ft)		
		Low	Medium	High	Low	Medium	High	Low	Medium	High
1	Mean	26.8	47.1	343.9	32.3	56.7	414.0	241.8	425.0	3100.6
	SD	1.4	2.6	16.4	1.2	2.0	9.5	12.8	21.6	60.9
	CV	5.3	5.5	4.8	3.6	3.5	2.3	5.3	5.1	2.0
2	Mean	77.7	127.3	1188.5	36.3	59.4	555.1	173.7	284.4	2656.2
	SD	4.1	5.4	24.1	2.0	2.9	20.6	9.8	11.8	39.3
	CV	5.2	4.3	2.0	5.5	4.9	3.7	5.6	4.1	1.5
3	Mean	448.4	269.6	16.1	661.8	398.4	24.0	3651.7	2198.4	132.1
	SD	35.4	13.6	0.8	29.0	15.3	2.8	136.0	62.3	12.8
	CV	7.9	5.1	5.2	4.4	3.8	11.6	3.7	2.8	9.7
4	Mean	300.1	204.4	18.9	215.4	147.5	14.0	1493.6	1023.3	97.6
	SD	72.8	41.9	2.7	17.1	11.5	3.3	125.4	91.7	23.4
	CV	24.3	20.5	14.3	7.9	7.8	23.2	8.4	9.0	24.0
5	Mean	60.8	13.4	30.1	87.4	23.2	45.3	171.9	45.9	89.1
	SD	50.4	8.9	23.5	11.1	13.4	3.6	22.9	26.8	5.9
	CV	82.9	66.3	77.9	12.7	57.7	7.9	13.3	58.3	6.6
6	Mean	229.9	78.3	4.8	108.1	36.2	2.3	278.8	94.0	5.8
	SD	54.1	27.9	1.4	9.7	5.4	0.6	11.2	17.4	1.0
	CV	23.5	35.6	28.9	9.0	14.9	25.1	4.0	18.5	17.3

Asphalt Sites

Summary of Level 1 Cracking Data

Site ID	Statistical Results	Longitudinal Crack (ft)	Transverse Crack (ft)	Slabs with Crack (%)	Slabs with Transverse Crack (%)	Longitudinal Crack (ft)			Transverse Crack (ft)		
						Low	Medium	High	Low	Medium	High
7	Mean	149.9	45.8	29.9	7.9	104.4	40.0	5.7	32.0	12.1	1.7
	SD	11.6	7.4	2.9	0.8	8.6	4.9	1.6	6.2	1.3	0.4
	CV	7.8	16.1	9.5	9.9	8.2	12.3	27.6	19.3	10.7	25.8
8	Mean	133.5	4.3	21.2	2.7	87.4	38.8	7.6	2.8	1.2	0.3
	SD	6.4	0.3	1.3	0.0	8.8	3.1	1.9	0.2	0.1	0.1
	CV	4.8	6.3	6.0	1.6	10.0	7.9	25.2	13.8	14.5	46.6
9	Mean	27.4	83.6	15.5	11.0	24.7	2.4	0.4	75.1	7.6	1.1
	SD	4.6	1.7	1.5	0.7	4.8	0.4	0.2	2.0	1.9	0.6
	CV	16.8	2.0	9.4	6.6	19.3	14.7	50.5	9.5	26.8	47.8
10	Mean	391.6	389.3	63.8	51.6	238.9	130.7	22.0	237.4	129.9	21.9
	SD	21.2	5.1	1.6	1.8	15.2	8.0	1.5	7.0	4.3	1.9
	CV	5.4	1.3	2.5	3.6	6.3	6.1	6.9	9.5	9.6	11.7
11	Mean	396.9	1.6	47.1	1.5	289.4	96.1	11.3	1.1	0.4	0.0
	SD	5.5	0.4	1.0	0.0	9.4	9.6	4.2	0.3	0.1	0.0
	CV	1.4	23.8	2.2	3.0	3.2	9.9	36.9	23.7	22.4	NA
12	Mean	256.9	8.9	32.2	1.7	212.3	41.4	3.2	7.3	1.4	0.1
	SD	8.6	0.8	1.2	0.6	21.4	14.7	1.7	0.8	0.5	0.1
	CV	3.3	8.8	3.8	37.3	10.1	35.6	53.7	12.8	36.0	64.4

JPCP Sites

Conclusions of NCHRP 01-57A

- Accomplished five tasks for the project
  - Summary of existing cracking data collection practices through literature review and online survey
  - Summary of the role of cracking data in different levels of decision-making processes
  - Summary of desired cracking data by the SHAs
  - Recommendation of the most appropriate standard cracking definition for automated systems based on the results from previous work
  - Testing of the proposed levels of cracking definitions based on repeating field data collection on both asphalt and concrete pavements

Conclusions of NCHRP 01-57A

- Level 3 addresses cracking extent at the network level
  - Satisfies HPMS and MAP-21 reporting needs
  - Provides overall cracking information which can be used as the initial qualification and evaluation of potential technology suppliers
- Level 2 contains cracking information with low, medium, and high severity levels for pavements
  - Assist various network level PMS activities and identify locations with specific distress problems

Conclusions of NCHRP 01-57A

- Level 1: longitudinal and transverse cracking in non-wheel paths, wheel path crack from the wheel paths, and sealed cracks for asphalt pavement
- Level 1 proposes definition for concrete pavement
- Cracking analysis starts with Level 3, then to Level 2, and finally for the most detailed process to Level 1
- The team conducted initial field testing of the proposed cracking definitions on 12 pavement sites
  - The limited field testing shows that the results are highly repeatable

Recommendations for Future Work

- Solicit participation of a minimum of three SHAs to conduct field trials
- Design experiments for conducting data collection, define what “Ground-Truth” cracking is, and develop a process to obtain the “Ground-Truth” results
- Design and conduct data analysis based on the three levels of cracking definitions and the collected data, including fully automated results and “Ground-Truth” results

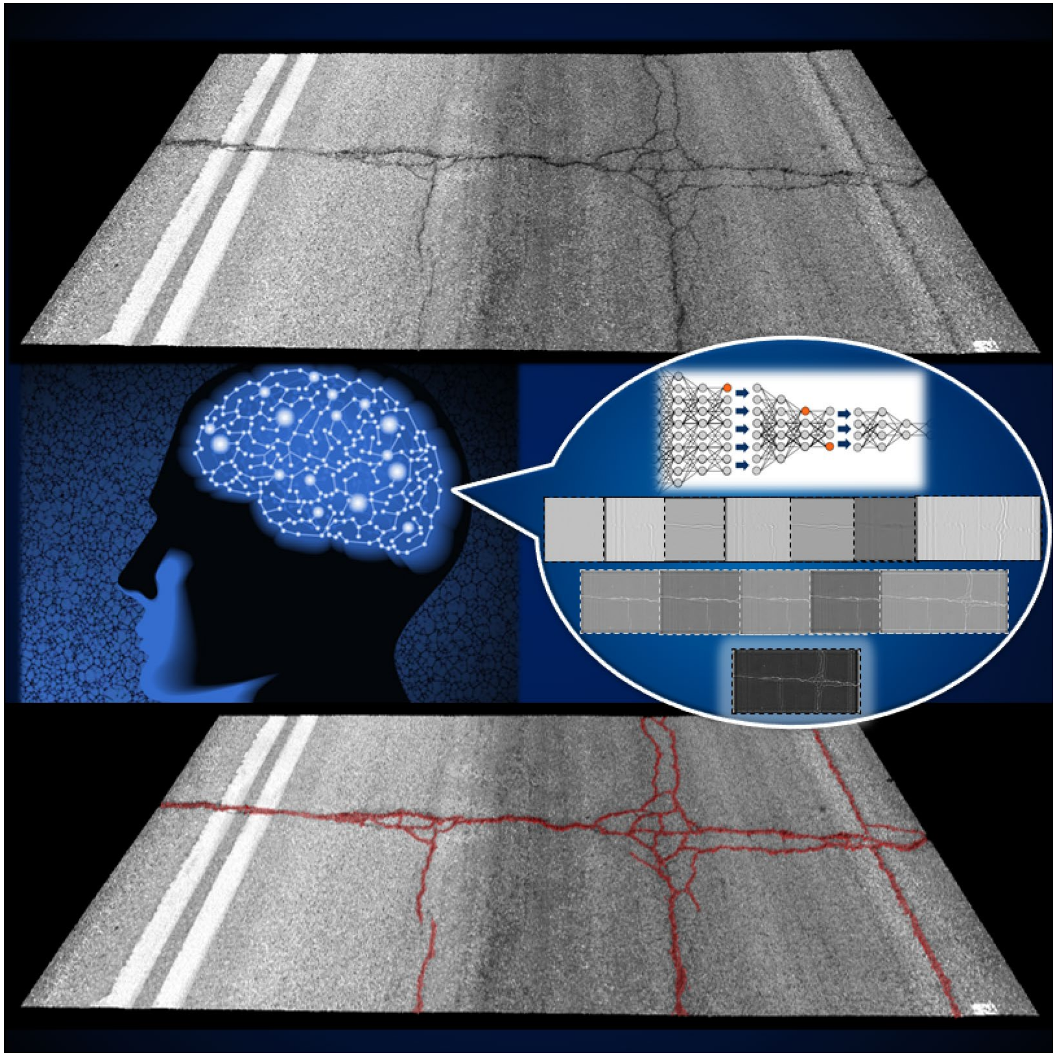
Recommendations for Future Work

- Identify gaps and shortcomings in the complete workflow in terms of meeting the needs of PMS, pavement design, and reporting, and propose modifications and fine-tuning of the cracking protocols
- Demonstrate true and fully automated cracking processing based on Deep-Learning methodology for both cracking identification and classification, and applications of the proposed cracking definitions on the fully automated results, and the "Ground-Truth" results
- Develop draft AASHTO standard for consideration by the AASHTO Committee on Materials and Pavements

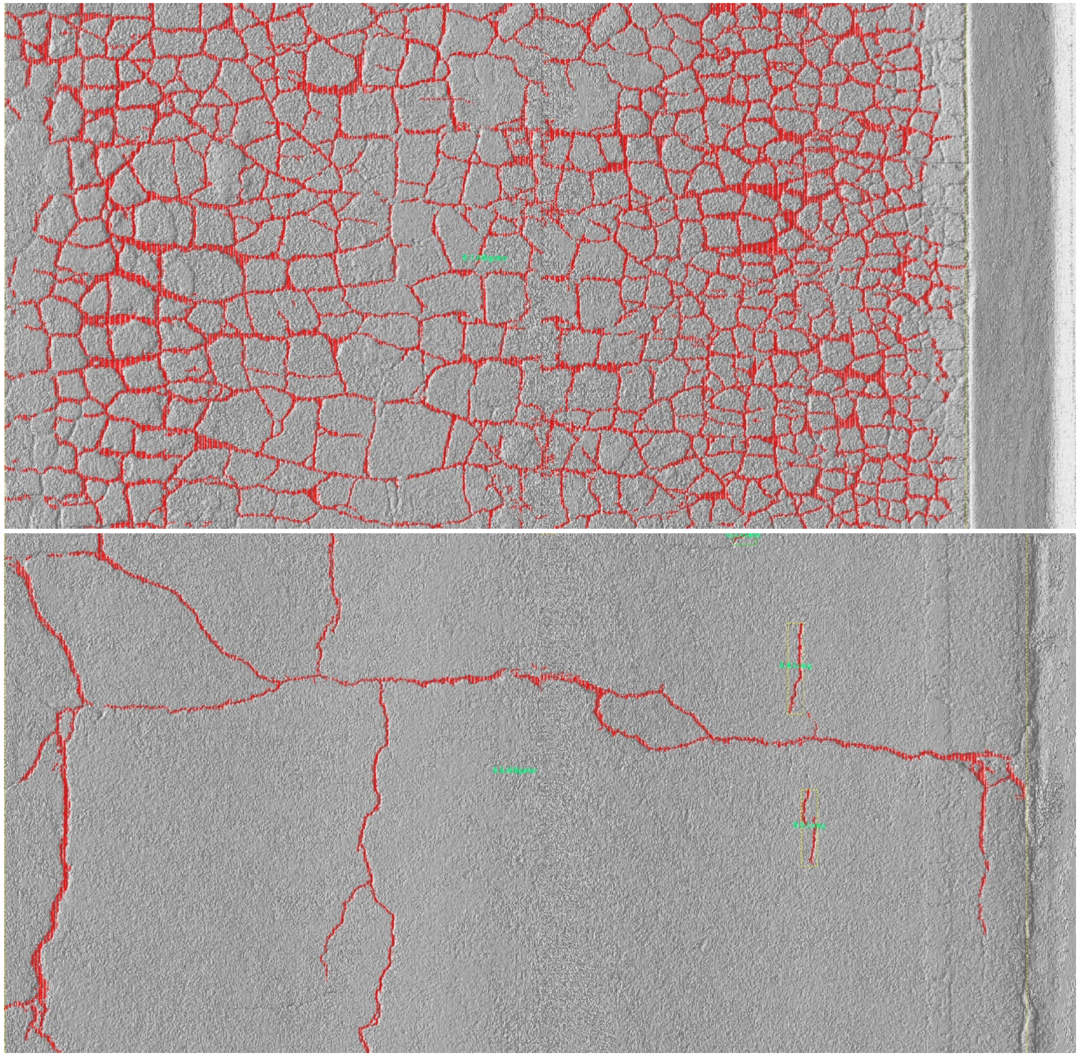
Automation of Pavement Distress Survey

- Challenging Task
  - Precision & Bias
  - Decades of Efforts: Slow Progress
- High Quality & Consistent Data
  - Not possible 12 years ago
  - 0.5mm to 1mm resolution 3D laser imaging: commonly available
- Can human cognition be modeled into automated system?

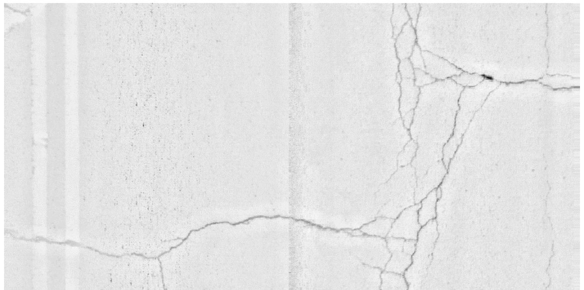
Deep-Learning for Cognition Capability



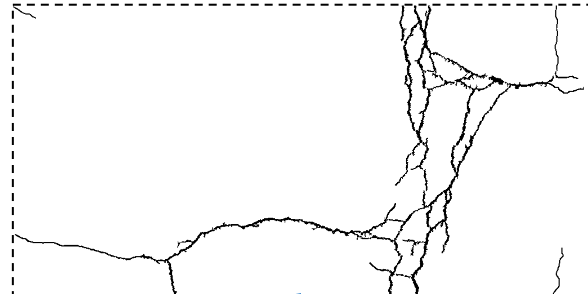
Learning Database: Critical for Learning



CrackNet: from Training to Operation

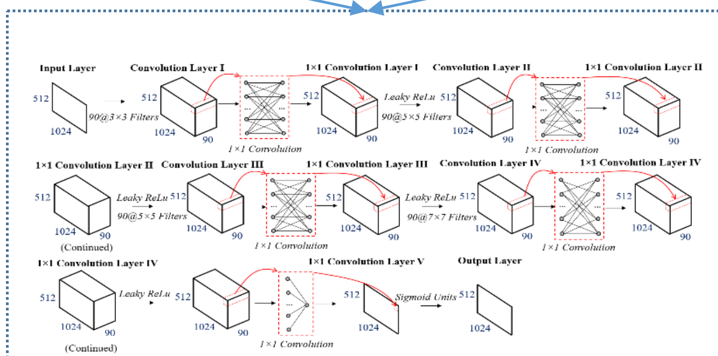


Input Image

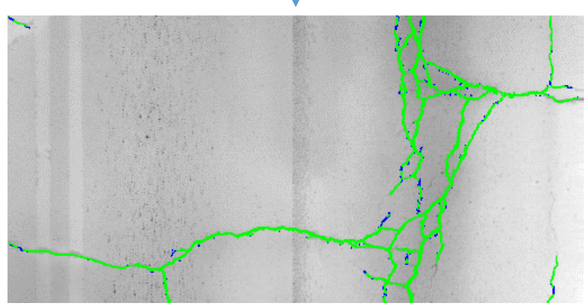


Ground Truth with Pixel-Perfect Accuracy

DL Network

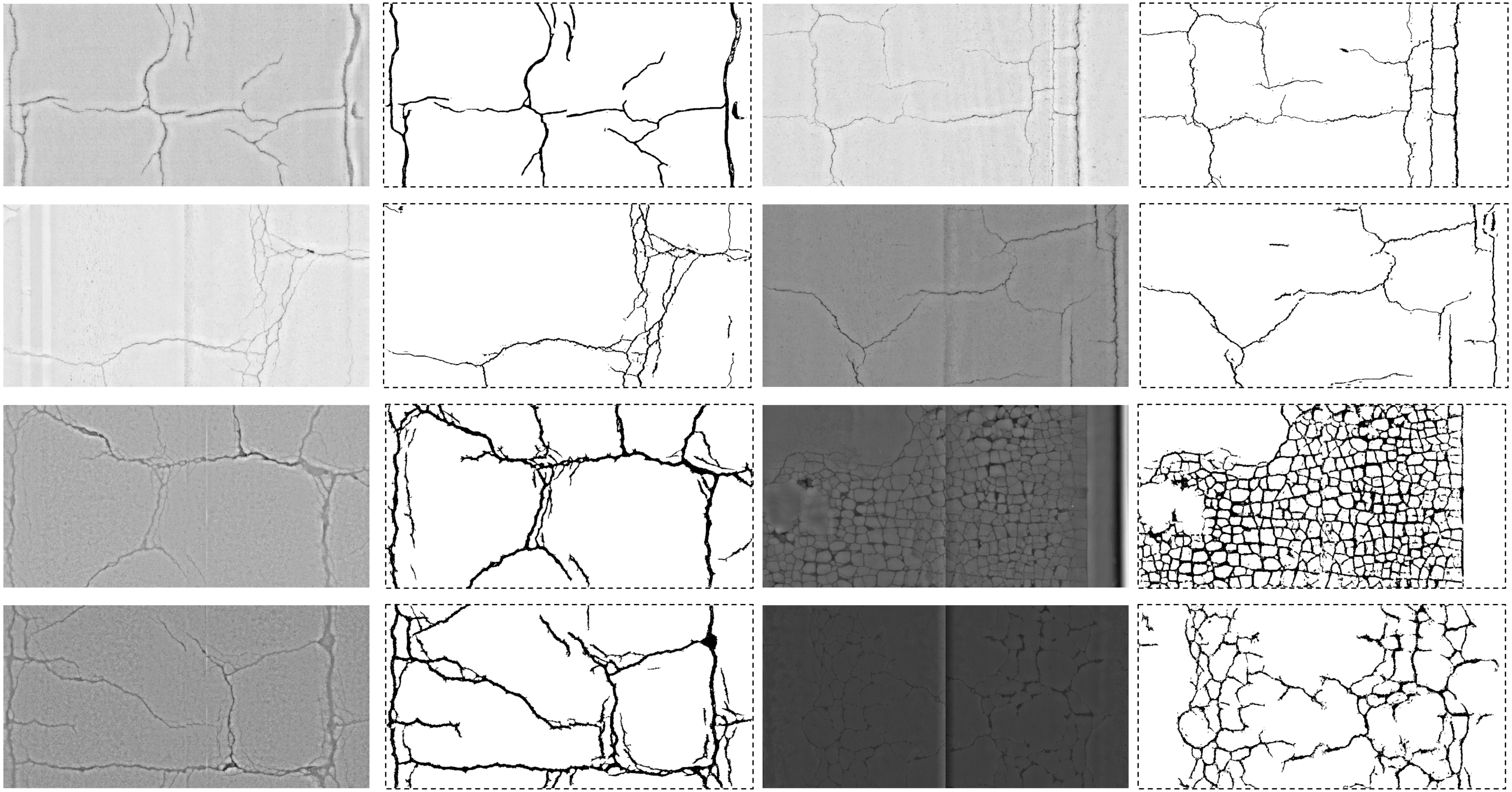


Recursive Training



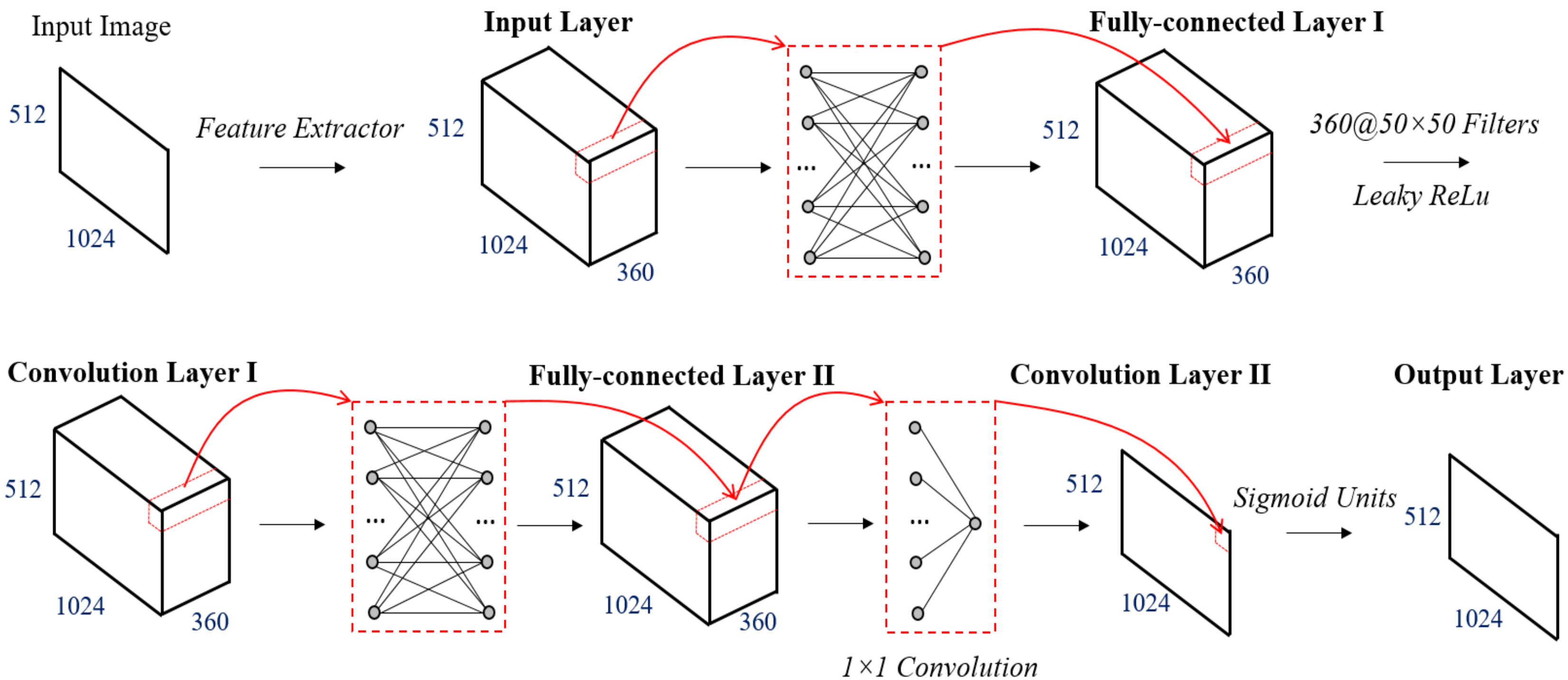
Detection Output with Pixel-Level Accuracy

Pixel Level Intelligence



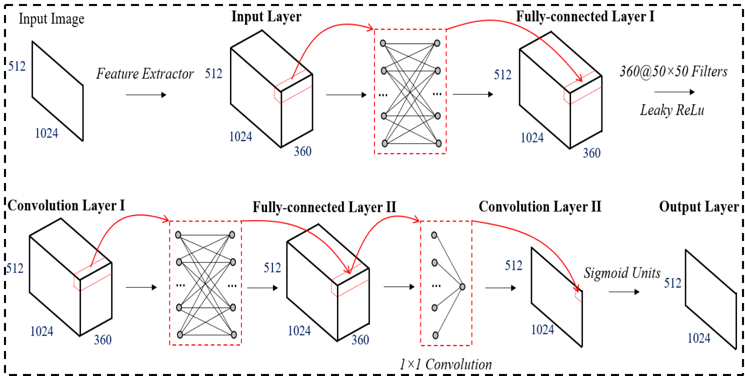
Automated Pixel-level Pavement Crack Detection on 3D Asphalt Surfaces with a Recurrent Neural Network [J], *Computer-Aided Civil and Infrastructure Engineering*, https://doi.org/10.1111/mice.12409.

