



LESSONS LEARNED FROM TPP TEST DATA

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OUTLINE



- ACKNOWLEDGEMENTS
- INTRODUCTION OF FIVE TPP TESTS
- LESSONS LEARNED FROM EACH TPP TEST DATA ANALYSIS
- SUMMARY

ACKNOWLEDGEMENT



- **TXDOT: SPONSORSHIP, MANAGEMENT, AND COORDINATION (JENNY LI, HUI WU, TODD COPENHAVER)**
- **QES: KNOWLEDGE AND EXPERIENCE SHARING (JEFF UHLMAYER, MATTHEW BAKER)**
- **PATHWAY: VOLUNTEERING FOR THE TPP TEST AND SHARING DATA (SCOTT MATHISON, EVERETT SCHMITZ)**

INTRODUCTION OF FIVE TPP TESTS



Test tracks are enclosed; no traffic control is required.



PP 106 STATIC TEST



Single-Piece Straightedge



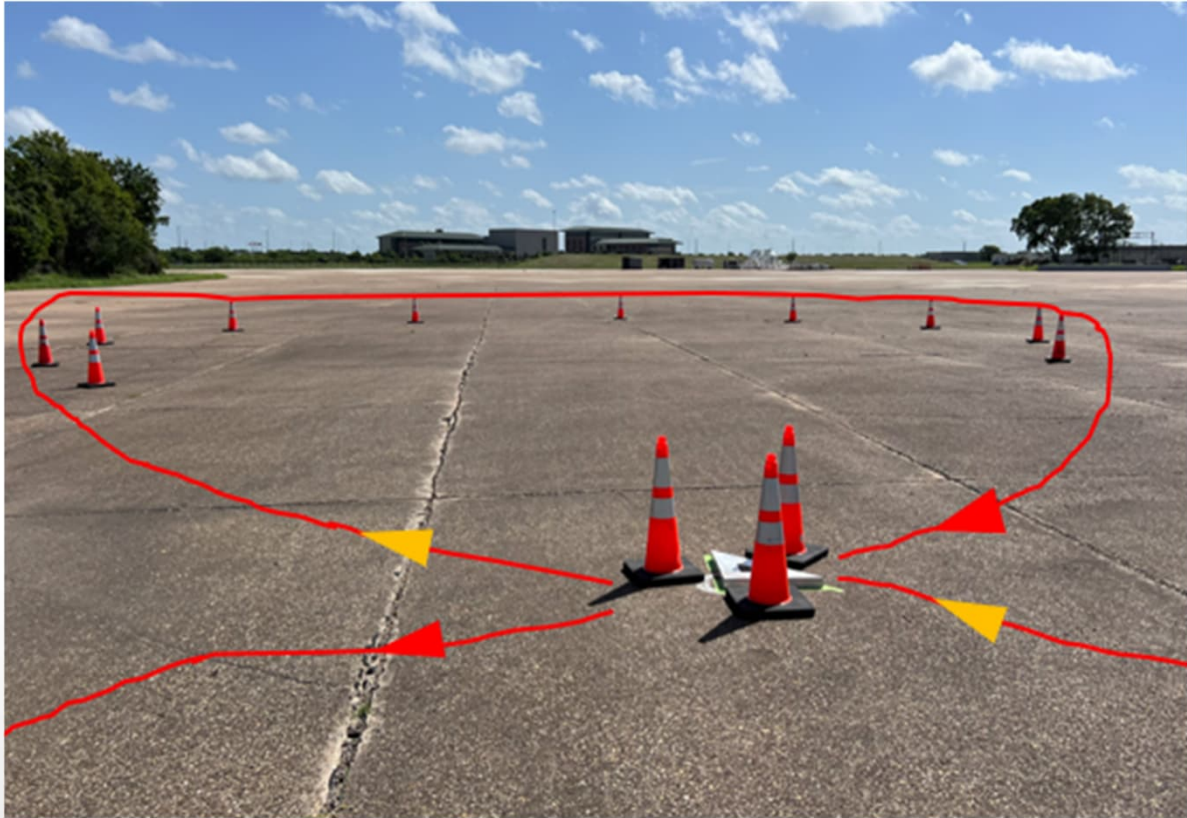
Segmented Straightedge



PP 107 BODY MOTION TEST



PP 108 NAVIGATION DRIFT TEST



PP 109 HIGHWAY PERFORMANCE TEST



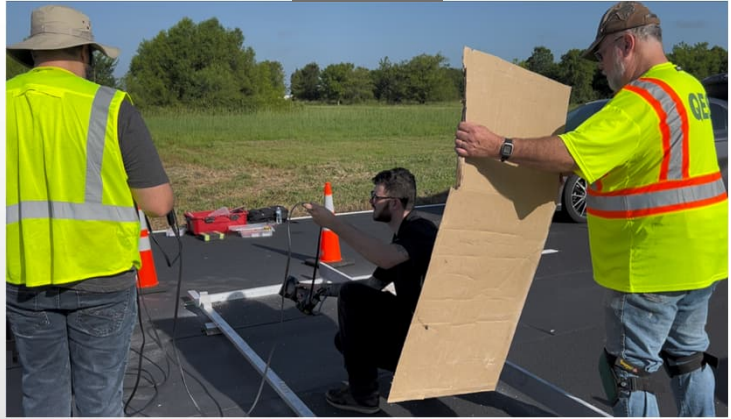
Simulated rutted sections, including shallow and deep rutting levels.



