Accuracy and Precision of High-Speed Field Measurements of Pavement Surface Rutting and Cracking

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Introduction

- Transportation agencies use, or are transitioning to, 3D automated distress measurement systems
- Accuracy of the automated measurements is the biggest challenge faced by developers of these systems
- Agencies have to choose between prompt delivery and enhanced accuracy
- Errors in distress data can lead to increased maintenance costs and inappropriate project prioritization

Objective

Independent evaluation of the accuracy and precision of high-speed measurements of rutting and cracking in Texas highways accounting for:

- Pavement Surface Type (HMA, Surface Treatment, JCP, CRCP)
- Distress Type and Extension (rut depth, Crack type and width)
- Surface Macro-Texture (MPD)
- Level of Manual intervention (automated vs corrected)

- Phase 1: Evaluation of Rutting Measurements
- Phase 2: Evaluation of Cracking Measurements

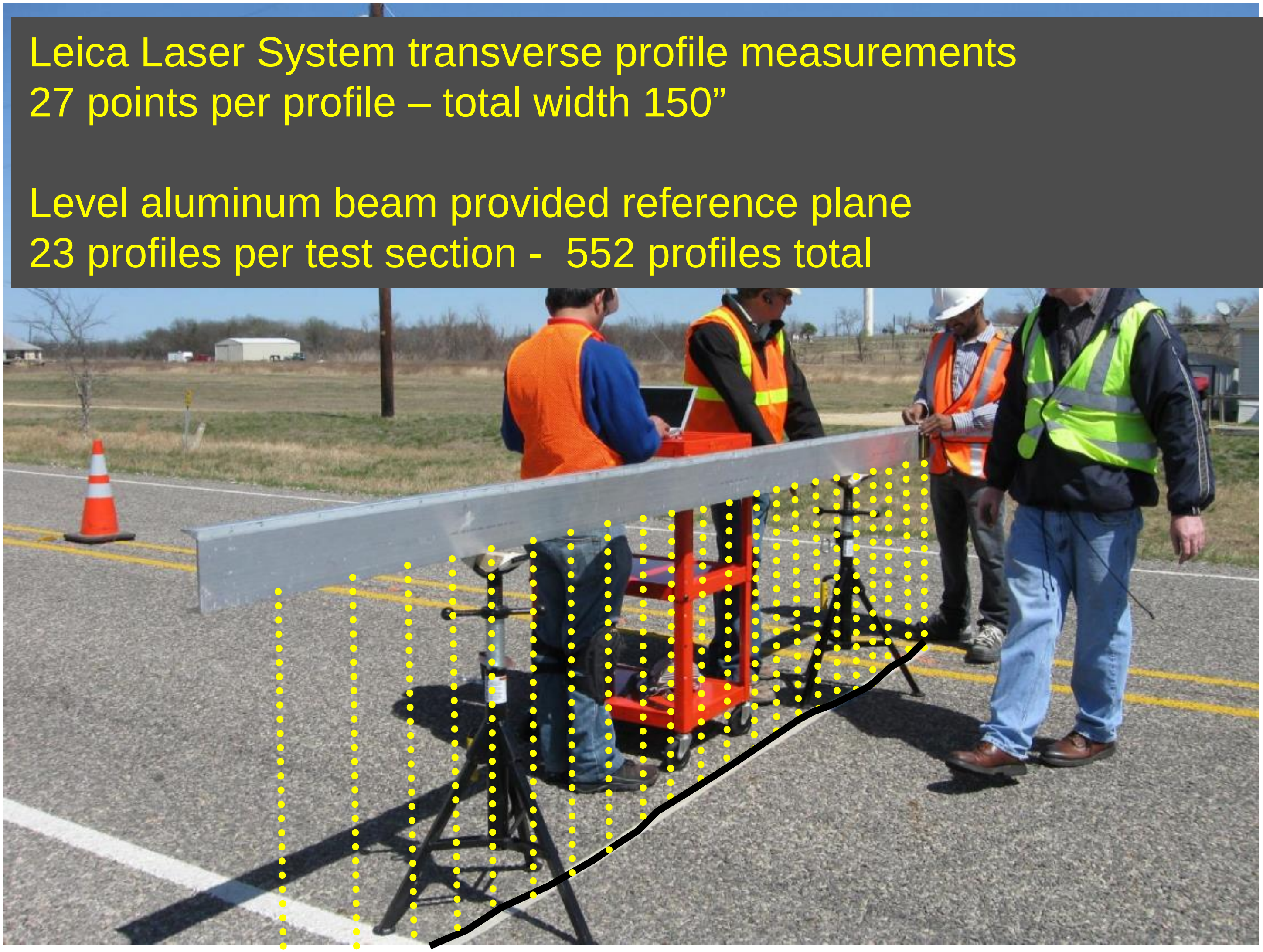
Phase 1 - Experimental Design

- Twenty-four 550-ft long highway sections:
  - Different rut severity levels and representative of Texas highways
  - RD every 5-ft, both WP (5,328 meas) + Profiles every 25-ft (552 tr prof)

Collection of Reference Transverse Profiles

Leica Laser System transverse profile measurements
27 points per profile – total width 150”

Level aluminum beam provided reference plane
23 profiles per test section - 552 profiles total

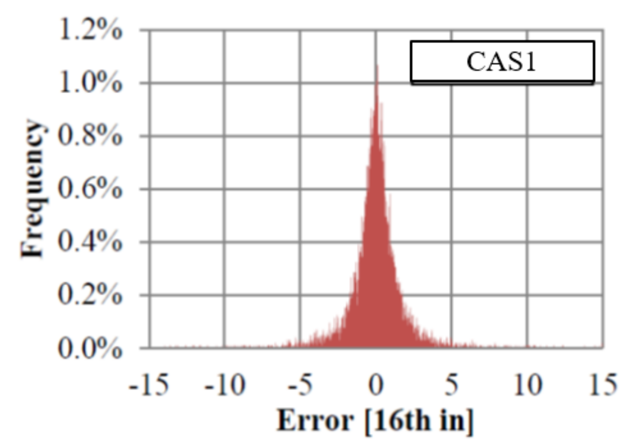


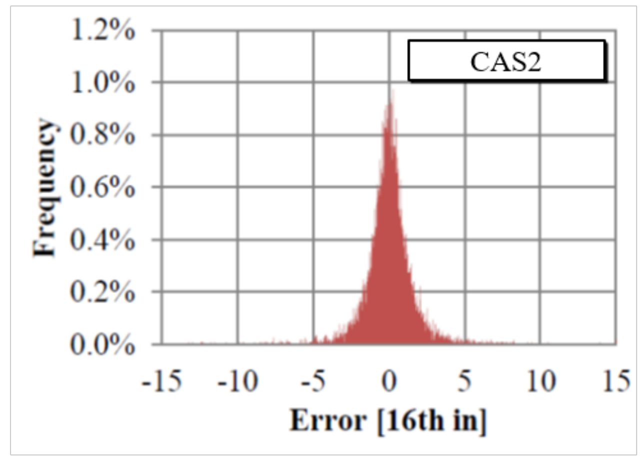
Collection of Reference Transverse Profiles

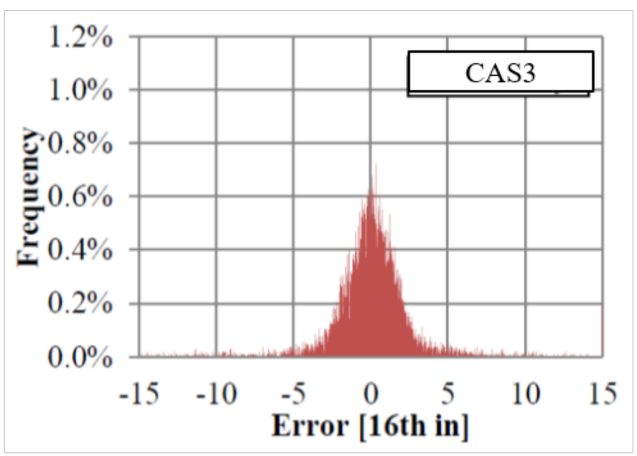
Manual 6’ straight edge rut depth measurements
222 measurements per test section – over 5,200 measurements total