First-Gen CrackNet (2016)



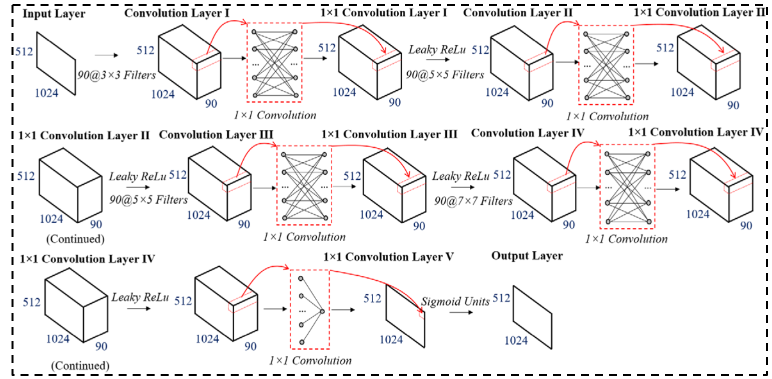
- ❑7 Layers
- ❑1,159,561 Parameters

Developments of CrackNet (2015 to 2019)



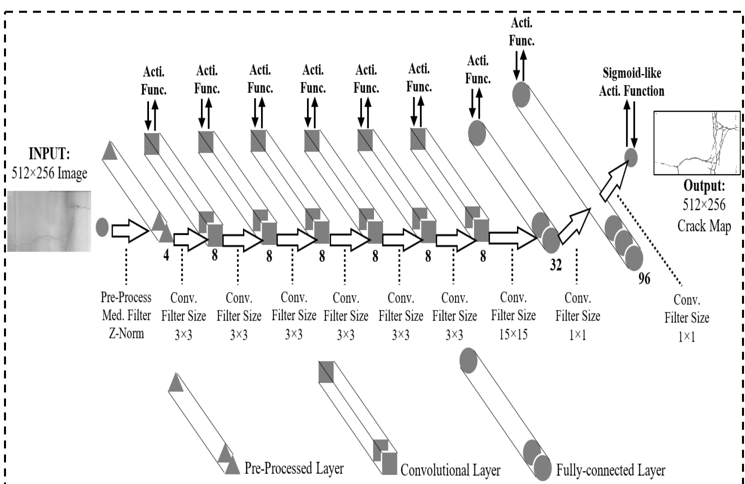
CrackNet

Automated Pixel-level Pavement Crack Detection on 3D Asphalt Surfaces Using a Deep-Learning Network, *Computer-Aided Civil and Infrastructure Engineering*, 32(10), 805-819



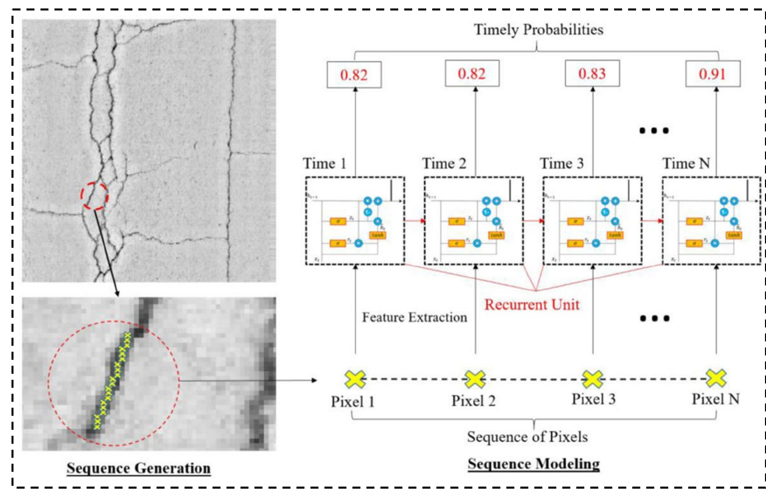
CrackNet II

Deep-Learning based Fully Automated Pavement Crack Detection on 3D Asphalt Surfaces with an Improved CrackNet, *Journal of Computing in Civil Engineering*, 32(5), 04018041.1-14.



CrackNet-V

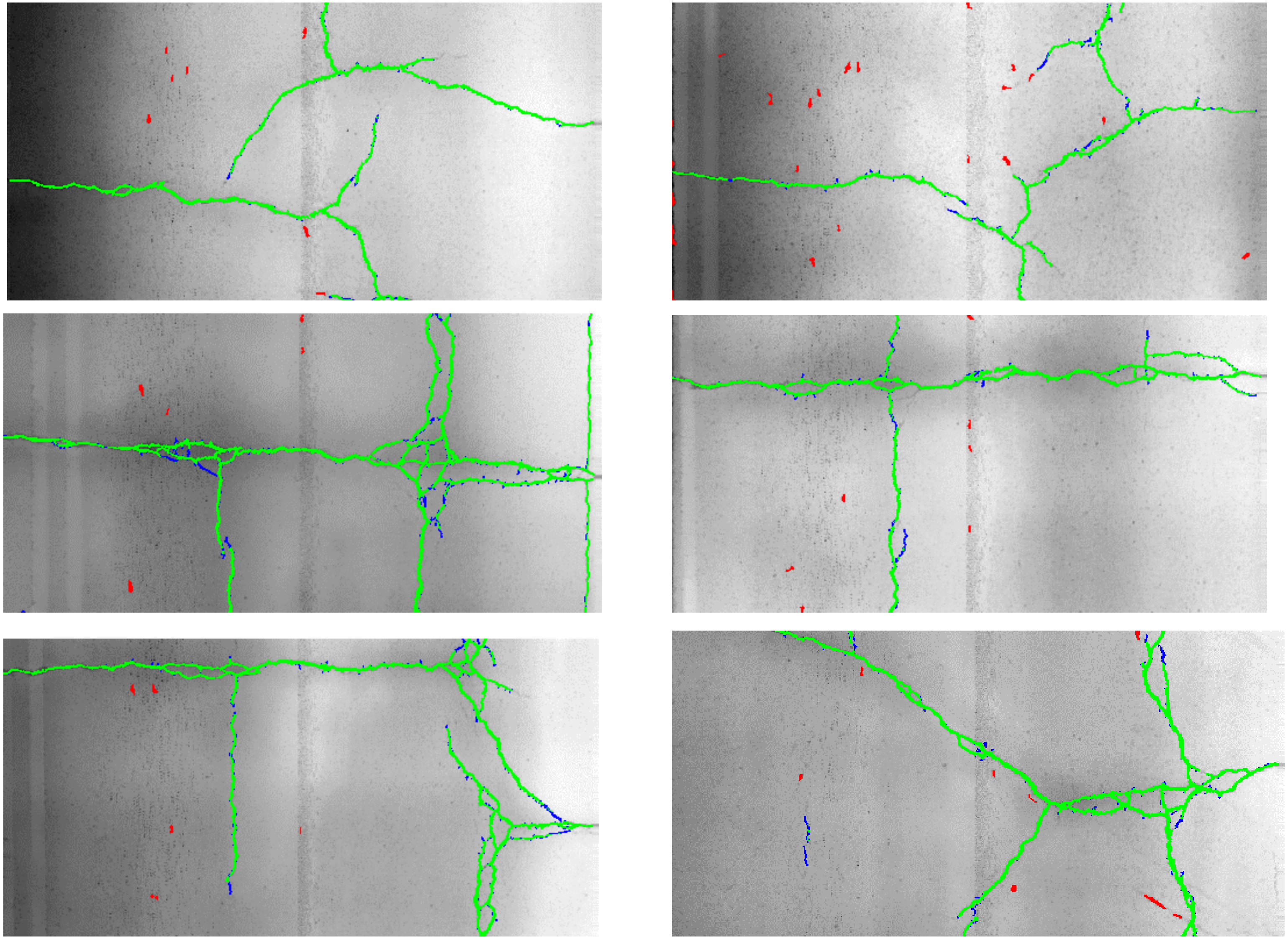
Pixel-Level Cracking Detection on 3D Asphalt Pavement Images through Deep-Learning based CrackNet-V, *IEEE Transactions on Intelligent Transportation Systems*, In Press.



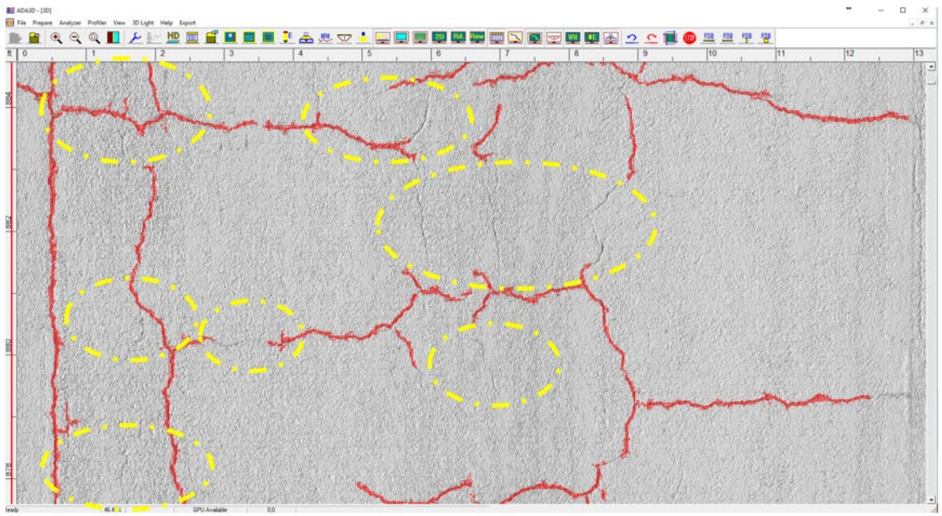
CrackNet-R

Automated Pixel-level Pavement Crack Detection on 3D Asphalt Surfaces with a Recurrent Neural Network, *Computer-Aided Civil and Infrastructure Engineering*, https://doi.org/10.1111/mice.12409.