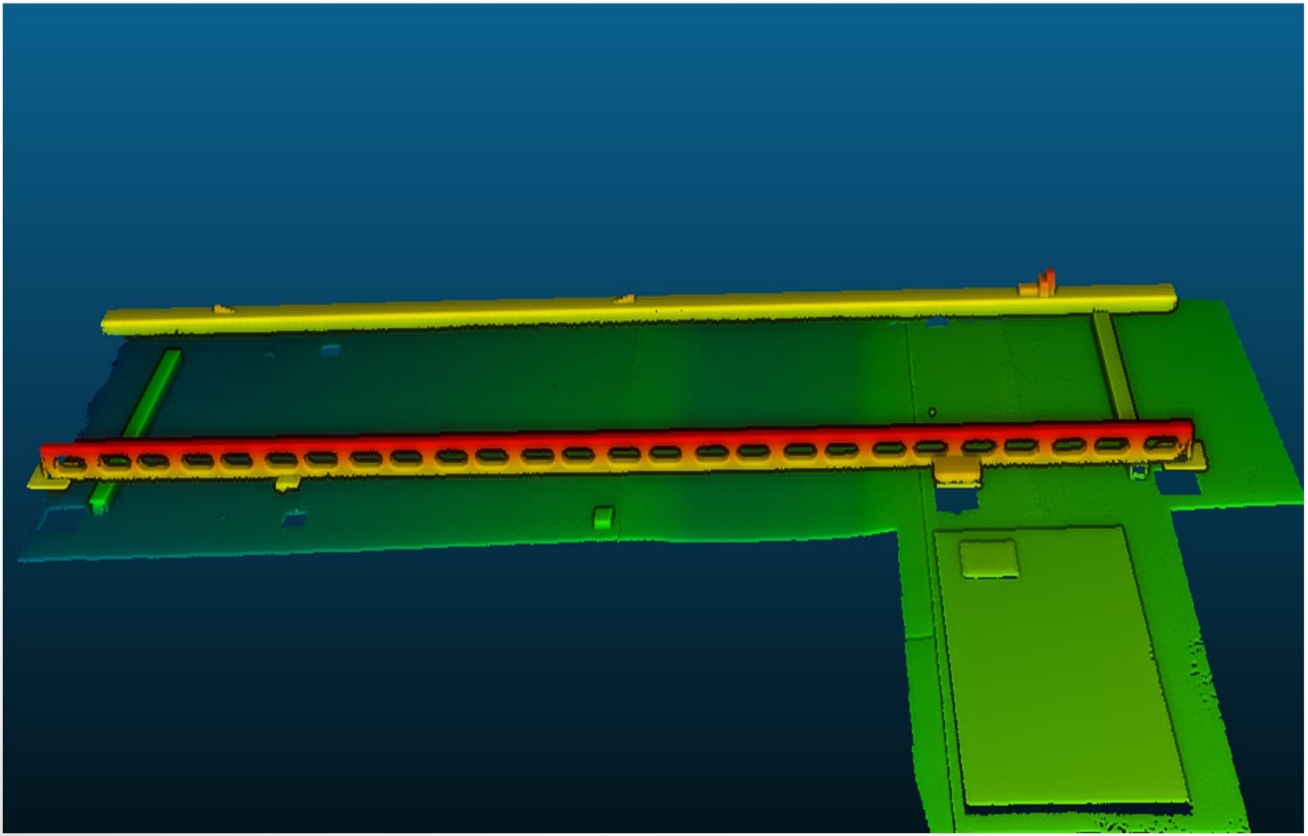
PP 110 GROUND REFERENCE TEST



2024

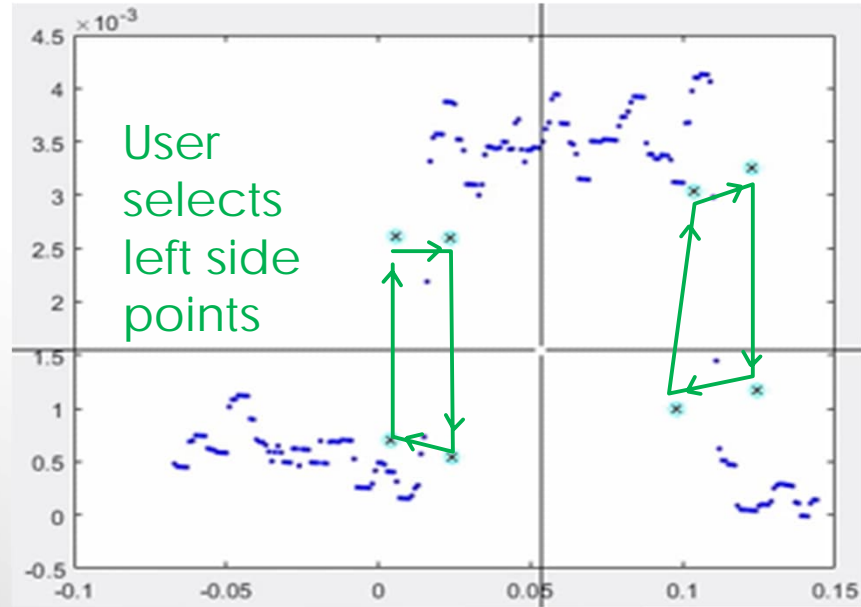
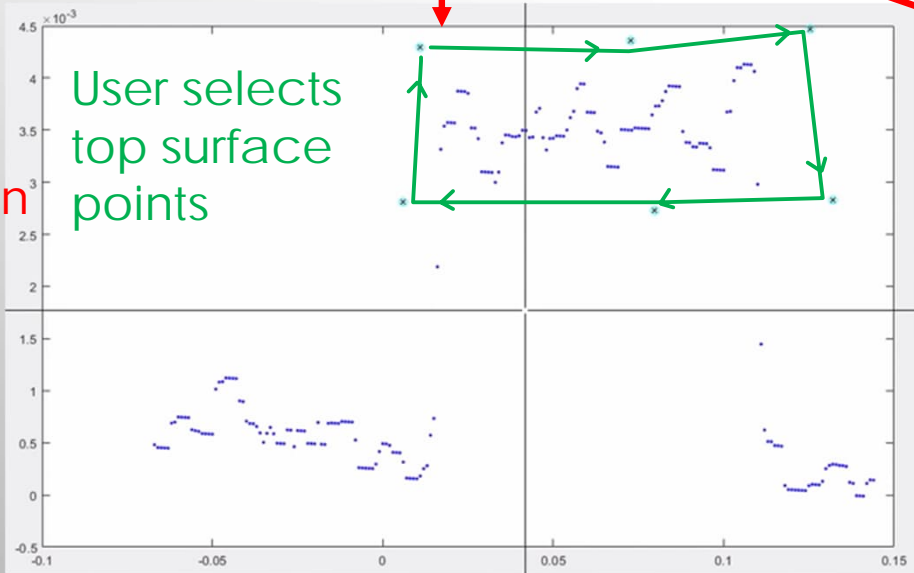
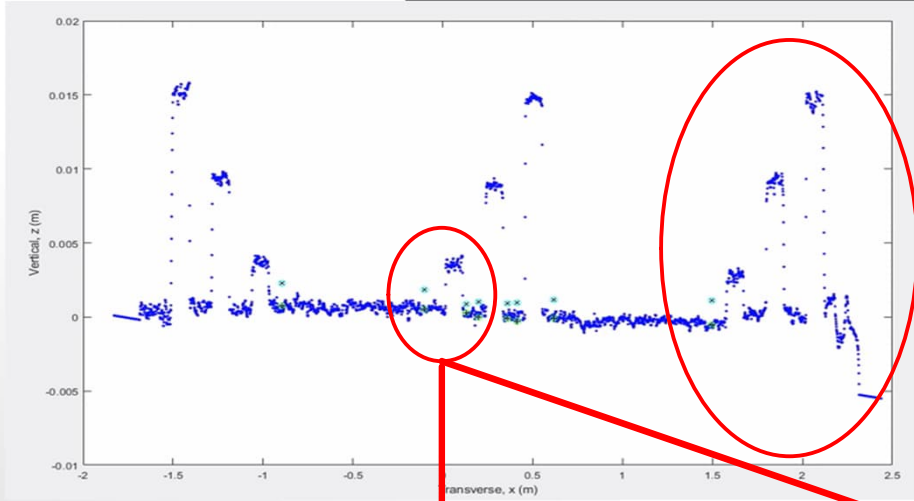


2025



LESSONS LEARNED FROM PP 106 STATIC TEST

Manual Object Identification Process



- Each Profiler:
- 10 Scans
 - 9 block/scan
 - Repeat 90 times

User selects right side points



LESSONS LEARNED FROM PP 106 STATIC TEST

Automated Process



PP 106: TPP Static Performance Analysis

DATA FILE

TPP File

No file selected

Browse...

SCAN SETTINGS

Number of Scans to Use

10

standard = 10

Number of Gauge Blocks

0 (no gauge blocks) 9

GAUGE BLOCK SETTINGS

Block Width (metres)

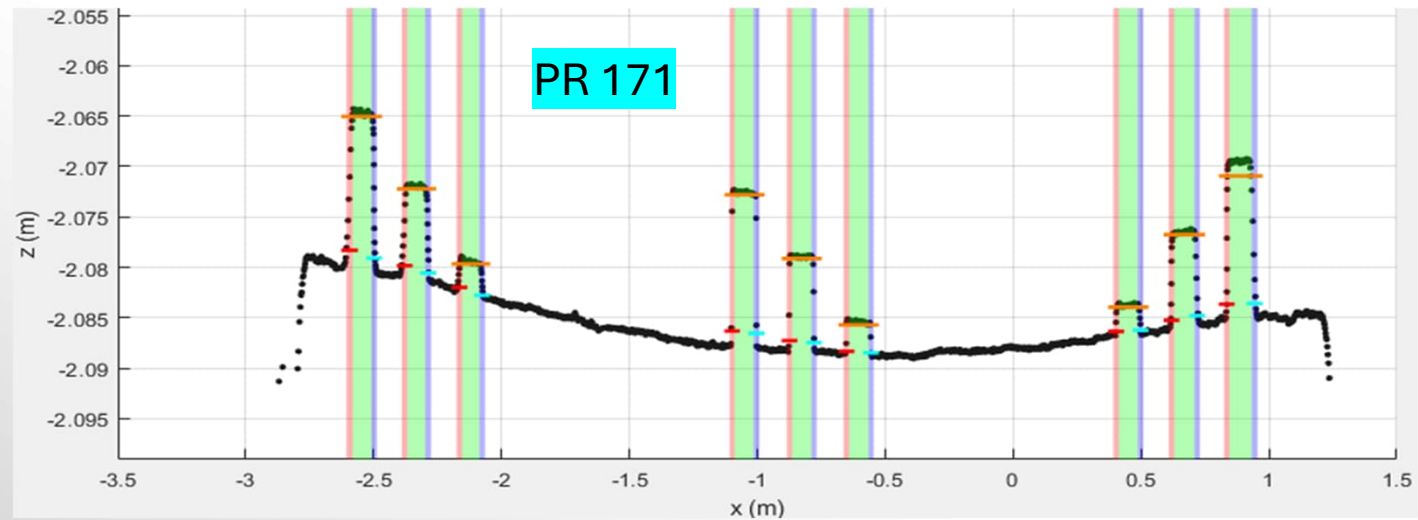
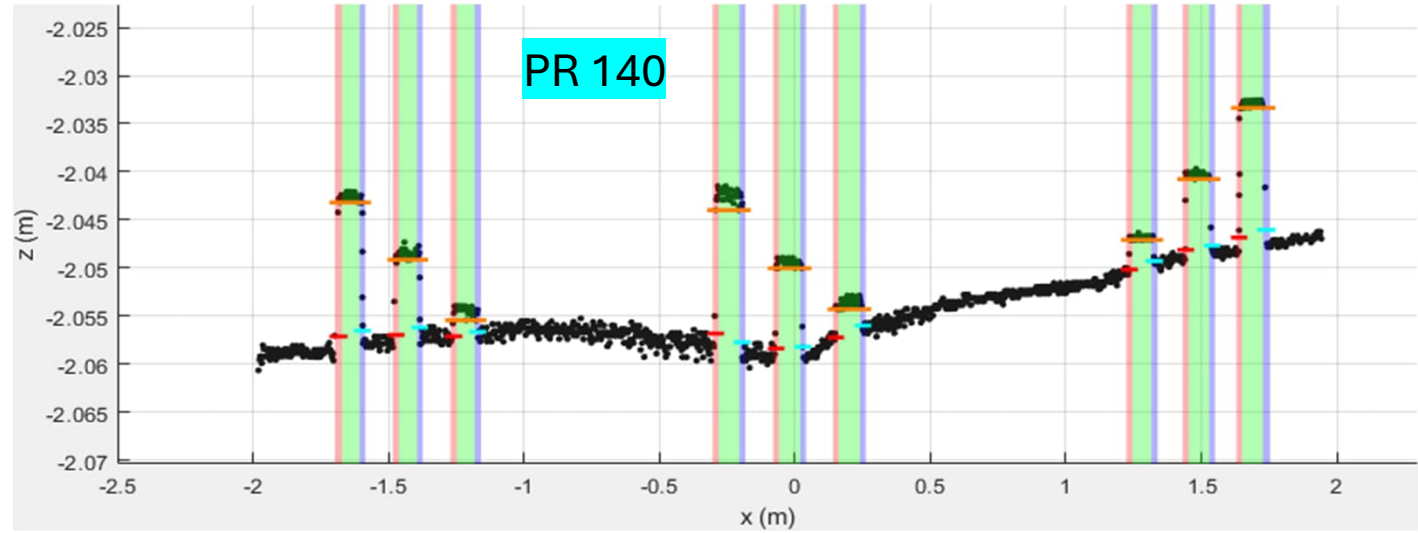
0.09525

same for all blocks

Block Heights (metres) one value per block

Block 1	<input type="text" value="0.015875"/> m	Block 2	<input type="text" value="0.009525"/> m	Block 3	<input type="text" value="0.003175"/> m
Block 4	<input type="text" value="0.015875"/> m	Block 5	<input type="text" value="0.009525"/> m	Block 6	<input type="text" value="0.003175"/> m
Block 7	<input type="text" value="0.003175"/> m	Block 8	<input type="text" value="0.009525"/> m	Block 9	<input type="text" value="0.015875"/> m

Run Analysis



LESSONS LEARNED FROM PP 106 STATIC TEST

Analysis Result: Manual vs. Automated Process



Transverse Measurement Error

Straightness Error

QES-User1

Vehicle	5 th (-7.5 mm)	25 th (-5 mm)	75 th (5 mm)	95 th (7.5 mm)
PR140	-6.1	-4.4	1.7	4.4
PR171	-4.3	-1.7	3.0	7.4

Vehicle	5 th (-2.5 mm)	25 th (-1 mm)	75 th (1 mm)	95 th (2.5 mm)
PR140	-2.7	-0.7	1.0	1.9
PR171	-2.5	-1.2	0.6	3.1

TTI-User1

PR140	-11.7	-4.0	3.6	10.0
PR171	-4.9	-1.2	2.7	7.9

PR140	-2.0	-0.5	0.6	1.5
PR171	-0.9	-0.3	0.3	1.2

TTI-User2

PR140	-9.8	-1.7	1.0	9.6
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PR140	-1.0	-0.4	0.4	1.0
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Automated

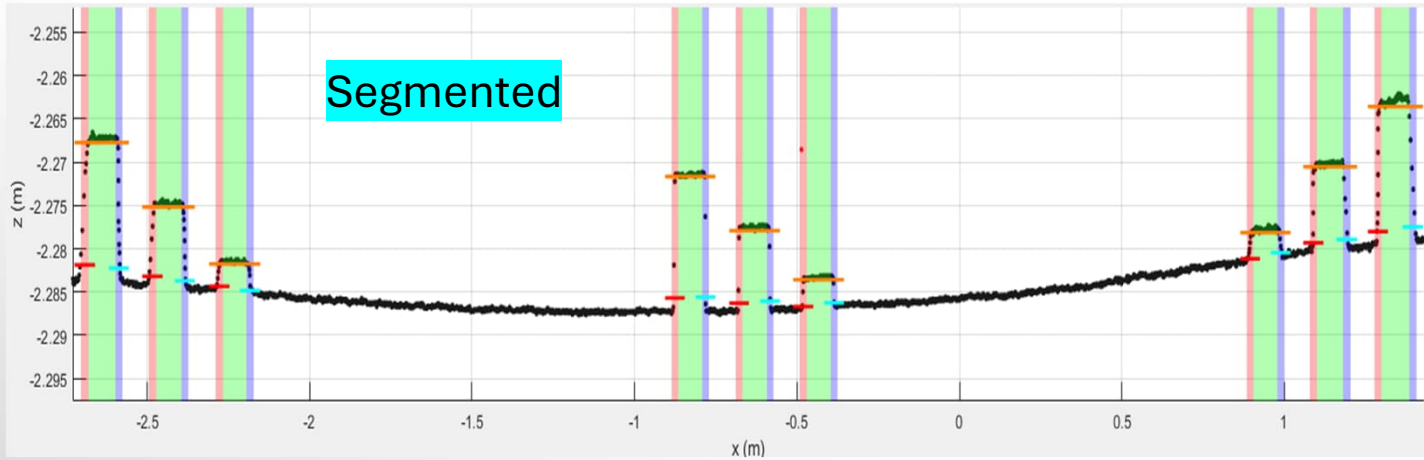
PR140	-9.6	-5.9	-0.09	5.4
PR171	-4.3	-2.8	0.34	7.4