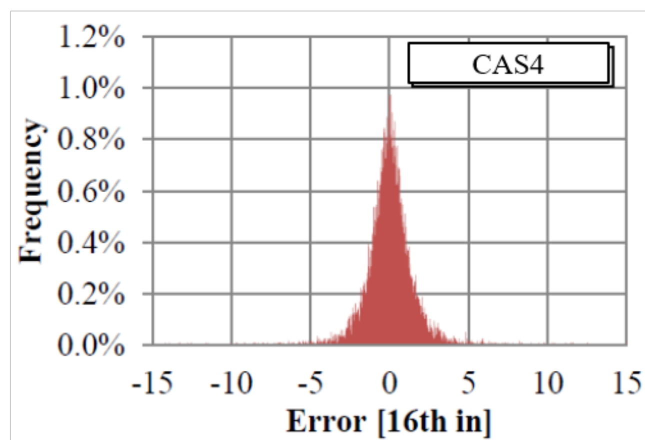
Automated Survey of Rutting

Comparison of Transverse Profiles



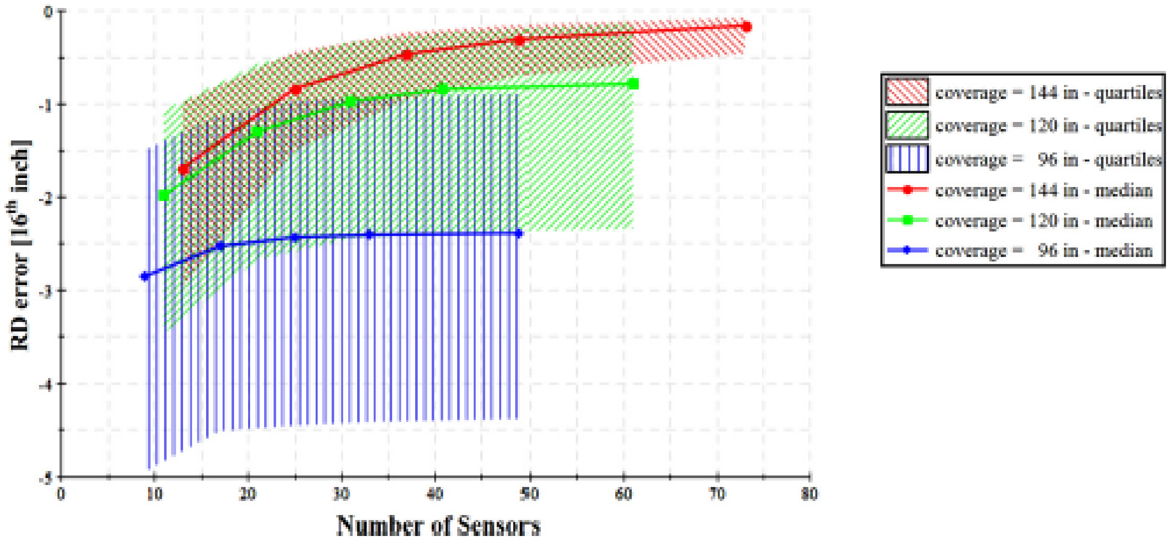






Comparison of Rut Depth Values

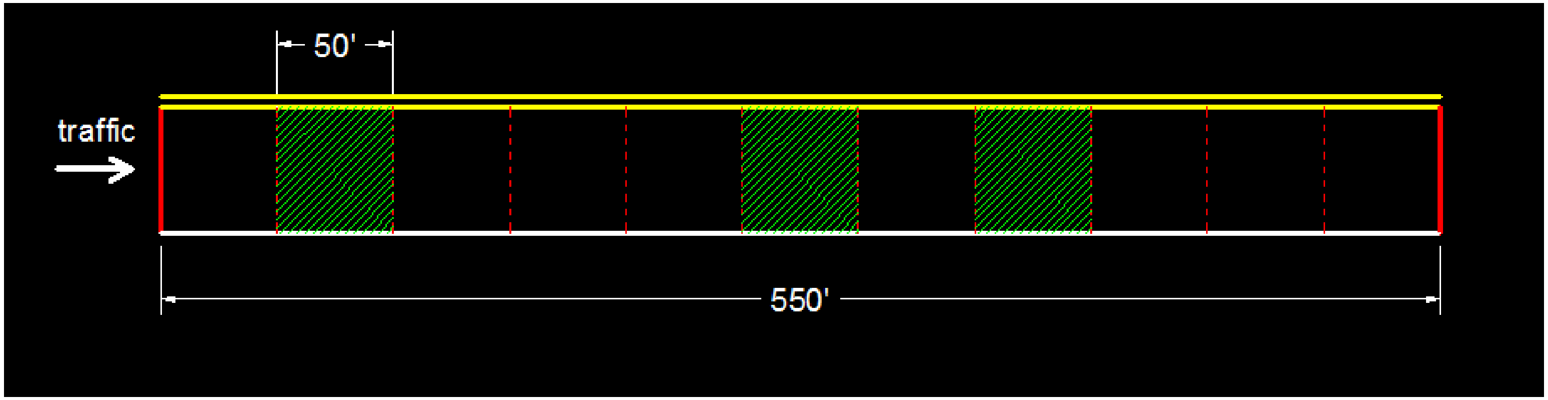
	Accuracy (1/16 in.)	Precision (1/16 in.)	$\beta_{RD} = \Delta RD_{error}/\Delta RD$
CAS 1	−0.83	3.14	0.10
CAS 2	−0.87	2.52	0.15
CAS 3	−0.99	2.67	0.09
CAS 4	−2.45	5.22	0.58
CAS 5	−3.10	4.37	0.46



Phase 2 - Experimental Design

- Twenty 550-ft long highway sections:
  - Divided into eleven 50-ft subsections (220 total)
  - LTPP protocols

Type of Pavement		Number of Sections
Flexible	HMA	7
	Surface Treatments	8
Rigid	JCP	2
	CRCP	3
Total		**20**

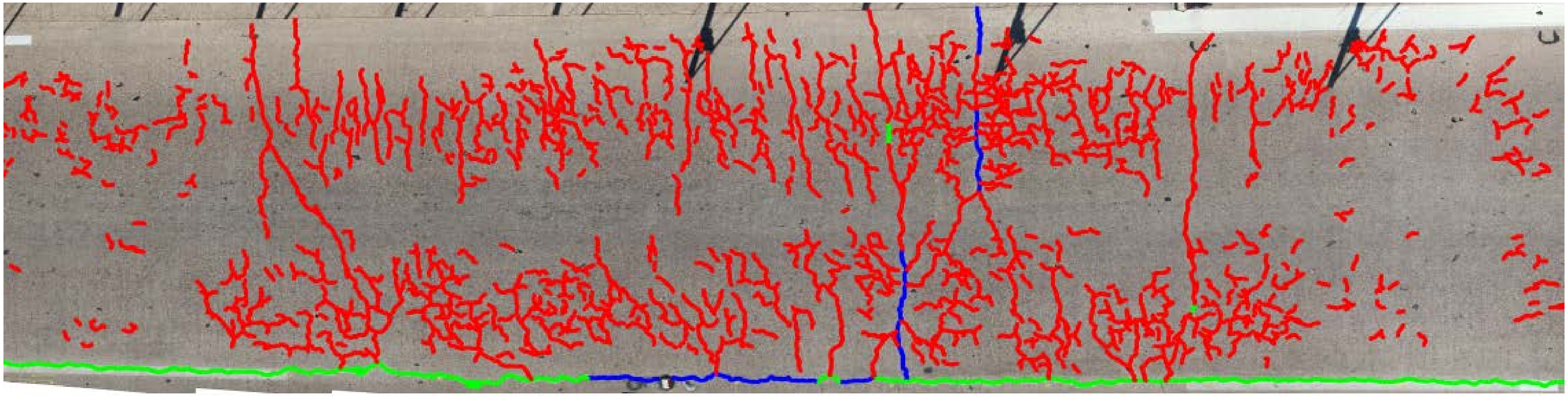


Manual Distresses Surveys

- Experienced LTPP Raters
  - Distresses summarized every 50 ft

Reference Crack Maps

- Three crack width categories:
  - < 3 mm (red) / 3 mm - 6 mm (blue) / > 6 mm (green)



Manual Crack Map

Automated Survey of Distresses

Comparative Analysis

- Summary Statistics of Cracking Measurements
  - False Positives and Missed Cracks

Cracking Type	System	False Positives		B&A effect	Missed Cracks		B&A effect
		Before # (%)	After # (%)		Before # (%)	After # (%)	
Fatigue	INO LCMS 1	23 (26%) **	20 (23%) **	not sig.	40 (52%) **	44 (57%) *	not sig.
	INO LCMS 2	33 (38%) *	34 (39%) *	not sig.	36 (47%) **	25 (32%) ***	12-01
	PaveVision	12 (14%) ***	12 (14%) ***	-	36 (47%) **	36 (47%) **	-
Longit.	INO LCMS 1	81 (74%) **	45 (41%) ***	49-13	22 (20%) **	37 (34%) **	<u>17-32</u>
	INO LCMS 2	83 (75%) **	69 (63%) **	18-04	08 (07%) ***	07 (06%) ***	not sig.
	PaveVision	64 (58%) ***	64 (58%) **	-	41 (37%) *	41 (37%) **	-
Transv.	INO LCMS 1	90 (63%) **	11 (08%) ***	81-02	17 (22%) **	18 (24%) *	not sig.
	INO LCMS 2	97 (67%) **	79 (55%) *	18-00	04 (05%) ***	03 (04%) ***	not sig.
	PaveVision	27 (19%) ***	27 (19%) **	-	11 (14%) **	11 (14%) **	-
Notes:	**** highest ranked; ** middle ranked; and * lowest ranked*						
	underlined cells indicate statistically significant worsened effect						