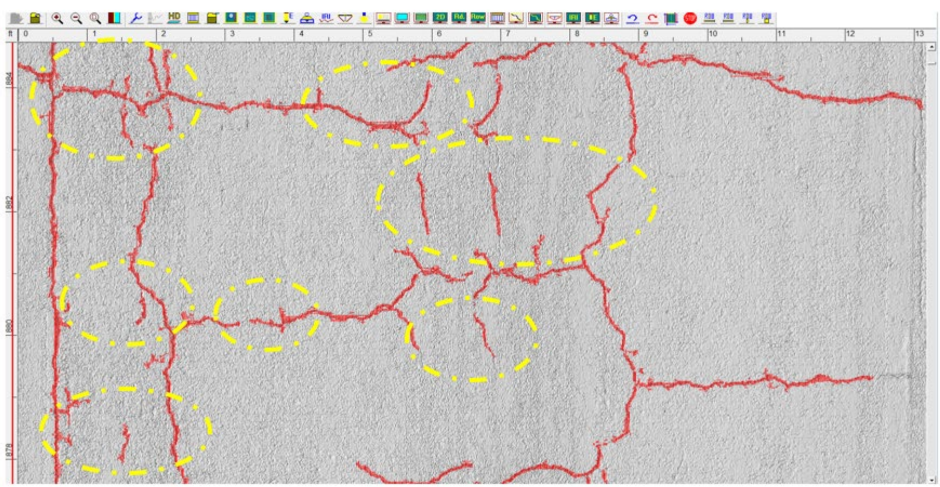
Sample Results of 1st Gen CrackNet



Samples of 2nd Gen CrackNet

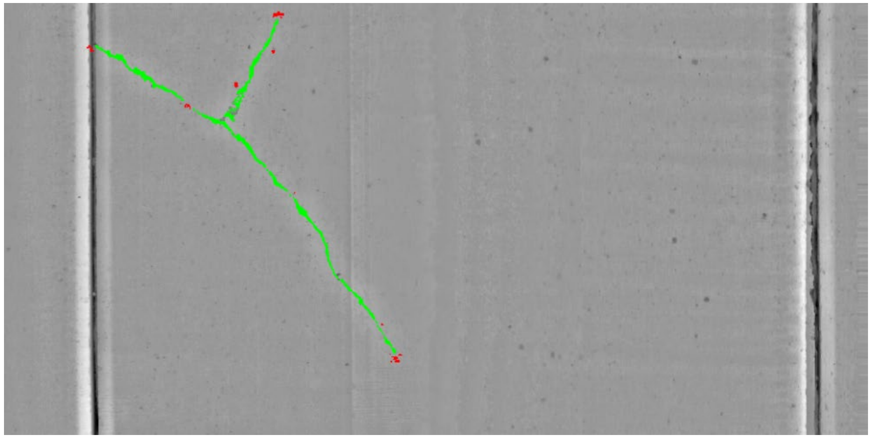


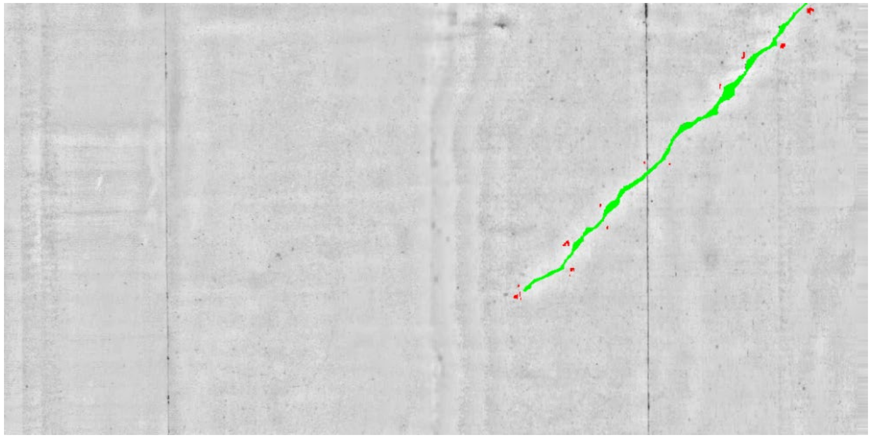
Best CrackNet



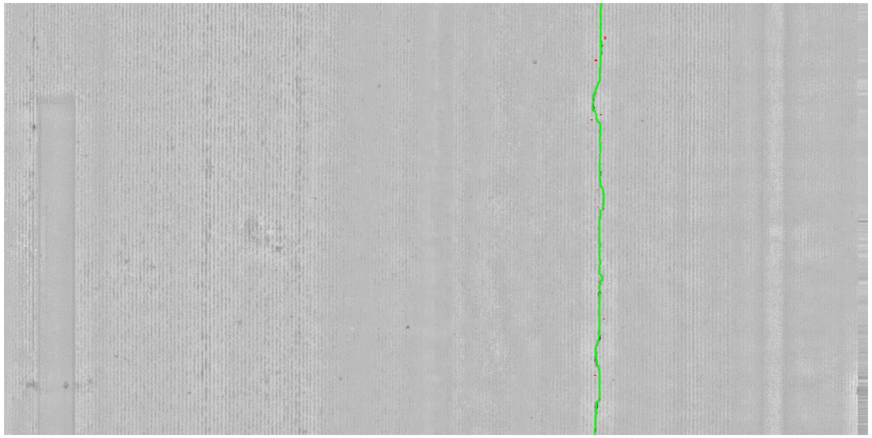
Best CrackNet + RNN

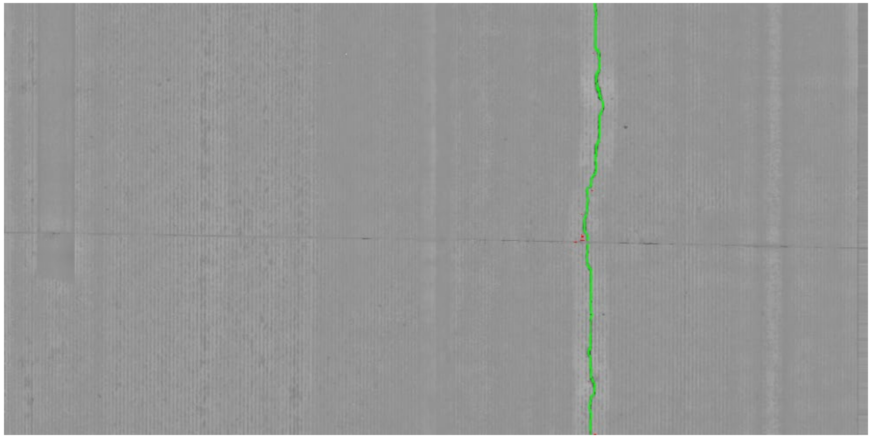
CrackNet on Concrete Pavements





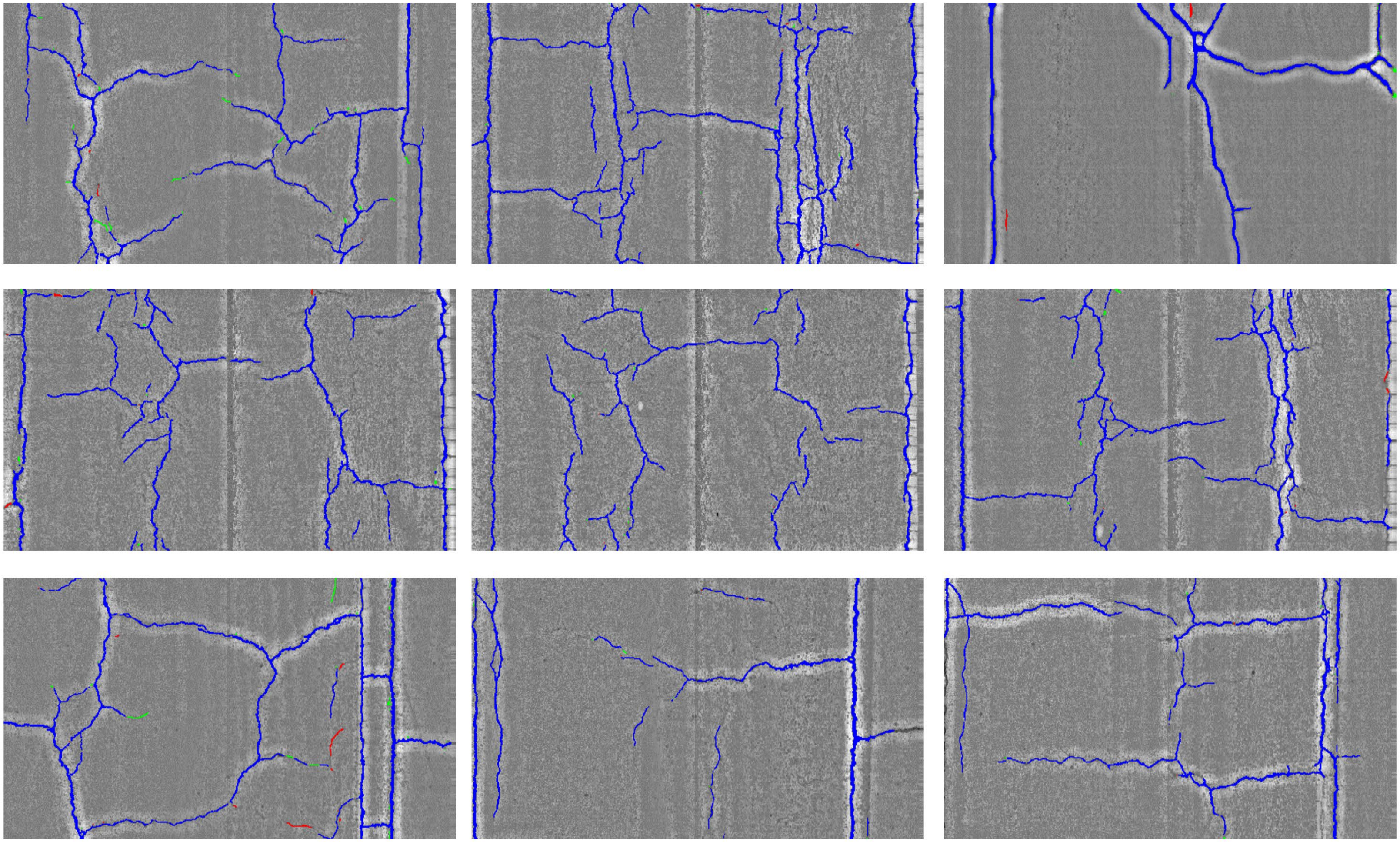
Non-Grooved Jointed Surface



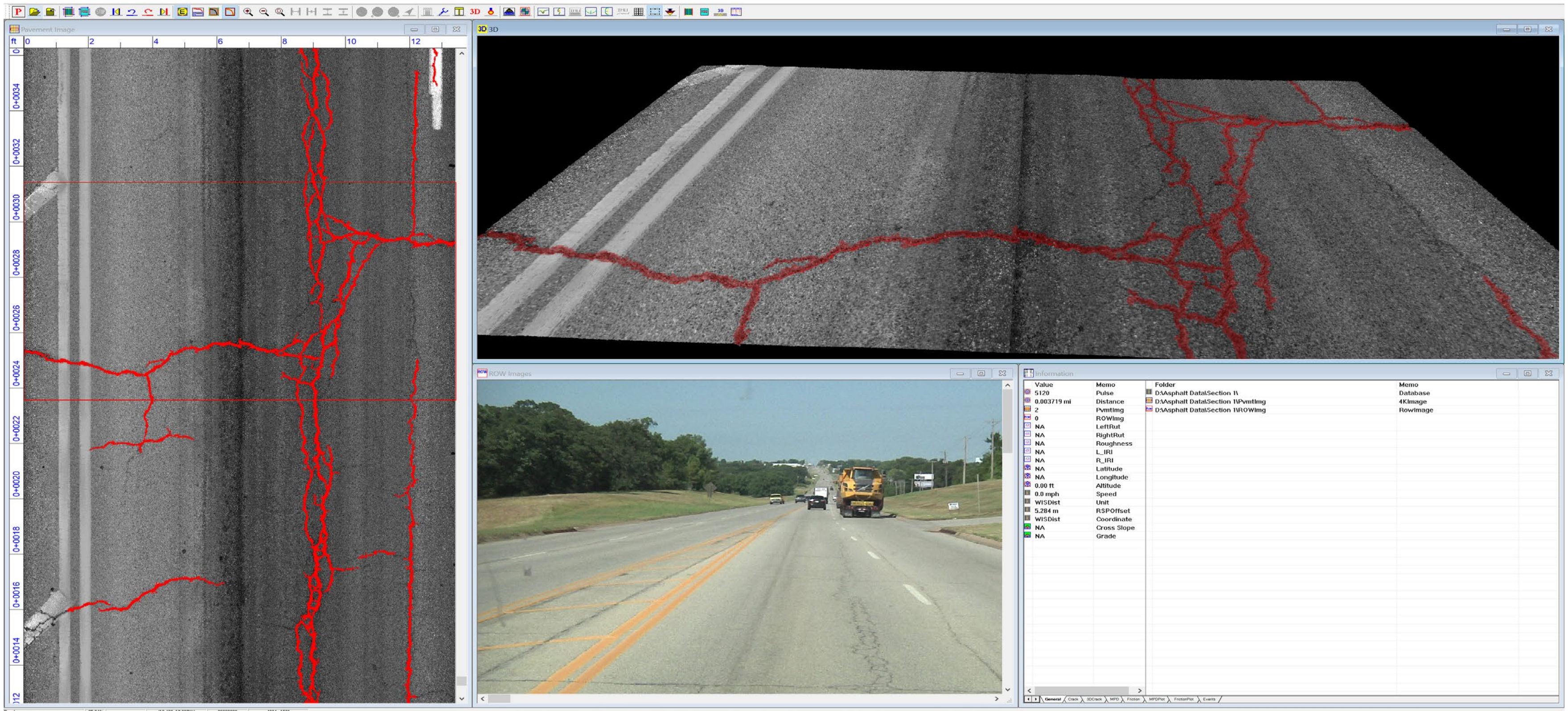


Grooved Jointed Surface

Recent Developments of CrackNet

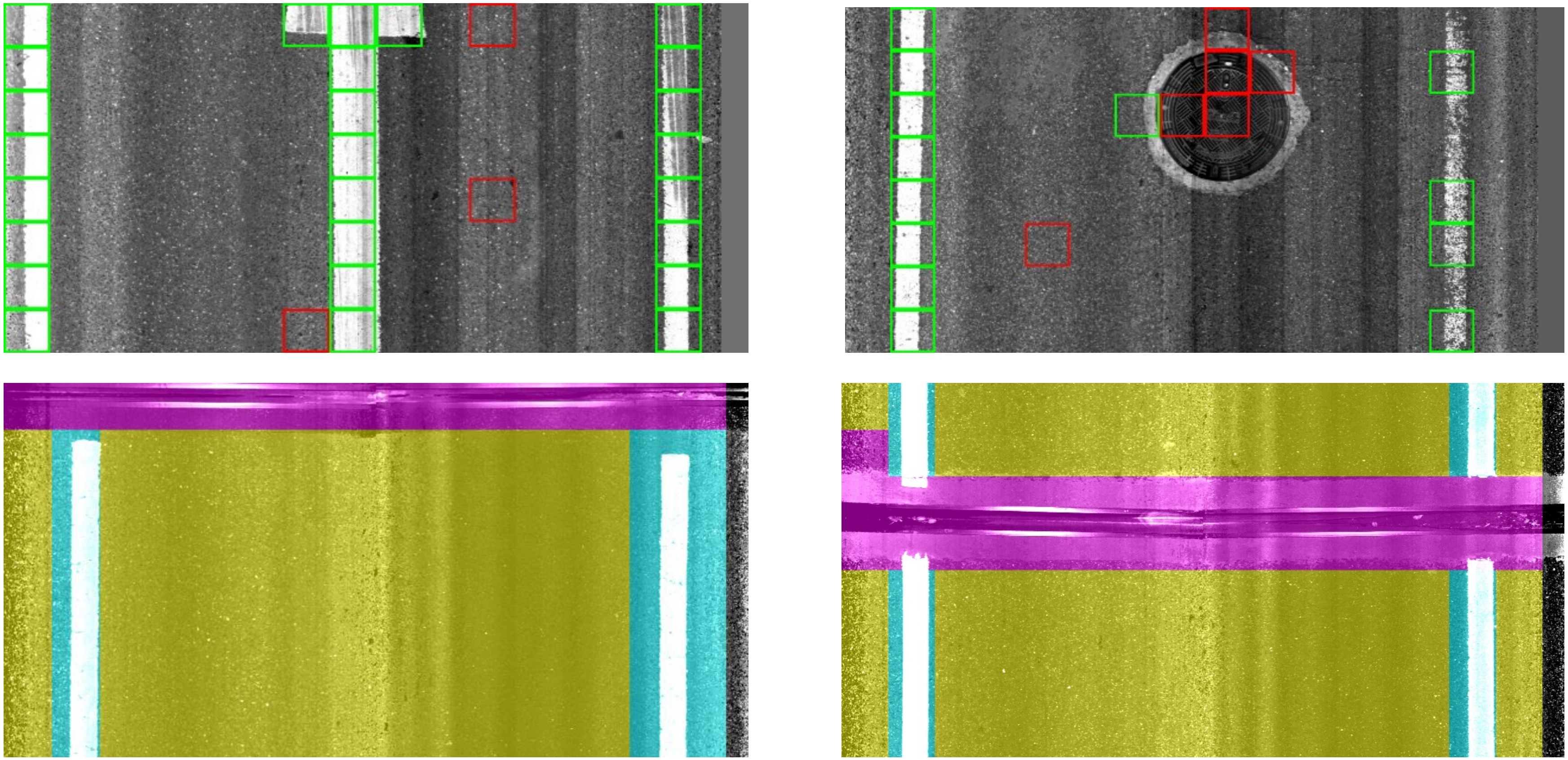


Recent Developments of CrackNet

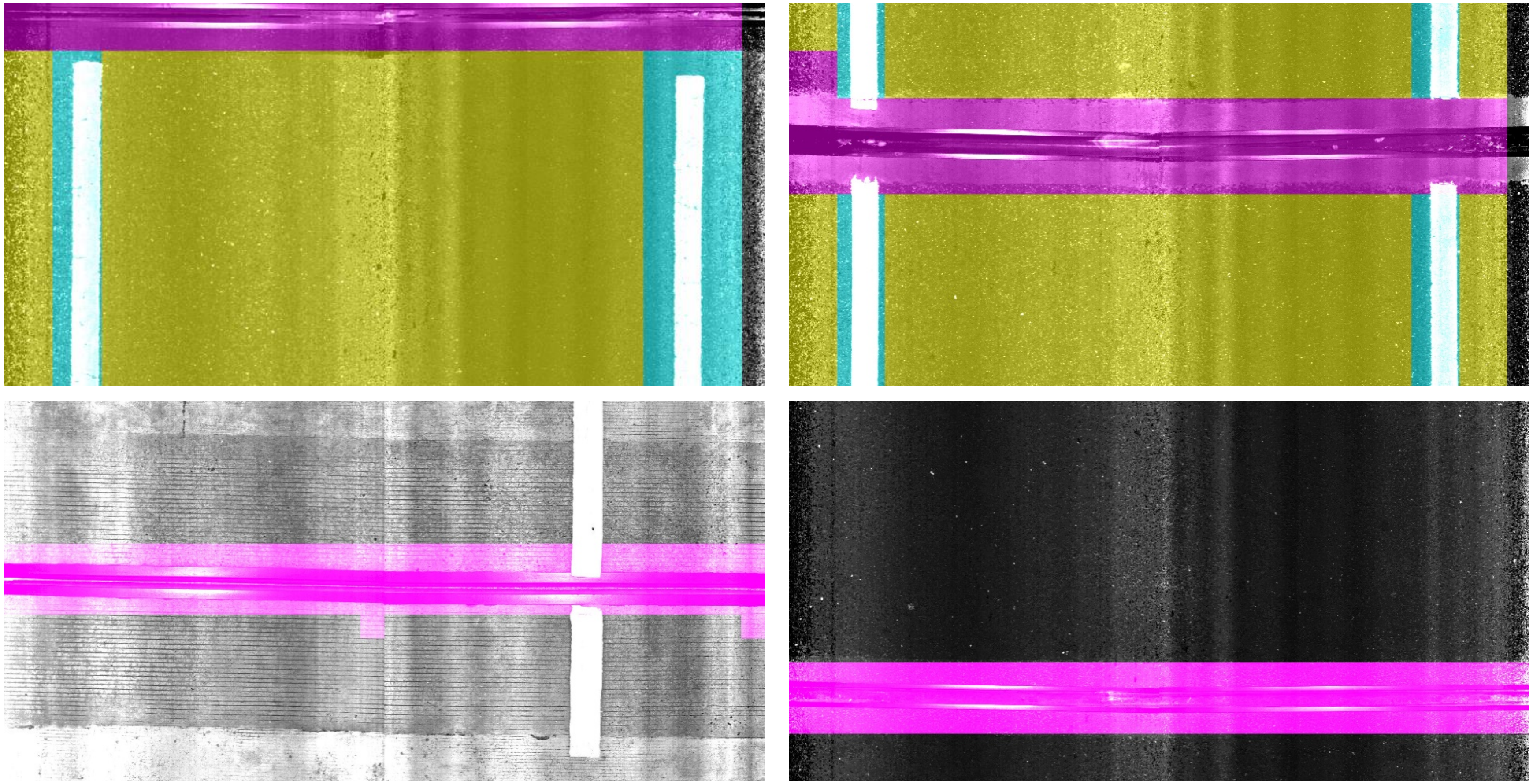


- Real-time Collection & Detection
- Processing Speed: 90 MPH

Other Non-Cracking Features: Markings, Man-Hole, Bridge Expansion Joint

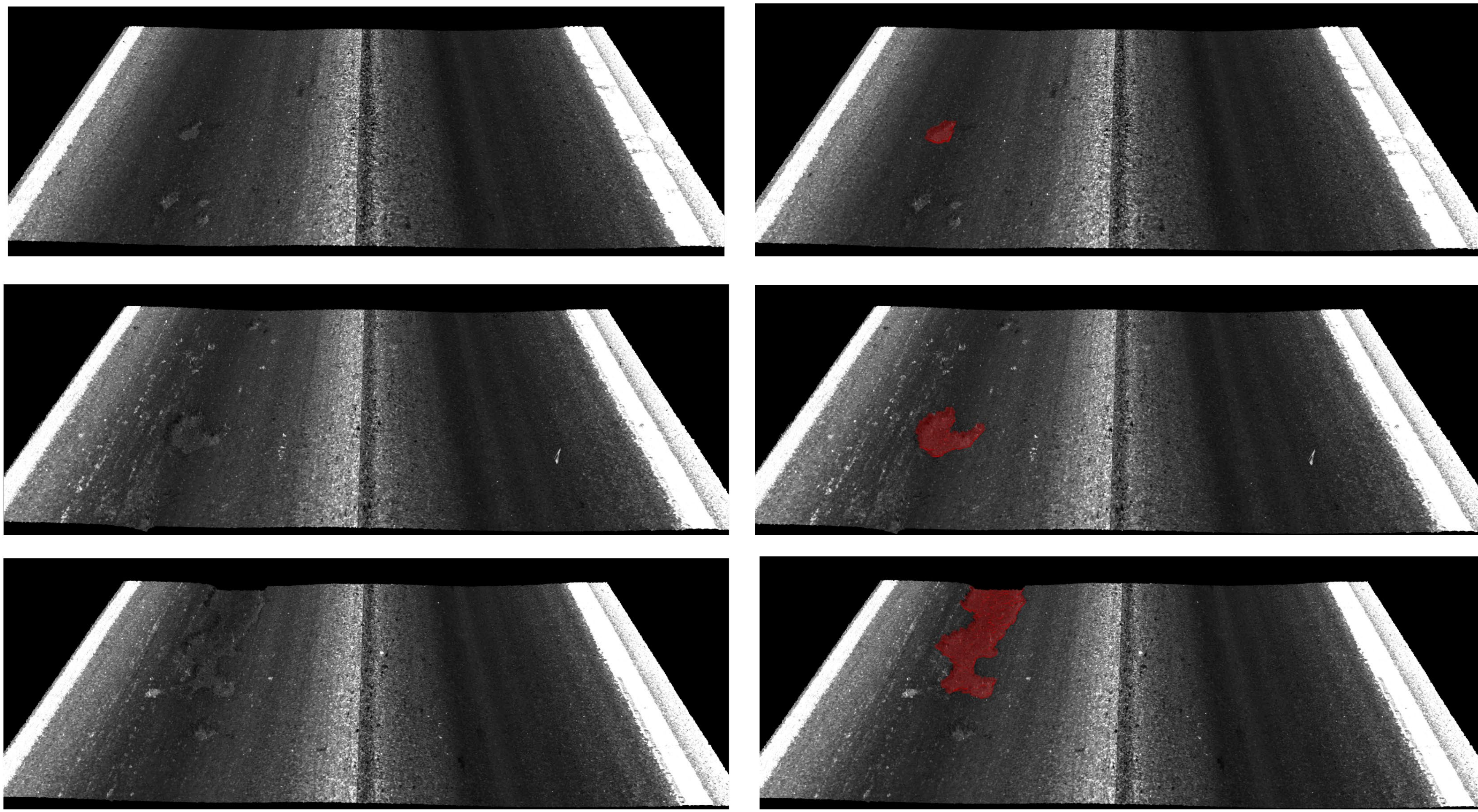


Expansion Joint Detection

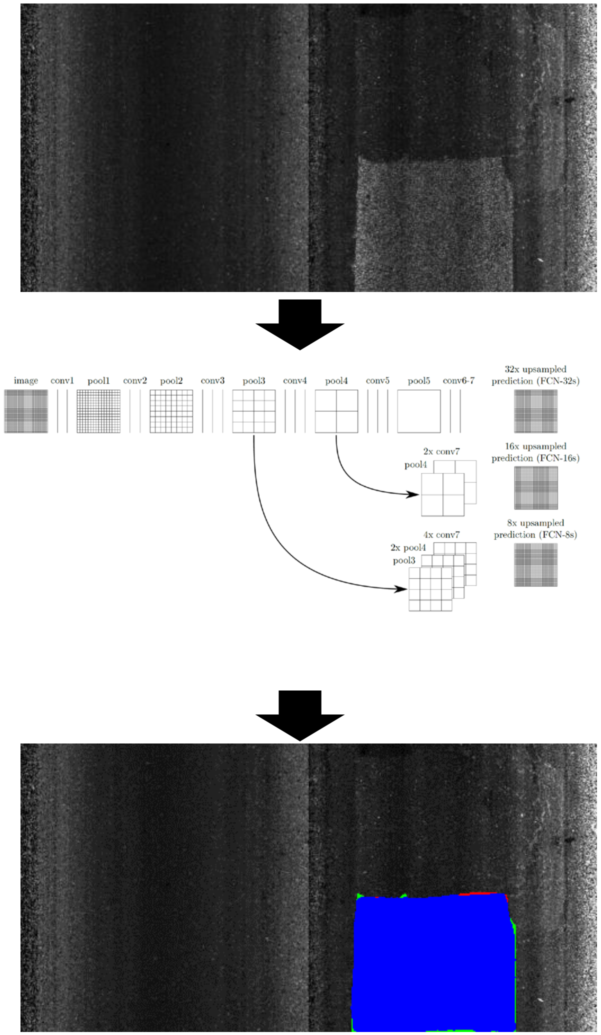


Accuracy: 93% **Processing Speed: 50 MPH**

Pothole Identification

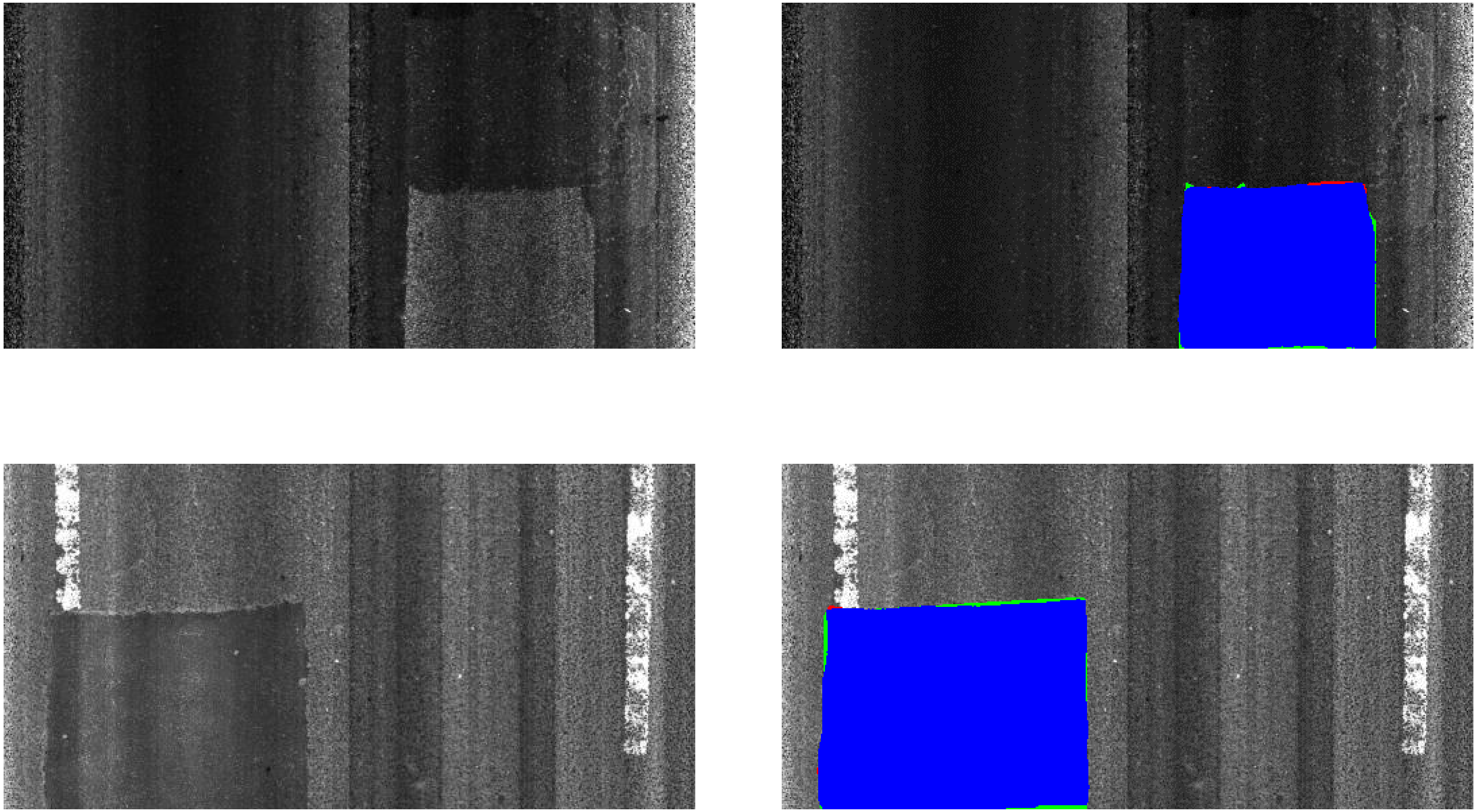


Pavement Patch Detection

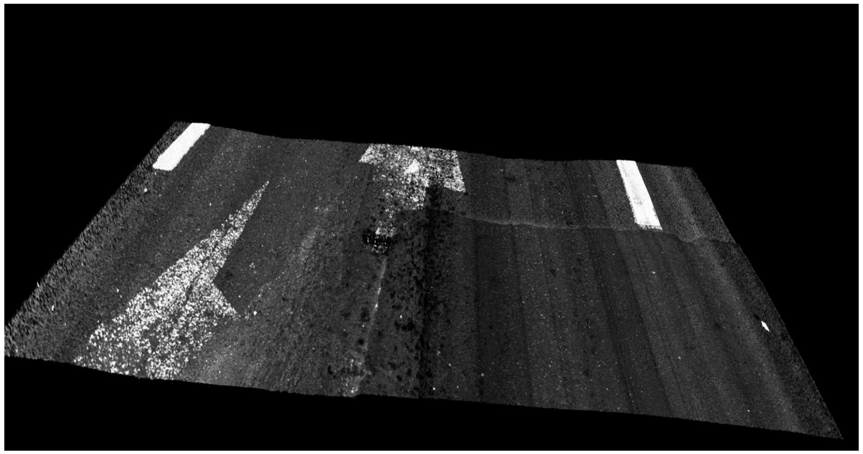


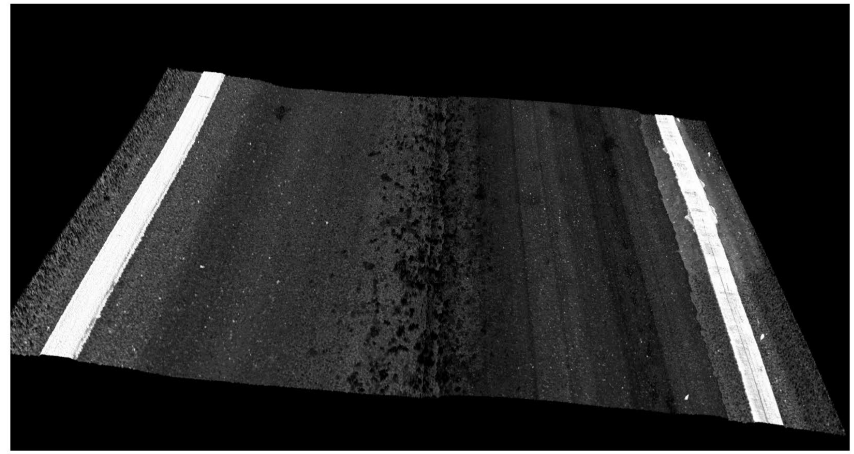
- Training & Testing Images Library
  - 22,000 manually annotated sample images
- Deep Learning for Semantic Segmentation
  - Pixel-level accuracy
- Accuracy
  - **84.58%**
- Processing Speed
  - **>100 MPH**