PR140	-2.5	-0.7	0.8	2.1
PR171	-1.7	-1.3	1.2	2.9

LESSONS LEARNED FROM PP 106 STATIC TEST

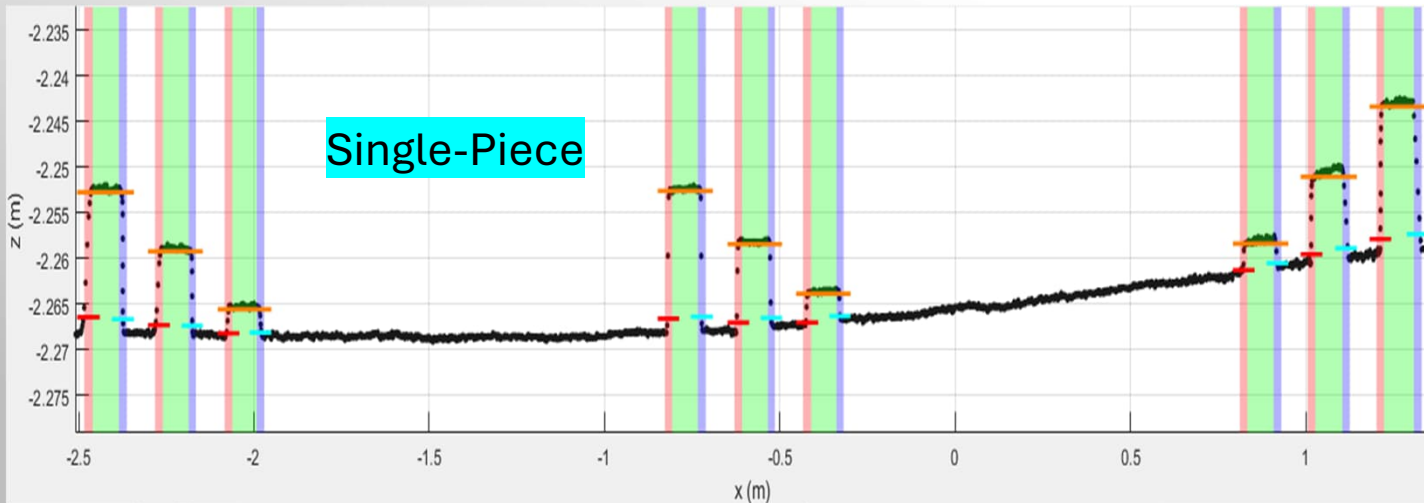


Analysis Result: Segmented vs. Single-Piece Straightedge, PR 181



Transverse Measurement Error

Straightedge	5 th (-7.5 mm)	25 th (-5 mm)	75 th (5 mm)	95 th (7.5 mm)
Segmented	-2.0	-0.1	6.1	7.8
Single-Piece	-5.5	-2.5	0.72	6.1



Straightness Error

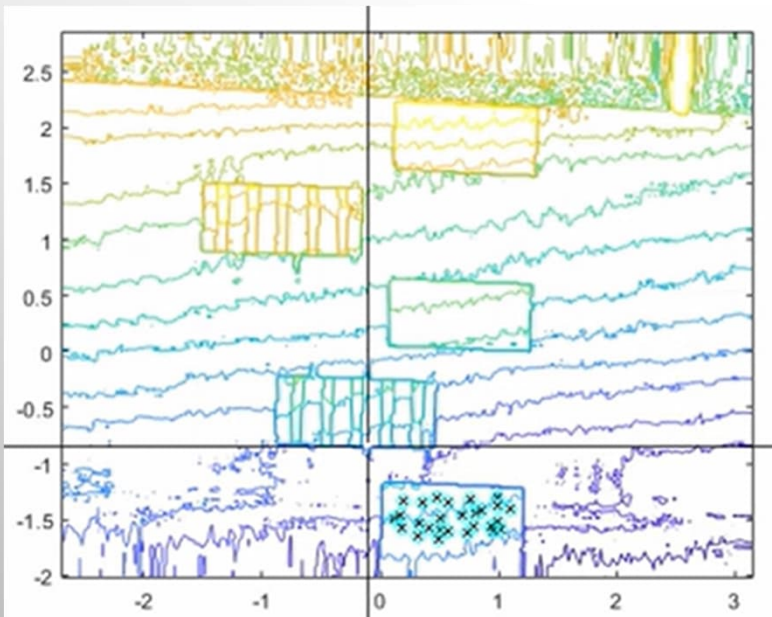
Straightedge	5 th (-2.5 mm)	25 th (-1 mm)	75 th (1 mm)	95 th (2.5 mm)
Segmented	-1.6	-1.2	1.1	2.8
Single-Piece	-1.5	-1.0	0.7	2.3

LESSONS LEARNED FROM PP 107 BODY MOTION TEST

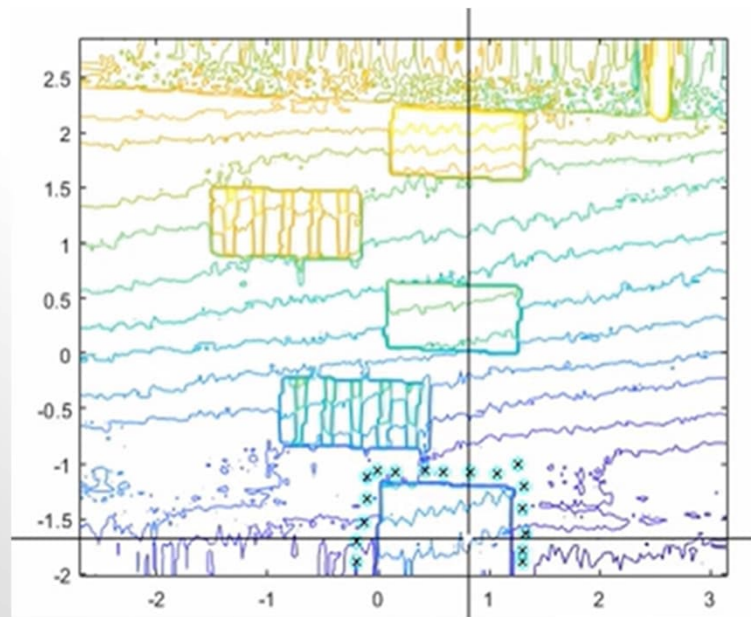
Manual Object Identification Process



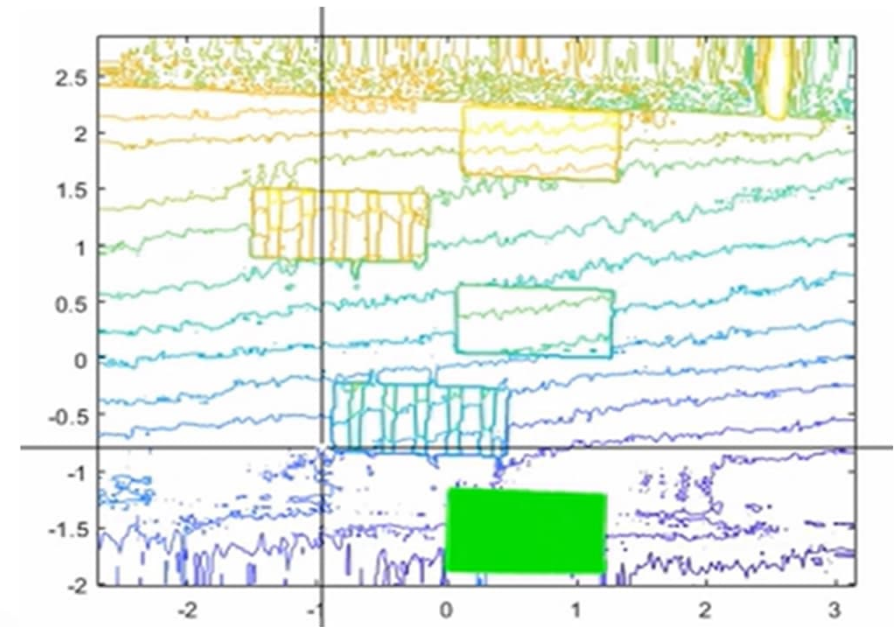
- Contour plot represents a 3D surface on a 2D (XY) plane
- Uses contour lines connecting equal-value (Z) points
- Dense contour lines indicate sharp changes (possible edges); *Not true object edges*