Comparative Analysis

- Summary Statistics of Cracking Measurements
  - Quantification of Measurement Errors

Crack Type	System	Quantification Errors						B&A effect
		Before			After			
		avg	sd	med	avg	sd	med	
Fatigue	INO LCMS 1	-11.76 m^2 **	9.34 m^2	-80%	0.69 m^2 ***	16.49 m^2	07%	improved
	INO LCMS 2	-6.56 m^2 ***	11.31 m^2	-56%	2.32 m^2 ***	10.92 m^2	33%	improved
	PaveVision	-13.88 m^2 *	8.62 m^2	-92%	-13.88 m^2 *	8.62 m^2	-92%	-
Longit.	INO LCMS 1	1.09 m ***	9.86 m	13%	4.1 m ***	11.95 m	17%	not sig.
	INO LCMS 2	4.41 m **	10.70 m	57%	1.51 m ***	8.51 m	11%	improved
	PaveVision	7.24 m **	23.73 m	09%	7.24 m *	23.73 m	09%	-
Transv.	INO LCMS 1	-15.54 m *	23.75 m	-44%	-1.24 m ***	13.08 m	01%	improved
	INO LCMS 2	-8.36 m ***	17.41 m	-30%	-3.55 m **	13.39 m	-11%	improved
	PaveVision	-12.79 m **	15.94 m	-54%	-12.79 m *	15.94 m	-54%	-
Notes:	**** highest ranked; ** middle ranked; and * lowest ranked*							

Phase 1 - Conclusions

- Transverse Profiles (hardware capabilities)
  - All five systems tested were capable of capturing surface transverse profiles with the necessary accuracy
- Rut Depth values (both hardware and software capabilities)
  - Three of four systems (INO LRMS sensors attached to the survey vehicle) produced similar RD values to the manually measured ones for all practical purposes
  - All showed a high dispersion of their measurements errors
  - Data processing algorithms can be further improve to improve accuracy and precision for roadways in Texas.
- Impact on TxDOT Pavement Management System Scores
  - Moving from a 5-point system to a continuous system will result in improved accuracy and higher levels of rutting (Condition Score dropped significantly, approx. 19 points)

Phase 2 – Conclusions (1/2)

- Accuracy Before Manual Post-Processing :
  - Both systems using INO LCMS sensors performed similarly. They tended to overestimate the number of sections with cracking
  - Although PaveVision system slightly outperformed the other two for some error types, all systems showed poor overall accuracy and precision, which highlights the importance of manual intervention
  - None of the systems outperformed the others on the quantification of cracking for all cracking types. All of them largely underestimated fatigue and transverse cracking, and overestimated long cracking

Phase 2 – Conclusions (2/2)

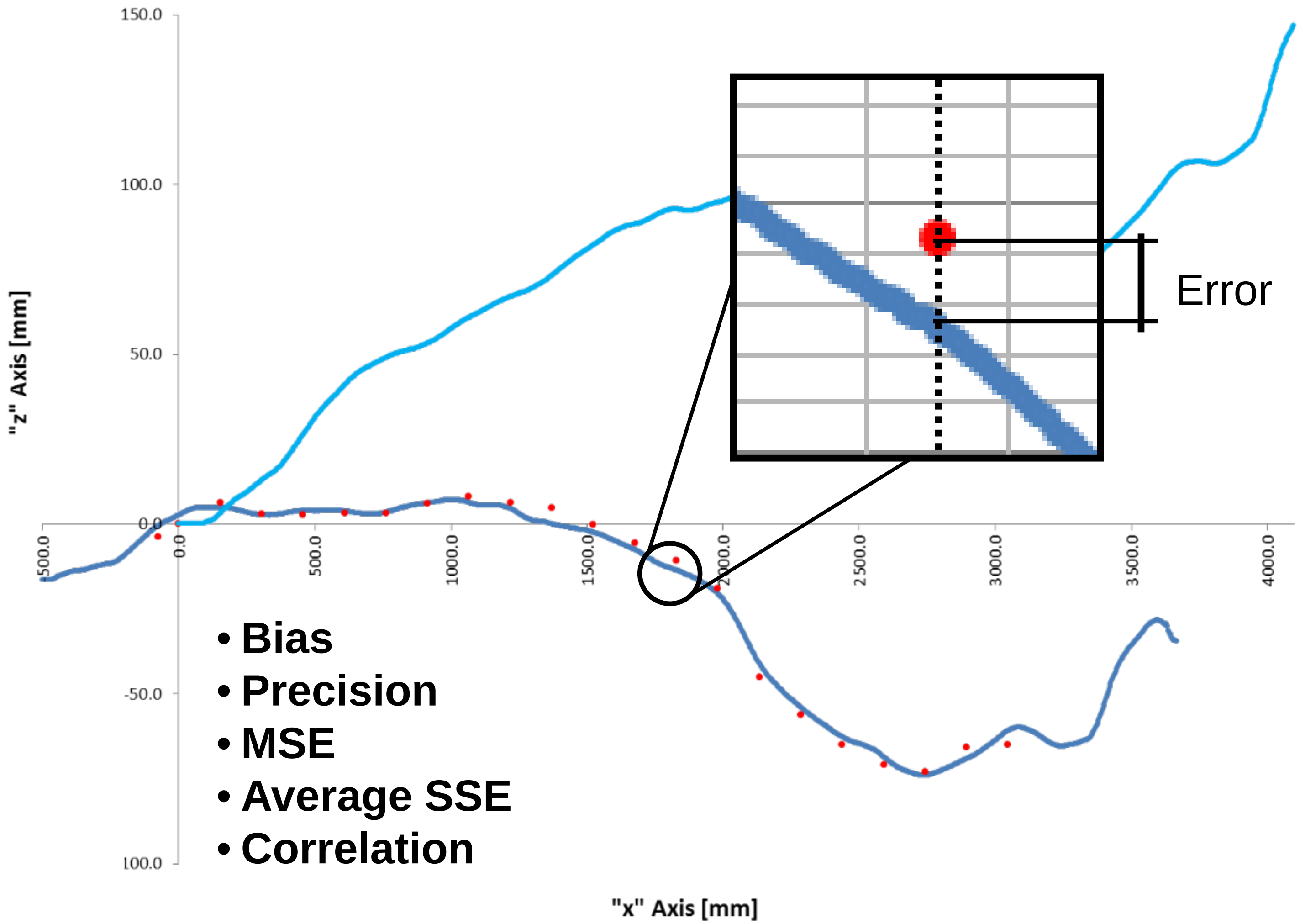
- Effect of Manual Post-Processing:
  - Both INO LCMS systems significantly improved their accuracy after manual intervention for most cracking types
  - However, the amount of reported false positives was still large (>30%) for several combination of vendors and crack types
  - Manual corrections were more effective at removing cracks incorrectly detected than at adding cracks missed by their algorithm
  - None of the vendors’ measurement precision improved after applying manual post-processing
  - Several types of distresses, such as patching, punchouts, spalling, and joint damage, were reported only after manual post-processing of the crack maps