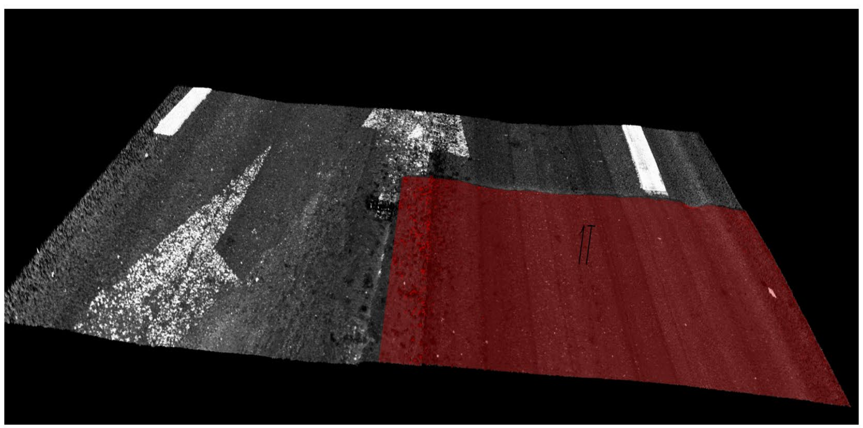
Pavement Patch Detection

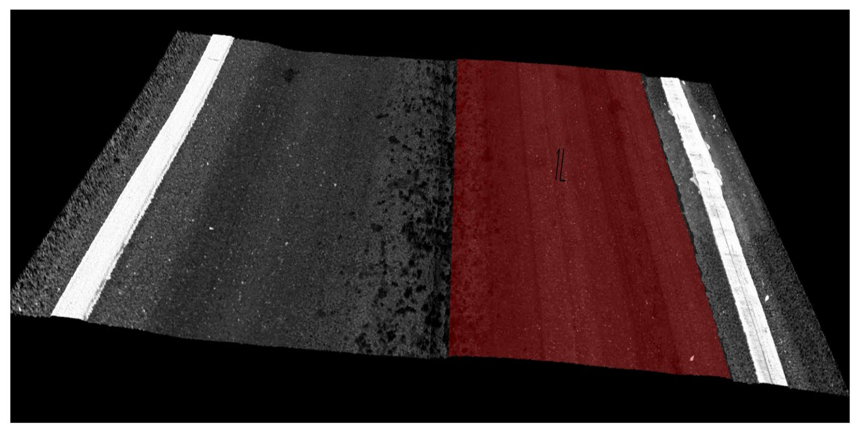


Patching Identification

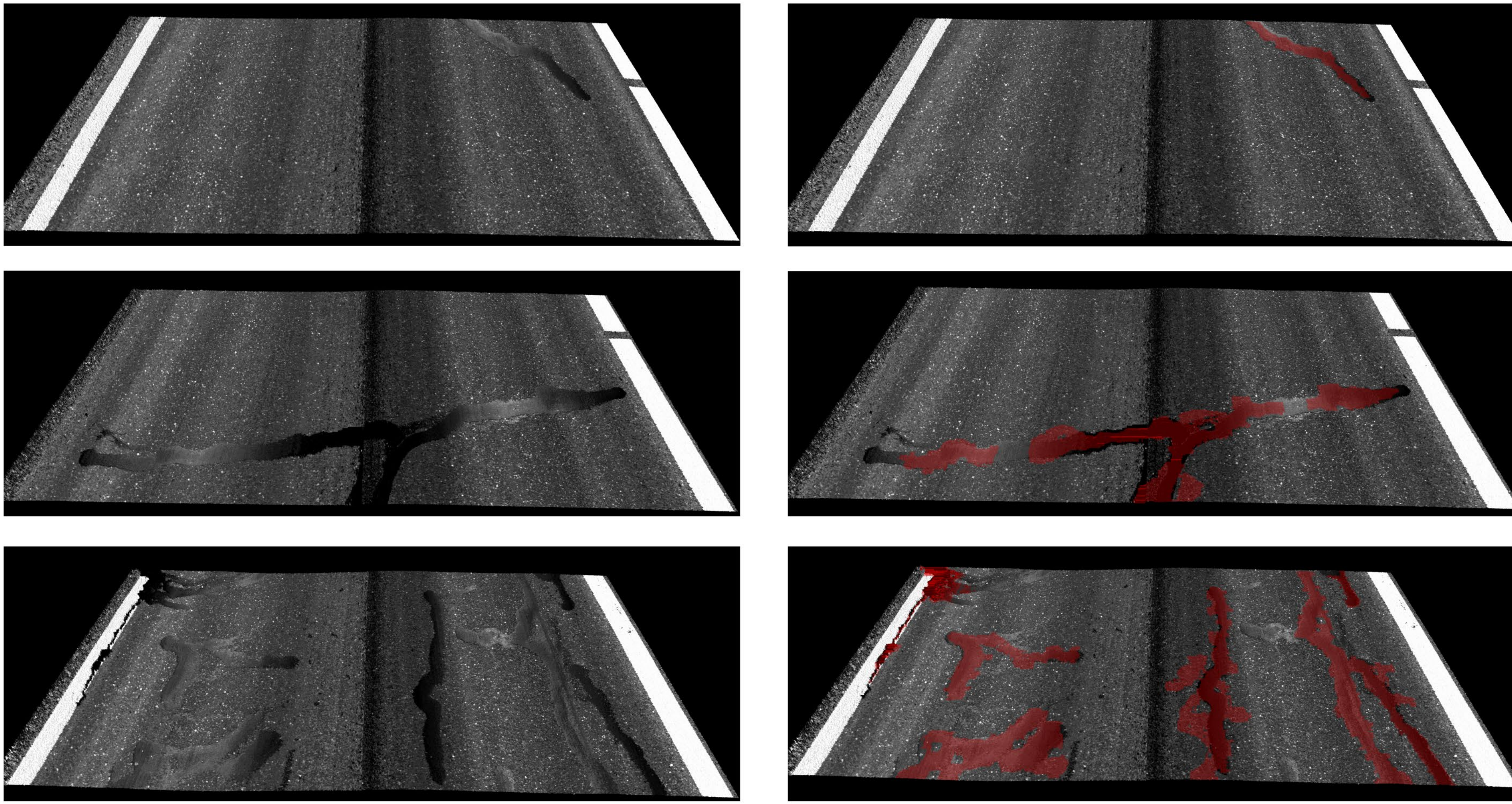




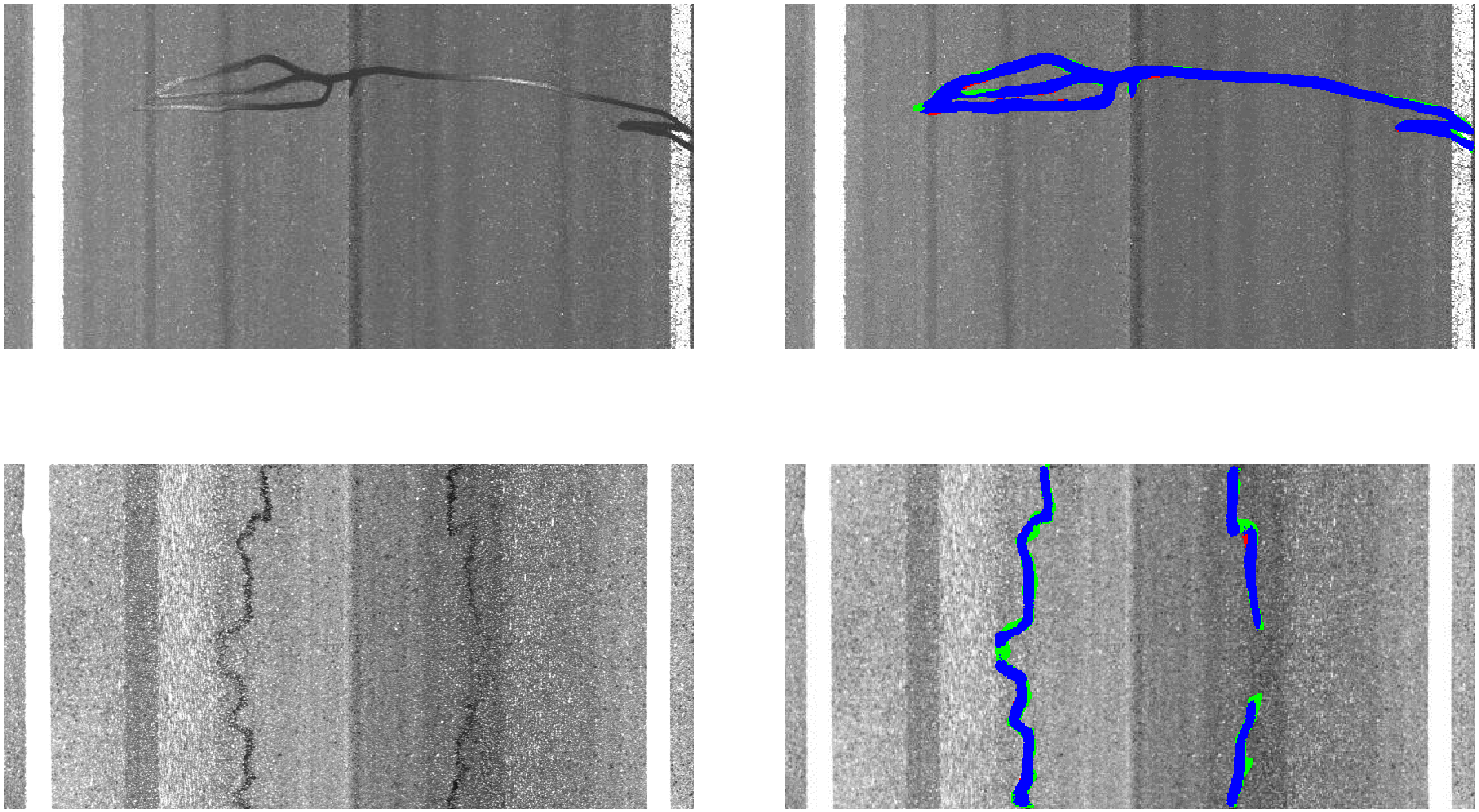




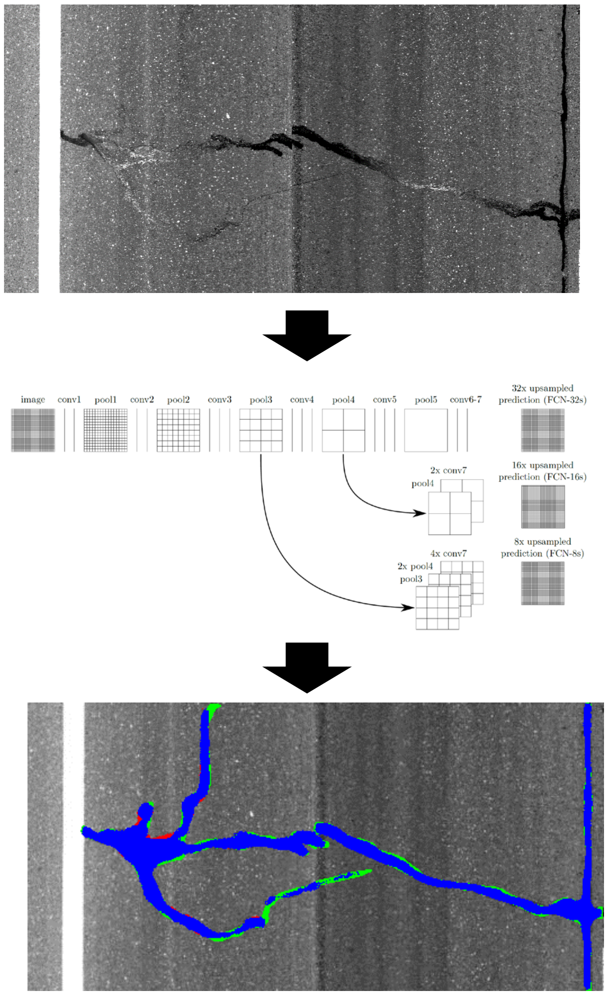
Sealed-Cracking Identification



Sealed-Cracking Identification

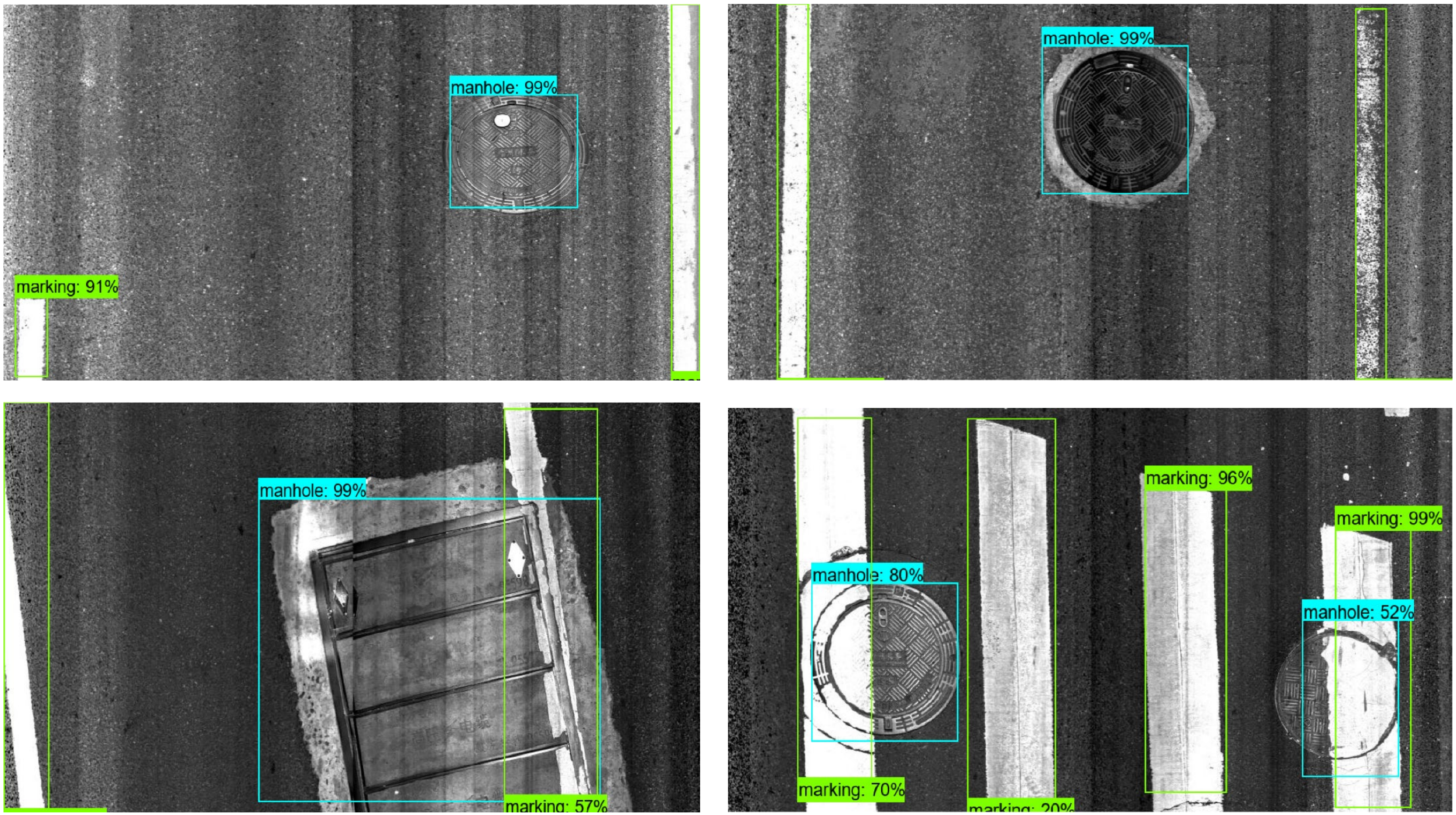


Sealed-Cracking Identification



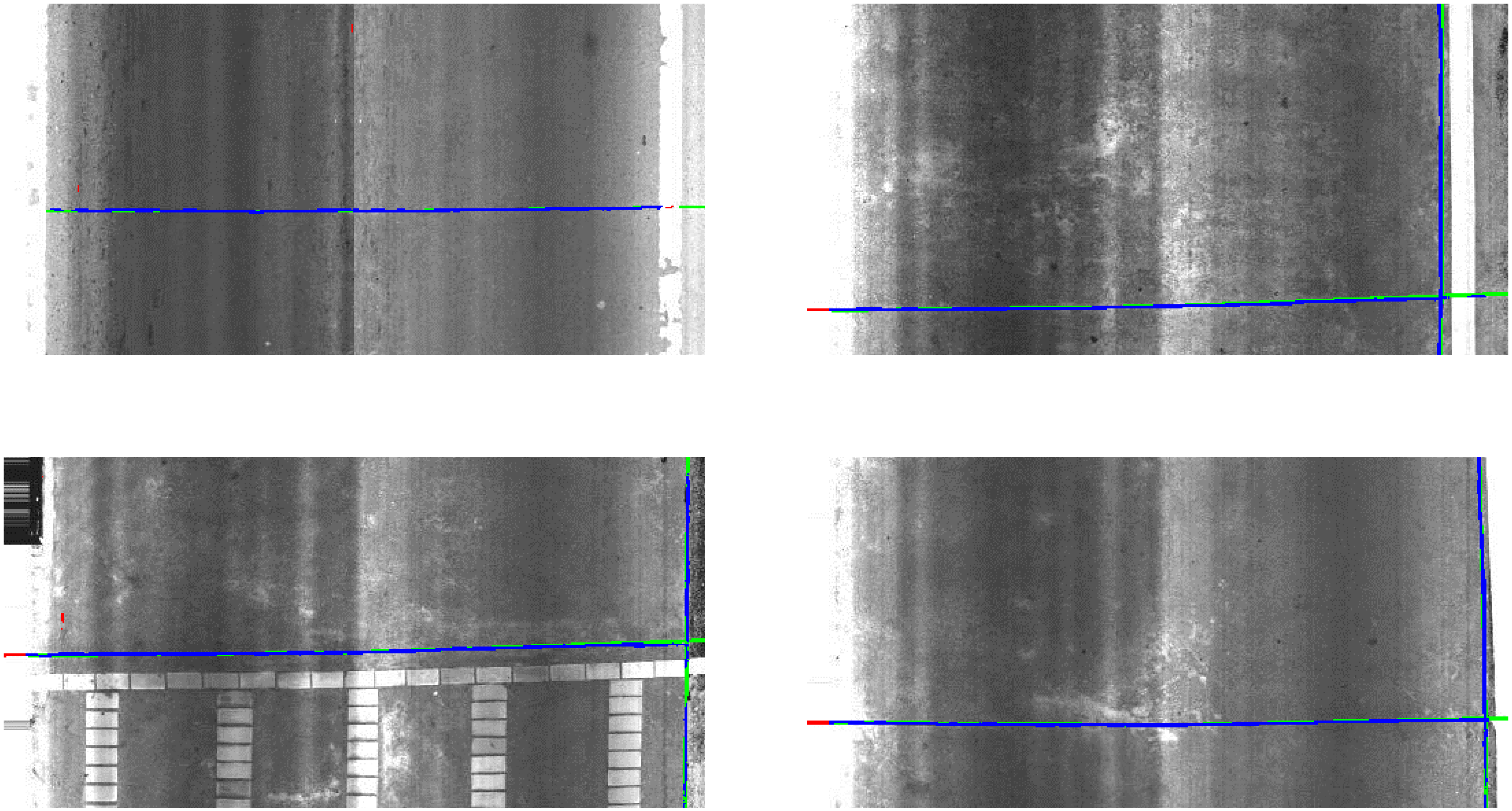
- Training & Testing Images Library
  - 3,500 manually annotated sample images
- Deep Learning for Semantic Segmentation
  - Pixel-level accuracy
- Accuracy
  - **85.04%**
- Processing Speed
  - **>100 MPH**

Manhole Detection

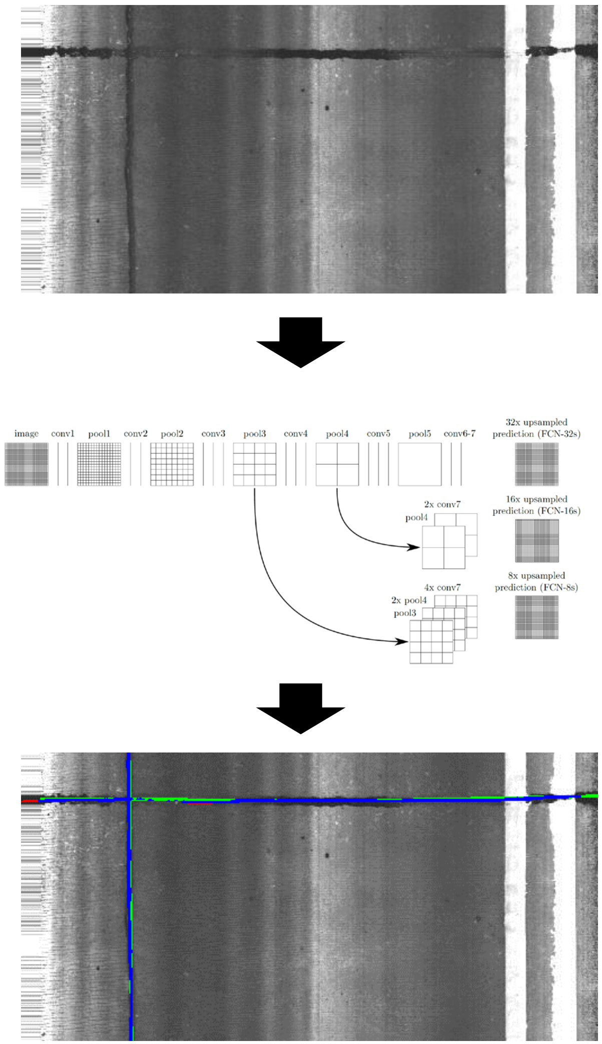


Accuracy: >80%   Processing Speed: 80 MPH

Faulting Detection: Joint First



Faulting Detection

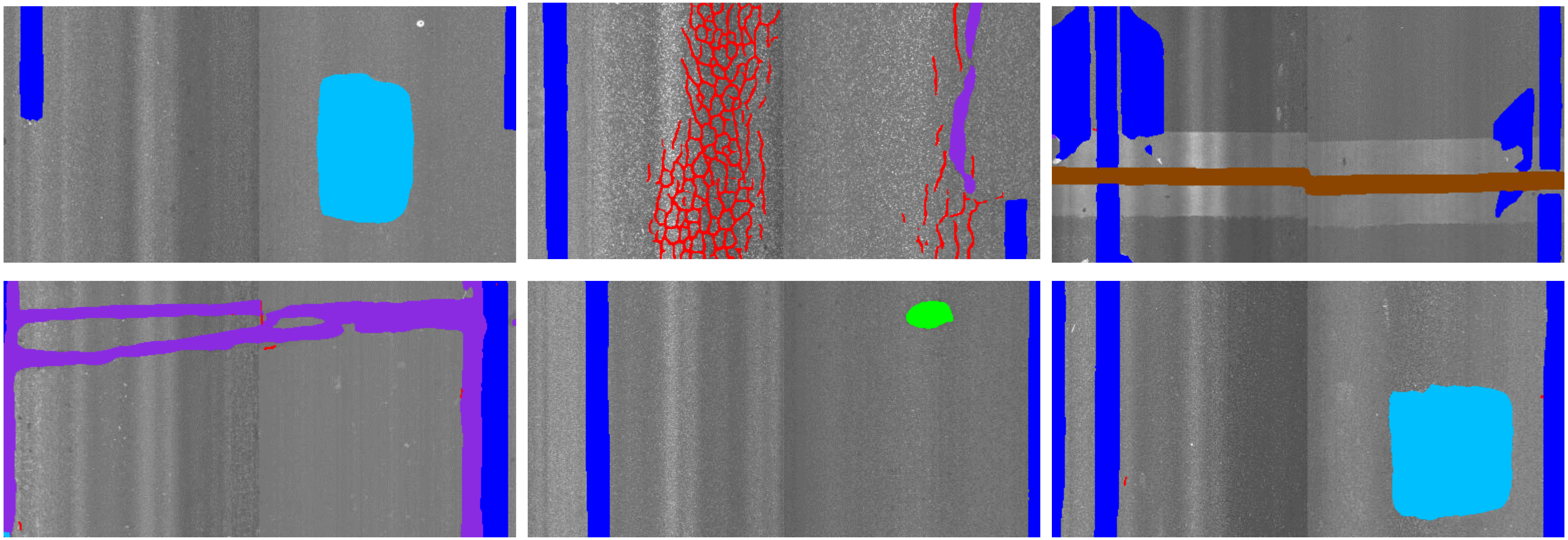


- Pavement Joint Detection via Deep Neural Network
  - 3,000 manually annotated sample images
  - Accuracy: >85%
  - Processing Speed: >100MPH
- Faulting Detection based on Full-lane 3D Pavement Surface Data

