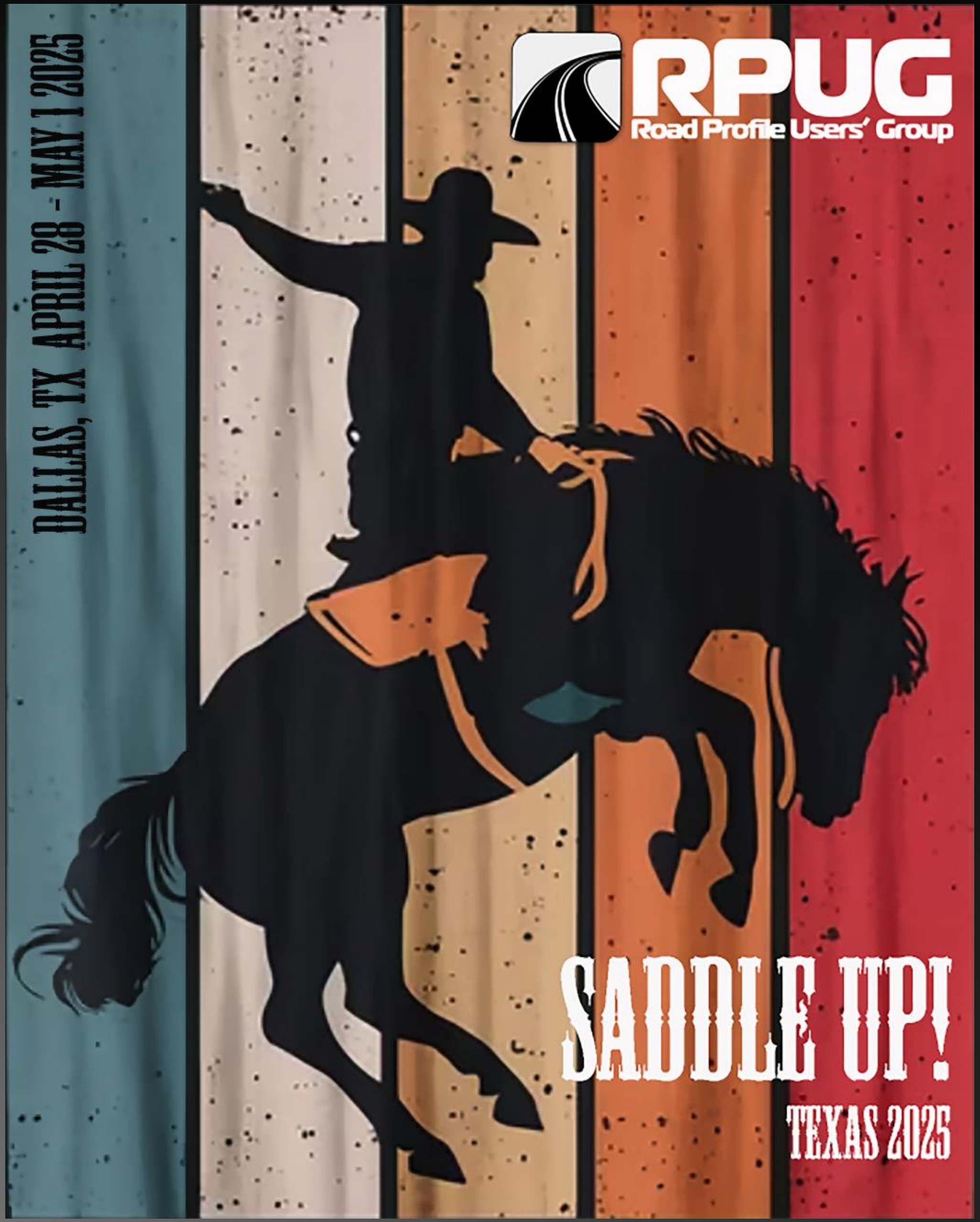

PROPOSAL FOR AN INTERNATIONAL STANDARD CRACK MAP

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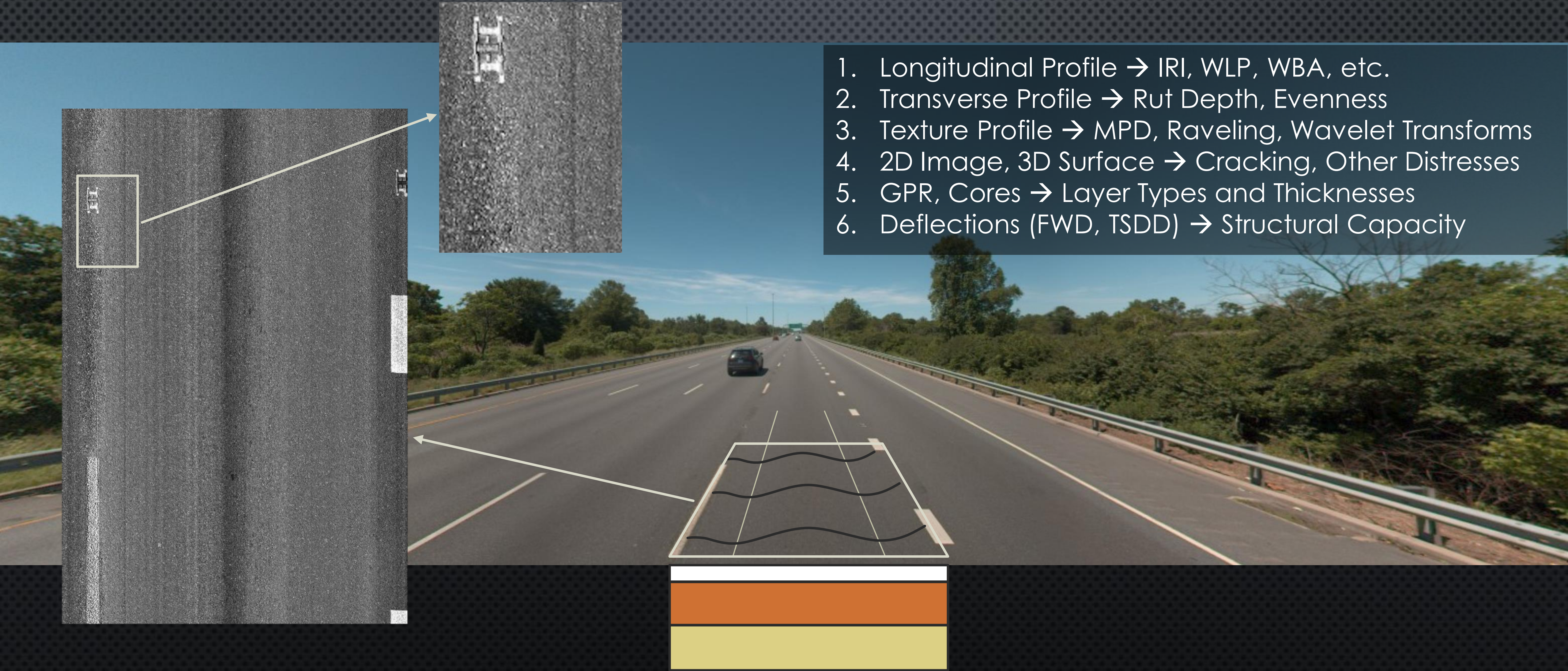
RPUG
Road Profile Users' Group

OUTLINE

- Reasons *for* and *against* measuring cracking
- Image vs Crack Map
- Crack Map Representation
- Image & Crack Map Library
- Usage Example in Python
- Towards System Certification for Cracking

CONDITION MEASURES AND DATA SOURCES



1. Longitudinal Profile → IRI, WLP, WBA, etc.
2. Transverse Profile → Rut Depth, Evenness
3. Texture Profile → MPD, Raveling, Wavelet Transforms
4. 2D Image, 3D Surface → Cracking, Other Distresses
5. GPR, Cores → Layer Types and Thicknesses
6. Deflections (FWD, TSDD) → Structural Capacity

REASONS FOR NOT MEASURING CRACKING

Philosophical

- Cracking is a lagging indicator of pavement condition
- Structural measures are more important than functional measures
- Of the functional measures, roughness, rutting, and texture are more important