Thanks for your attention

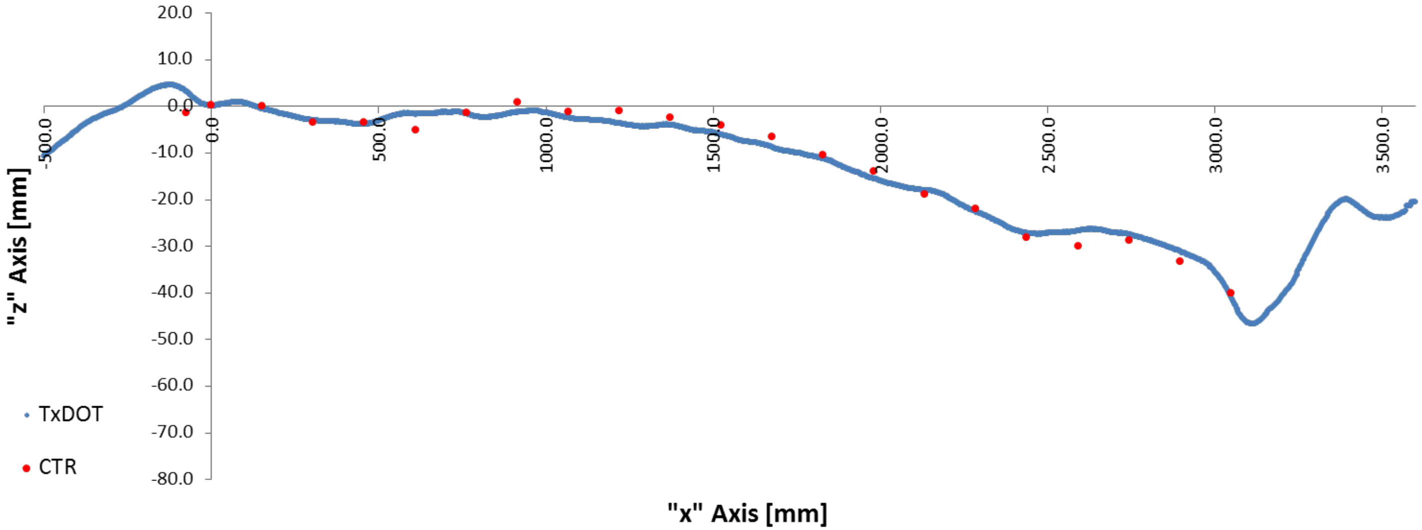
Extra Slides

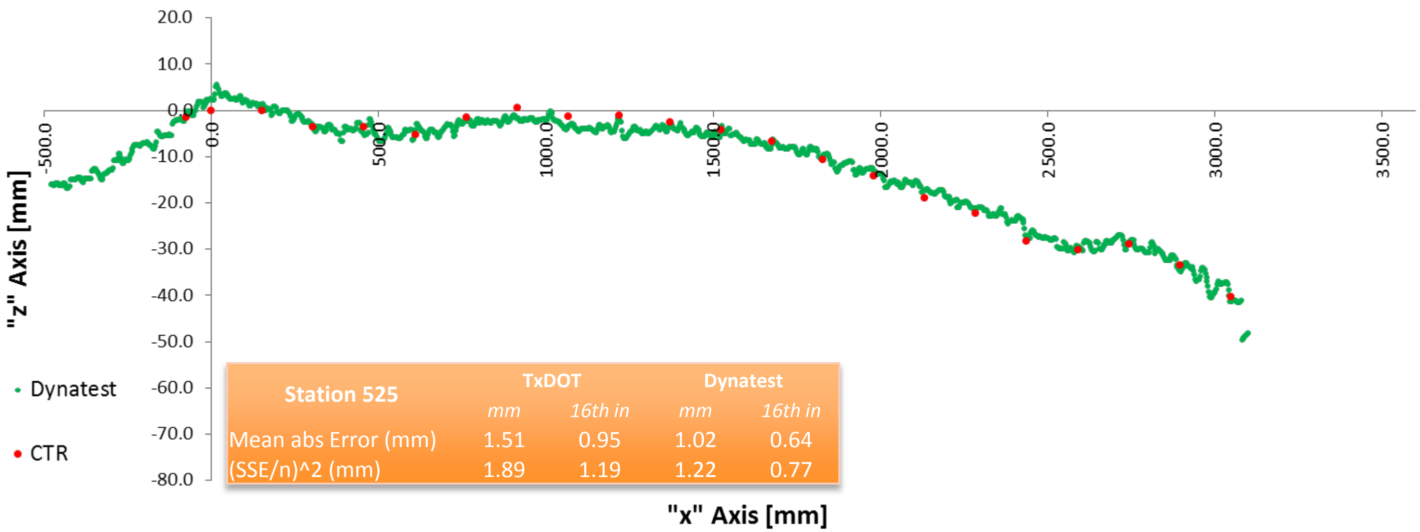
Laser distancemeter – DISTO D8

Leica System – Data collection on section 23



- **Bias**
- **Precision**
- **MSE**
- **Average SSE**
- **Correlation**

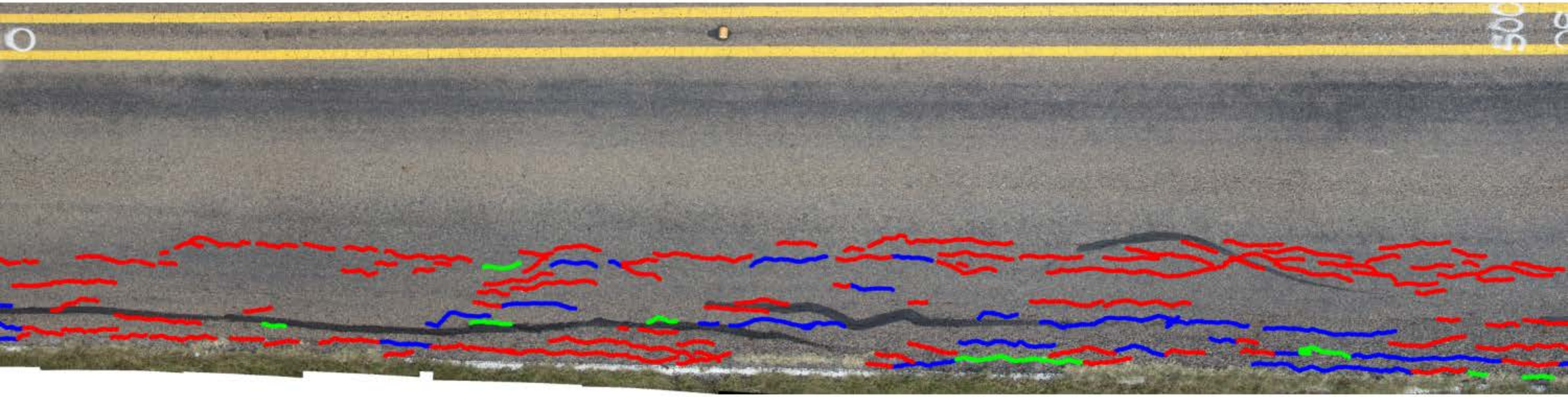




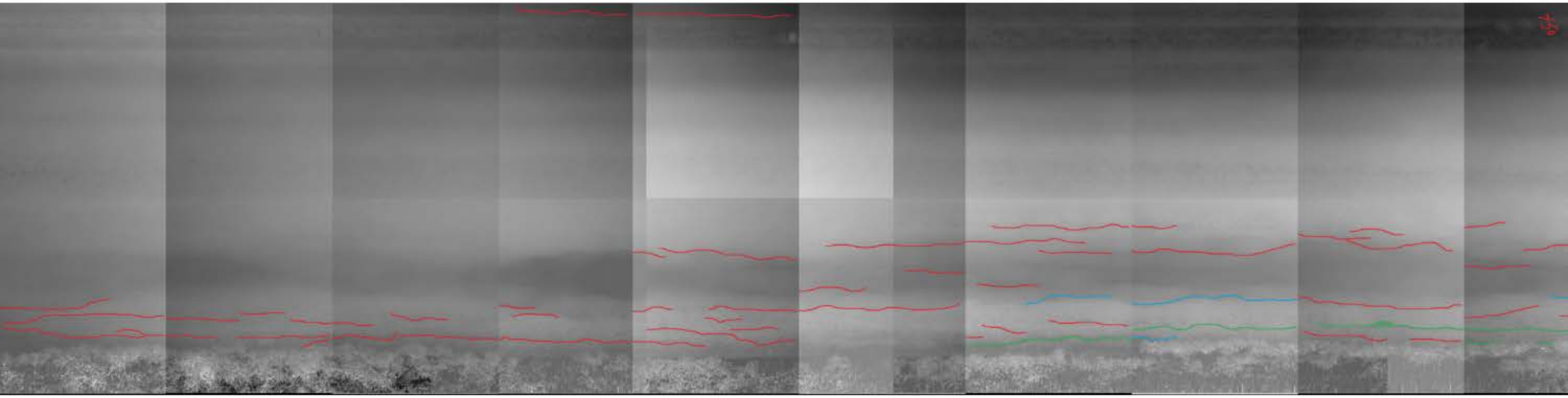
Station 525	TxDOT		Dynatest	
	mm	*16th in*	*mm*	*16th in*
Mean abs Error (mm)	1.51	0.95	1.02	0.64
(SSE/n)^2 (mm)	1.89	1.19	1.22	0.77