User selects points inside the plate



User selects points outside the plate to define a polygon boundary

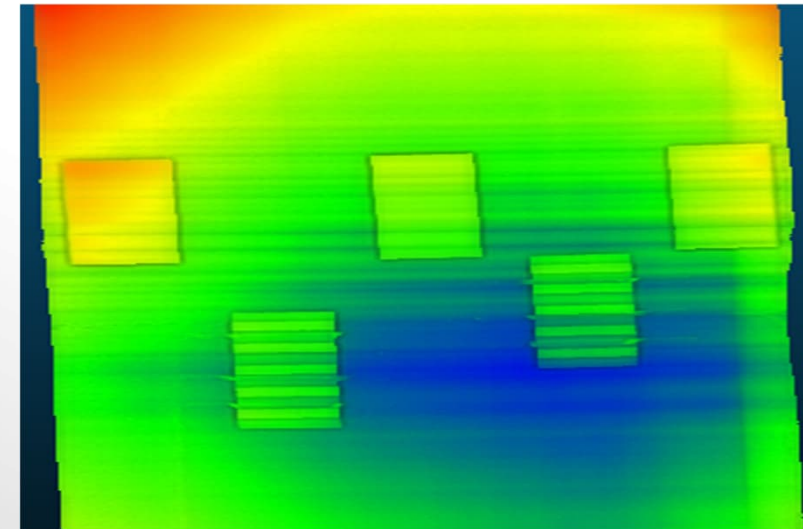
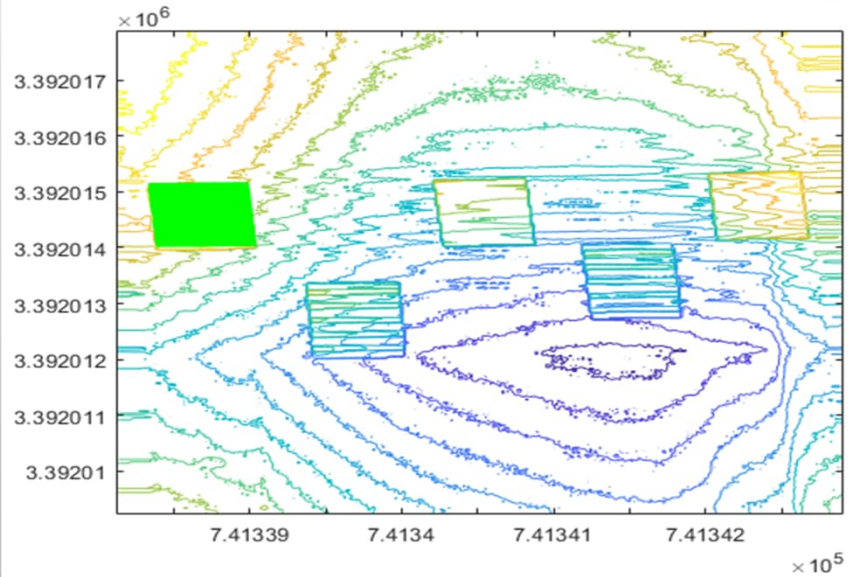
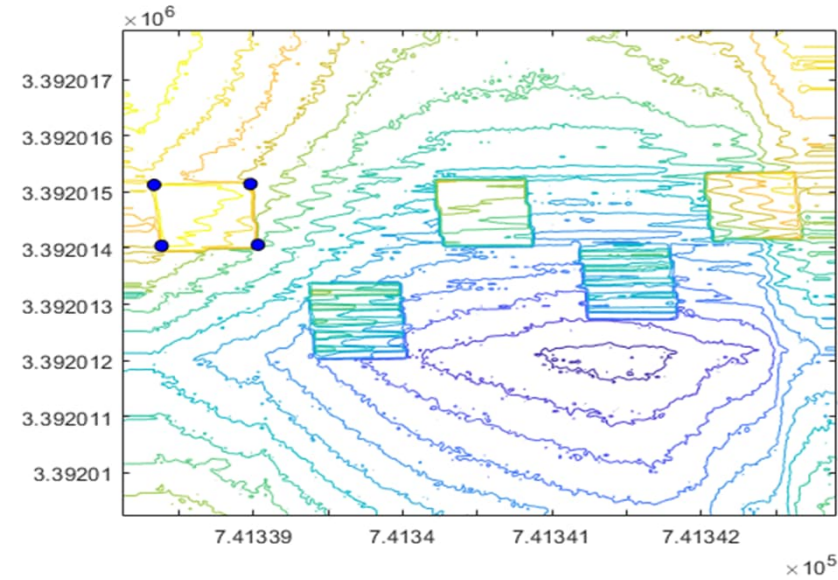
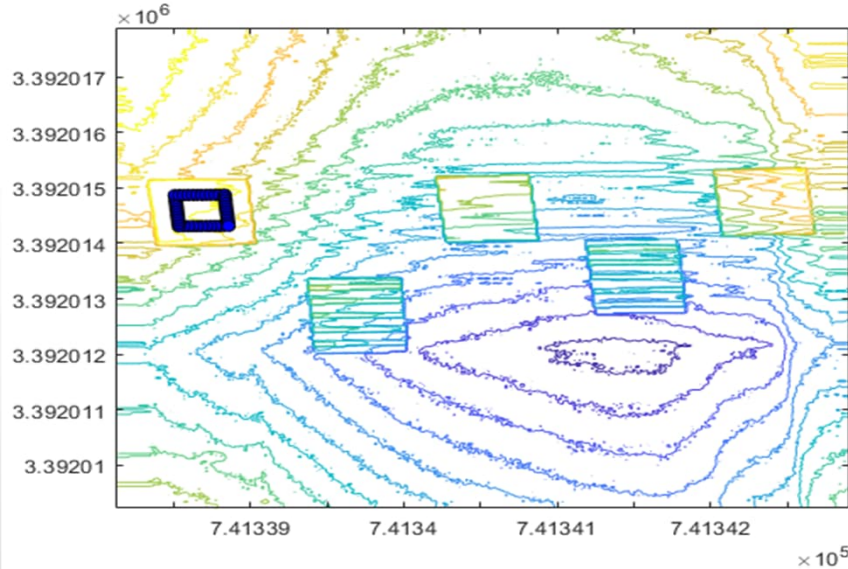


- Fits a plane from inside points
- Computes distances of polygon points to the plane
- Classifies points below a threshold as surface points (green)

Each profiler: 3 speeds (6, 9, 12 mph), 3 repeats per speed (9 files), 3 plates/file; Repeat 27 times.

LESSONS LEARNED FROM PP 107 BODY MOTION TEST

Automated Process



LESSONS LEARNED FROM PP 107 BODY MOTION TEST



Analysis Result: Manual vs. Automated Process

Vehicle Body Motion Error – for Cross Slope Analysis

QES-User1

Vehicle	5 th (-8 mm)	25 th (-5 mm)	75 th (5 mm)	95 th (8 mm)
PR140	-7.5	-2.2	2.7	4.7
PR171	-3.8	-1.8	1.7	4.1

TTI-User1

PR140	-8.9	-3.5	3.8	6.4
PR171	-3.9	-1.8	1.8	4.1

TTI-User2

PR140	-9.4	-3.8	4.0	6.5
PR171	-4.0	-1.8	1.8	4.1

Automated

PR140	-6.0	-1.6	2.1	3.9
PR171	-3.5	-1.7	1.7	3.8

Vehicle Body Motion Error – for Edge/Curb Analysis

Vehicle	5 th (-4 mm)	25 th (-2.5 mm)	75 th (2.5 mm)	95 th (4 mm)
PR140	-8.4	-2.3	2.9	5.8
PR171	-4.1	-1.7	1.6	4.3

PR140	-9.4	-2.9	3.5	6.7
PR171	-4.4	-1.8	1.6	4.8

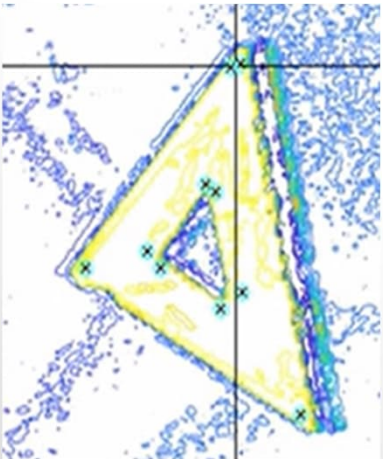
PR140	-9.7	-3.5	3.7	7.1
PR171	-4.5	-1.8	1.7	5.1

PR140	-6.0	-1.3	2.0	3.7
PR171	-3.6	-1.6	1.4	3.7

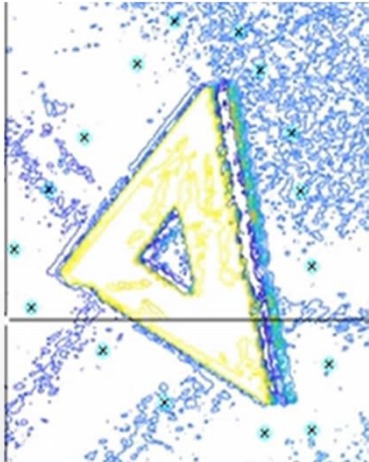
LESSONS LEARNED FROM PP 108 NAVIGATION DRIFT TEST



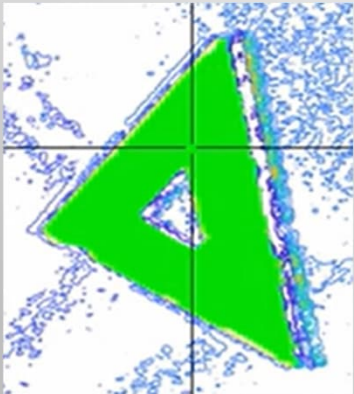
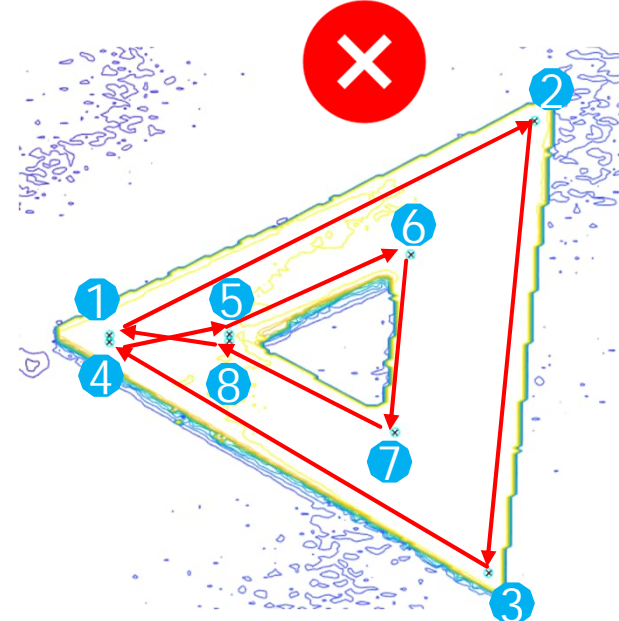
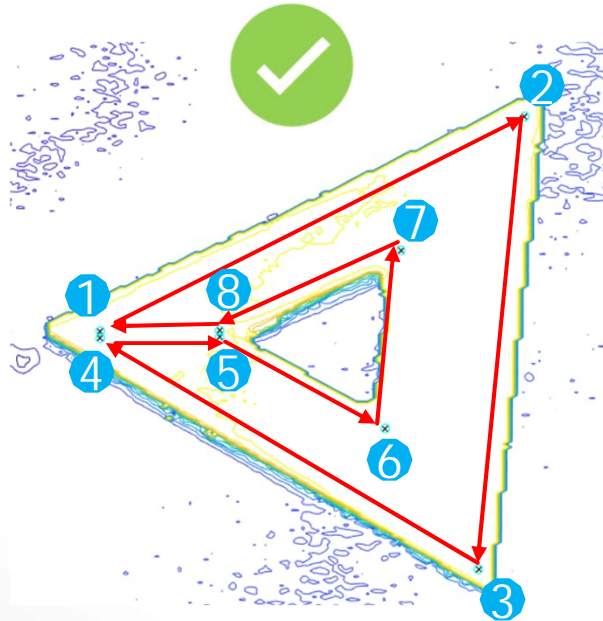
Manual Object Identification Process



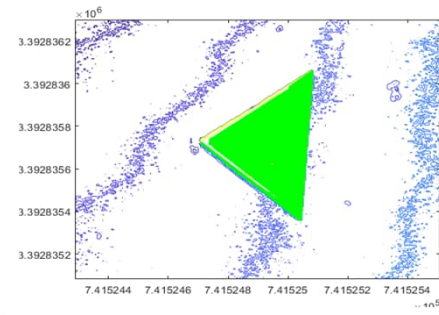
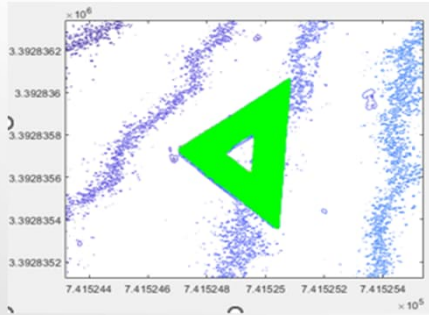
User selects points inside the plate