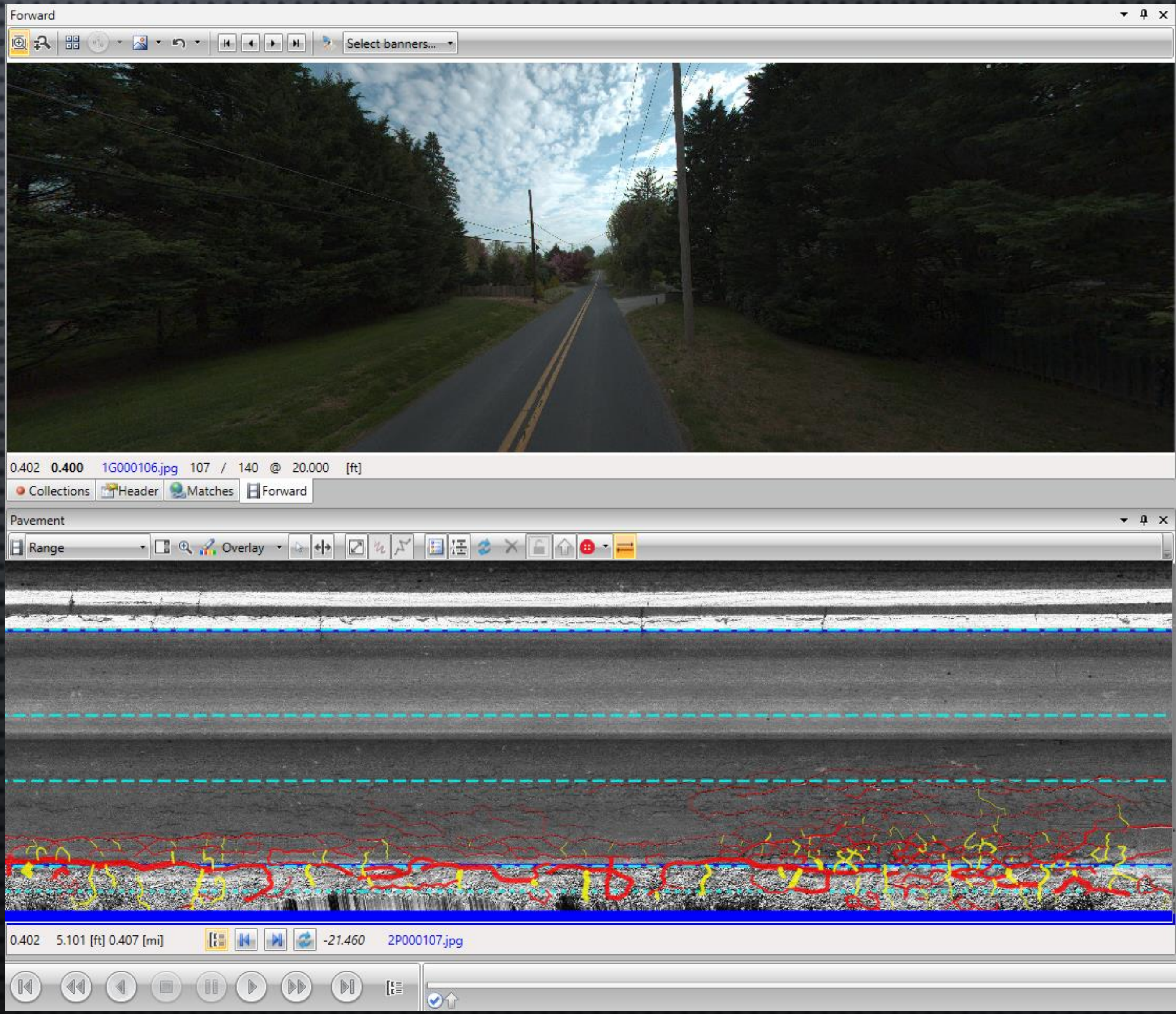
Practical

- Cracking is difficult to measure and requires costly, specialized equipment and processing software
- Traditional measurements are difficult to match with new sensors and automation
- Agreement on definitions of crack types has been elusive; industry standards are missing

REASONS FOR MEASURING CRACKING

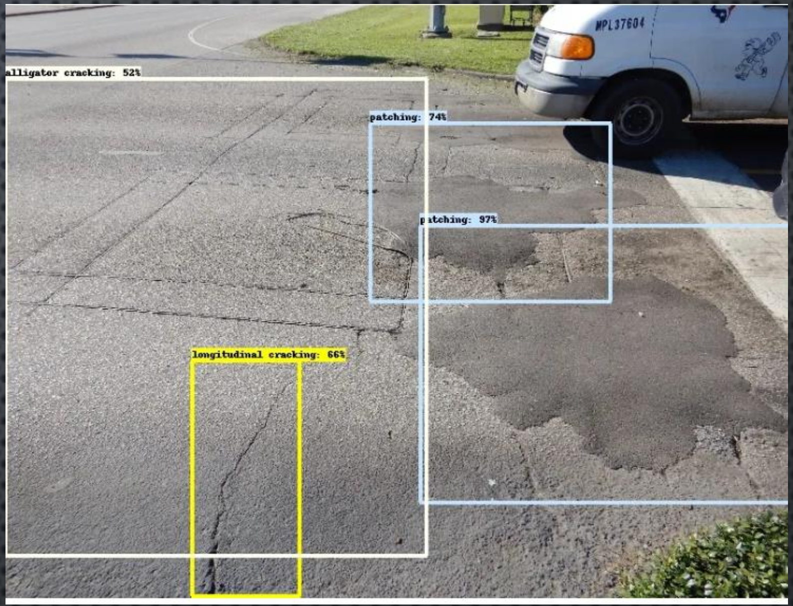
DON'T GIVE UP JUST BECAUSE IT'S DIFFICULT!

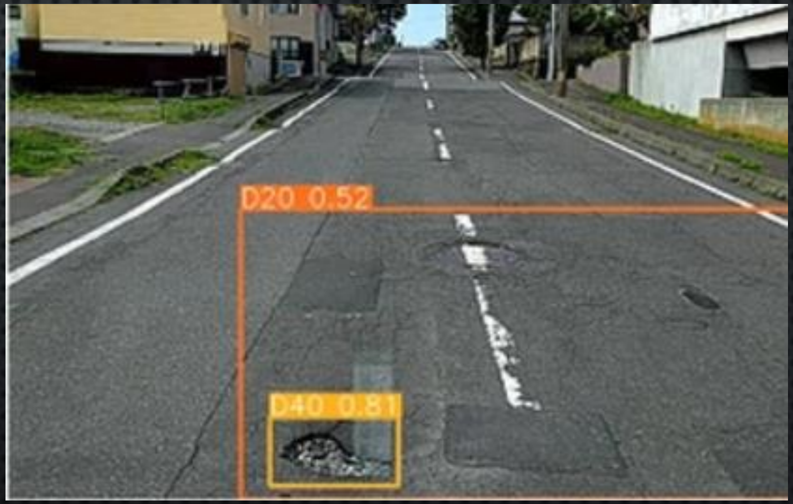
- Functional condition measures like cracking reflect **real (actual)** road deterioration
- Cracking allows **water** into the pavement and causes accelerated deterioration; thus, cracking is a **key defect** that should be understood
- Cracking can and should **trigger repairs**
- The type of cracking present can indicate the **root causes of the road deterioration**, whether it is primarily environment-related, frost-related, load-related, or material/construction related. The same factors can also cause negative changes in IRI, rutting, and texture.



SHOULD WE START CRACKING ANALYSIS FROM IMAGES?