Future CrackNet: Multiple-Distress in 2021

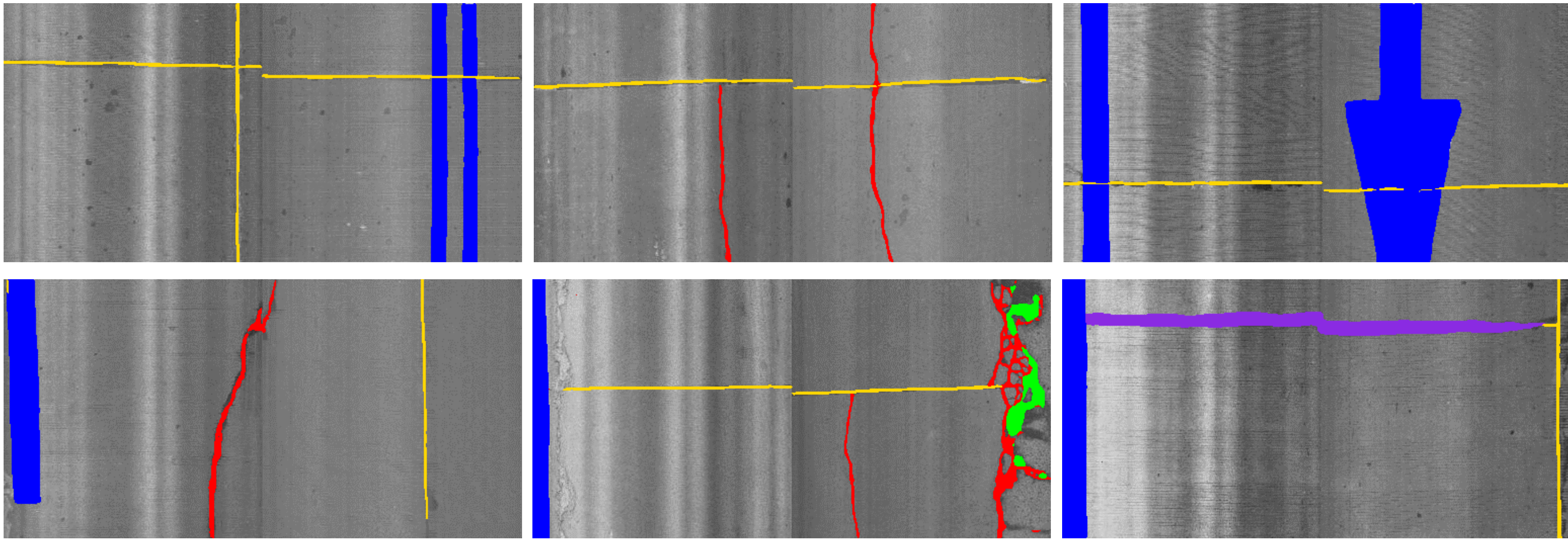
- ❑Pixel-Level Accuracy
- ❑Diverse Training Data
- ❑Deep Neural Networks & Parallel Computing
- ❑Efficiency
- ❑Including Non-Cracking Distresses
- ❑Real-Time Processing
- ❑Consistent Accuracy (Precision & Bias)
  - ❑Better than 90% All the Time

Multi-Distress Single-Network on AC



- Distresses and typical patterns
  - Crack, Pothole, Patch, Sealing, Marking, Expansion joint, Manhole
- Performance
  - Pixel-level accuracy: 91%
  - Processing Speed: 125 MPH

Multi-Distress Single-Network on Rigid



- Distresses and typical patterns
  - Crack, Pothole, Corner break, Divided slab, Sealing, Patch, Joint spalling, Joint, Marking, Manhole
- Performance
  - Pixel-level accuracy: 88%
  - Processing Speed: 125 MPH

Conclusions

- LTPP Distress Definitions & ASTM PCI
  - Important, But not applicable to fully automated surveys at network level
- New Definitions in Implementation: Next Decade
- Multiple-Objective DL
  - Real-Time Processing to Meet Precision & Bias Needs
- Frontier: Self-Learning
  - Build Networks to Generate Training Data Sets (Labeling Data) with No or Limited Human Intervention

Acknowledgement

- NCHRP
- USDOT UTC Programs
- FHWA
- FAA Tech Center
- INDOT, ARDOT, ODOT
- Other Users & Sponsors Worldwide

Automated Pavement Distress Data Collection and Analysis Using Drones

David Lee, Ph.D., P.E.
Professor of Civil and Environmental Engineering
Director of Laboratory for Advanced Construction Technology
Iowa Technology Institute, University of Iowa

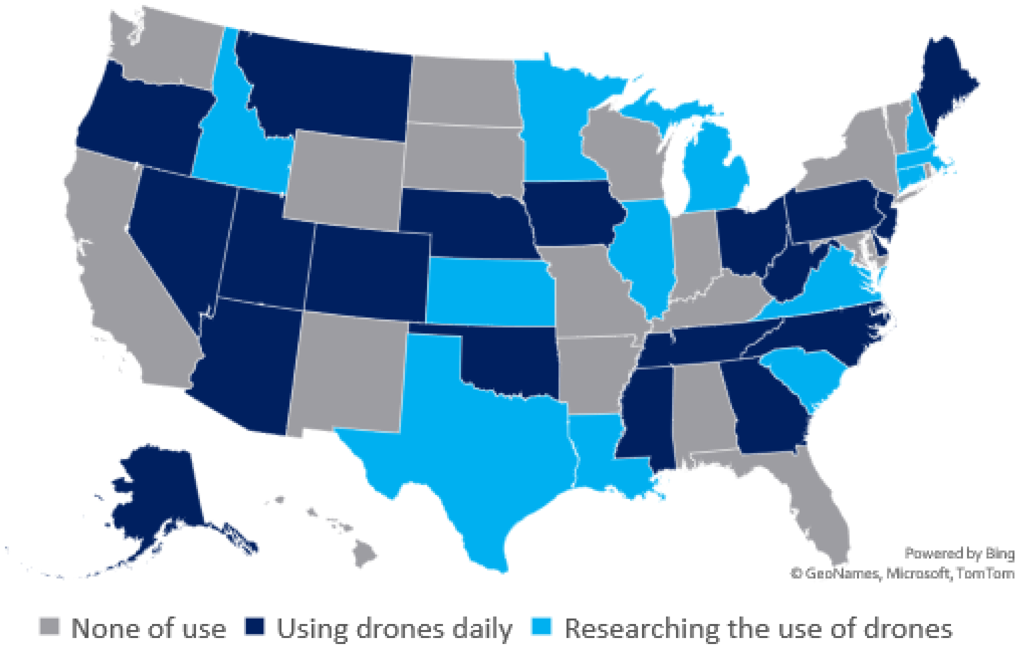
TRB Webinar on Advances in Pavement Condition Surveys

April 7, 2021

Acknowledgments

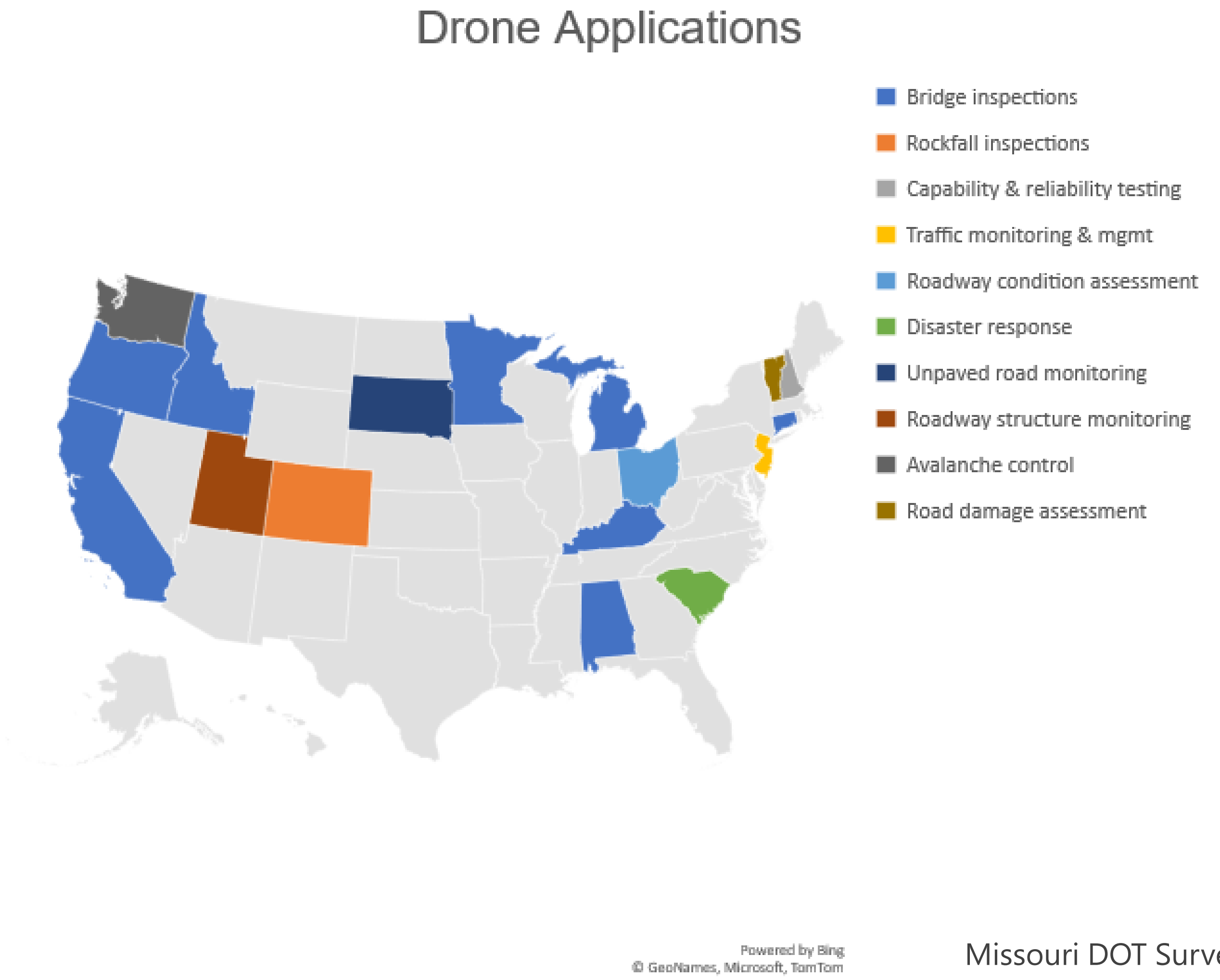
- Brian Moon, Ph.D. student R.A., Iowa Technology Institute, UI
- Brian Shanahan, B.S./M.S. student R.A., Iowa Technology Institute, UI
- David Wu, B.S. student R.A., Iowa Technology Institute, UI

More state DOT's are utilizing drones….



- Bridge Inspection: 10 states
- Pavement Inspection: 6 states

2018 AASHTO Survey



Missouri DOT Survey

DJI Phantom 4 Drone

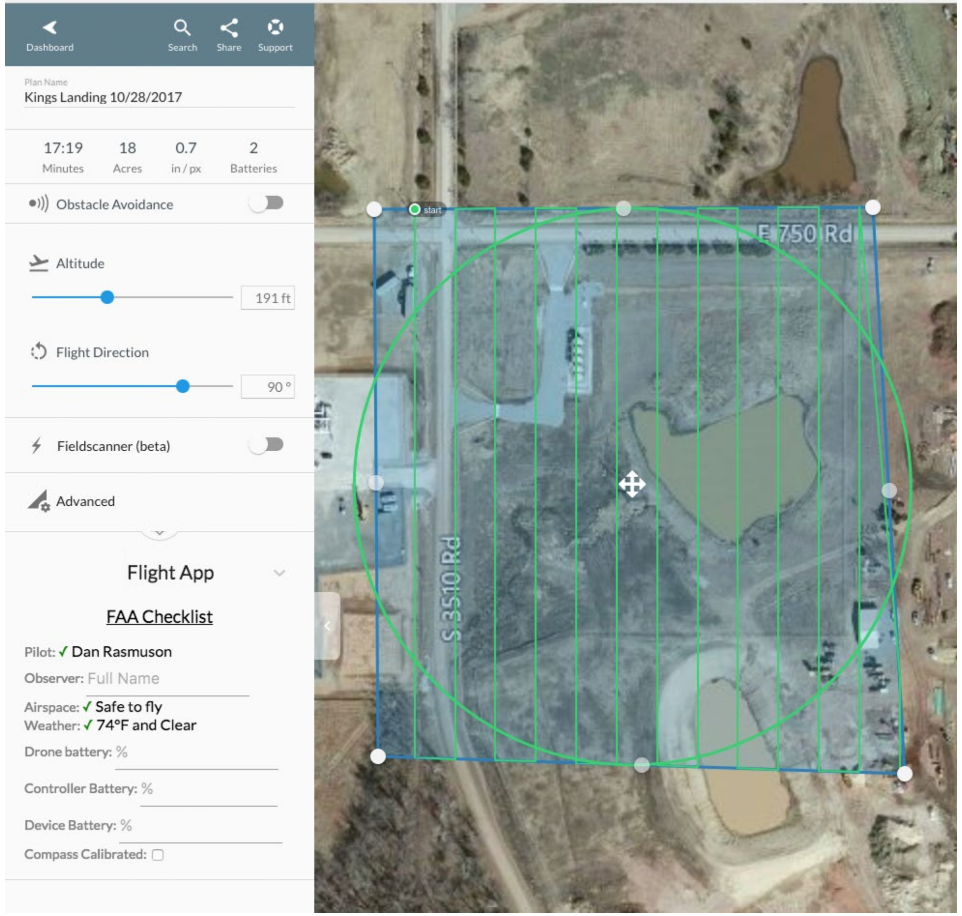
UAV	DJI Phantom 4 Pro
Weight	1.388kg
Fuselage length	350mm
Maximum flight time	30 minutes
Maximum flight speed	50km/h (Mode P)
Camera sensor	1-inch CMOS, Effective pixels 20M
Camera lens	FOV 84°, f/2.8-f/11, auto focus at 1m-∞
ISO Range	100~3,200 (Auto)
Shutter speed	8-1/2,000 sec
Wireless range	Up to 7km
Price	$1,500

“DroneDeploy” App Market

- The industry’s largest drone data platform, with more than 60 public apps available across nine different industries.
- DroneDeploy’s open APIs allow users to build custom, private apps for their team right on top of DroneDeploy’s intuitive user interface—and deploy them through the App Market.
- User can leverage DroneDeploy’s platform to deploy custom apps for flight, analysis, and reporting within a user’s organization.
- User can use DroneDeploy’s private app APIs to streamline workflows, improve collaboration, and increase efficiency.

Flight Plan with Pre-Flight Checklists

- Automatically create a flight plan to fly over jobsite by exporting geolocation data to DroneDeploy.
- It is simple to repeat flight plans instantly based on site location.
- It allows users to generate custom settings based on common locations.
- It makes flight planning simple, repeatable, and scalable.



Pavement Analysis for the city of Elko New Market, Minnesota using Drones (Bolton & Menk Co.)

- Used DJI Phantom 4 drone.
- Used DroneDeploy's Enterprise platform to access the open APP market and used Linear Flight Plan App to plan and map flights across the whole city.
- 26-mile pavement condition evaluation project was completed in 18 flights by two-person crew.
- Took two days to fly and capture data for the project instead of a week to traverse the 26 miles by car/foot using the traditional method (Reduced the time by 60%).
- It took one day to process the drone images.

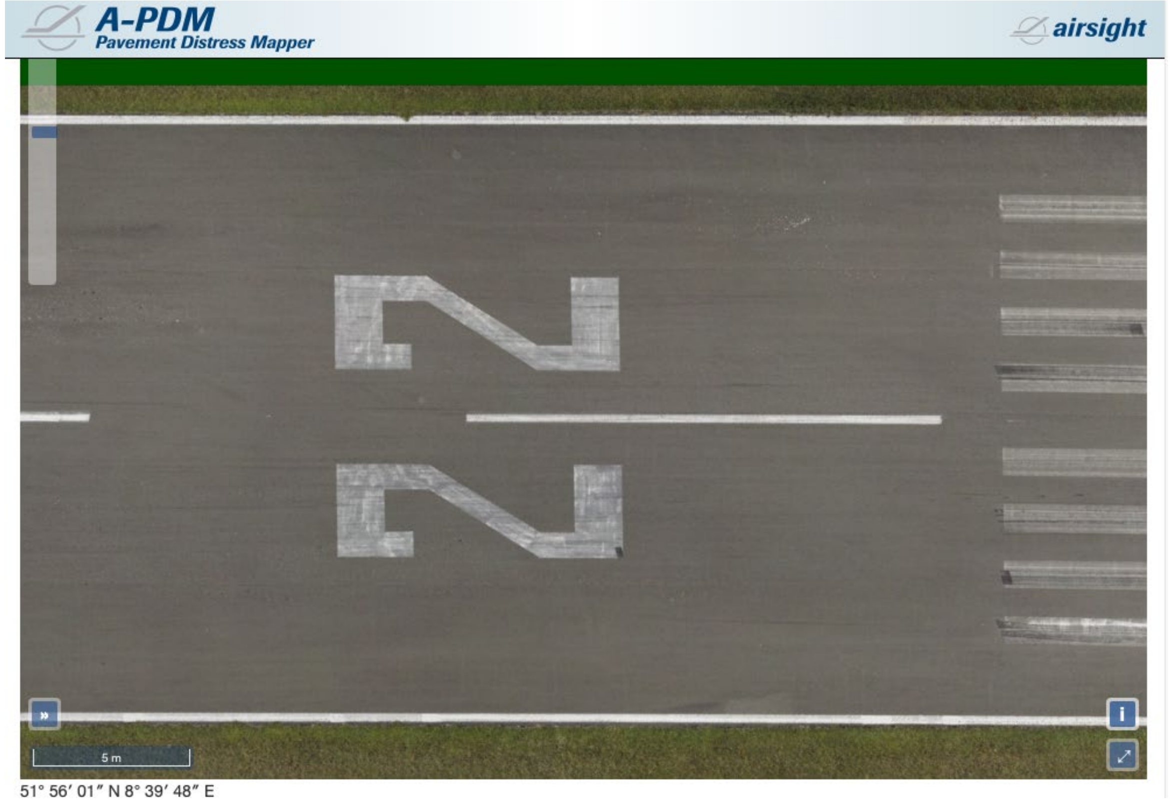
https://blog.dronedeploy.com/

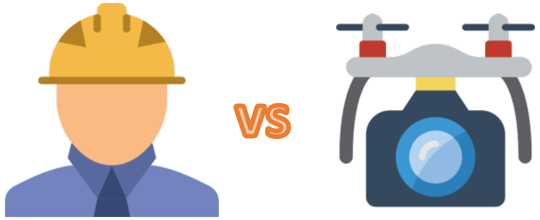
Export data for GIS Applications

- Collected data was integrated with GIS applications to generate condition ratings.
- Yielded more precise measurements than ground surveys for a more accurate condition evaluation of pavement conditions.
- Easier for city staff to analyze data and prioritize roadway maintenance.
- Delivered a more thorough analysis of the pavement conditions for a better road maintenance at a lower cost for the city.

https://blog.dronedeploy.com/

Inspection of International aerodrome with a single runway using Drones by airsight Co.



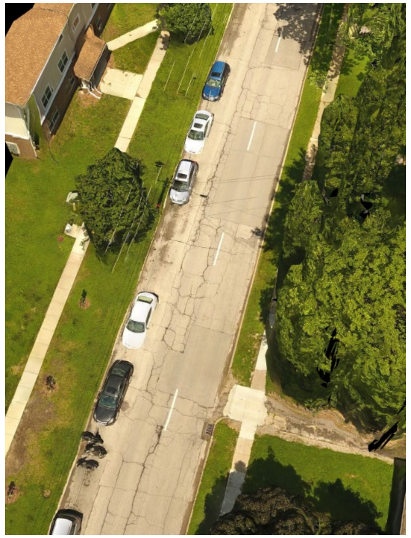
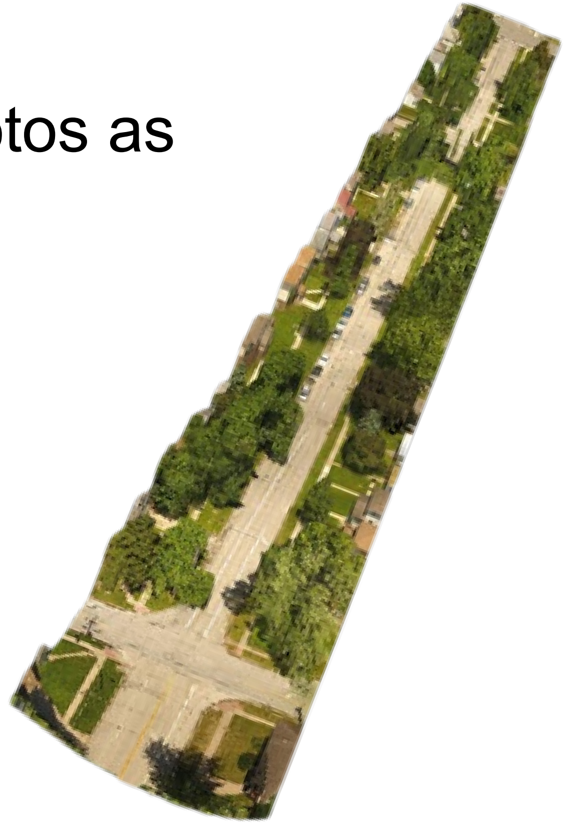


	Conventional	UAV
Runway Inspection Time	6-8 hours	$\leq$ 0.5 hours
Taxiway Inspection Time	30 hours	$\leq$ 2 hours
Number of Inspections	17 inspections	2 inspections
Personnel for Inspections	136 man-hours	32 man-hours
Data Post-processing	15 man-days	15 man-days
Reproducibility of Results	✖	○
Potential for Post-analysis	✖	○
Traceability	✖	○

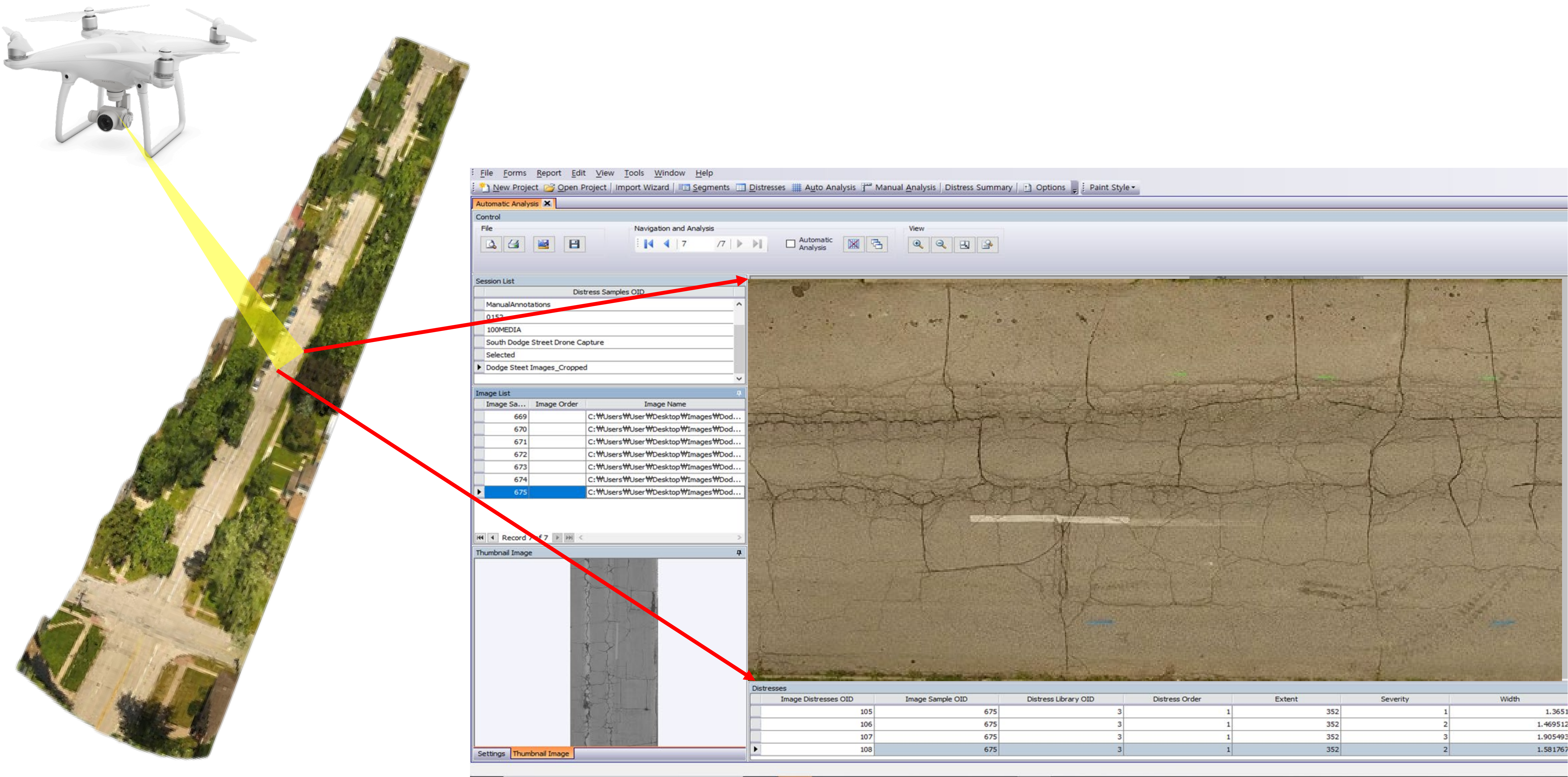
www.airsight.de/projects/item/airfield-pavement-inspections-using-drones/.

