RPUG
Road Profile Users' Group

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2026 RPUG CONFERENCE ★ PITTSBURGH, PA ★ APRIL 28 - MAY 1

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 Uhlmeyer, 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.

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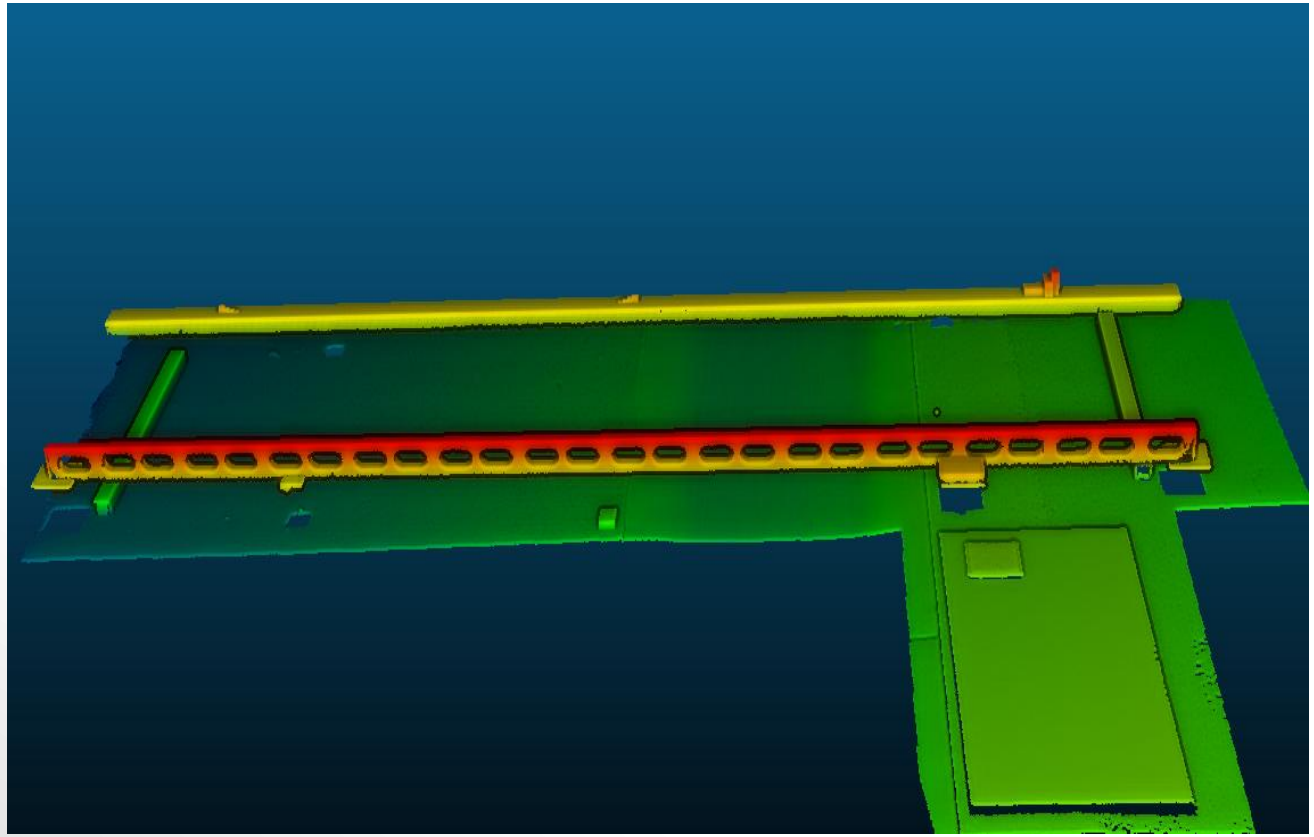
PP 110 GROUND REFERENCE TEST