AI-BASED DETECTION FROM RIGHT-OF-WAY IMAGES



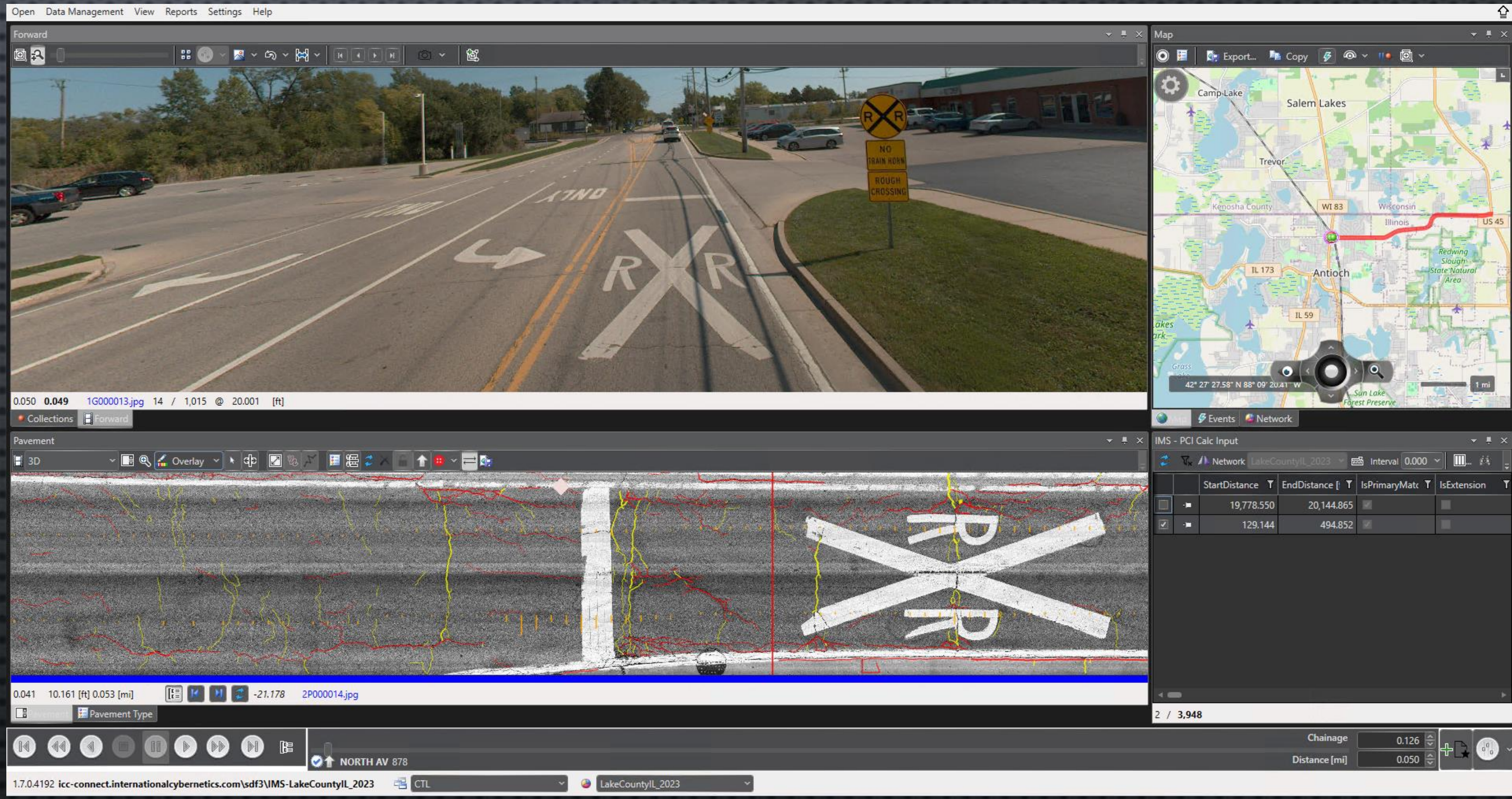


Difficult to measure length or area
Difficult to quantify severity
Not repeatable

FUNDAMENTAL CHALLENGES WITH CAMERA-BASED SOLUTIONS

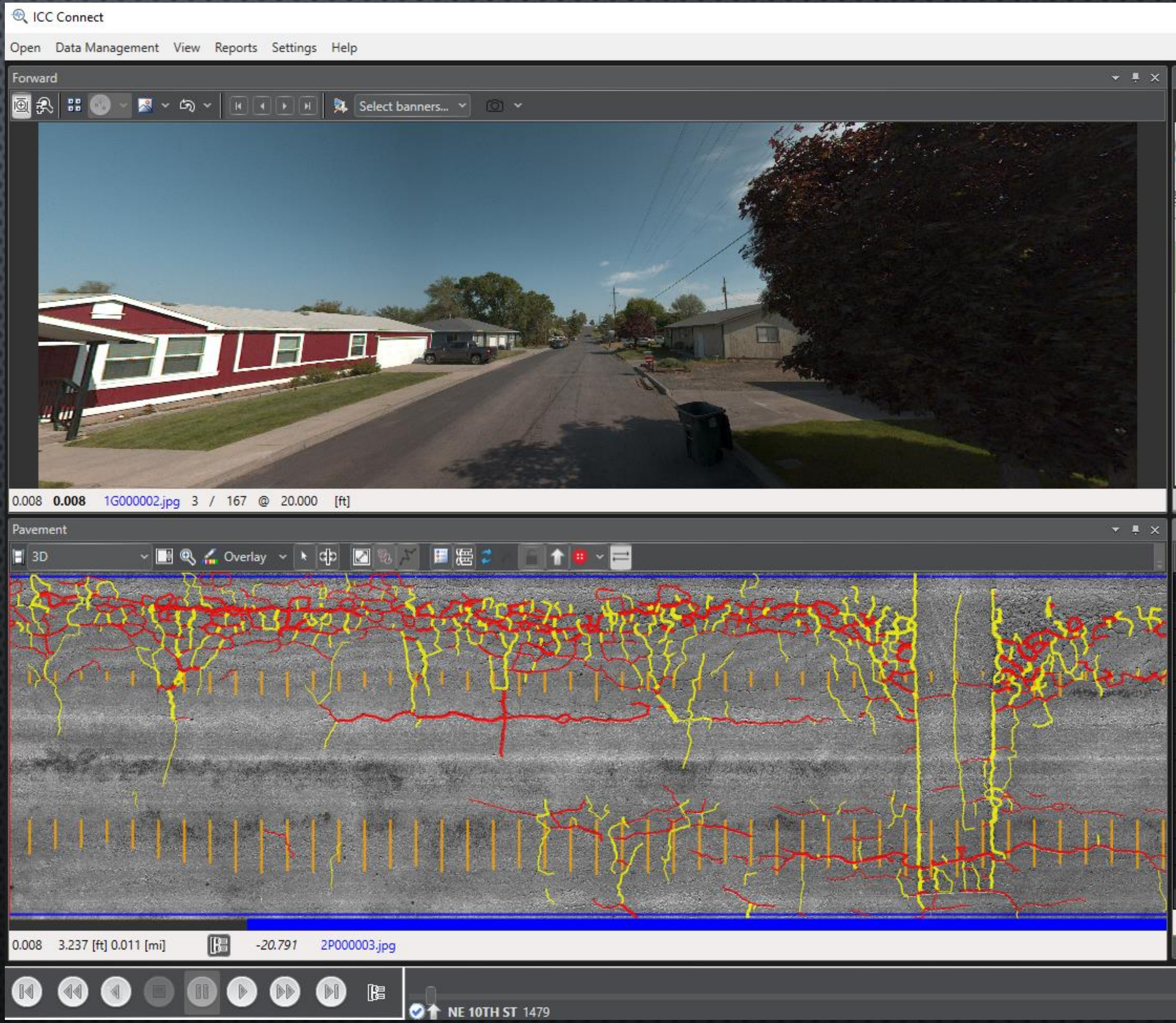
VISUAL ARTIFACTS COMPLICATE DISTRESS DETECTION

- **PAVEMENT MARKINGS**
- **SHADOWS FROM TREES, POLES, OVERHEAD WIRES, SIGNS, ETC.**
- **DIFFERENT LIGHTING CONDITIONS (WEATHER, TIME OF DAY)**
- **INABILITY TO CAPTURE DEPTH WITH HIGH ACCURACY**