Phase 2 - Automated Surveys

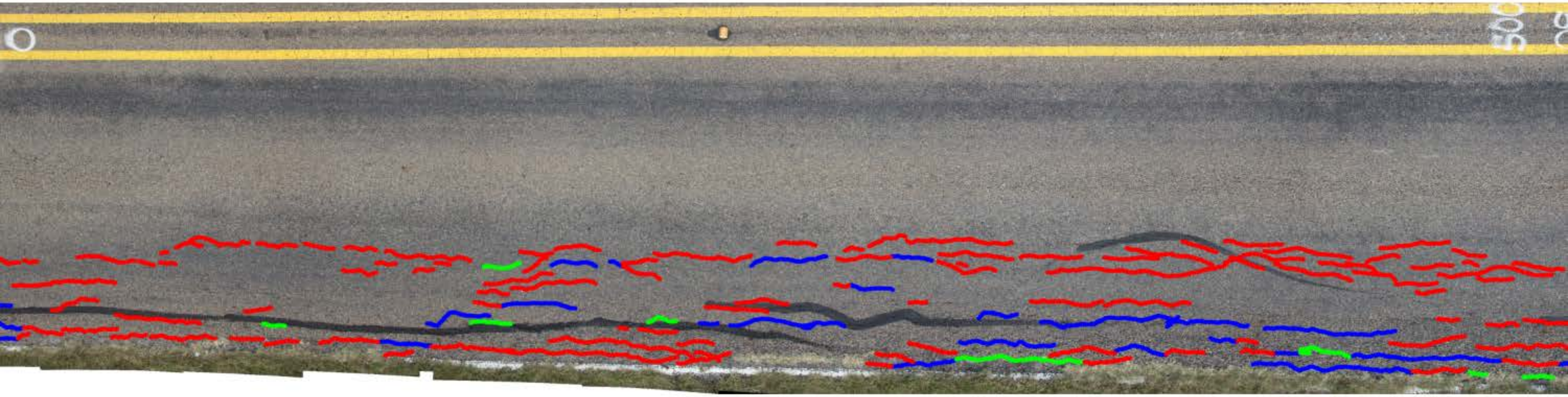
- Data delivery time-frames analyzed in this study:
  - **Before** manual post-processing,
    - for data delivered within 2 business days
    - Faster results without manually correct the results produced by their system's algorithms.
  - **After** manual post-processing,
    - for data delivered within 4 weeks.
    - Detailed manual inspection and corrections of their algorithm's results, producing their most accurate results.



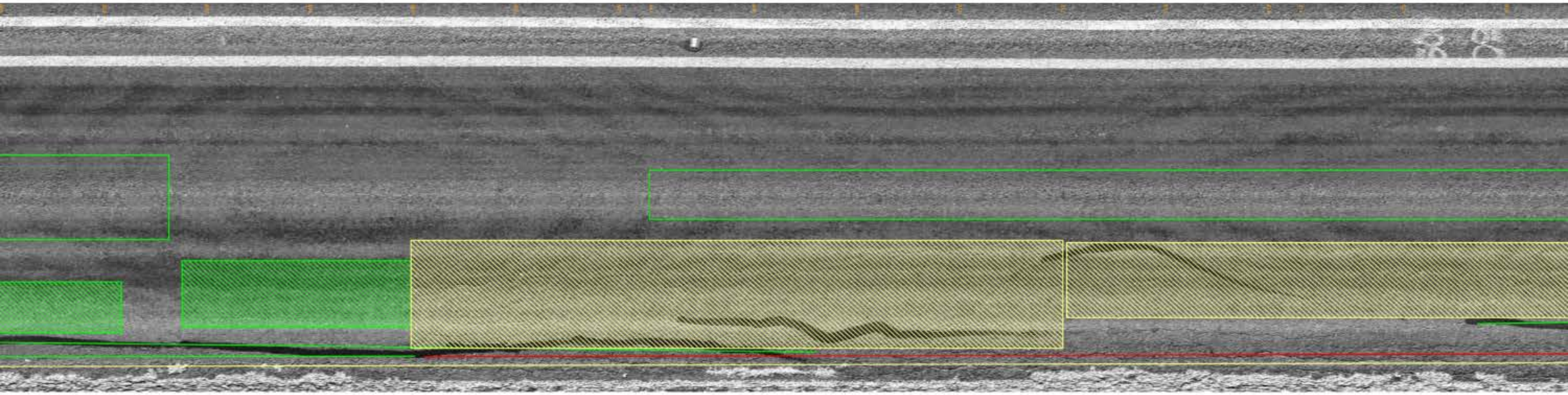
Manual Crack Map



PaveVision

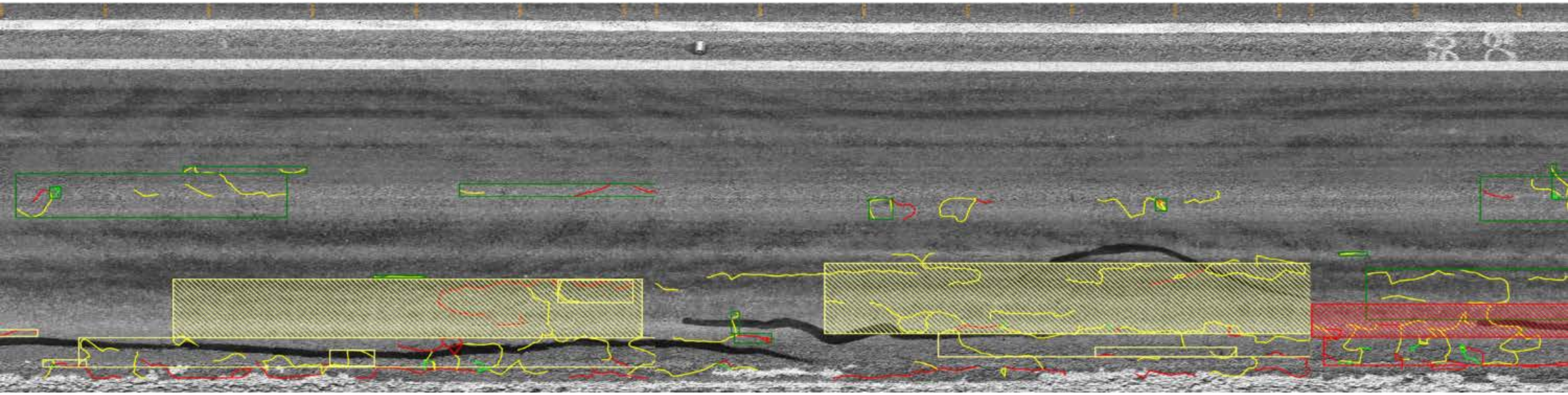


Manual Crack Map

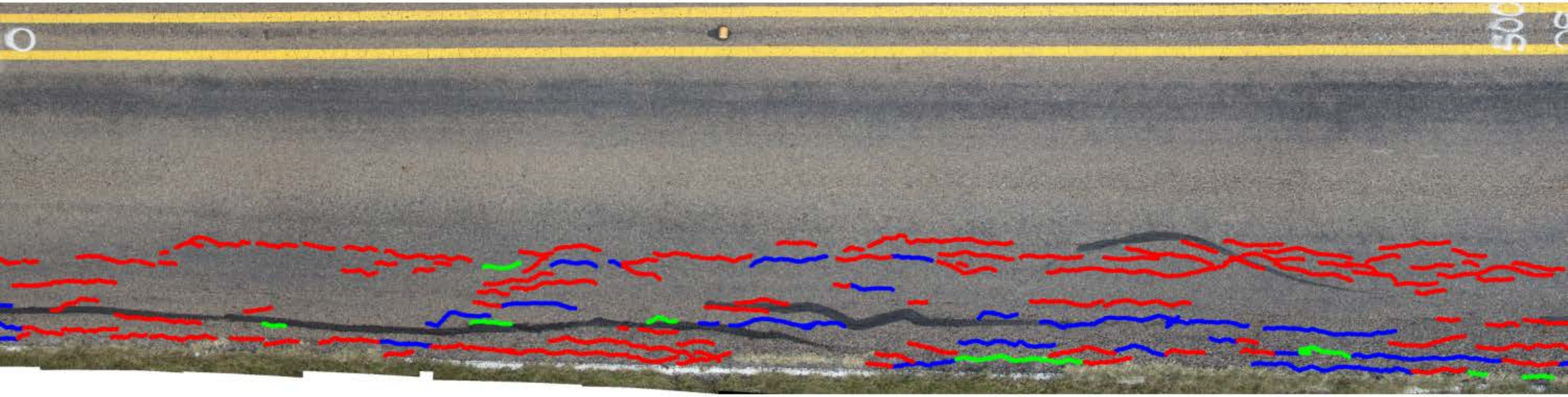


INO LCMS 1 (before)

Manual Crack Map



INO LCMS 1 (after)