Drones to Capture Pavement Images for Point Cloud

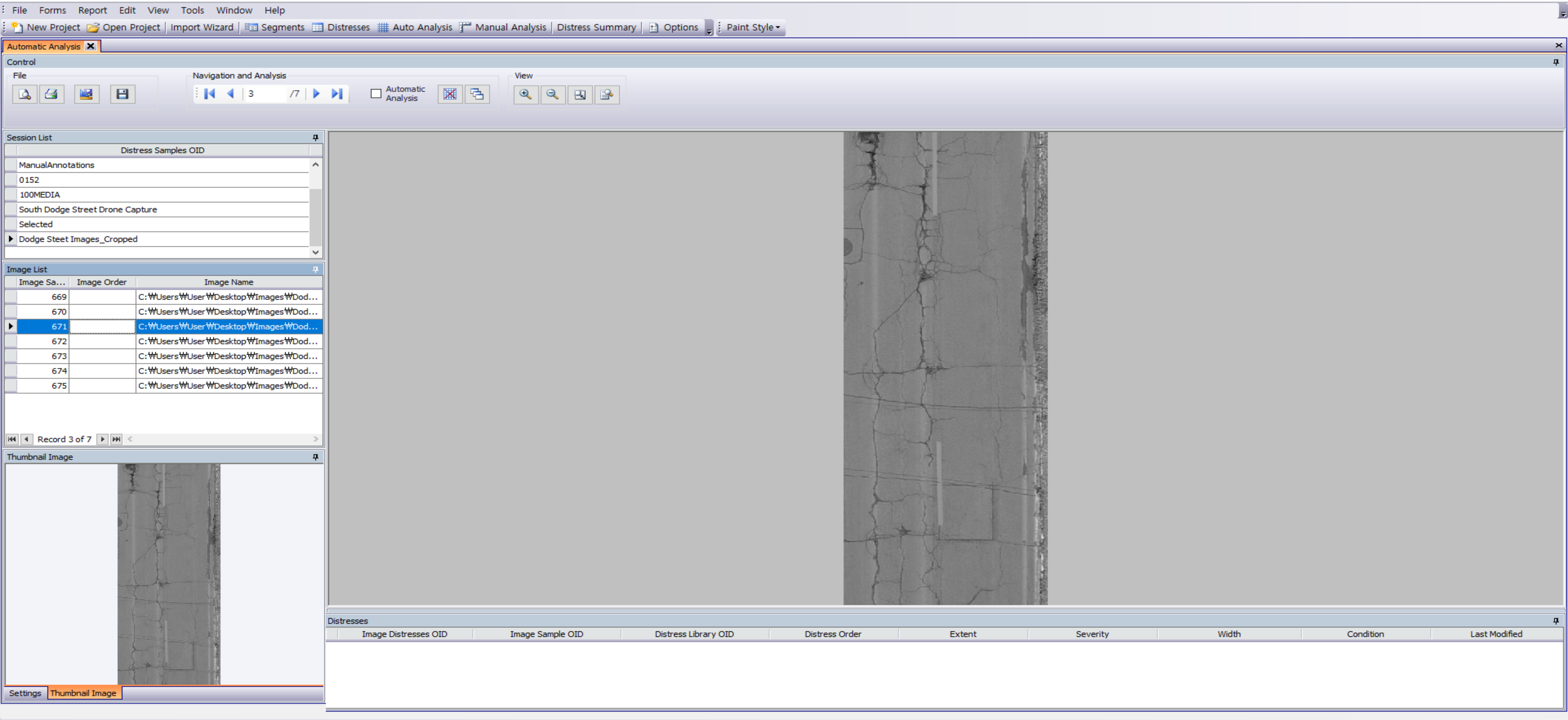
1. Set up the project using DroneDeploy App
   - Create a new project by entering street name
   - Set a boundary for the project by dragging the boundary points
   - An estimated time and necessary battery life for task completion will be shown
2. Push start button
   - The drone will automatically fly and take as many photos as necessary to complete 3D models

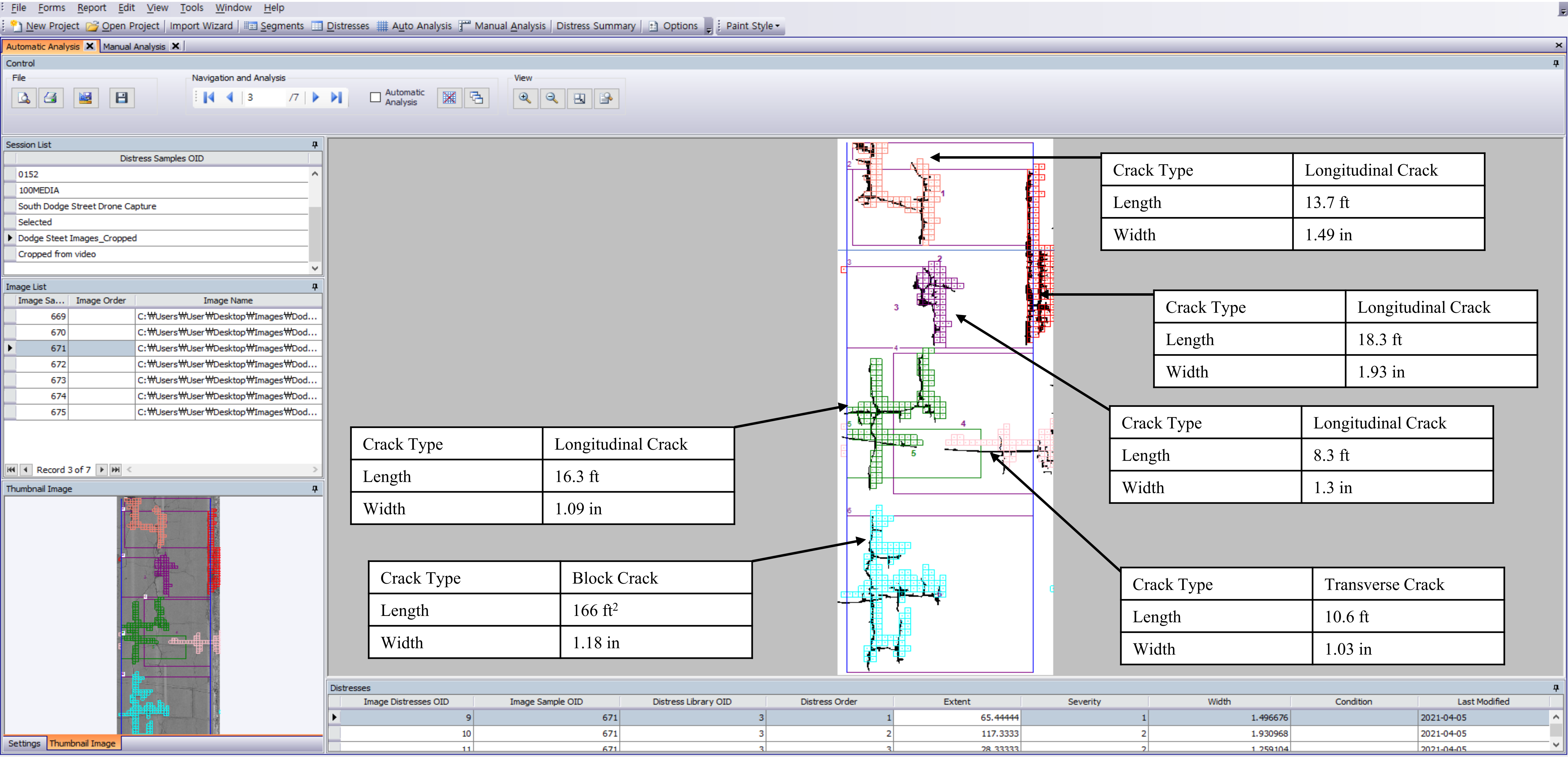
PicCrack Pavement Image Analysis Software



Open drone image using PicCrack software



Analyze drone image using PicCrack software



Crack Type	Longitudinal Crack
Length	13.7 ft
Width	1.49 in

Crack Type	Longitudinal Crack
Length	18.3 ft
Width	1.93 in

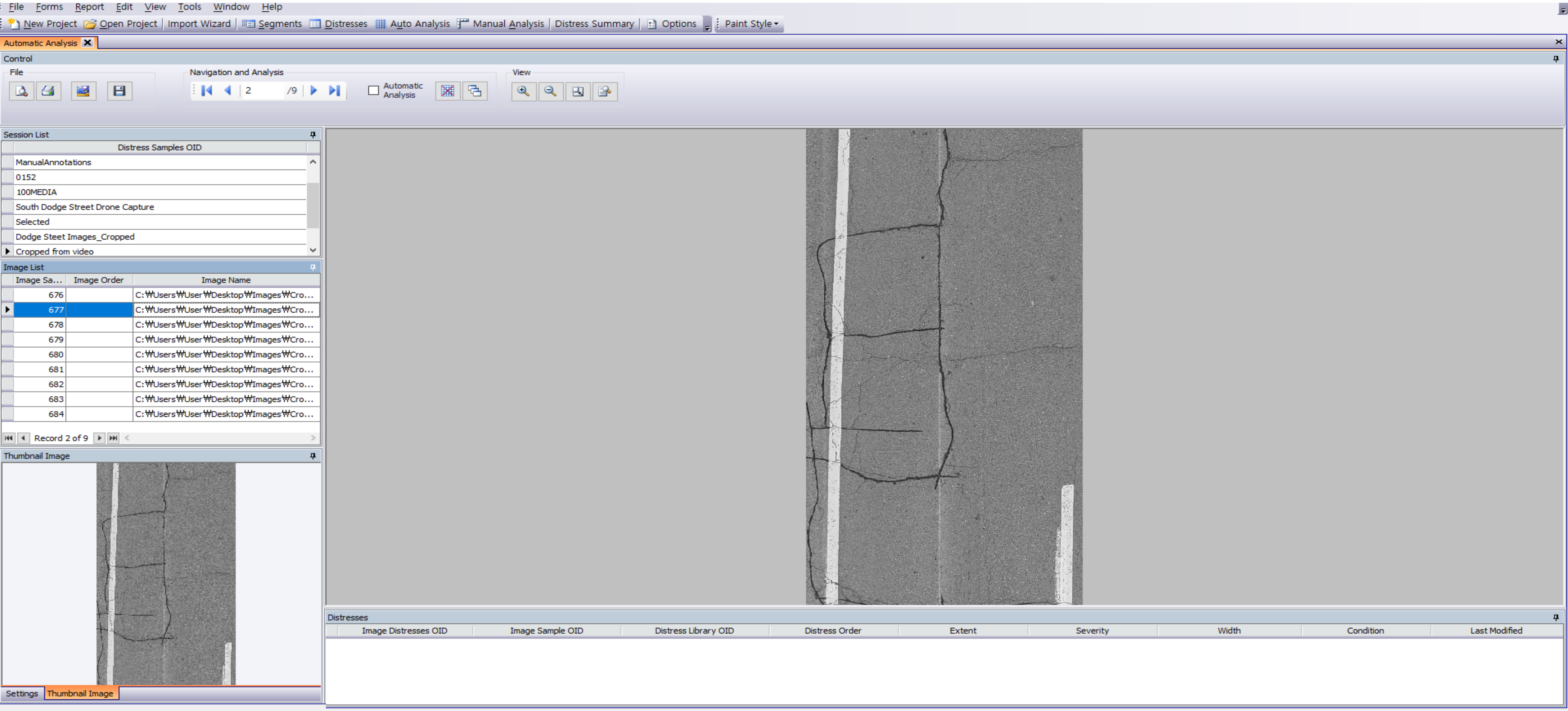
Crack Type	Longitudinal Crack
Length	8.3 ft
Width	1.3 in

Crack Type	Longitudinal Crack
Length	16.3 ft
Width	1.09 in

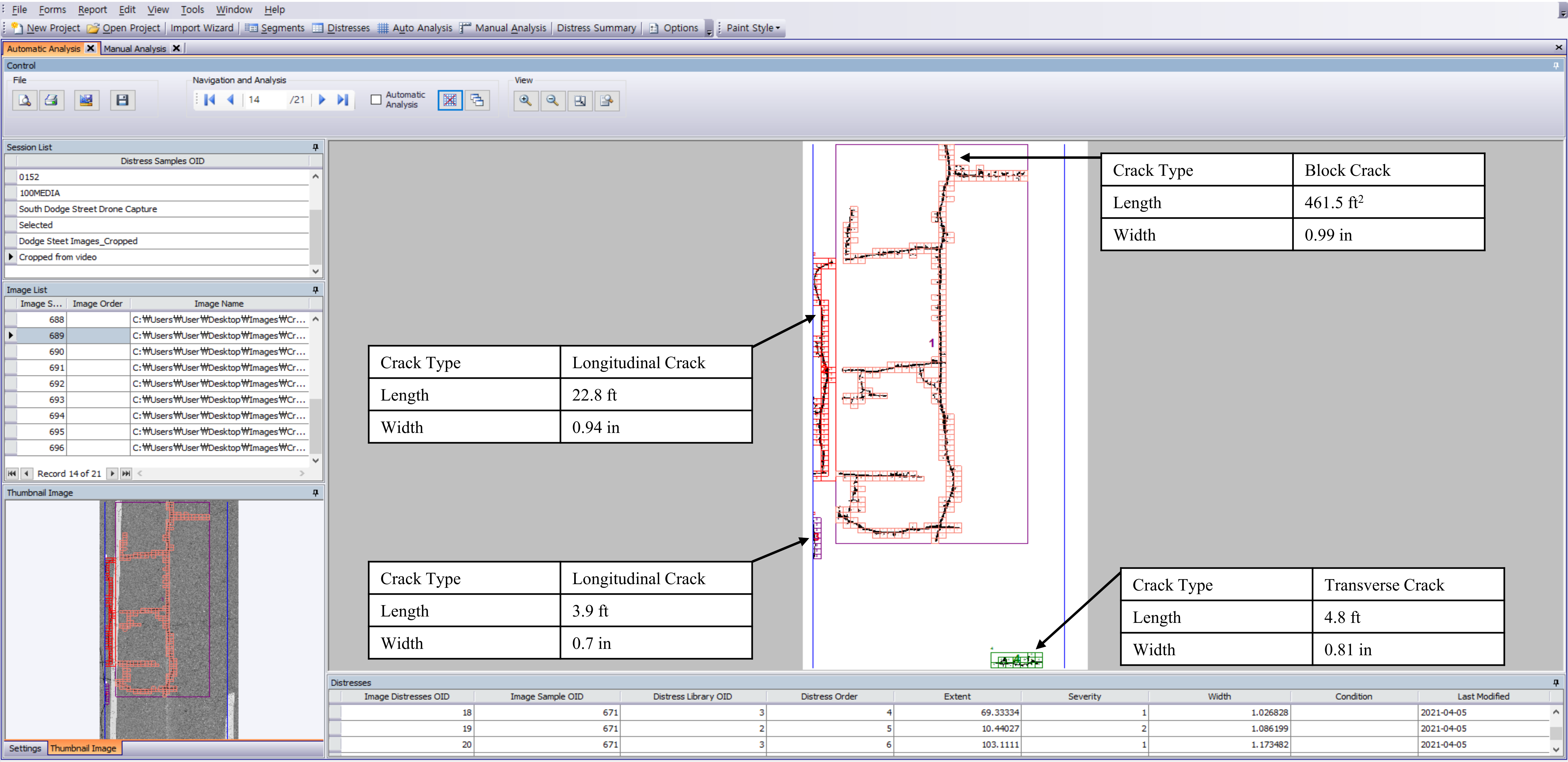
Crack Type	Block Crack
Length	166 ft^2
Width	1.18 in

Crack Type	Transverse Crack
Length	10.6 ft
Width	1.03 in

Open drone image using PicCrack software



Analyze drone image using PicCrack software



Crack Type	Block Crack
Length	461.5 ft^2
Width	0.99 in

Crack Type	Longitudinal Crack
Length	22.8 ft
Width	0.94 in

Crack Type	Longitudinal Crack
Length	3.9 ft
Width	0.7 in

Crack Type	Transverse Crack
Length	4.8 ft
Width	0.81 in

Detection of Asphalt Pavement Potholes and Cracks Based on Unmanned Aerial Vehicle Multispectral Imagery

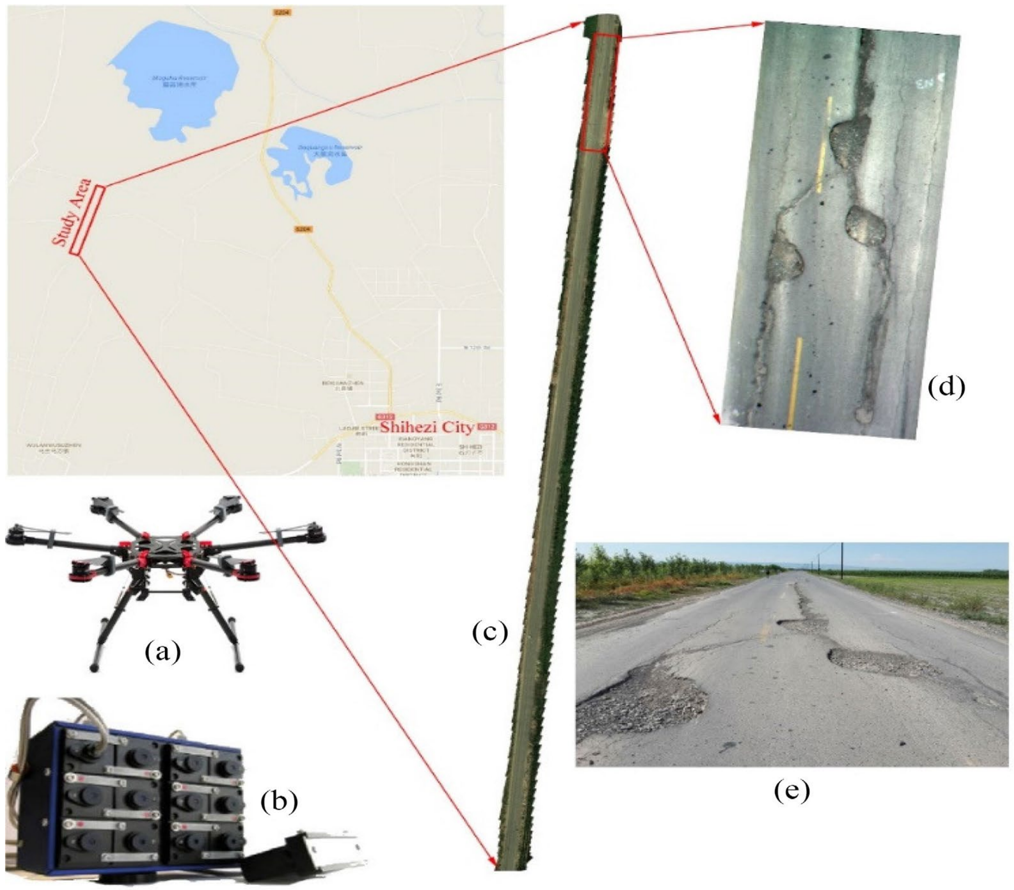
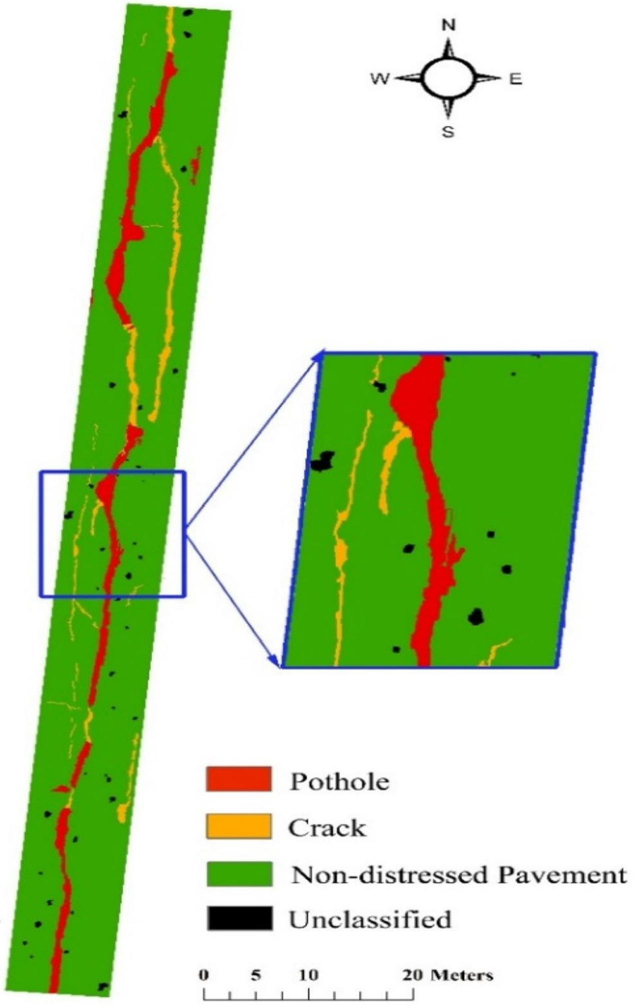


Figure (a) Six-spreading-wings UAV. (b)MCA snap12 camera. (c) Full MCA road image. (d) Sample MCA road image. (e) Spot photo of the study road



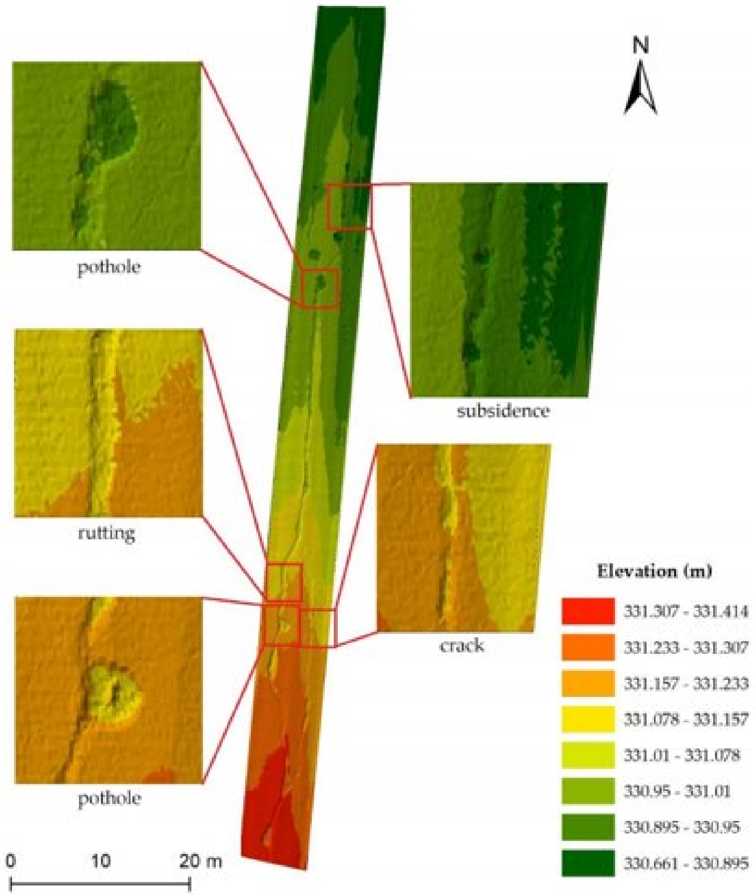
Classification result of a sample road segment using the RF18-C7 model

- Random Forest(RF18-C7) model and multispectral pavement images.
- Pix4D software was used to mosaic all the image tiles into one full image
- The 98.3% accuracy of the classification, which is the fraction of correctly classified image objects with regard to all image objects of that ground truth class.