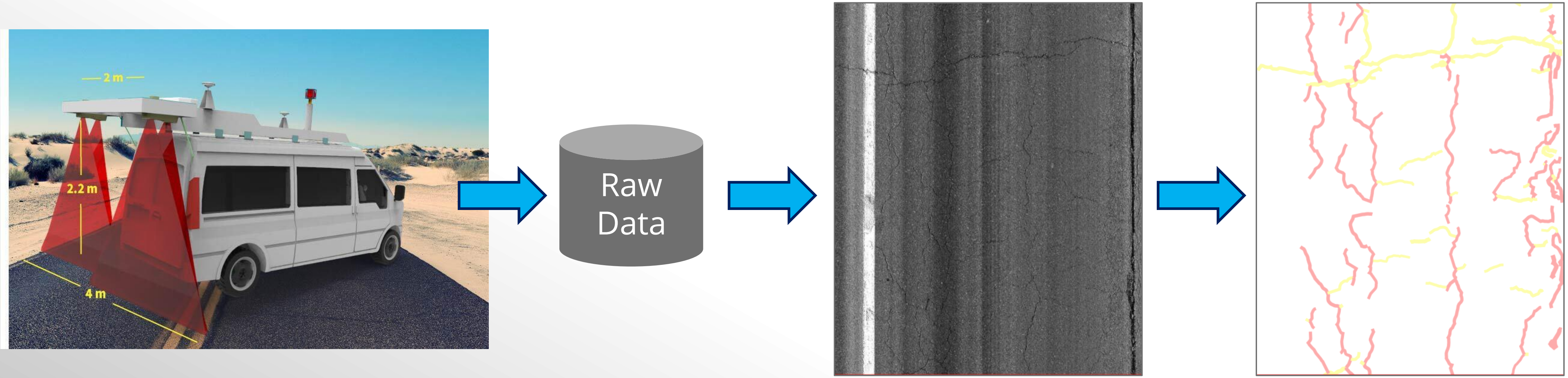


DEDICATED PAVEMENT IMAGING SYSTEMS

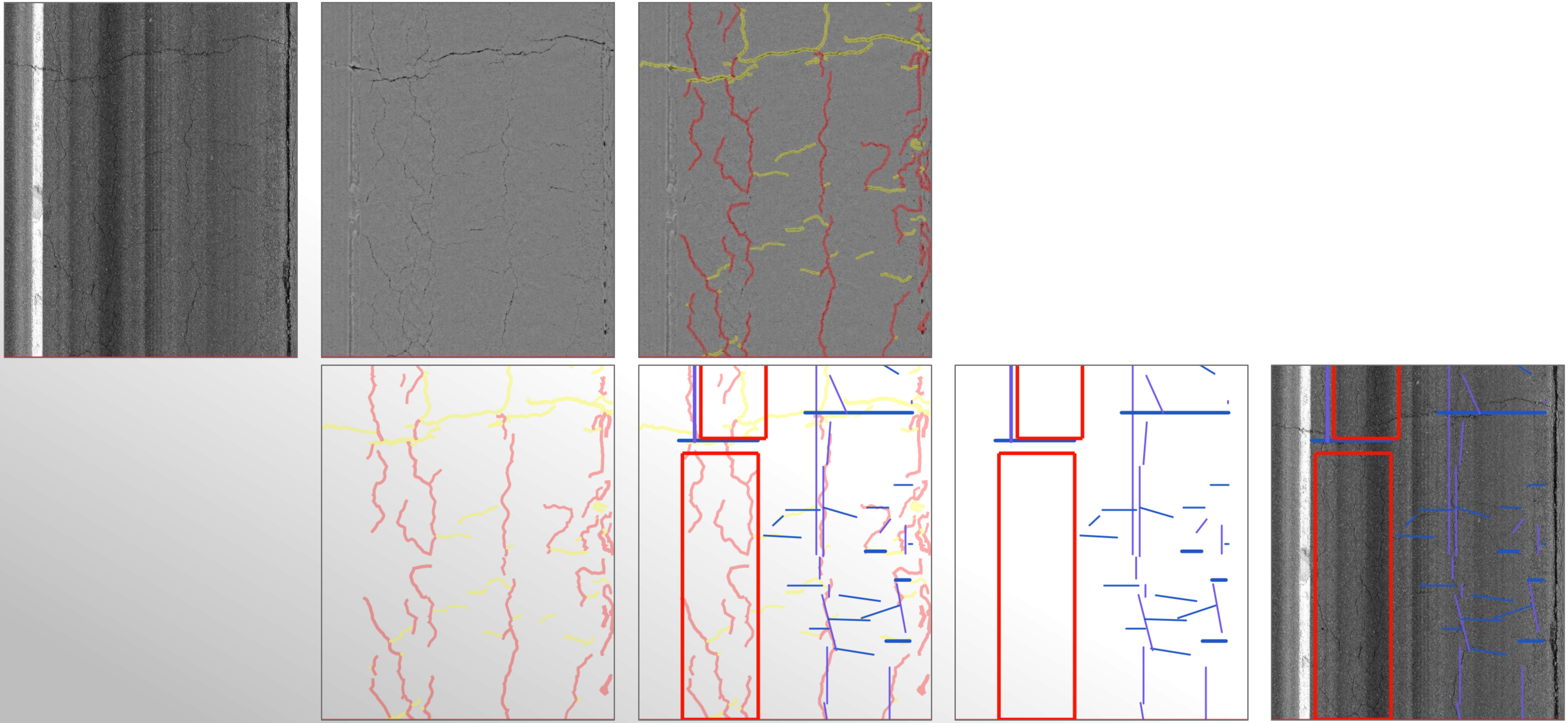
- **SPECIALLY-DESIGNED SYSTEMS LIKE LCMS-2:**
  - Provide consistent lighting conditions
  - Eliminate effect of shadows
  - Generate reliable 2D and 3D data useful for further analysis
  - Measure crack lengths, widths, and depths directly
  - Measure transverse profiles and ruts also
- **THE INDUSTRY HAS NOT FULLY TAPPED THE CAPABILITIES OF THESE SYSTEMS**