User selects points outside the plate



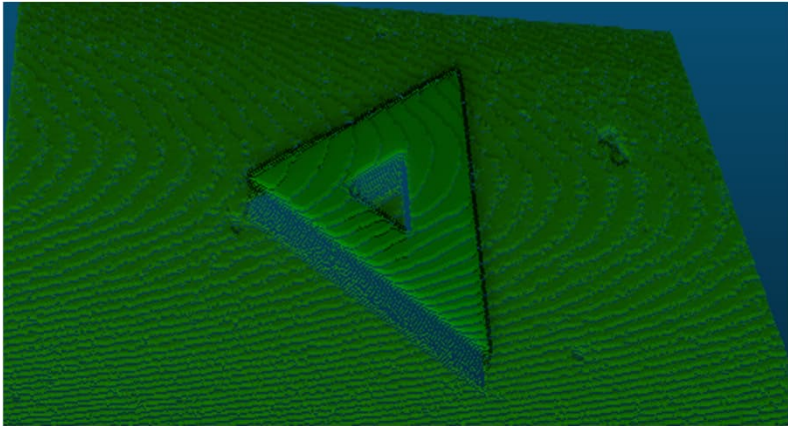
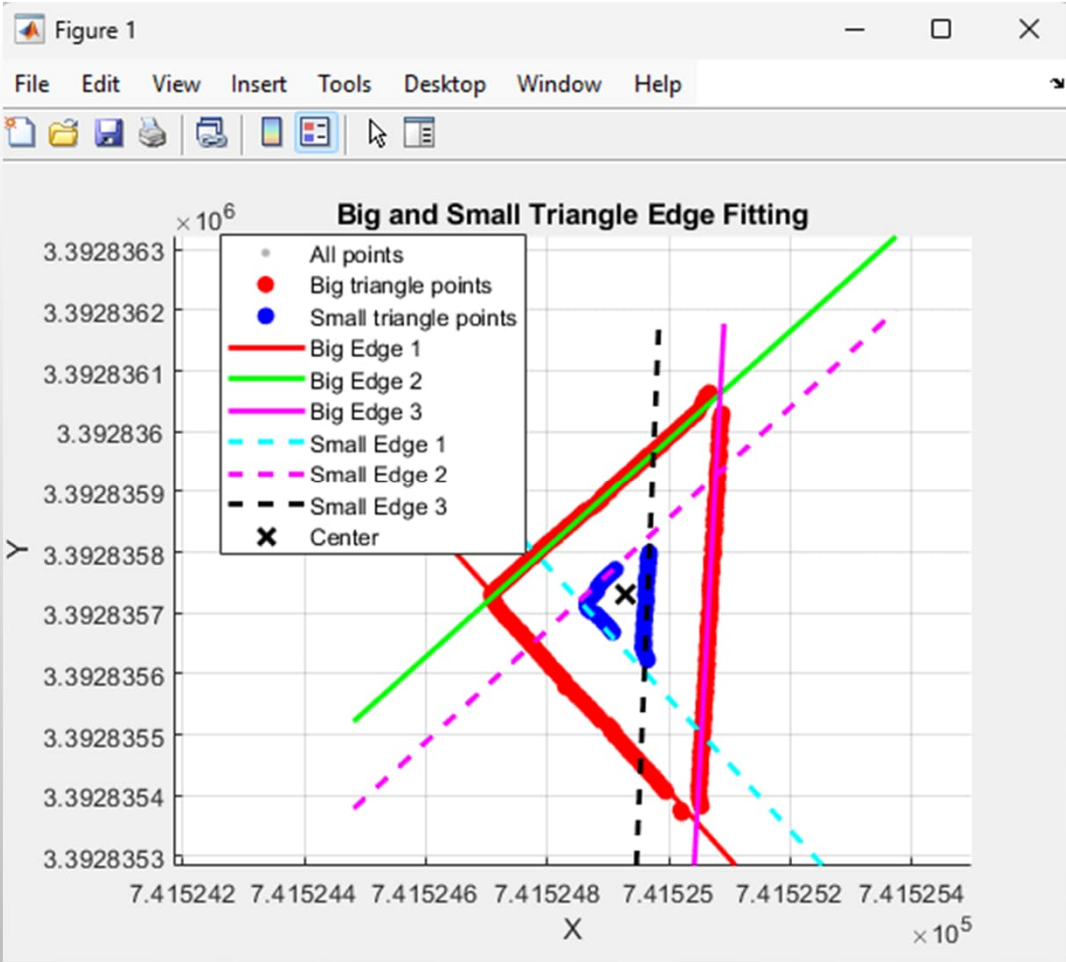
- Fits a plane
- Computes distances
- Identifies surface points



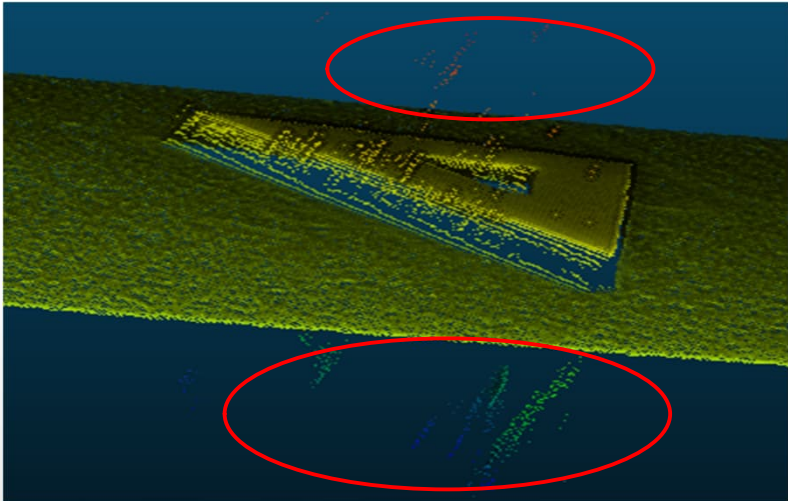
Each profiler: 5 repeat runs, 2 files/run; Repeat 10 times.

LESSONS LEARNED FROM PP 108 NAVIGATION DRIFT TEST

Automated Process



Clean Data



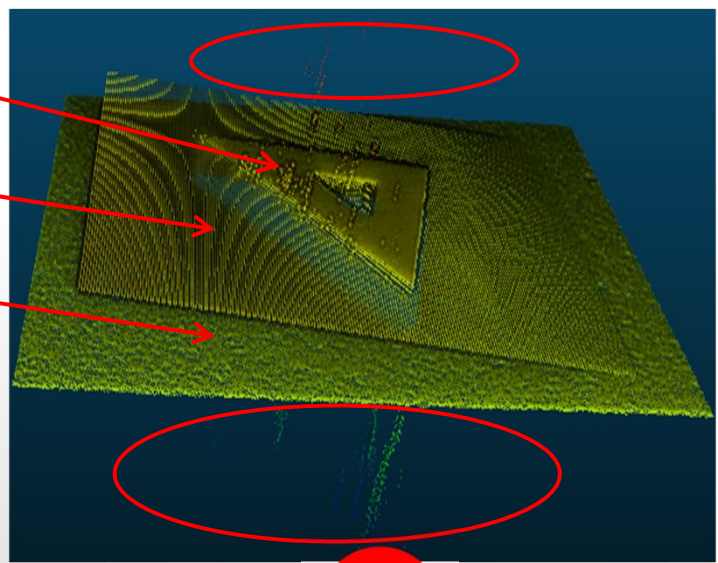
Data with outliers, PR160, Montana, 2025

LESSONS LEARNED FROM PP 108 NAVIGATION DRIFT TEST



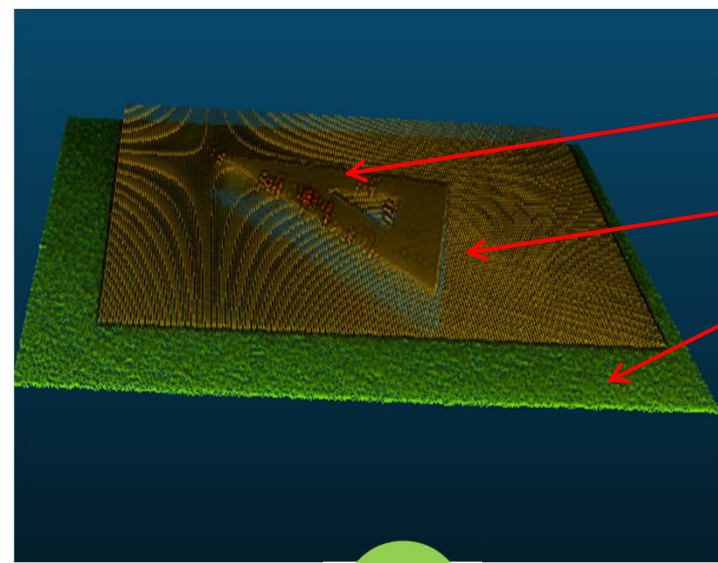
Before Outlier Removal: Misfitted Plane

- Ref. Obj. Surface
- Misfitted Plane
- Ground



After Outlier Removal: Properly Fitted Plane

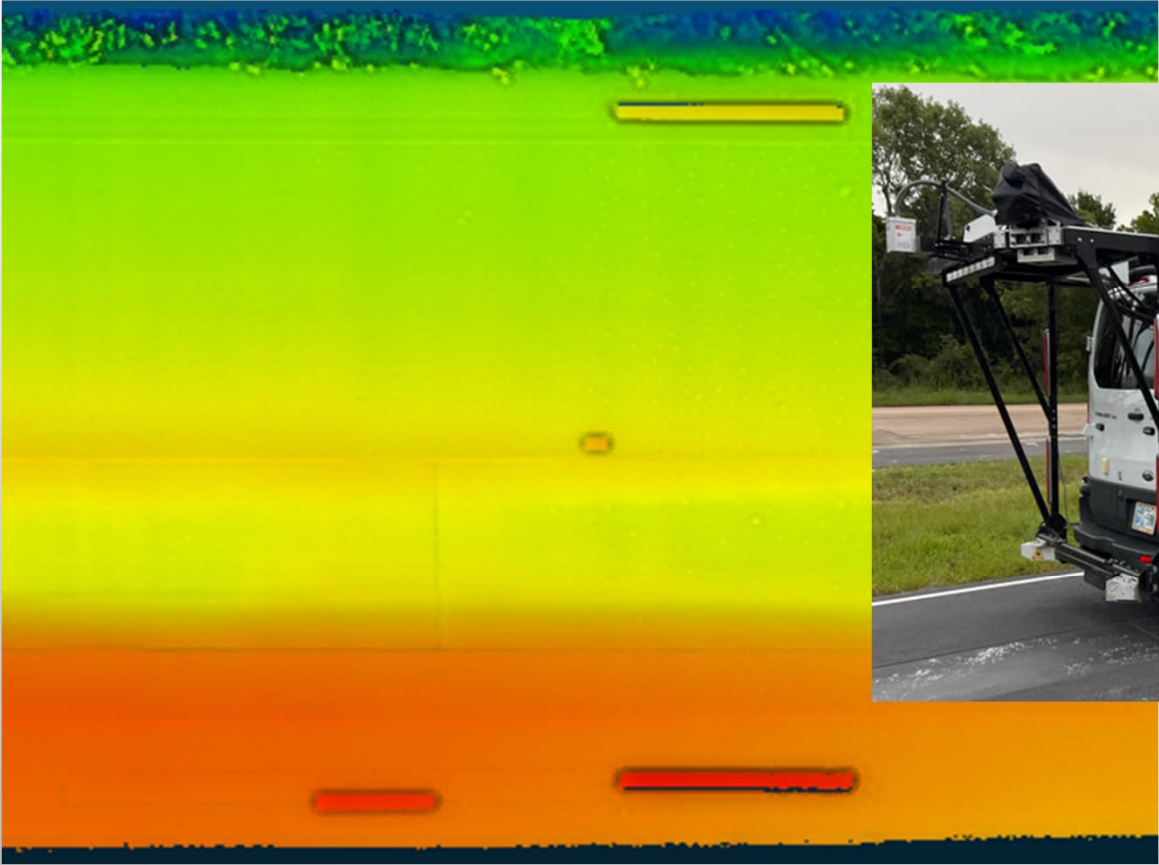
- Ref. Obj. Surface
- Properly Fitted Plane
- Ground