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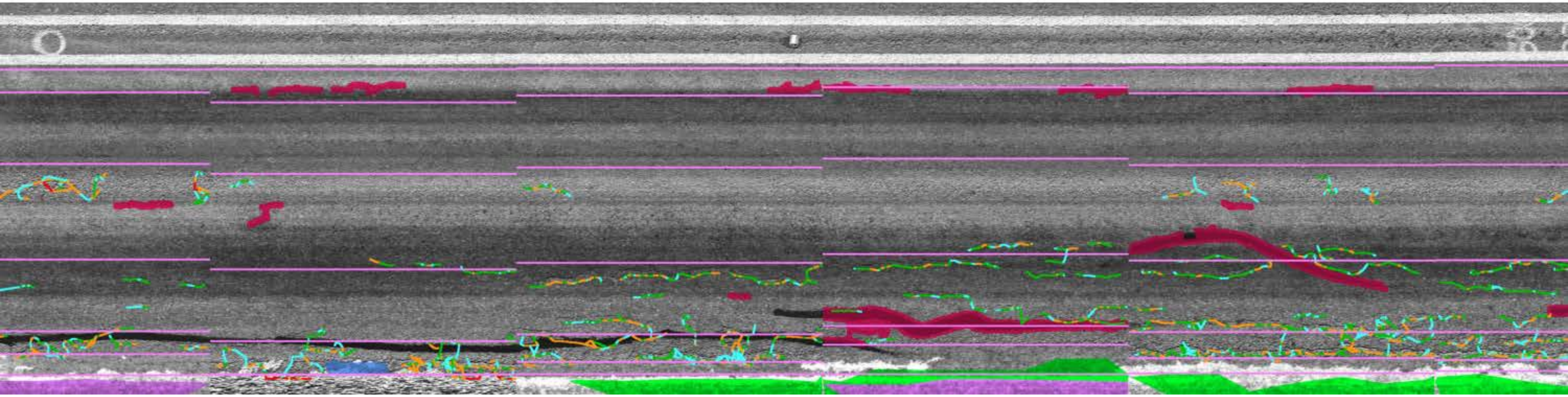
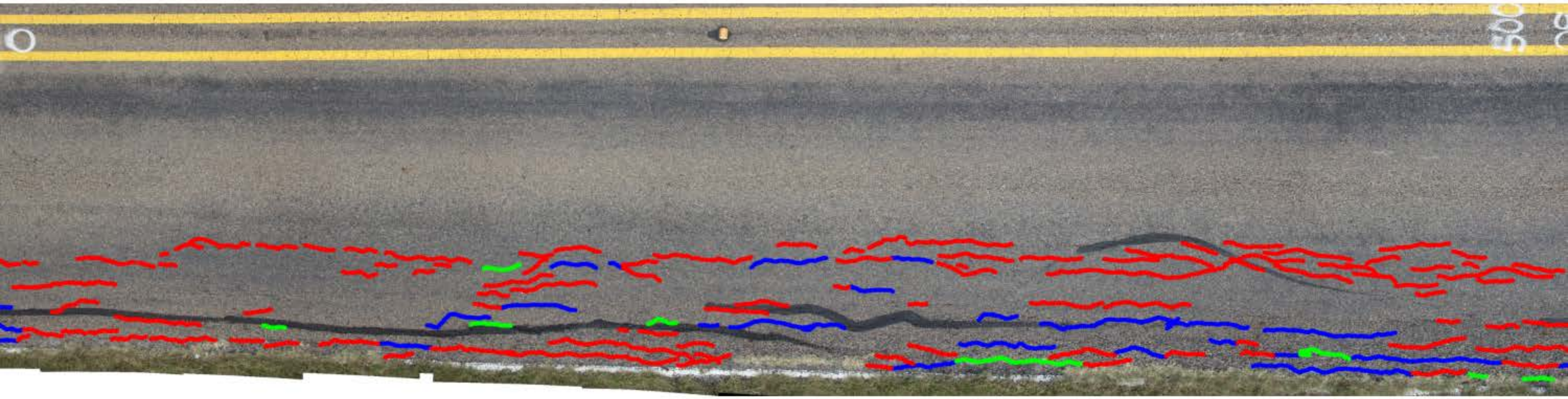


INO LCMS 2 (before)



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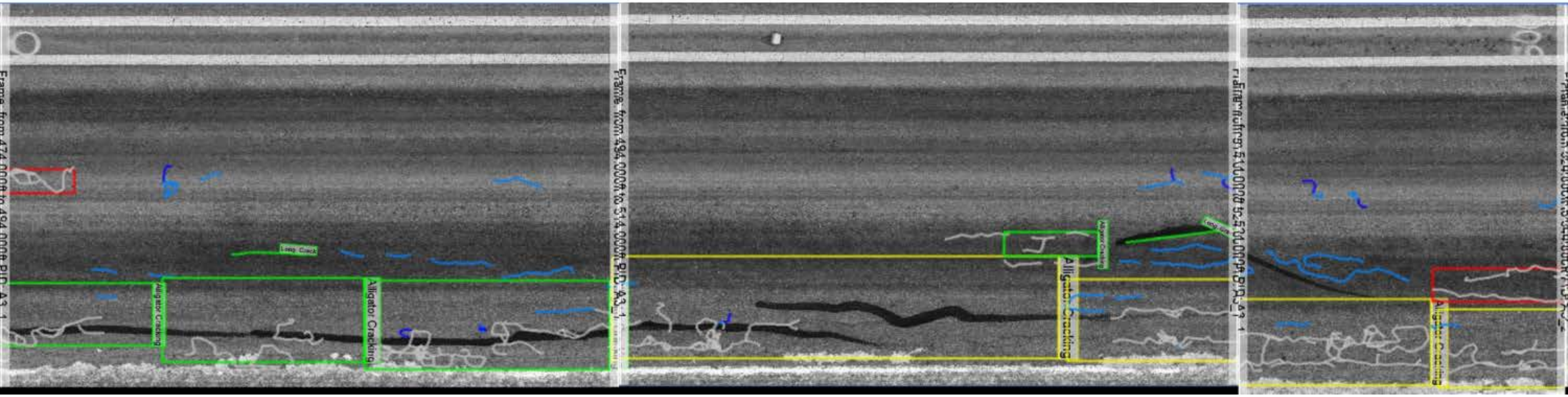
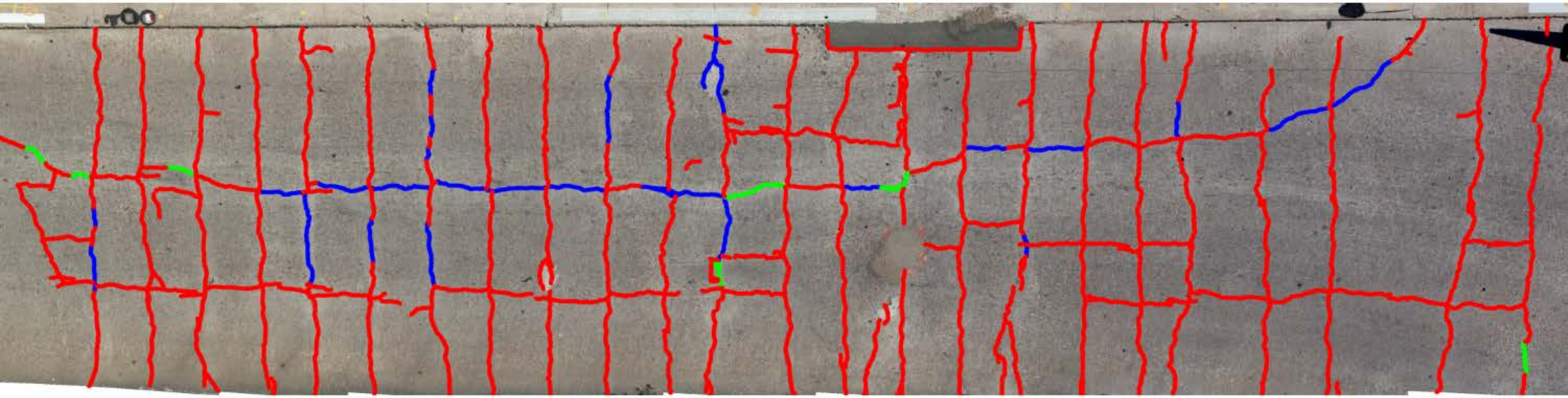


INO LCMS 2 (after)