CRACK RATING PROCESS BREAKDOWN

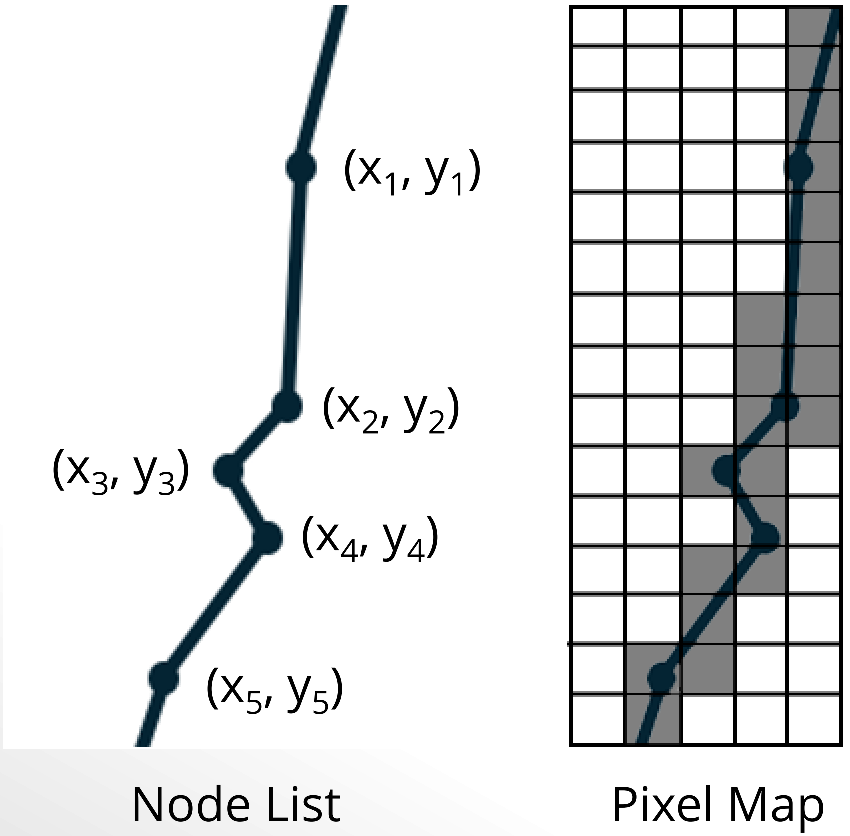


CRACK RATING PROCESS BREAKDOWN



CRACK MAP DEFINITION

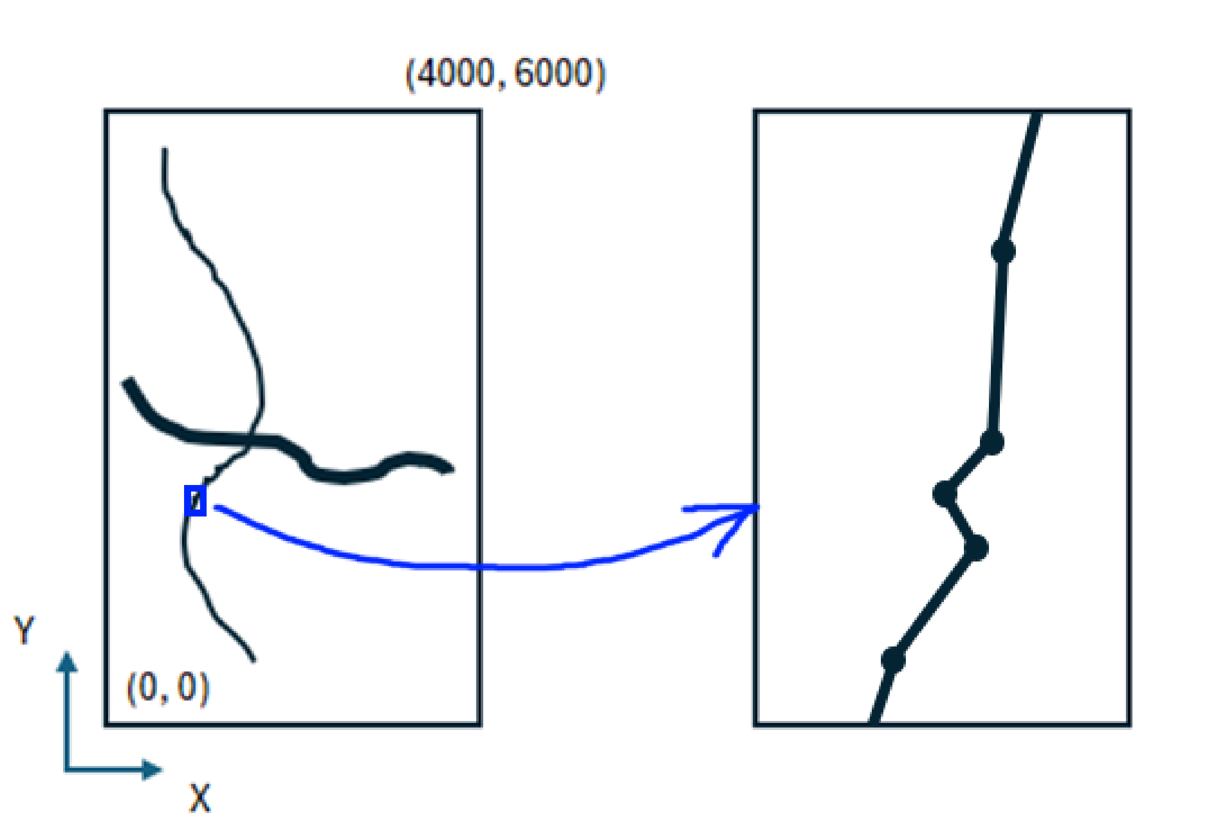
- Two Common Approaches
  - Node List
  - Pixel Map



CRACK MAP AS NODE LIST

DEFINING THE REPRESENTATION OF CRACKS

- A **crack map** is an **ordered list** [i, j, X, Y, Z, W]
  - i cracks consisting of j nodes
  - Located within a frame considered orthogonal
- For i^{th} crack and j^{th} node:
  - X, Y coordinate is the node location in the frame
  - Nodes are assumed to connect with straight lines
  - Z is average depth to next node
  - W is average width to next node



CRACK MAP STORAGE FORMAT

LCMS XML output


```xml
<CrackInformation>
  <DataFormat>1.4</DataFormat>
  <Unit>
    <X>millimeter</X>
    <Y>millimeter</Y>
    <Width>millimeter</Width>
    <Depth>millimeter</Depth>
    <Length>meter</Length>
  </Unit>
  <CrackList>
    <Crack>
      <CrackID>0</CrackID>
      <Length>0.38</Length>
      <WeightedDepth>0.85</WeightedDepth>
      <WeightedWidth>2.72</WeightedWidth>
      <Node>
        <X>1271.0</X>
        <Y>3764.8</Y>
        <Width>2.5</Width>
        <Depth>0.7</Depth>
      </Node>
      <Node>
        <X>1298.0</X>
        <Y>3749.8</Y>
        <Width>2.5</Width>
        <Depth>0.6</Depth>
      </Node>
      <Node>
        <X>1317.0</X>
        <Y>3739.9</Y>
        <Width>2.5</Width>
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      </Node>
      <Node>
```
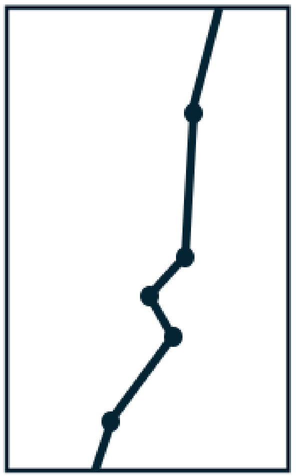




Transform to geospatial representation

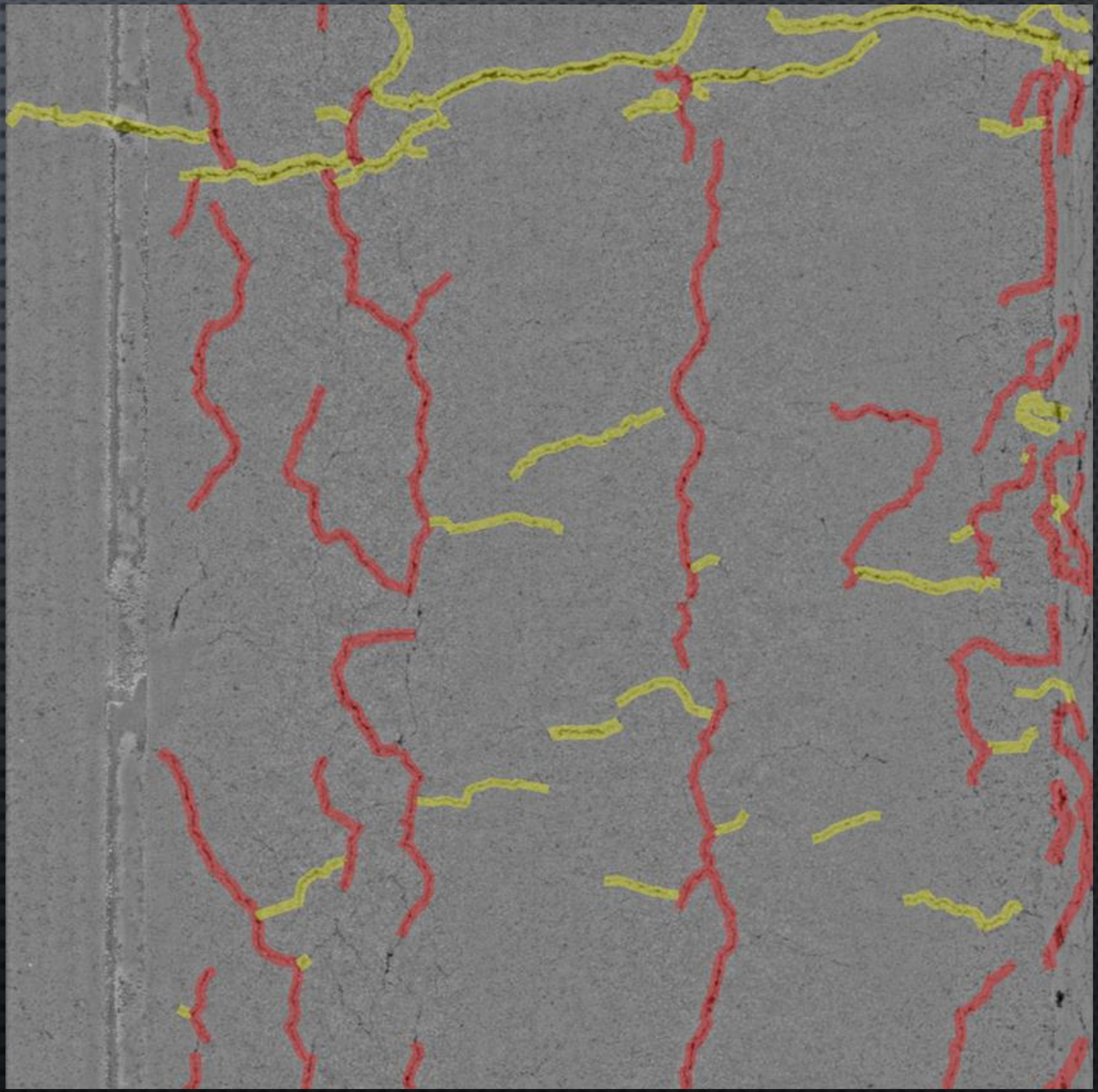
- Use existing standard: WKB (Well Known Binary)
- Binary equivalent of WKT (Well Known Text)
  - Text markup language for representing vector geometry objects, as defined by Open Geospatial Consortium (OGC) in the ISO/IEC 13249-3:2016 standard
  - X, Y and Z are the 3D spatial coordinates, and M as a 4th numerical attribute which is often used for linear reference systems (measured polylines)
- Use X, Y for **node coordinates**
- Use Z for **crack depth**
- Use M for **crack width**
- Save to repository as a **GEOMETRY** data type