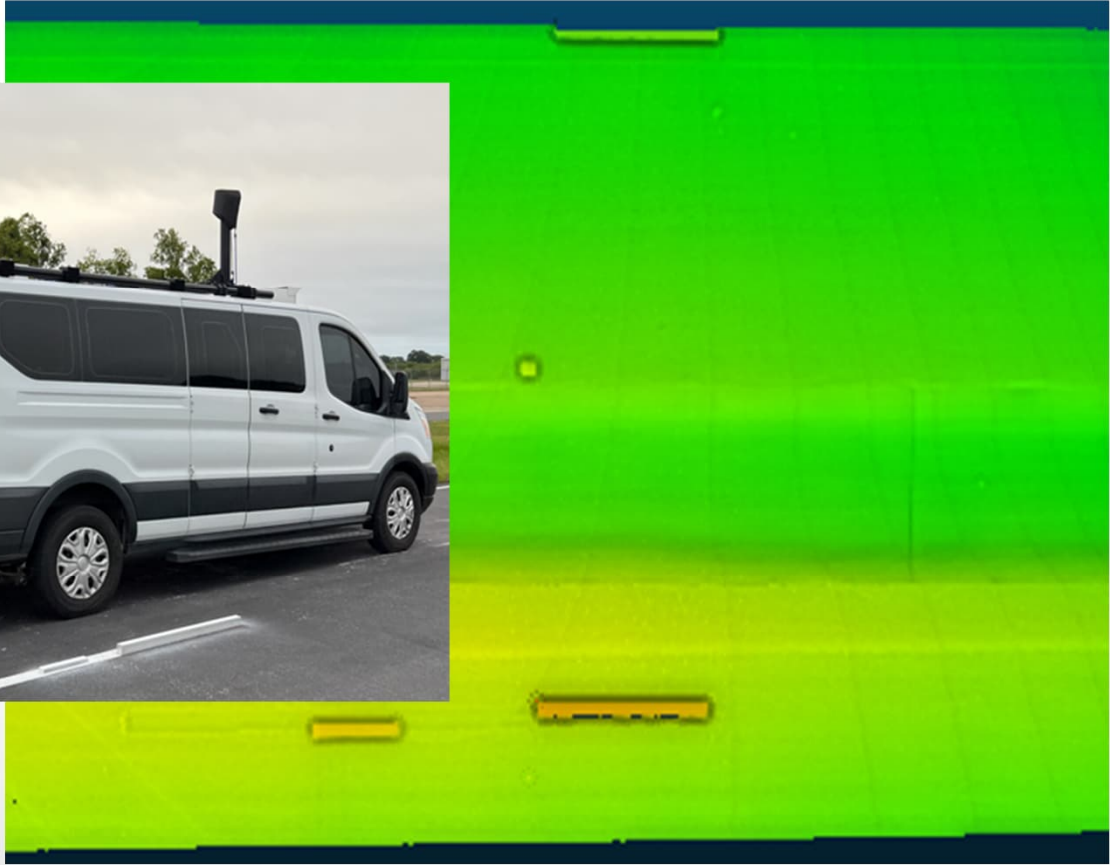
LESSONS LEARNED FROM PP 109 HIGHWAY PERFORMANCE TEST



PR171, 20 mph, Run1, 2024 TTI Test Track



PR 136, 35 mph, Run1, 2024 TTI Test Track

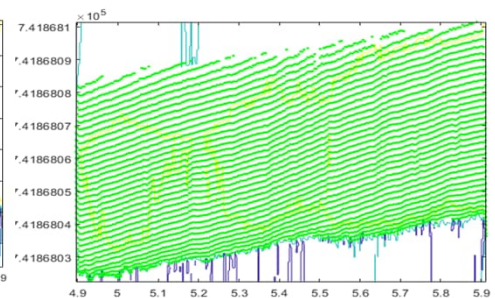
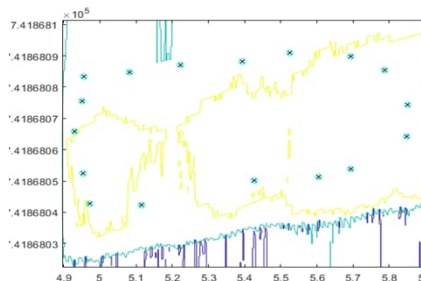
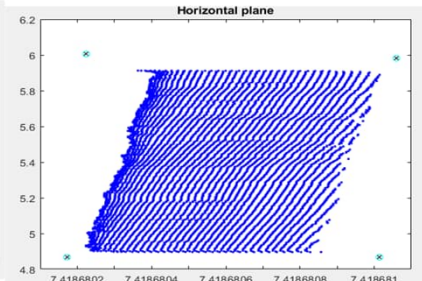
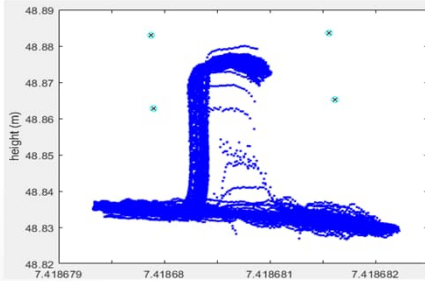
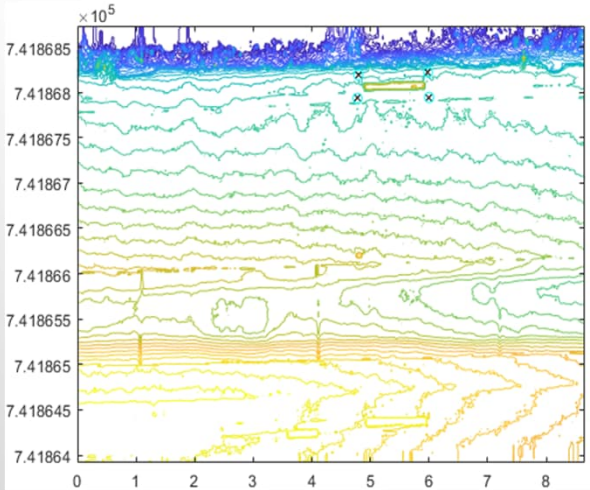


LESSONS LEARNED FROM PP 109 HIGHWAY PERFORMANCE TEST

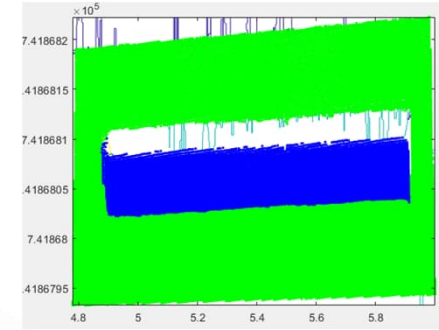
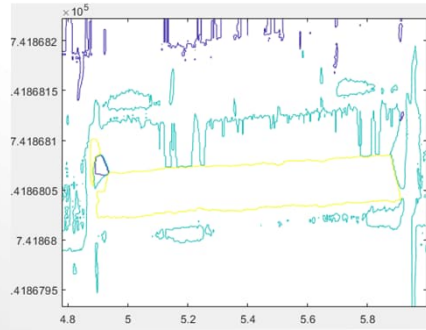
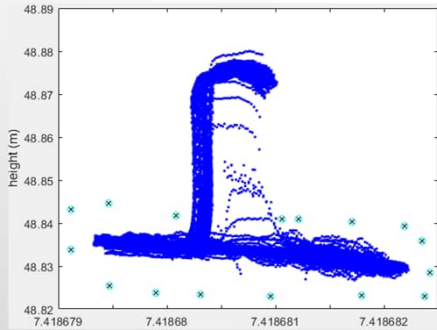
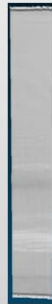
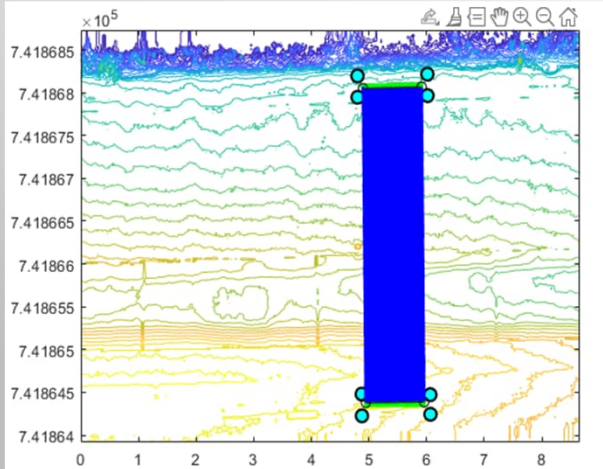
Manual Object Identification Process



Left Beam Top Point Selection (Top View → Side View → Top View Again)



Left Beam Bottom & Road Point Selection



Each profiler: 9 files (3 speeds × 3 runs); each file has 2 beams and 1 block → Repeat 27 times.