Yui Fan et al. (2018). Detection of Asphalt Pavement Potholes and Cracks Based on the Unmanned Aerial Vehicle Multispectral Imagery, IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING, VOL. 11, NO. 10, OCTOBER 2018

Identifying Asphalt Pavement Distress Using UAV LiDAR Point Cloud Data and Random Forest Classification

UAV	B1-100 manufactured by Scout
Laser Scanner	RIEGL VUX-1LR, accuracy of 15mm
Operating time	2 hr
Flight altitude/Speed	30m, 5 m/s
Length/Collecting point cloud points	400 m / 70,000,000 points

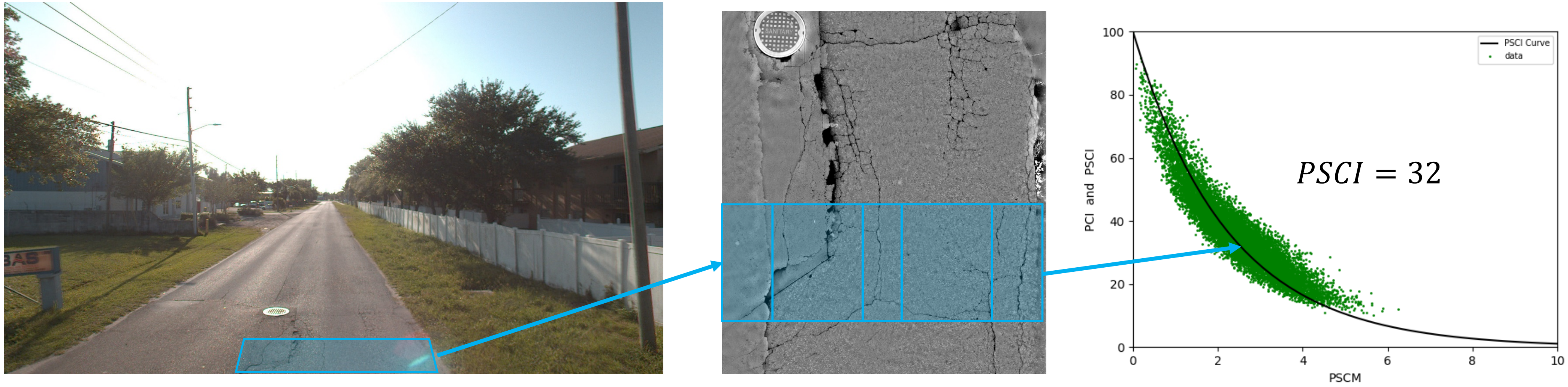


Random Forest Classification with multi dimensional features, including the elevation features, multiscale statistical features, reflection intensity feature, and object-oriented geometric features.

Li, Zhiqiang & Cheng, Chengqi & Kwan, Mei-Po & Tong, Xiaochong & Tian, Shaohong. (2019). Identifying Asphalt Pavement Distress Using UAV LiDAR Point Cloud Data and Random Forest Classification. ISPRS International Journal of Geo-Information. 8. 39. 10.3390/ijgi8010039.

Summary and Conclusions

- More state DOT's and companies are using drones for bridge and pavement inspection.
- Drones was used to capture pavement surface images in a high resolution at a low cost.
- PicCrack was used to analyze a drone image and various software packages can be used to analyze drone images.
- Drone images can be integrated with a GIS.
- Images can be automatically obtained and stored in a point cloud for 3-D modeling.



$PSCM = 2.5\%$

Pavement surface cracking metric and index

Michael Nieminen, P.Eng., Danilo Balzarini, Ph.D., James Erskine, P.E.

7 April 2021

Outline

- Objectives
- Definition of the Pavement Surface Cracking Metric (PSCM)
- Application of the PSCM
- Definition of the Pavement Surface Cracking Index (PSCI)
- Conclusions

Objectives

GOALS

- Overcome **subjectivity** of crack classification and **binning** problem
- Overcome **repeatability and reproducibility** problems
- Take advantage of **technology improvements**

CHARACTERISTICS

- **Clear:** Metrics should be *quantitatively and clearly defined*.
- **Repeatable:** Users should get *consistent results* on the same roads, within tolerances.
- **Reproducible:** Different users should get the *same results*, within tolerances.
- **Useful:** Metrics should be *useful for pavement management*, especially when combined with other pavement distresses (rutting, raveling, IRI, etc).
- **Simple:** The proposed index should have a *physical intuitive meaning*.

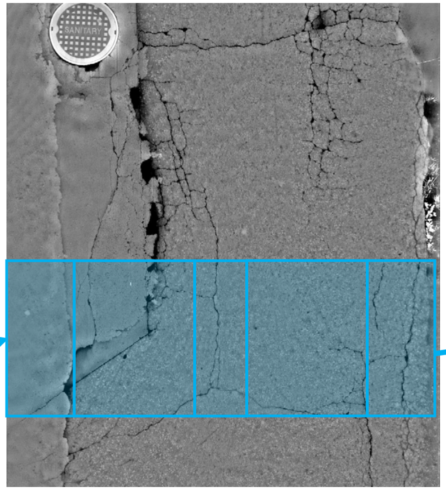
Procedure

1. Define the pavement sections for which the PSCM and PSCI will be calculated.
2. Define the analysis tiles for which the PSCM will be calculated.
3. Measure the crack length and crack width for each crack identified during the collection and analysis.
4. Calculate the area, total crack length, average crack width weighted by crack length, and crack density for each analysis tile.
5. Calculate the PSCM for each analysis area.
6. Calculate the PSCM for the pavement section.
7. Calculate the PSCI value for the pavement section

Procedure

1. Real world

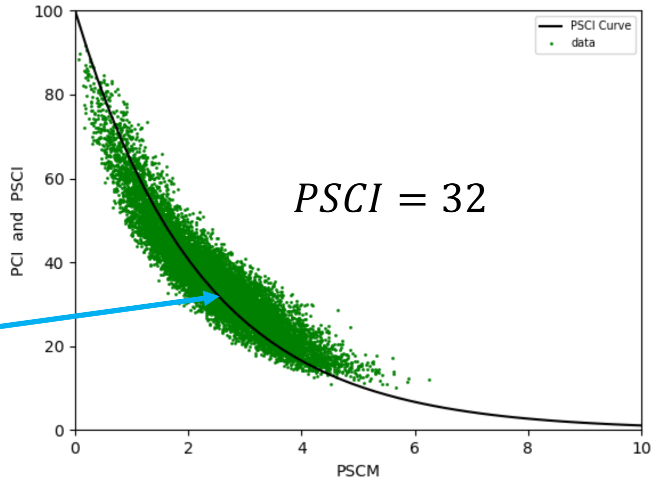
2. 2D/3D pavement image



$PSCM = 2.5\%$

3. Cracking calculation

4. Index calculation



Pavement Surface Cracking Metric (PSCM)

- Measure **crack length**, **crack width**, and **area** being surveyed
- Define the **Pavement Surface Cracking Metric (PSCM)** as:

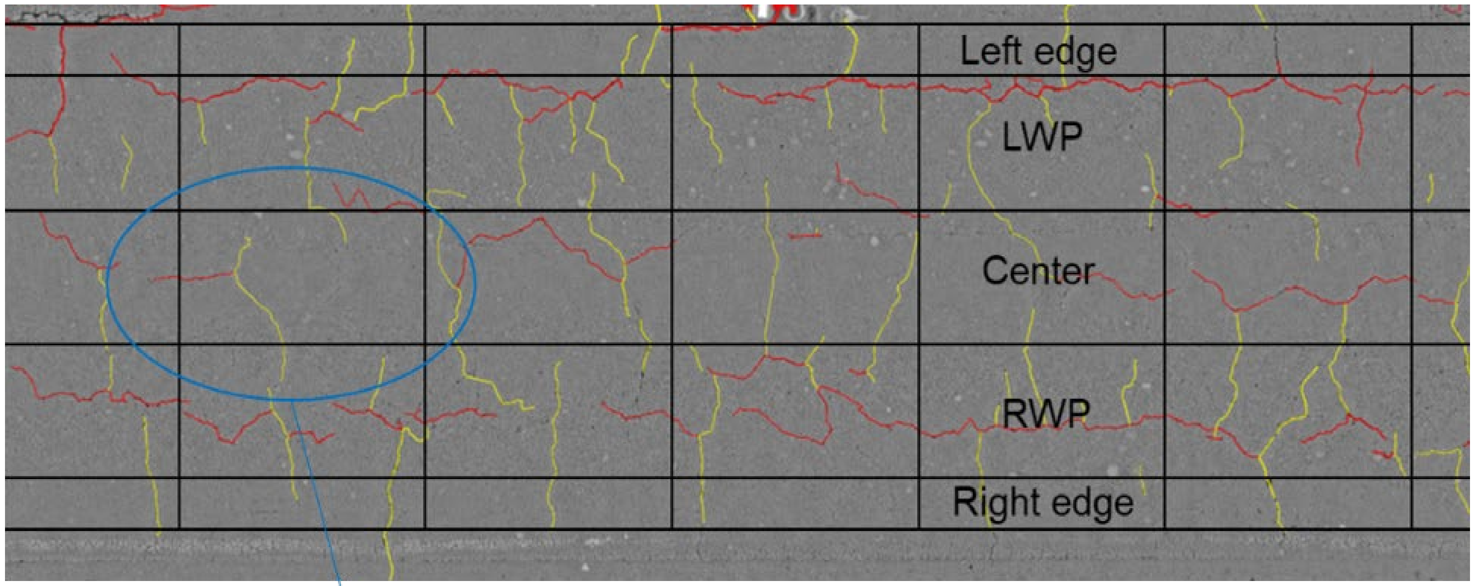
$$PSCM = 100 \cdot \frac{\sum_i^n l_i \cdot w_i}{A}$$

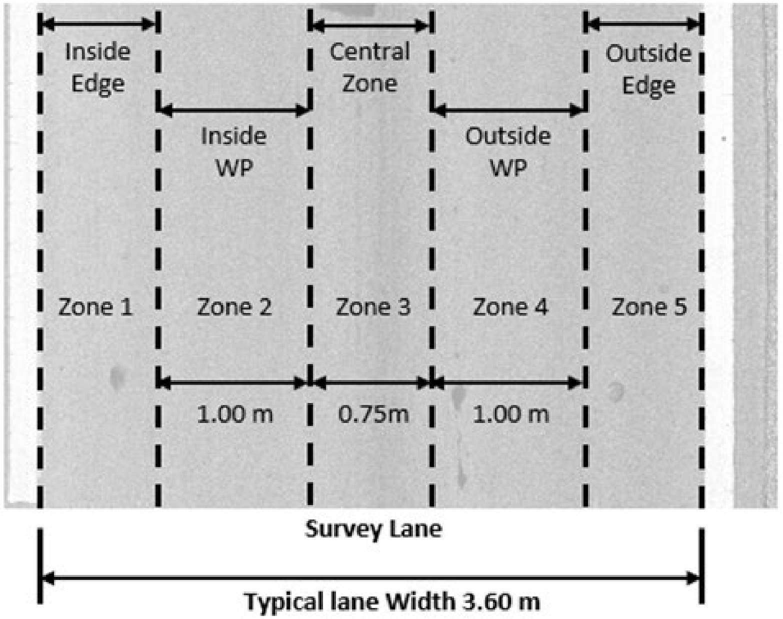
Where:

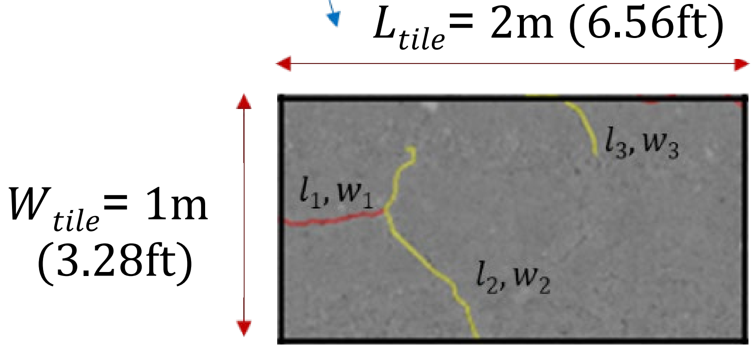
l_i = length of the crack i
w_i = average width of the crack i
A = pavement area where the PSCM is calculated
n = number of cracks present in the pavement area

Effectively, the PSCM is the percentage of “open” pavement area

Calculation example





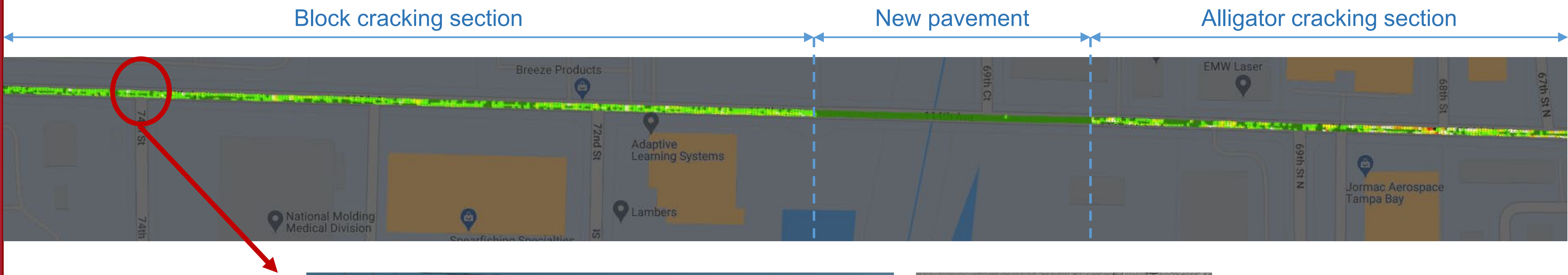


$$PSCM = 100 \cdot \frac{l_1 \cdot w_1 + l_2 \cdot w_2 + l_3 \cdot w_3}{L_{tile} \cdot W_{tile}}$$

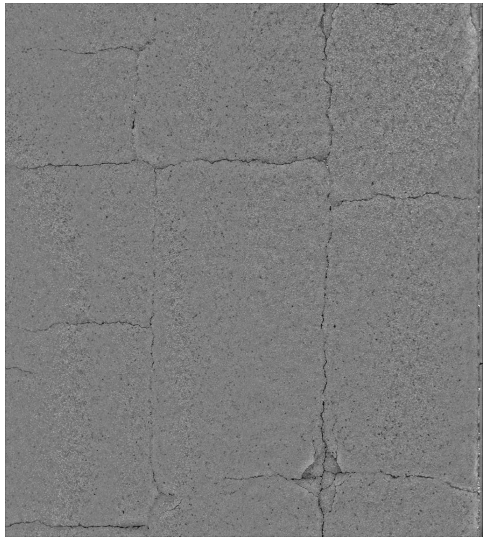
Suggested analysis area defined by intersection of:

- Road zones (transverse)
- 2m analysis interval (longitudinal)

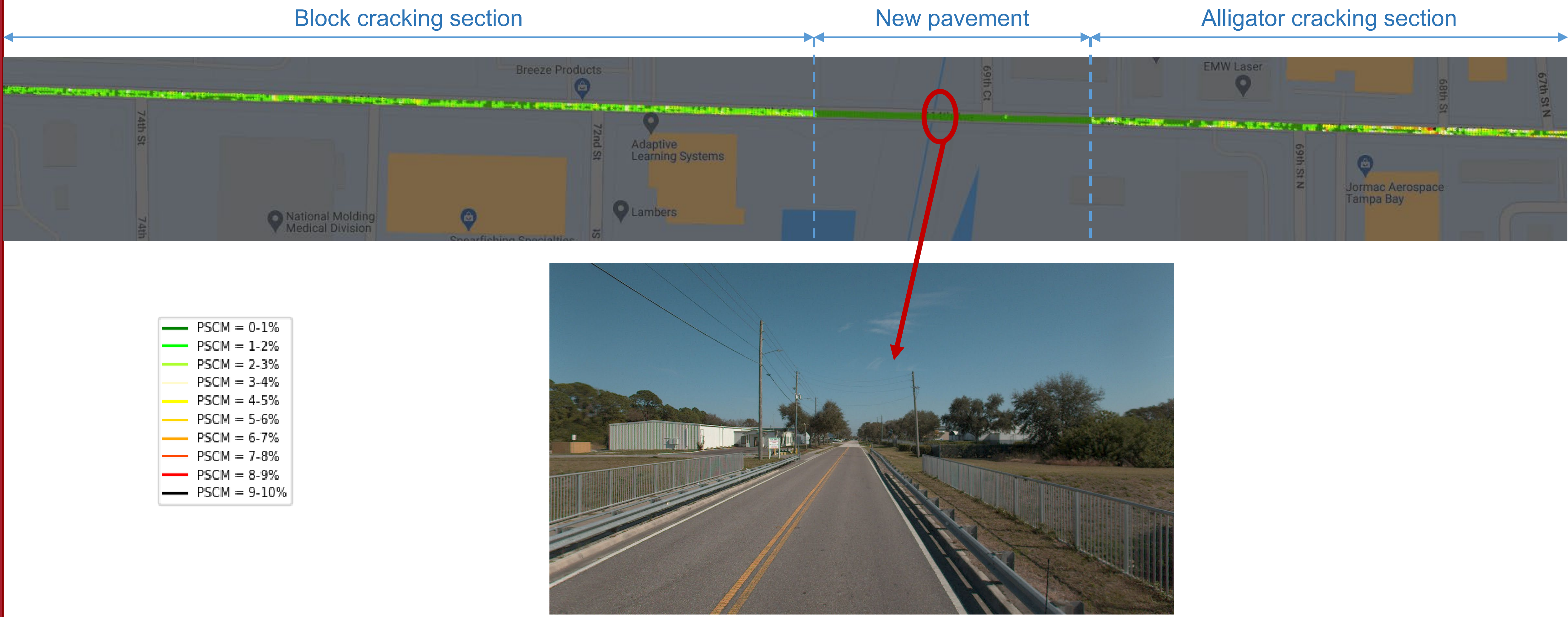
How PSCM relates to Pavement Conditions



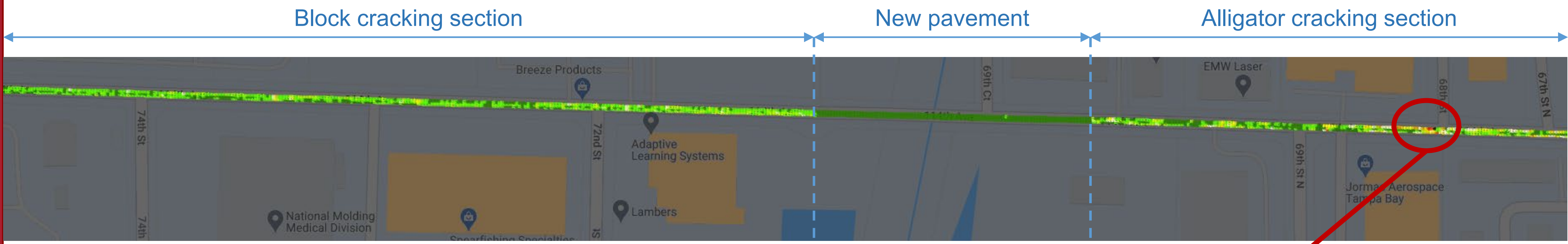
- PSCM = 0-1%
- PSCM = 1-2%
- PSCM = 2-3%
- PSCM = 3-4%
- PSCM = 4-5%
- PSCM = 5-6%
- PSCM = 6-7%
- PSCM = 7-8%
- PSCM = 8-9%
- PSCM = 9-10%

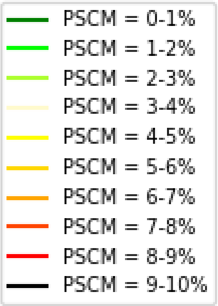


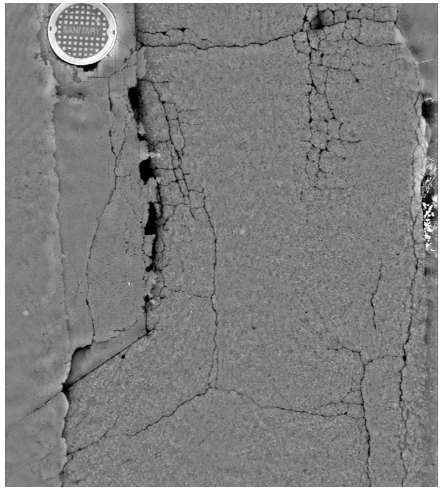
How PSCM relates to Pavement Conditions



How PSCM relates to Pavement Conditions







Aggregate PSCM values

Calculate the PSCM for the pavement section:

$$PSCM = \frac{1}{A_{section}} \sum_{i} A_i \, PSCM_i$$

Where:

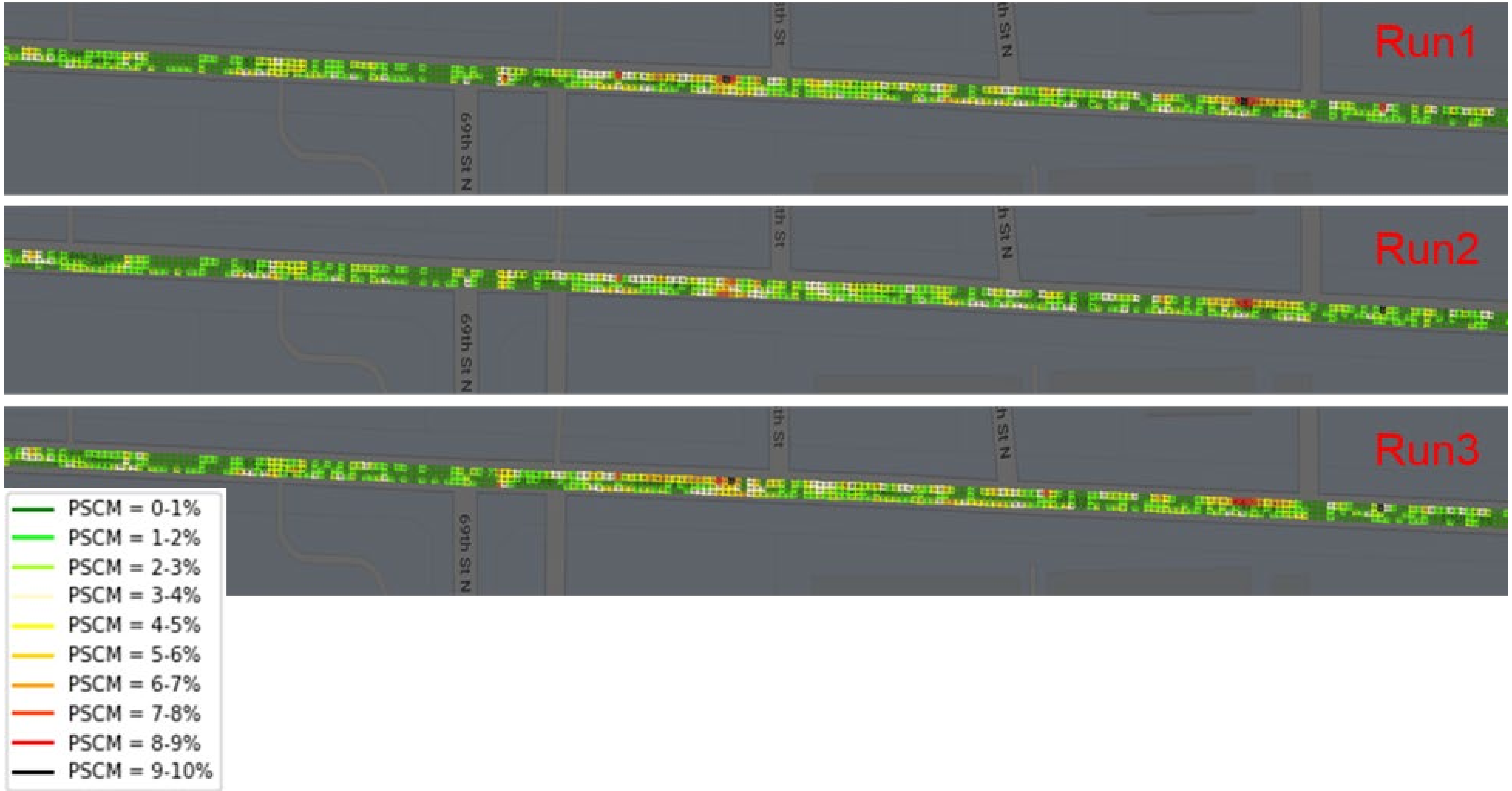
$PSCM_i$ = $PSCM$ of the analysis area i

A_i = area of the analysis area i

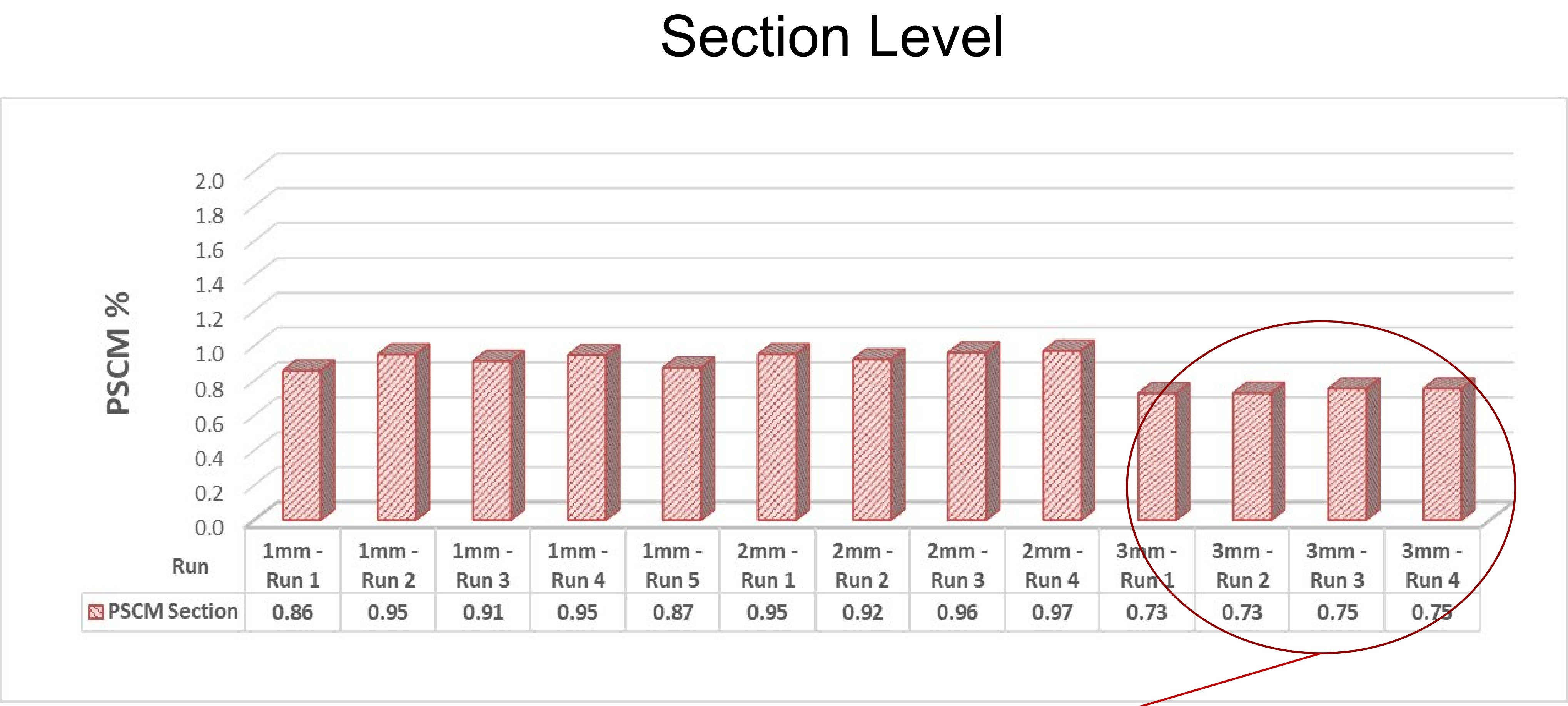
$A_{section}$ = sum of the analysis areas (A_i)

Repeatability of PSCM

Tile level

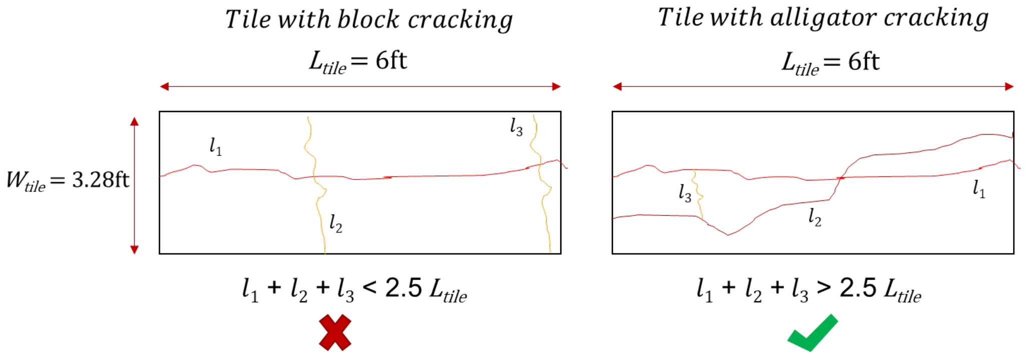


Repeatability of PSCM

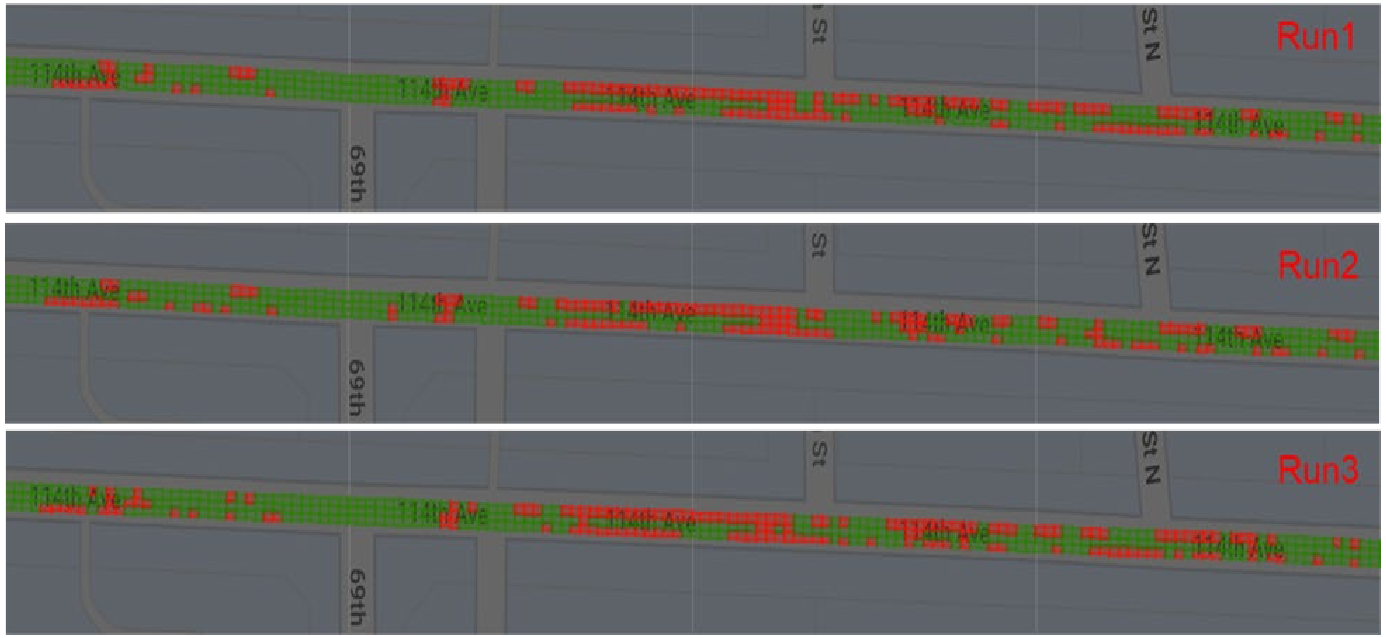


Using lower equipment resolution, some cracks remain undetected

Use of PSCM to classify cracking



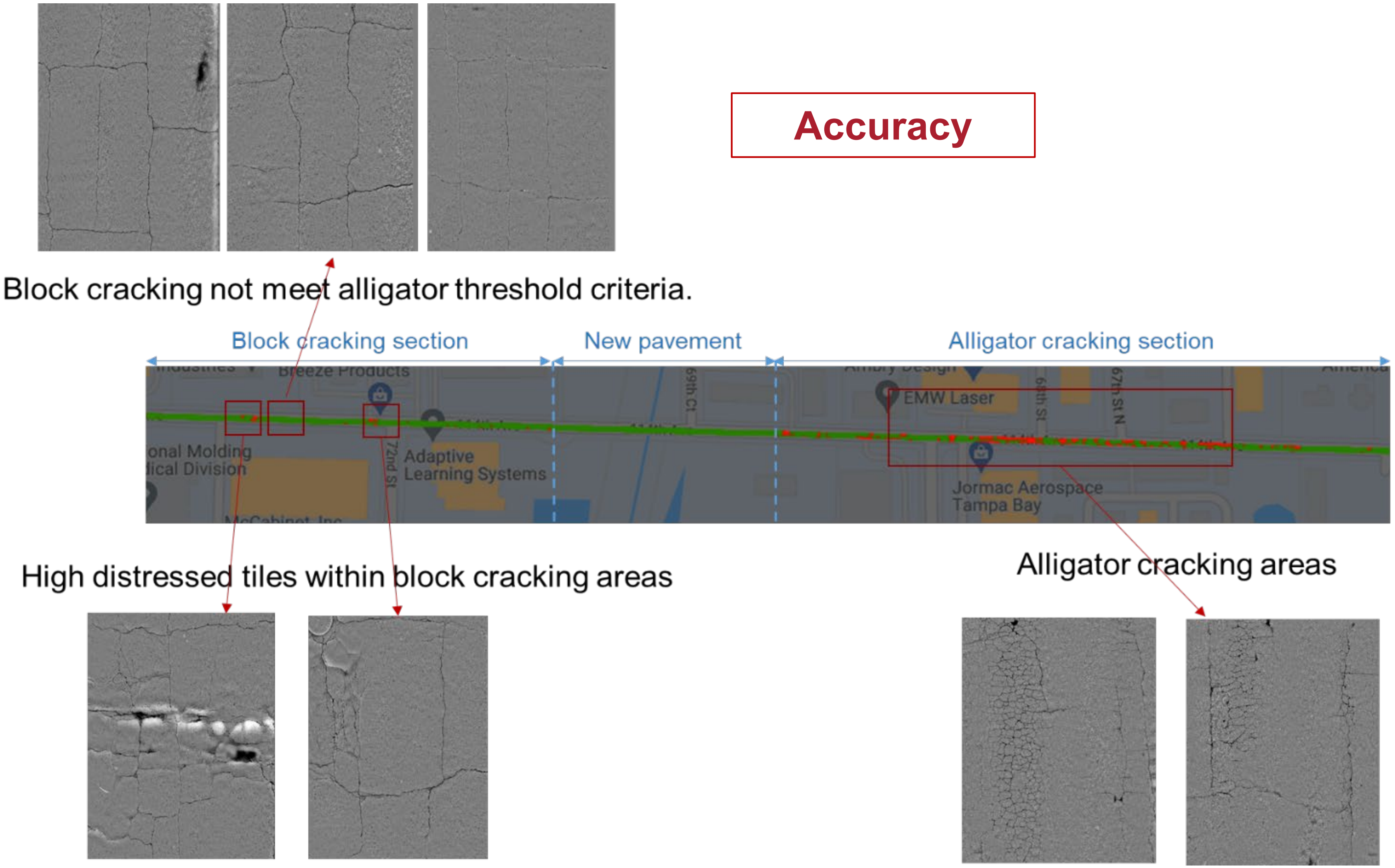
A tile can be considered affected by alligator cracking when the total length of cracking within the tile is greater than 2.5 times the length of the tile



Repeatability

Use of PSCM to classify cracking

Accuracy



Inclusion of other distresses

- Additional distresses could be included in the calculations (Pavement Surface Cracking, Potholes and Repairs Metric):

$$PSCPRM = PSCM + A_{Pot}/A_{Section} + W_f \cdot A_{Patch}/A_{Section} + (L_{SC} \cdot w_{SC})/A_{Section}$$

Where:

A_{pot} = sum of the potholes areas

A_{patch} = sum of the patching areas

W_f = weight factor → $W_f = 10\%$ means that the PSCM of the pavement underneath the patch would be 10% (severely distressed) had the patching not been applied

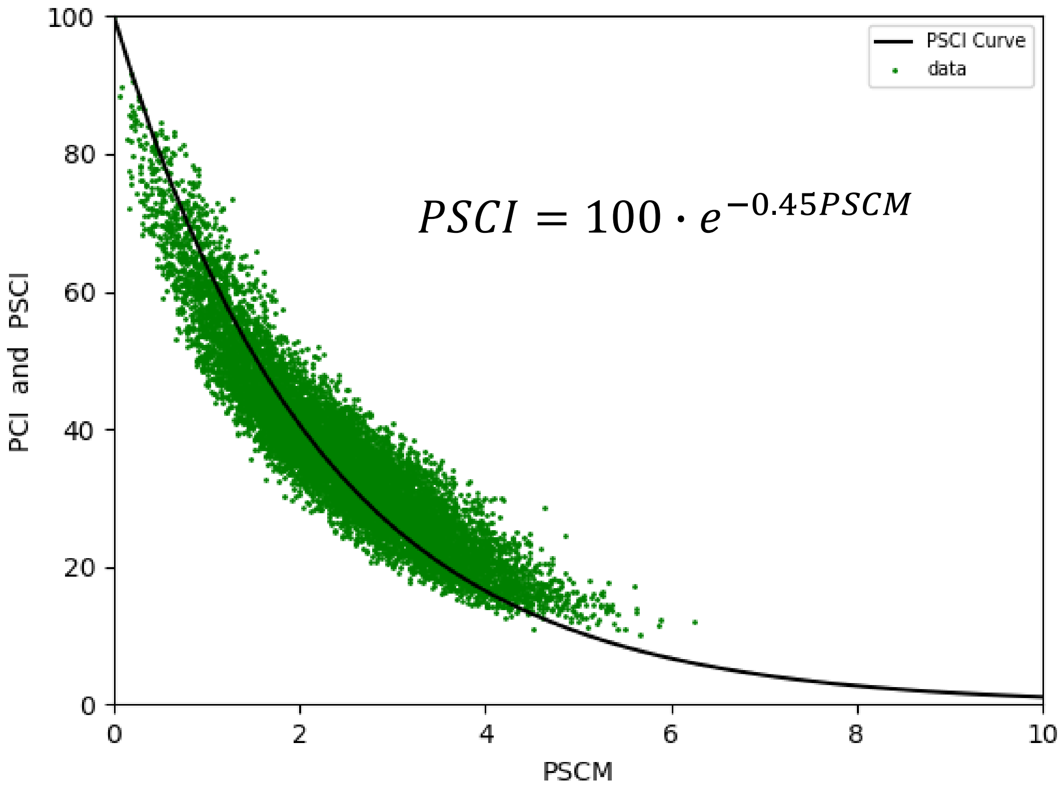
L_{SC} = total length of sealed cracking

w_{SC} = arbitrary sealed cracking width

Determination of the PSCI curve

- Simulated 10,000 random pavement sections*
- Calculated PCI (ASTM D6433) and PSCM for each

*Simulated pavements had only the following surface cracking distress:
- longitudinal and transverse
- slippage cracking
- alligator cracking
- block cracking

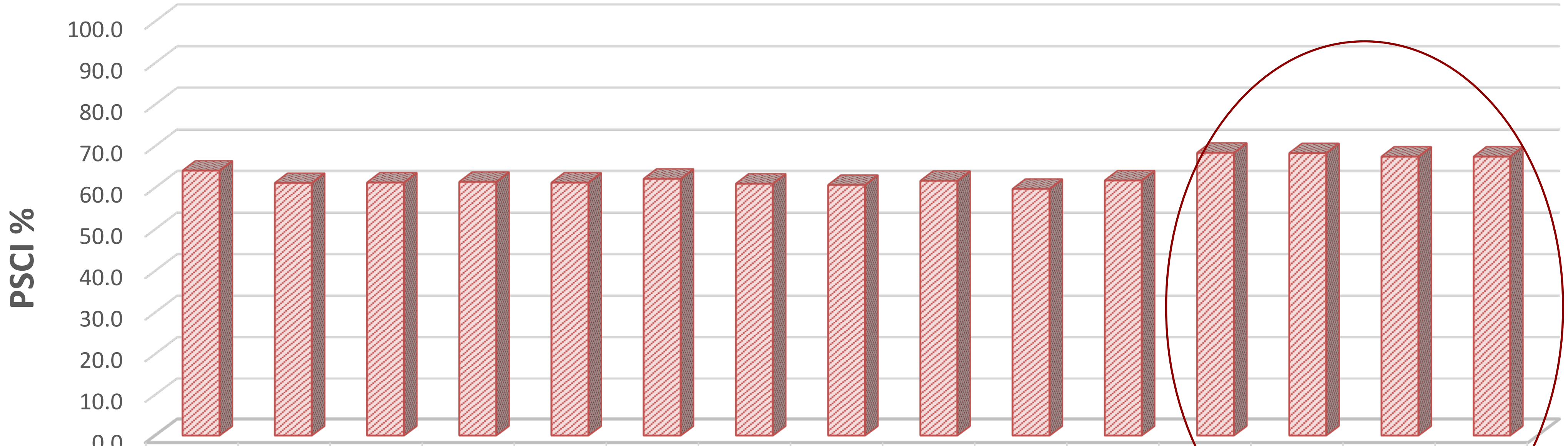


The formula for PSCI is derived with the intention of loosely following PCI, so that the numbers will appear similar to end users for sections that have just cracking.

The intent is **not** to *match* PCI

- ➢ **No Binning**
- ➢ **No Crack classification**
- ➢ **Only surface distresses**

Repeatability of PSCI



Run	Run1 - 1mm	Run2 - 1mm	Run3 - 1mm	Run4 - 1mm	Run5 - 2mm	Run6 - 2mm	Run7 - 2mm	Run8 - 2mm	Run9 - 2mm	Run10 - 2mm	Run11 - 2mm	Run12 - 3mm	Run13 - 3mm	Run14 - 3mm	Run15 - 3mm
PSCI Section	64.1	61.1	61.2	61.4	61.2	62.1	61.0	60.7	61.7	59.7	61.8	68.4	68.3	67.5	67.5

Using lower equipment resolution, some cracks remain undetected

	PSCI - Considering only 1,2mm
standard deviation	1.08
CV	1.7%

Conclusions

- The PSCM is designed to overcome **subjectivity** of crack classification and **binning** problem
- Good **repeatability** of PSCM and PSCI, but results depend on **equipment quality**. Some cracks remain undetected with low resolution equipment. More studies will be conducted on precision and bias.
- PSCM/PSCI must be **combined with other measurements** such as rutting, IRI, etc. to take **informed pavement management decisions**.
- PSCM can be used for **flexible and rigid** pavement. More investigations needed for rigid pavements.
- "*Two pavements with the **same PSCM** under differing circumstances would **not** necessarily behave or perform similarly. The interpretation and impact in each case rest on a **diagnosis and analysis** relevant to the **circumstances and objective**.*"

Today's Presenters

#TRBWebinar

- Kelvin Wang, *Oklahoma State University*
- Andy Mergenmeier, *Federal Highway Administration*

Federal Highway Administration RESOURCE CENTER 20 YEARS OF SERVICE

- David Lee, *University of Iowa*
- Michael Nieminen & Danielo Balzarini, *International Cybernetics*

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