CRACK MAP REPRESENTATION BENEFITS

- Example spatial operations applied to geometries:
  - Intersections of polylines with polygons for determining the road zones distribution (wheelpaths, edges, center)
  - Buffering and union operations for pattern identification
  - Crack density calculation using a tile method for classifying alligator and block cracking
  - Linear regression for line fitting and classification of transverse, longitudinal, and meandering cracking
  - Consolidating overlapping polylines

PROPOSED INTERNATIONAL STANDARD CRACK MAP

- **Standardization leads to innovation**
- Could we have standard **.CRK files** produced by multiple sensors and ingested by multiple software applications in the future?
- Could we consider a crack map representation for a future ASTM and/or ISO/EN standard?
- N.B. This does <u>not</u> imply that *crack types* or *cracking metrics* must be common to all users!



STANDARD CRACK MAP BENEFITS

Independent of sensor type and vendor

Anyone can open and process the same crack maps

Crack maps requires far less storage: **6 MB per mile** vs **175 MB per mile** for full resolution images

Suitable as an input for many types of analytical methods

Far faster crack classification than from images

Much easier to compare crack maps to each other (i.e. for accuracy) than to compare images

Basis for sensor system certification!

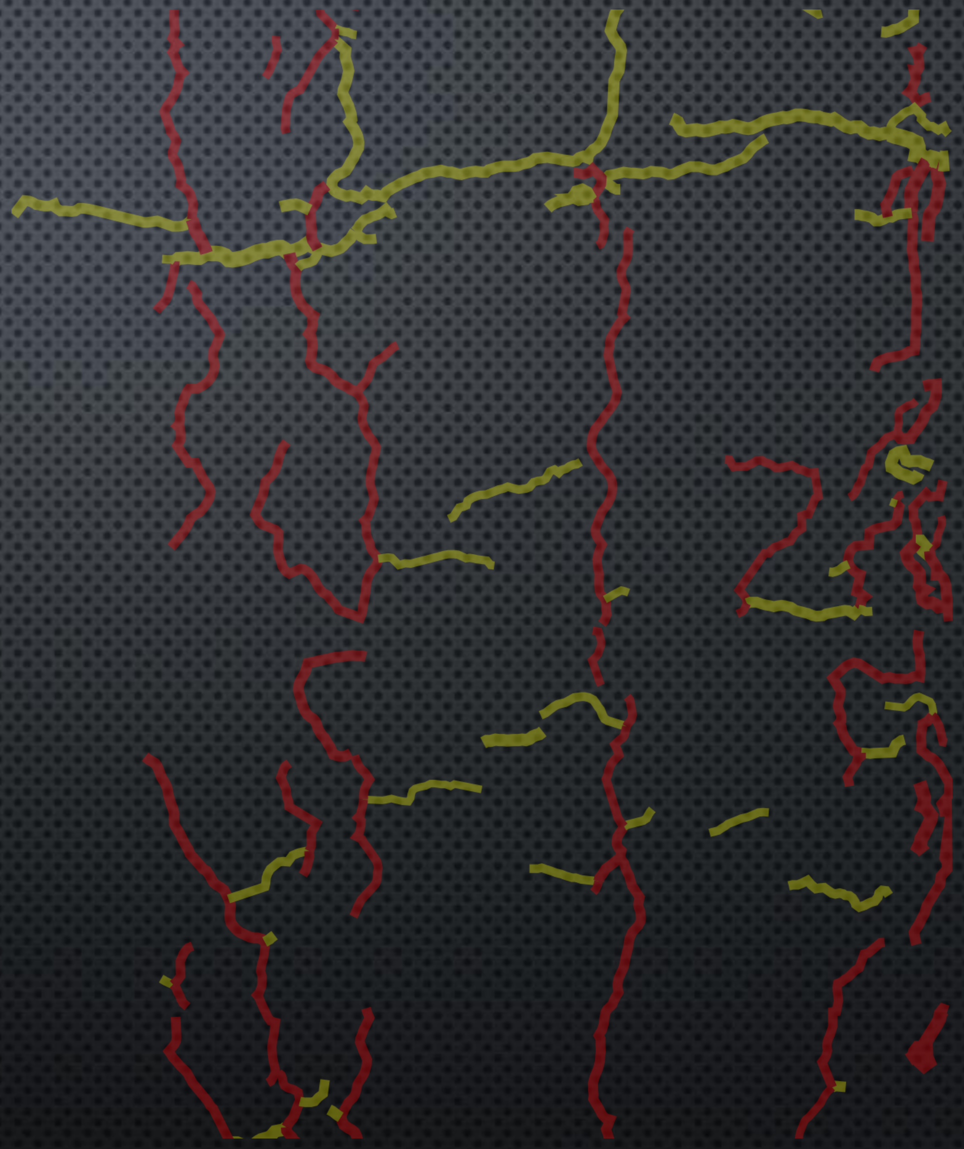
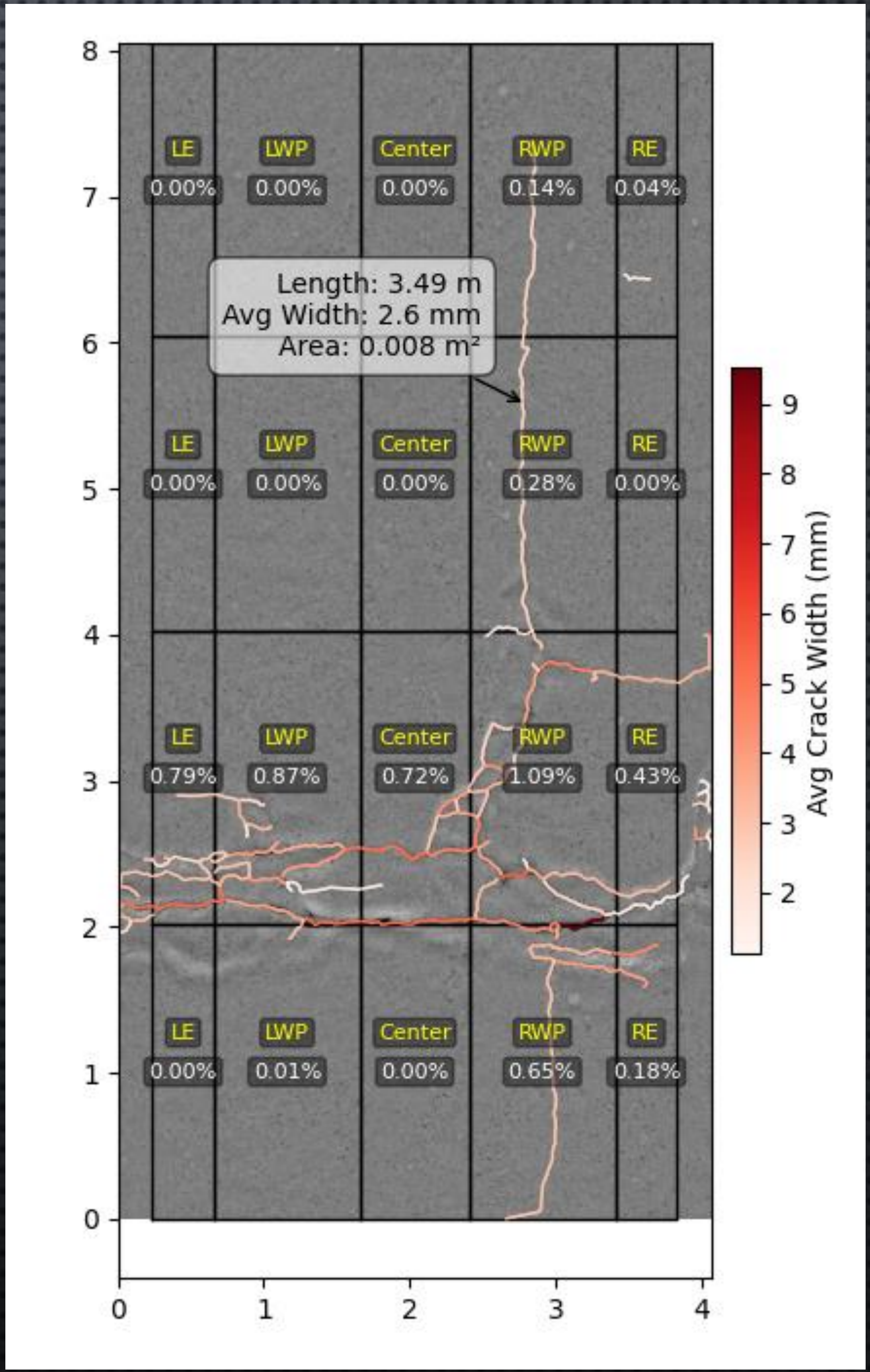