LESSONS LEARNED FROM PP 109 HIGHWAY PERFORMANCE TEST



Automated Process

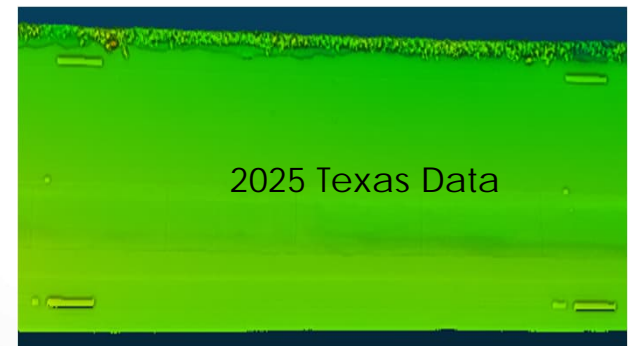
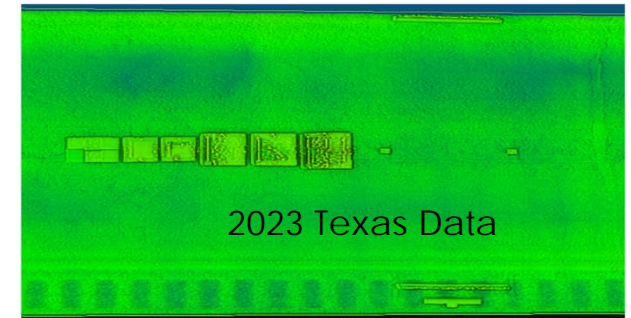
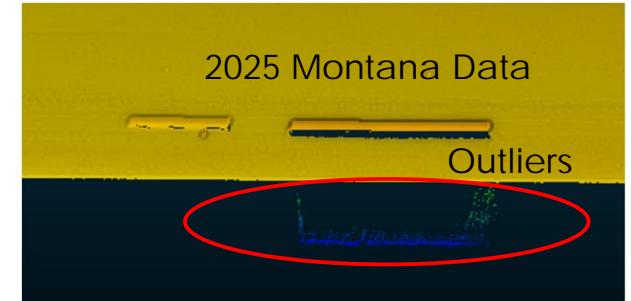
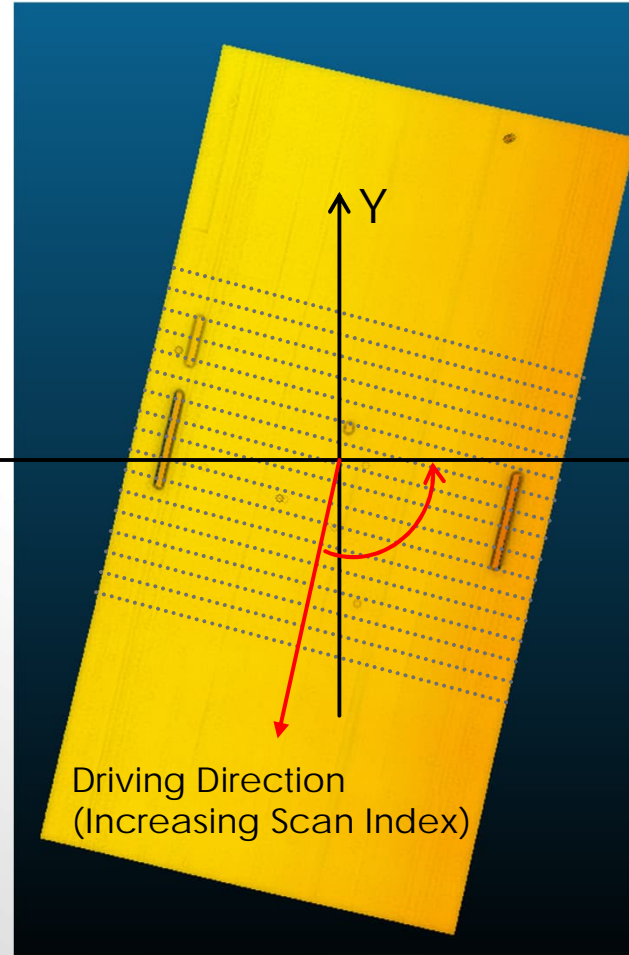
PP 109: TPP Highway Performance Analysis

Select Ground Reference File

Select TPP Root Folder

Idle

Success: 0 Failed: 0



LESSONS LEARNED FROM PP 109 HIGHWAY PERFORMANCE TEST

Algorithm for Rut Depth and Cross Slope Calculation

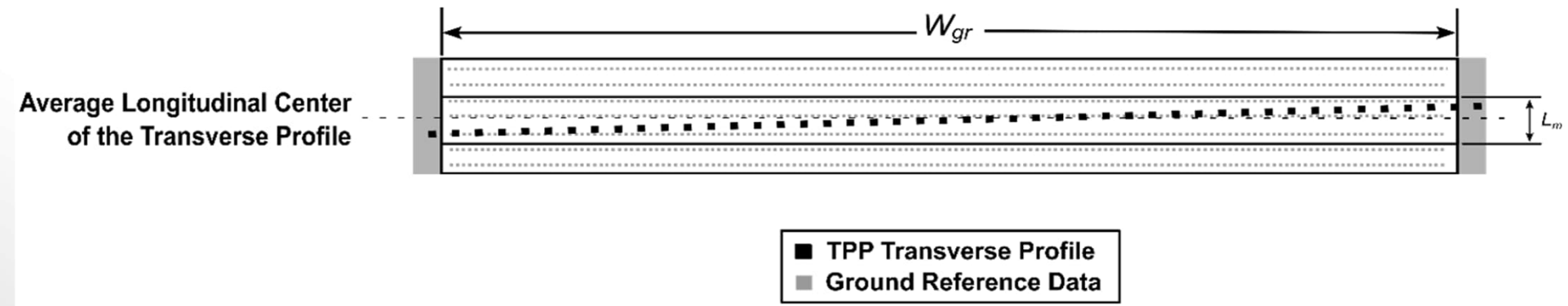
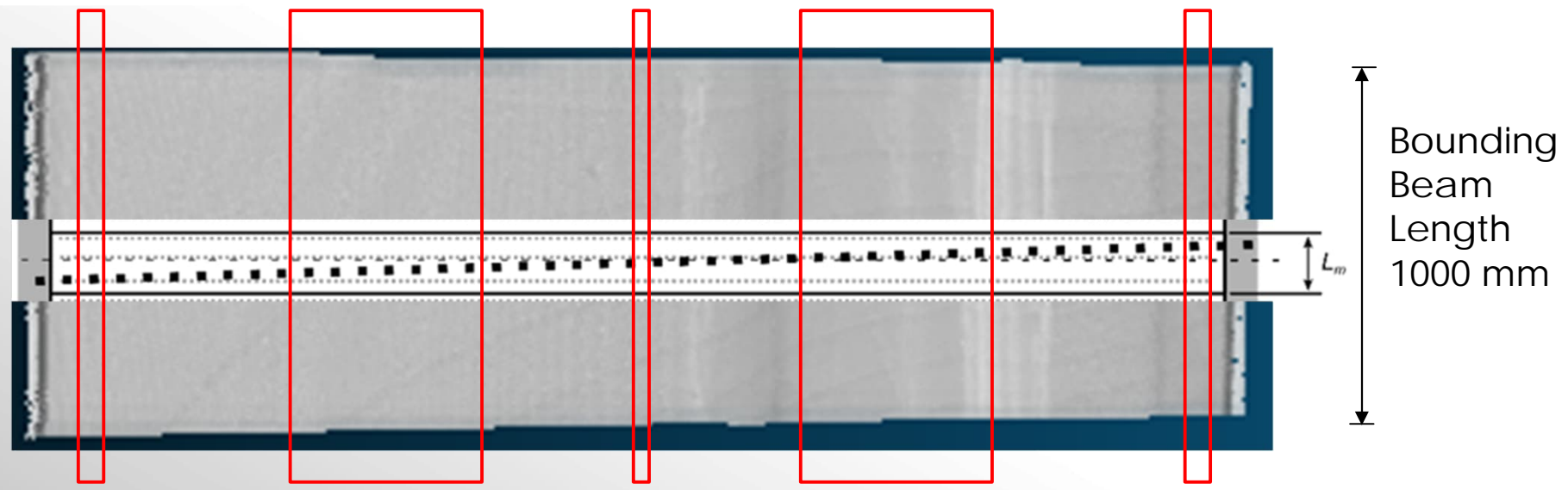


Figure 8—Identification of the Ground Reference Data Points for Calculation of Reference Cross Slope and Rut Depth

PP 109: $L_m = 100$ mm (max);
 no minimum L specified.

Too small $L \rightarrow$ insufficient
 points for rut calculation \rightarrow
 high variation or NA/NaN



Five Zones Specified in AASHTO R87 for Rut Calculation

LESSONS LEARNED FROM PP 109 HIGHWAY PERFORMANCE TEST



Rut Depth Results (Manual vs. Automated Process), 2024 Texas, 20 mph

Manual Process, Smaller L (~10 mm)

Vehicle	5 th (-2.5 mm)	25 th (-1.0 mm)	75 th (1.0 mm)	95 th (2.5 mm)
PR140	-0.85	-0.24	1.03	2.57
PR171	0.88	1.40	1.80	2.40
PR110	-1.11	0.00	0.00	10.24
PR115	-0.54	0.48	1.34	2.03
PR116	-0.63	0.00	2.10	13.40
PR118	-0.92	0.31	3.43	4.70
PR119	-0.34	0.62	2.43	3.57
PR121	-1.15	-0.16	10.09	12.62
PR131	-3.89	-2.62	0.64	3.31
PR136	0.00	1.33	2.74	10.18
PR138	-0.78	0.01	1.20	3.30
PR145	NA	NA	NA	NA

Automated Process, Larger L (~25 mm)

Vehicle	5 th (-2.5 mm)	25 th (-1.0 mm)	75 th (1.0 mm)	95 th (2.5 mm)
PR140	-2.68	-1.41	-0.38	0.83
PR171	1.21	1.57	1.86	2.08
PR110	-1.86	-1.56	0.32	1.28
PR115	-2.44	-1.62	-0.27	0.06
PR116	-0.64	-0.19	0.76	1.05
PR118	-1.93	-0.91	1.64	2.31
PR119	-0.65	-0.17	1.58	2.75
PR121	-1.76	-1.14	1.74	2.40
PR131	-4.26	-3.36	-0.78	0.48
PR136	-1.47	-0.69	1.58	2.12
PR138	-2.32	-1.61	-0.33	0.43
PR145	0.58	0.97	1.94	2.46

Left Wheel Path Rut Depth, mm

Vehicle	Mean (TPP)	Mean (GRE)	Difference	Std. (Runs)
PR140	2.5477	3.47	-0.92	0.09
PR171	5.3171	3.50	1.82	0.04
PR110	3.9313	3.50	0.43	0.18
PR115	2.1023	3.49	-1.39	0.24
PR116	3.3635	3.50	-0.14	0.02
PR118	5.1963	3.50	1.69	0.32
PR119	3.627	3.51	0.12	0.12
PR121	5.3674	3.50	1.87	0.33
PR131	2.8248	3.50	-0.68	0.89
PR136	2.9369	3.50	-0.56	0.19
PR138	2.0299	3.51	-1.48	0.08
PR145	5.4388	3.49	1.95	0.29

Right Wheel Path Rut Depth, mm

Vehicle	Mean (TPP)	Mean (GRE)	Difference	Std. (Runs)
PR140	17.979	18.90	-0.93	0.35
PR171	20.4723	18.89	1.58	0.06
PR110	17.313	18.90	-1.59	0.07
PR115	18.4657	18.88	-0.41	0.16
PR116	19.6818	18.90	0.78	0.12
PR118	17.8965	18.90	-1.00	0.63
PR119	20.6295	18.90	1.73	0.67
PR121	17.749	18.90	-1.15	0.41
PR131	15.4385	18.90	-3.46	0.58
PR136	20.4523	18.89	1.56	0.35
PR138	18.5693	18.90	-0.33	0.38
PR145	19.8749	18.89	0.99	0.25

- Separate Left/Right Wheel Paths
- Compare mean rut depth (Accuracy Check)
- Check standard deviation across repeat runs (Repeatability Check)