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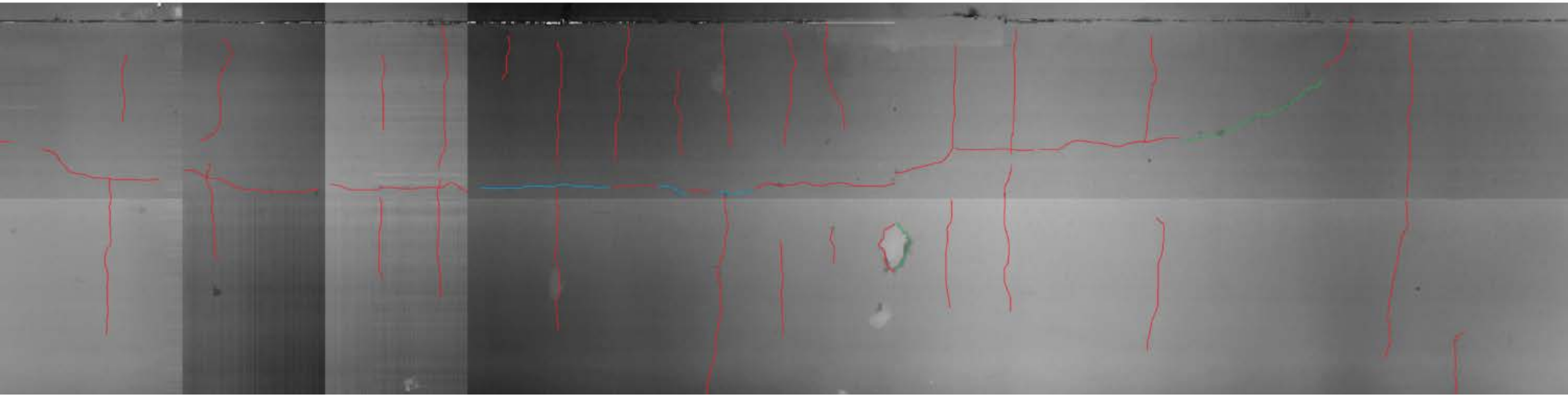
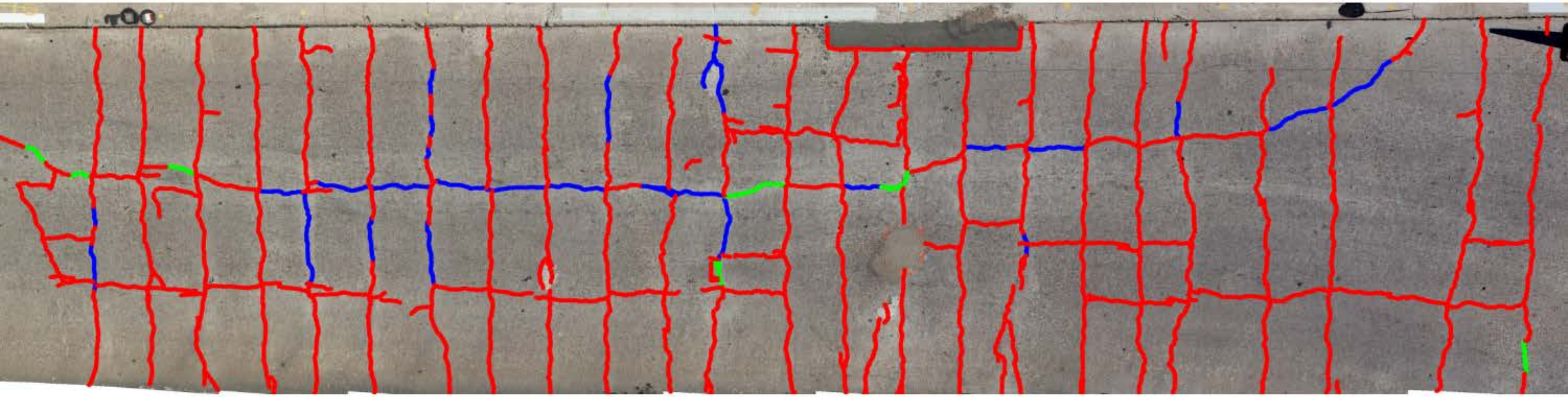


PaveVision



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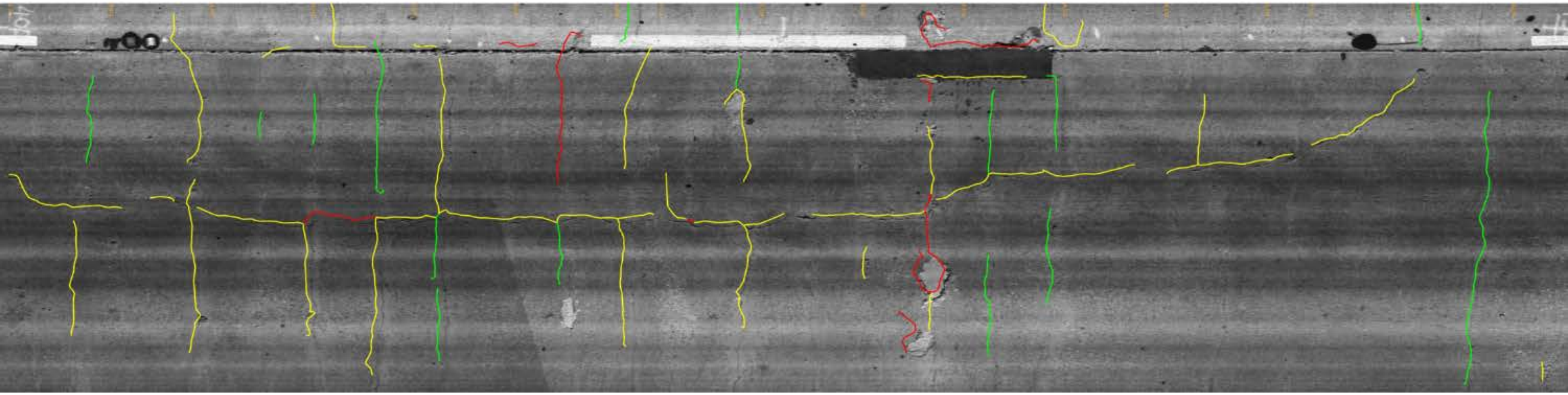
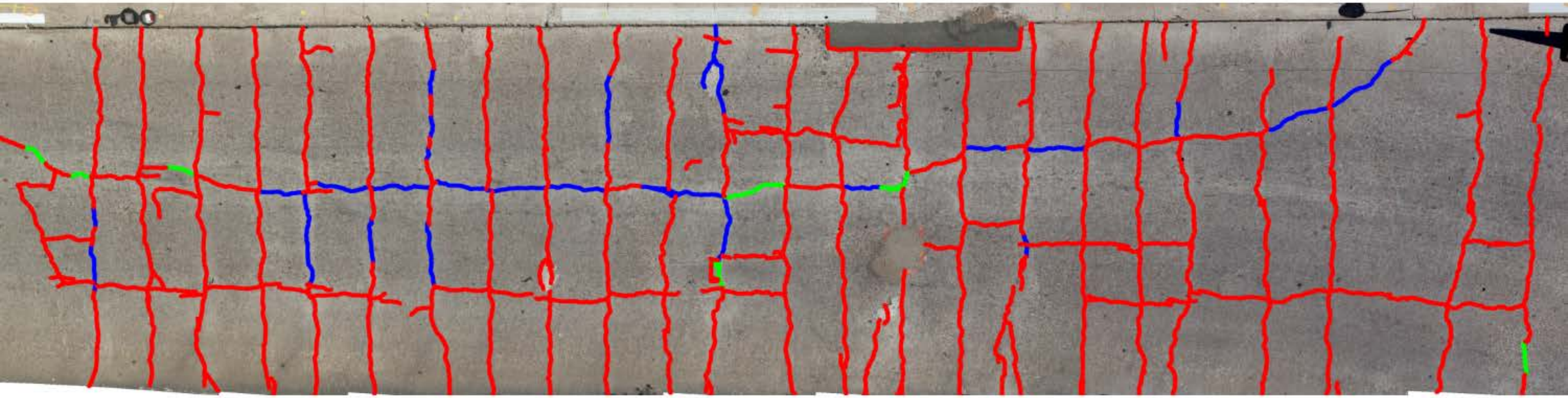


INO LCMS 1 (before)