IMAGE AND CRACK MAP LIBRARY

Next steps:

- Draft ASTM standard for the crack map format.
- Share library of high resolution 2D intensity images, 3D range images, and crack maps with the industry.
- Share sample Python code illustrating use cases.
- Develop system certification process for cracking.



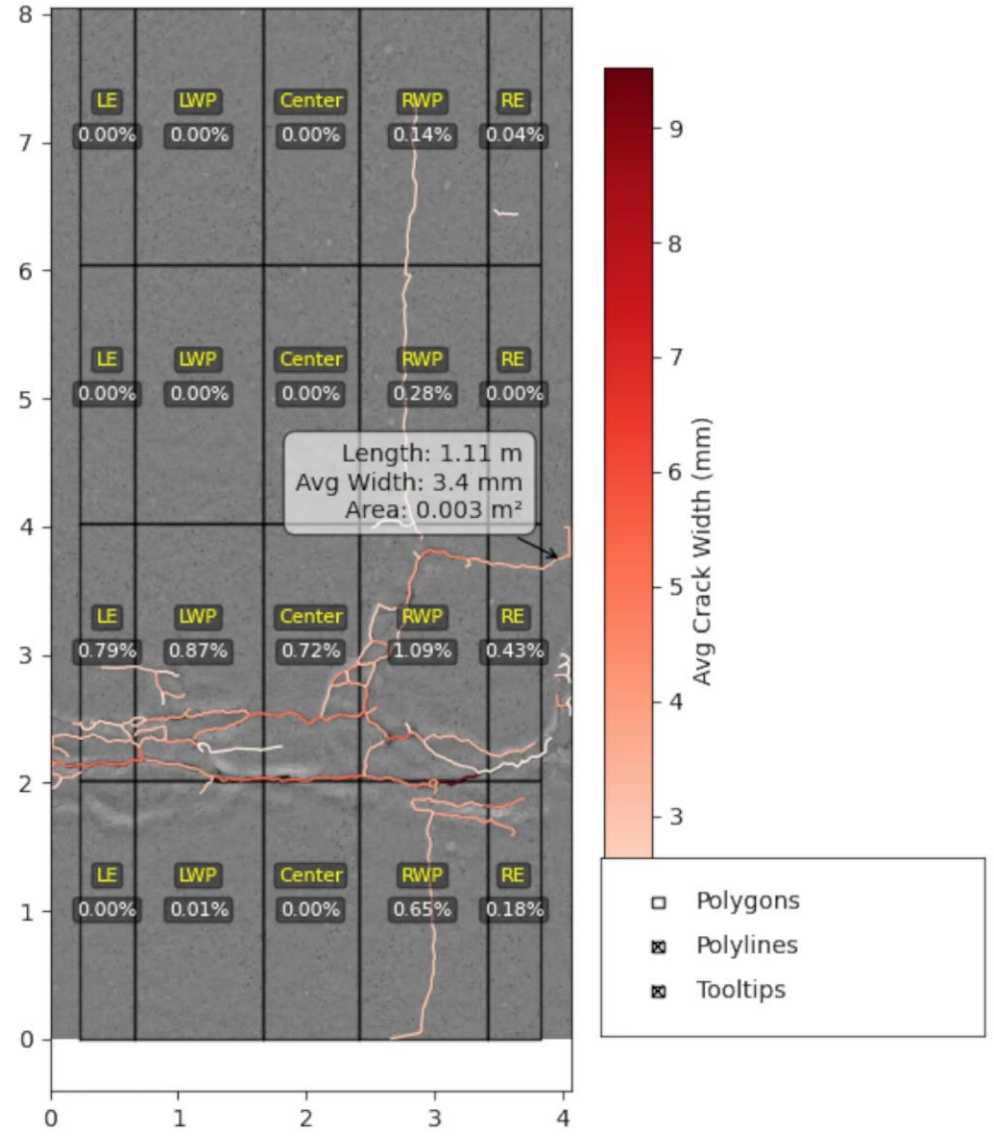
PYTHON CODE

We are providing sample Python code for working with the crack map files.

It demonstrates how to perform geometric operations with both polyline and polygon crack maps using the **shapely** library.

For more information, contact:

Michael Nieminen (mnieminen@icc-ims.com) or Danilo Balzarini (dbalzarini@icc-ims.com)



PYTHON CODE

Given any CRK files, the Python code calculates the ASTM E3303 metrics.