LESSONS LEARNED FROM PP 109 HIGHWAY PERFORMANCE TEST



Cross Slope Results (Manual vs. Automated Process), 2024 Texas, 20 mph

Manual Process, Smaller L (~10 mm)

Vehicle	5 th (-0.4)	25 th (-0.15)	75 th (0.15)	95 th (0.4)
PR140	-0.19	-0.16	0.11	0.19
PR171	-0.55	-0.52	-0.48	-0.44
PR110	-2.29	-2.12	-1.62	-1.11
PR115	0.47	0.60	0.95	1.22
PR116	-2.00	-1.80	-1.27	-1.05
PR118	1.19	-0.98	-0.86	-0.78
PR119	-2.33	-2.27	-2.14	-1.05
PR121	-1.20	-1.09	-0.97	-0.76
PR131	-1.14	-0.77	-0.60	-0.09
PR136	-1.45	-1.24	-1.00	-0.47
PR138	-2.33	-2.25	-2.13	-2.06
PR145	NA	NA	NA	NA

Automated Process, Larger L (~25 mm)

Vehicle	5 th (-0.4)	25 th (-0.15)	75 th (0.15)	95 th (0.4)
PR140	-0.17	-0.11	-0.01	0.02
PR171	-0.52	-0.49	-0.46	-0.45
PR110	-2.36	-2.29	-2.00	-1.87
PR115	0.22	0.48	0.92	1.23
PR116	-1.40	-1.25	-1.00	-0.91
PR118	-1.04	-0.96	-0.83	-0.71
PR119	-2.35	-2.29	-2.20	-2.11
PR121	-1.11	-1.08	-0.99	-0.87
PR131	-0.74	-0.68	-0.60	-0.53
PR136	-1.39	-1.25	-0.95	-0.84
PR138	-2.32	-2.21	-2.12	-2.00
PR145	1.45	1.54	1.62	1.69

Cross Slope, TPP vs. GRE, % (Accuracy Check)

Vehicle	Mean (TPP)	Mean (GRE)	Difference
PR140	2.23	2.30	-0.07
PR171	1.82	2.31	-0.49
PR110	0.17	2.31	-2.14
PR115	3.01	2.31	0.70
PR116	1.18	2.31	-1.13
PR118	1.43	2.31	-0.88
PR119	0.07	2.31	-2.24
PR121	1.29	2.31	-1.02
PR131	1.68	2.31	-0.63
PR136	1.22	2.31	-1.09
PR138	0.15	2.31	-2.16
PR145	3.88	2.31	1.57

Cross Slope, % (Repeatability Check)

Vehicle	Run 1	Run 2	Run 3	Std. (Runs)
PR140	2.24	2.20	2.25	0.02
PR171	1.83	1.82	1.83	0.00
PR110	0.18	0.14	0.18	0.03
PR115	3.07	2.98	2.99	0.05
PR116	1.33	1.14	1.06	0.14
PR118	1.43	1.40	1.45	0.02
PR119	0.09	0.06	0.07	0.02
PR121	1.35	1.26	1.26	0.05
PR131	1.67	1.69	1.68	0.01
PR136	1.18	1.10	1.36	0.14
PR138	0.08	0.21	0.17	0.07
PR145	3.82	3.89	3.94	0.06

LESSONS LEARNED FROM PP 109 HIGHWAY PERFORMANCE TEST



Other Results (Automated Process), 20 mph

Left Wheel Path Rut Depth, mm

Right Wheel Path Rut Depth, mm

Cross Slope, %

Vehicle	Mean (TPP)	Mean (GRE)	Diff.	Std (Runs)
PR110	11.42	11.91	-0.49	0.18
PR118	12.87	12.00	0.87	0.15
PR121	12.92	11.86	1.06	0.11
PR129	13.35	11.79	1.56	0.13
PR135	14.00	12.02	1.98	0.10
PR141	13.03	11.86	1.16	0.90
PR145	13.47	11.95	1.52	0.13
PR148	13.15	11.99	1.16	0.17

Vehicle	Mean (TPP)	Mean (GRE)	Diff.	Std (Runs)
PR110	4.90	5.19	-0.29	0.34
PR118	5.90	5.15	0.75	0.57
PR121	6.03	5.22	0.81	0.18
PR129	5.59	5.23	0.36	0.16
PR135	6.35	5.14	1.21	0.02
PR141	5.59	5.21	0.38	0.41
PR145	5.77	5.18	0.59	0.14
PR148	5.20	5.16	0.04	0.33

Vehicle	Mean (TPP)	Mean (GRE)	Diff.	Std (Runs)
PR110	0.27	1.63	-1.36	0.08
PR118	0.28	1.63	-1.34	0.12
PR121	0.31	1.64	-1.33	0.10
PR129	0.48	1.64	-1.15	0.04
PR135	0.20	1.63	-1.42	0.04
PR141	0.38	1.63	-1.25	0.05
PR145	0.35	1.63	-1.27	0.01
PR148	0.32	1.63	-1.30	0.13

Vehicle	Mean (TPP)	Mean (GRE)	Diff.	Std (Runs)
PR118	5.00	3.25	1.75	0.05
PR131	1.99	3.26	-1.27	0.03
PR132	5.09	3.33	1.76	0.01
PR136	3.57	3.29	0.28	0.04
PR181	5.19	3.32	1.87	0.12

Vehicle	Mean (TPP)	Mean (GRE)	Diff.	Std (Runs)
PR118	7.14	5.74	1.40	0.04
PR131	5.22	5.75	-0.53	0.04
PR132	7.29	5.76	1.53	0
PR136	6.03	5.75	0.28	0.17
PR181	7.25	5.76	1.49	0.03

Vehicle	Mean (TPP)	Mean (GRE)	Diff.	Std (Runs)
PR118	3.73	1.94	1.80	0.02
PR131	2.10	1.94	0.16	0.00
PR132	0.79	1.94	-1.15	0.00
PR136	3.34	1.94	1.40	0.01
PR181	2.10	1.94	0.16	0.02

Vehicle	Mean (TPP)	Mean (GRE)	Diff.	Std (Runs)
PR118	6.19	4.41	1.79	0.03
PR131	4.21	4.41	-0.20	0.02
PR132	6.18	4.41	1.78	0.01
PR136	5.15	4.41	0.74	0.11
PR181	6.35	4.42	1.93	0.02

Vehicle	Mean (TPP)	Mean (GRE)	Diff.	Std (Runs)
PR118	20.33	18.77	1.56	0.22
PR131	19.45	18.78	0.67	0.02
PR132	19.97	18.76	1.21	0.06
PR136	20.96	18.77	2.19	0.13
PR181	20.49	18.77	1.72	0.03

Vehicle	Mean (TPP)	Mean (GRE)	Diff.	Std (Runs)
PR118	3.67	2.09	1.58	0.02
PR131	2.13	2.10	0.04	0.01
PR132	0.75	2.09	-1.34	0.00
PR136	3.40	2.10	1.30	0.02
PR181	2.11	2.10	0.02	0.00

Vehicle	Mean (TPP)	Mean (GRE)	Diff.	Std (Runs)
PR160	8.68	7.22	1.46	0.12
PR162	8.46	7.23	1.24	0.06

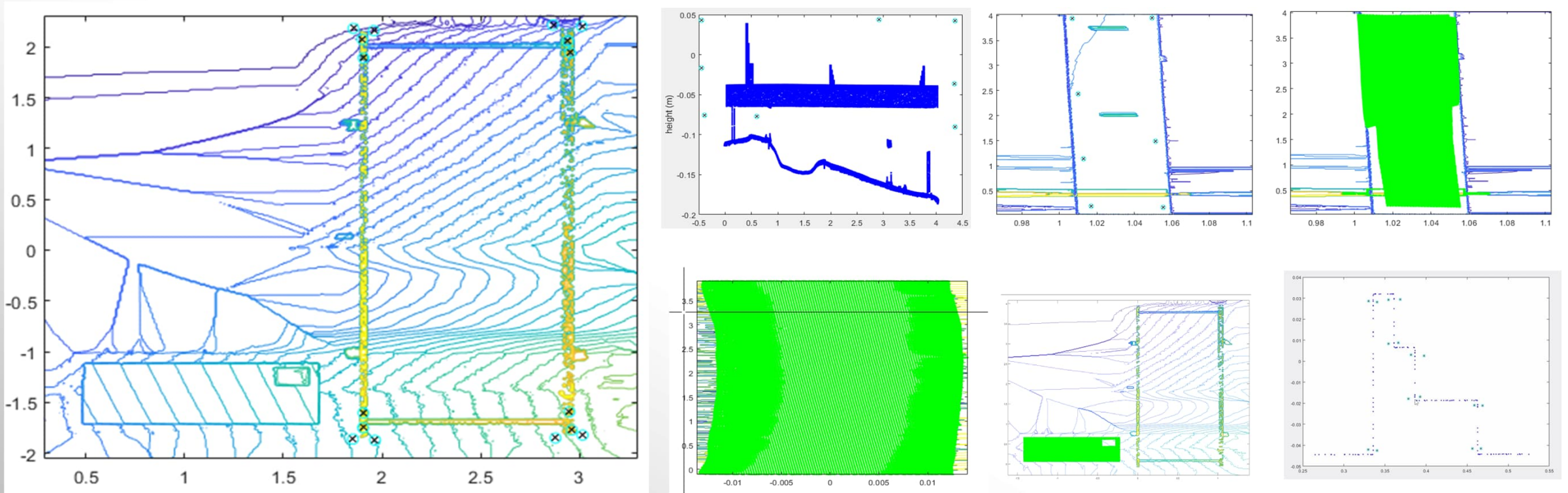
Vehicle	Mean (TPP)	Mean (GRE)	Diff.	Std (Runs)
PR160	5.03	3.6823	1.35	0.06
PR162	4.25	3.6796	0.57	0.08

Vehicle	Mean (TPP)	Mean (GRE)	Diff.	Std (Runs)
PR160	1.07	1.01	0.06	0.01
PR162	0.95	1.01	-0.06	0.00

- Rut & cross slope:
 - repeatable
 - Rut depths:
 - meet accuracy (assumed ±2.5 mm)
 - Cross Slopes:
 - mostly fail accuracy (assumed ±0.4%)
- 2023 Texas Data
- 2025 Texas Data, Shallow Rut Section
- 2025 Texas Data, Deep Rut Section
- 2025 Montana Data

LESSONS LEARNED FROM PP 110 GROUND REFERENCE TEST

Manual Object Identification Process



Automated process under development

SUMMARY



- DEMONSTRATE BENEFITS OF AUTOMATED TPP DATA PROCESSING:
 - EFFICIENT
 - CONSISTENT
- REFINE ALGORITHMS FOR MORE STABLE, REASONABLE RESULTS
- EXPLORE ALTERNATIVE PASS/FAIL CRITERIA FOR PRACTICAL IMPLEMENTATION
- HIGHLIGHT THE NEED FOR A ROBUST, TRANSPARENT, AUTOMATED TOOL FOR RELIABLE TPP IMPLEMENTATION



HONORING THE PAST. PAVING THE FUTURE.



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THANK YOU