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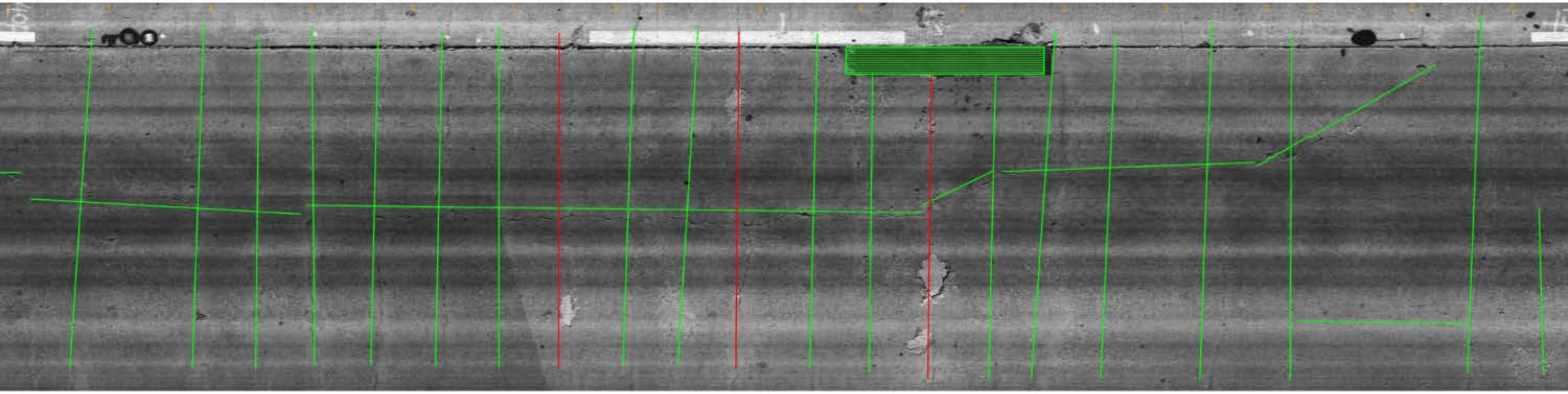
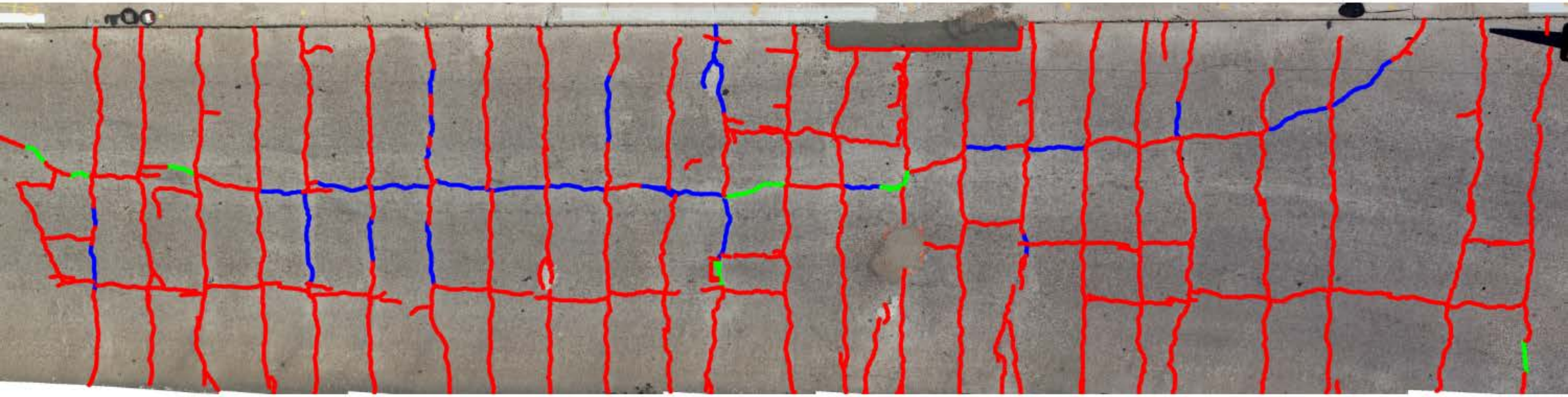


INO LCMS 1 (after)



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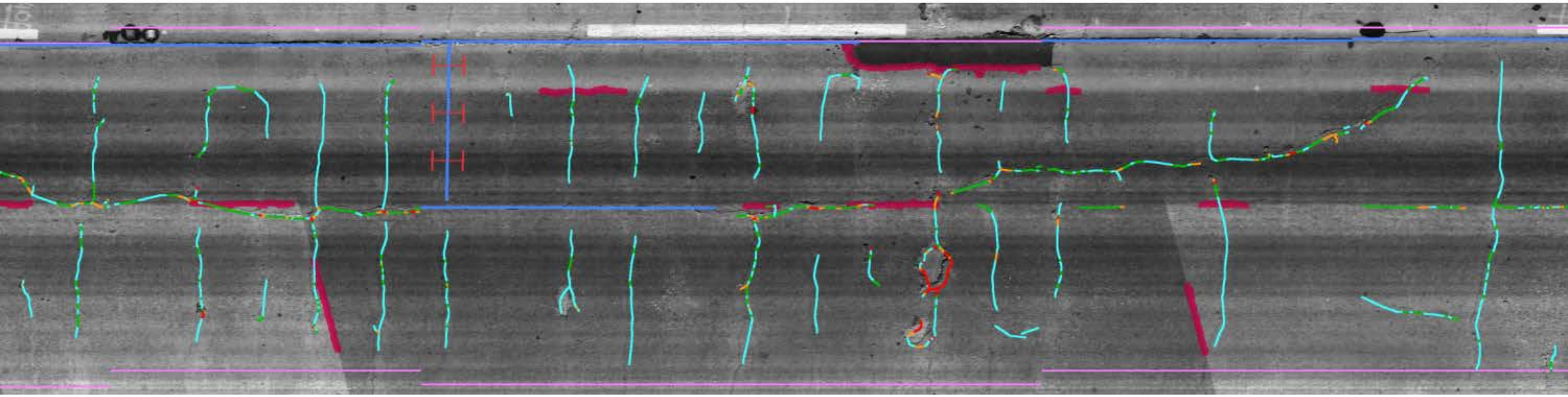
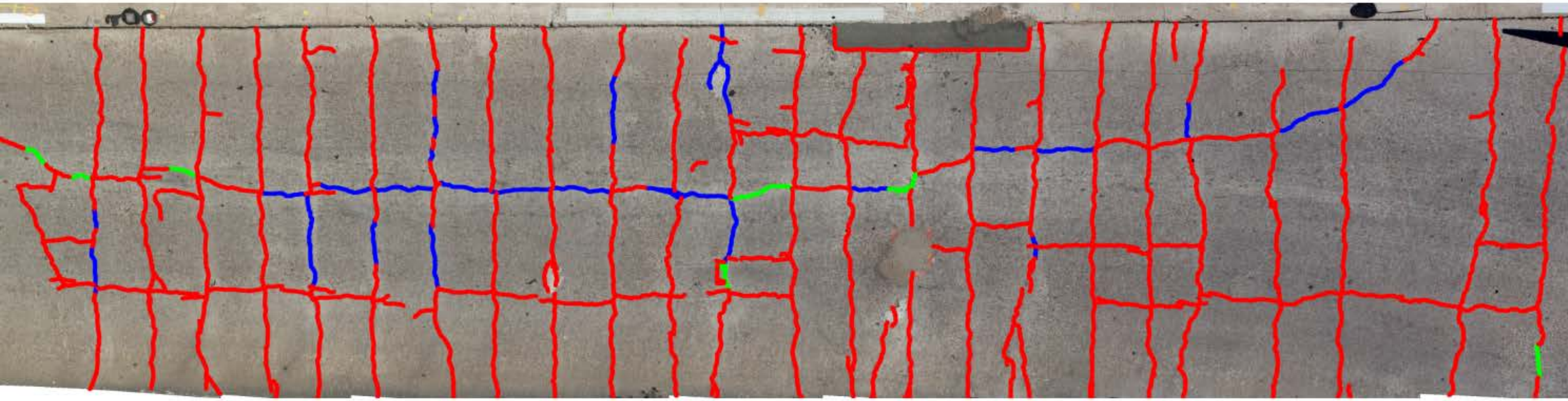


INO LCMS 2 (before)



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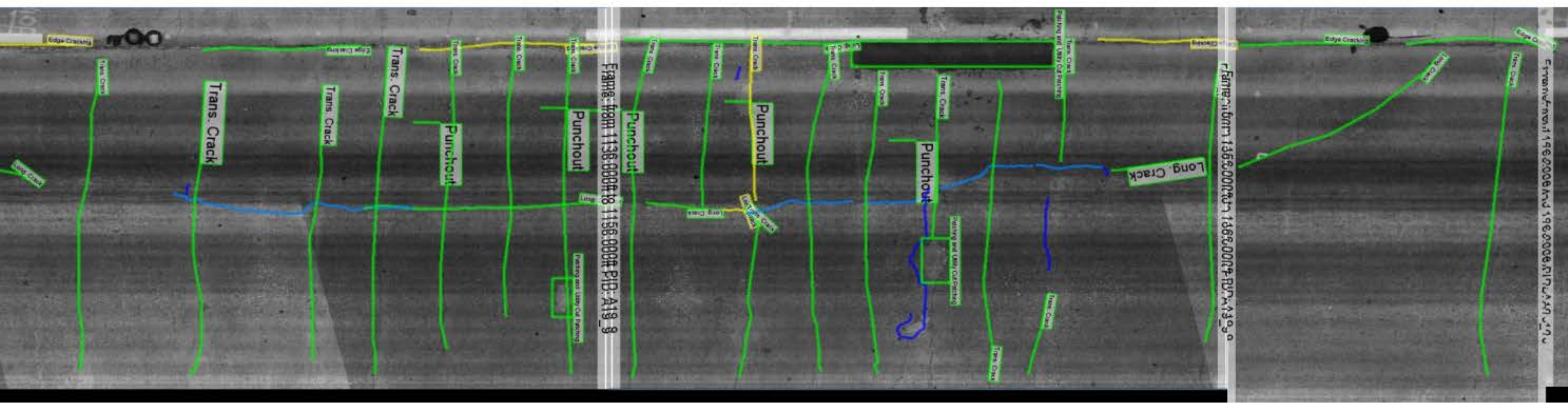

INO LCMS 2 (after)

Crack Maps Gral Observations

- The number of missed cracks was larger for the cracks < 3 mm wide
- The system using PaveVision sensor did not misidentified transverse and longitudinal joints as cracks whereas the other two did
- None of the systems presented large amount of false positives on PFC surface
- None of the systems was able to capture the very fine cracks on Jointed Concrete Pavement sections
- Significant improvement after manual intervention for both INO LCMS systems