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

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

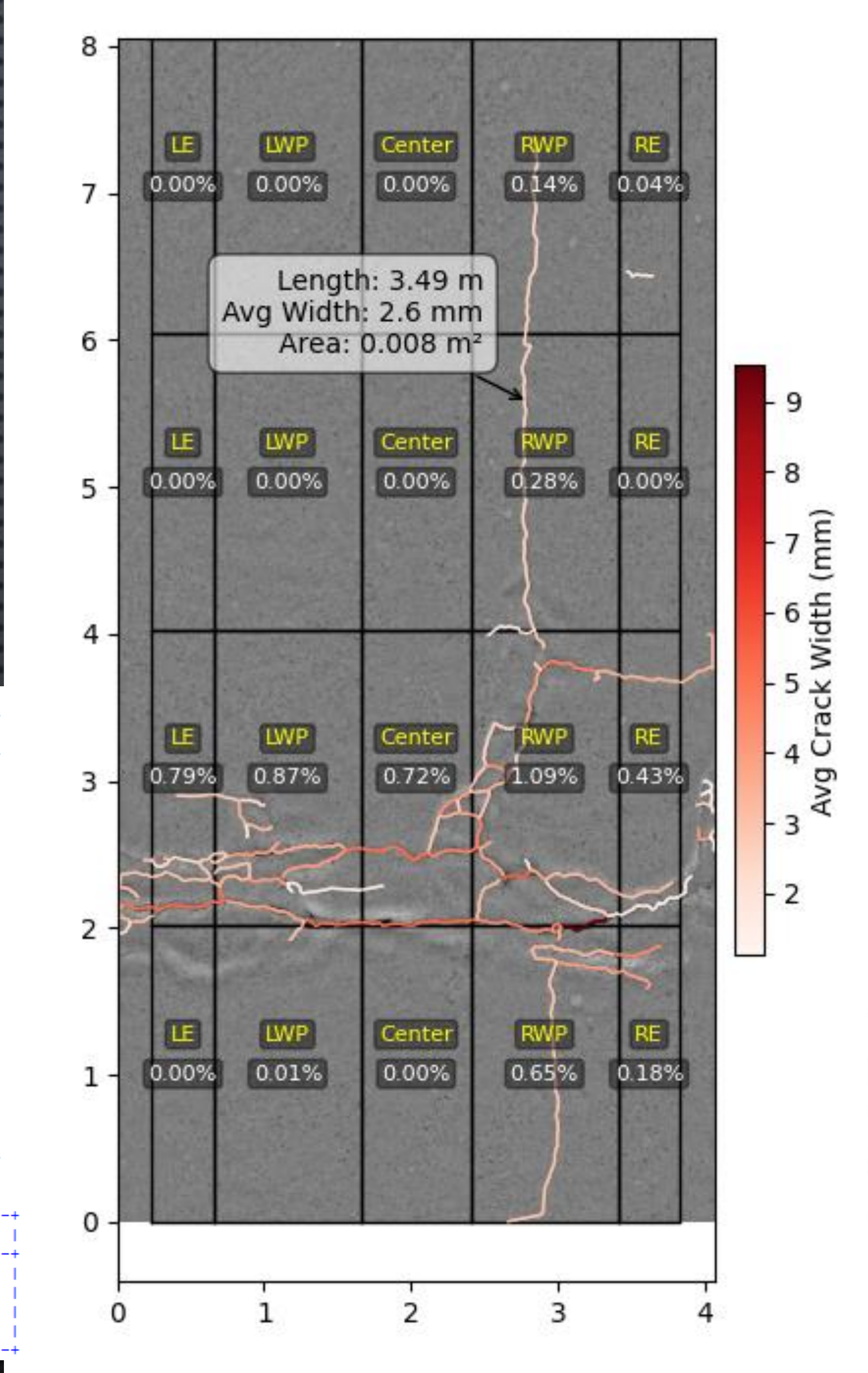
$$PSCI = 100 \cdot e^{-0.45 PSCM}$$

Zone Metrics:

Band	Zone	Crack Length (m)	% Cracked	Avg Width (mm)
1	LE	0.00	0.0%	0.0
1	LWP	0.13	0.0%	1.6
1	Center	0.00	0.0%	0.0
1	RWP	3.85	0.7%	3.4
1	RE	0.60	0.2%	2.6
2	LE	1.88	0.8%	3.6
2	LWP	5.30	0.9%	3.3
2	Center	2.61	0.7%	4.2
2	RWP	6.30	1.1%	3.5
2	RE	1.35	0.4%	2.7
3	LE	0.00	0.0%	0.0
3	LWP	0.00	0.0%	0.0
3	Center	0.00	0.0%	0.0
3	RWP	2.30	0.3%	2.5
3	RE	0.00	0.0%	0.0
4	LE	0.00	0.0%	0.0
4	LWP	0.00	0.0%	0.0
4	Center	0.00	0.0%	0.0
4	RWP	1.38	0.1%	2.1
4	RE	0.19	0.0%	1.8

Band Metrics:

Band	Total Length (m)	Avg Crack Length (m)	Density (m/m²)
1	4.58	0.51	0.63
2	17.45	0.29	2.41
3	2.30	0.77	0.32
4	1.58	0.79	0.22



TOWARDS CRACKING CERTIFICATION

Dr. James Tsai proposed a scoring method for comparing crack maps to a baseline, using Enhanced Buffered Hausdorff Distance, in 2017.*

Can this approach be extended for **node list crack maps**?

Areas for further work:

- Incorporate crack width into scoring (e.g. penalty should be higher for missing larger cracks)
- Address cross-correlation/alignment between multiple runs
- Develop certification criteria
- Identify certification track partner(s)

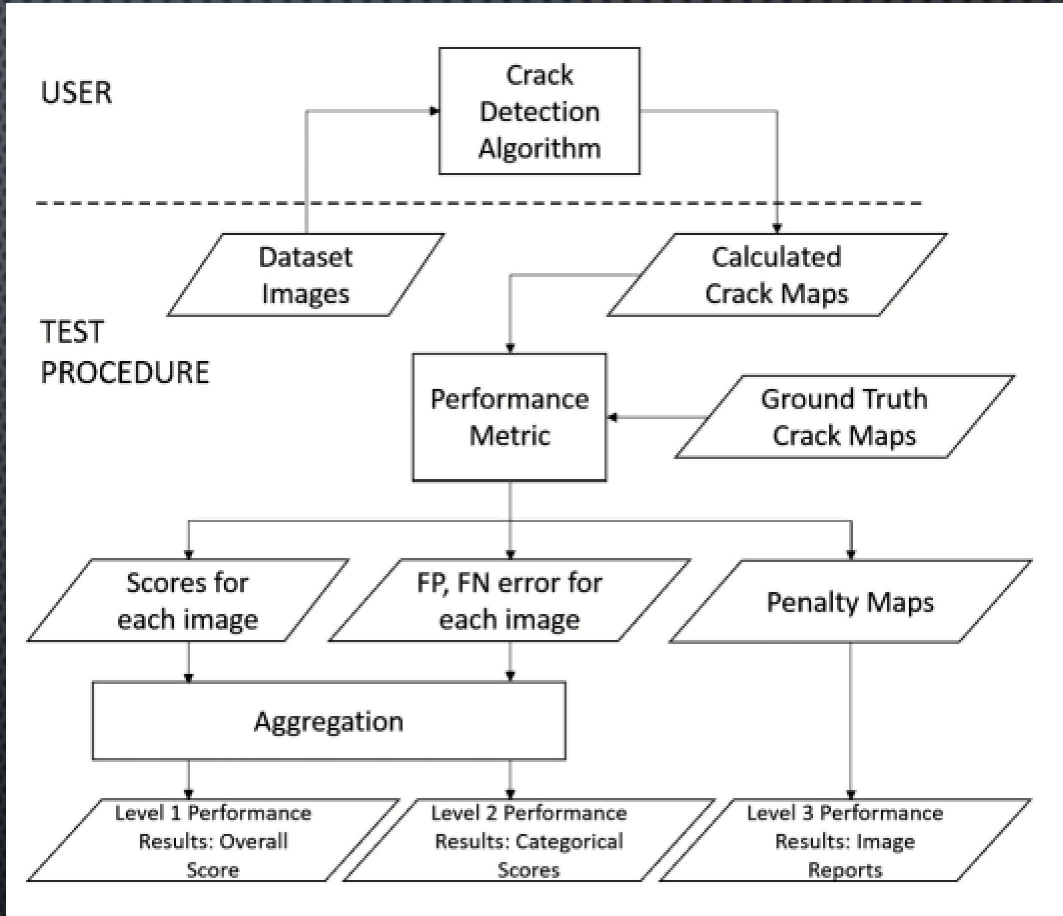


Fig. 10. Flowchart of using CDA-PES

*Tsai, Y., Chatterjee, A., Comprehensive, Quantitative Crack Detection Algorithm Performance Evaluation System, Journal of Computing in Civil Engineering, 2017, 31(5): 04017047

THANK YOU

Acknowledgements: Danilo Balzarini, PhD; Paul Voicu; Adison Hiday; Ryan Salameh, PhD.

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