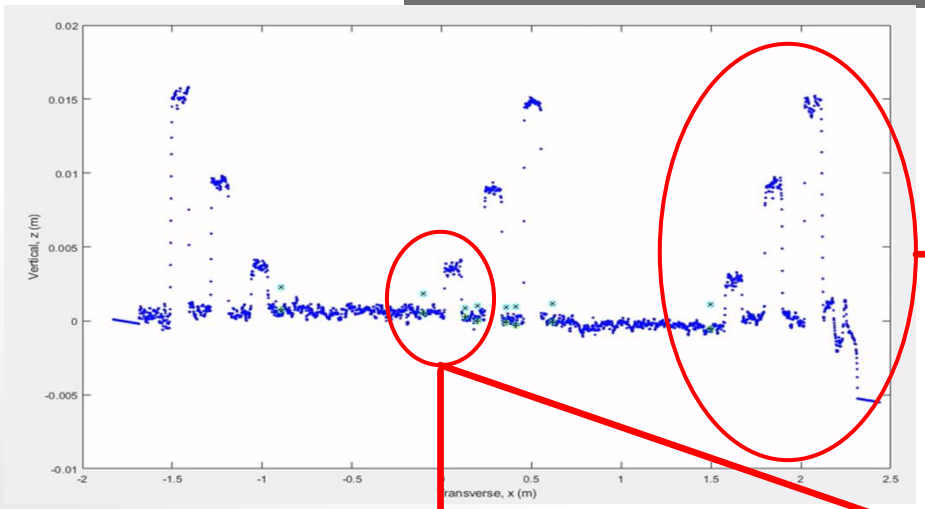
2024

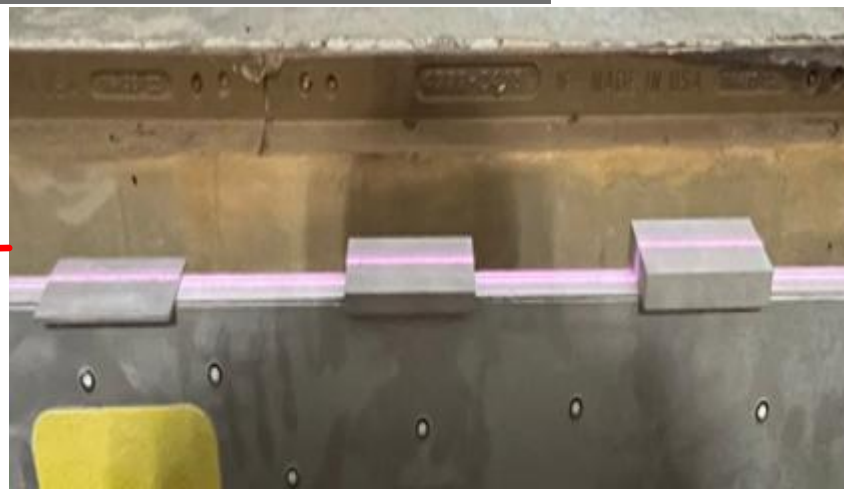
2025

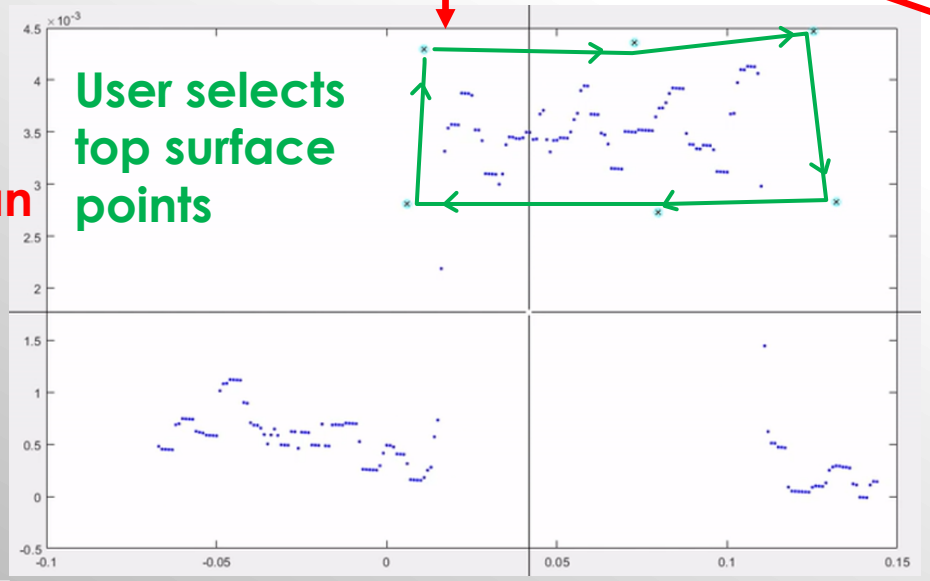


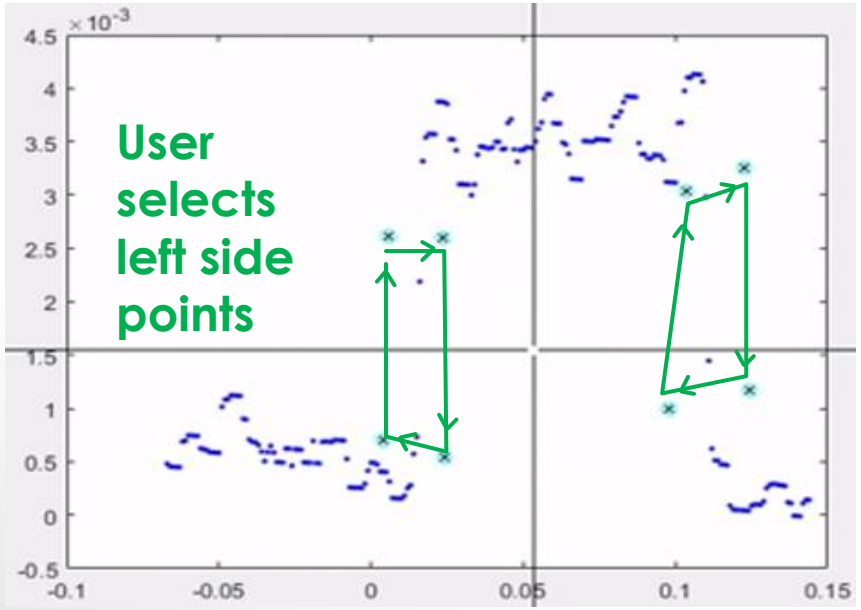
LESSONS LEARNED FROM PP 106 STATIC TEST

Manual Object Identification Process

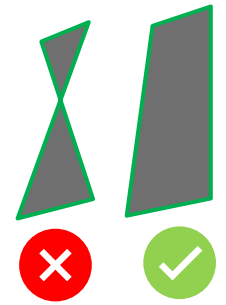








User selects right side points



Each Profiler:

- 10 Scans
- 9 block/scan
- Repeat 90 times

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

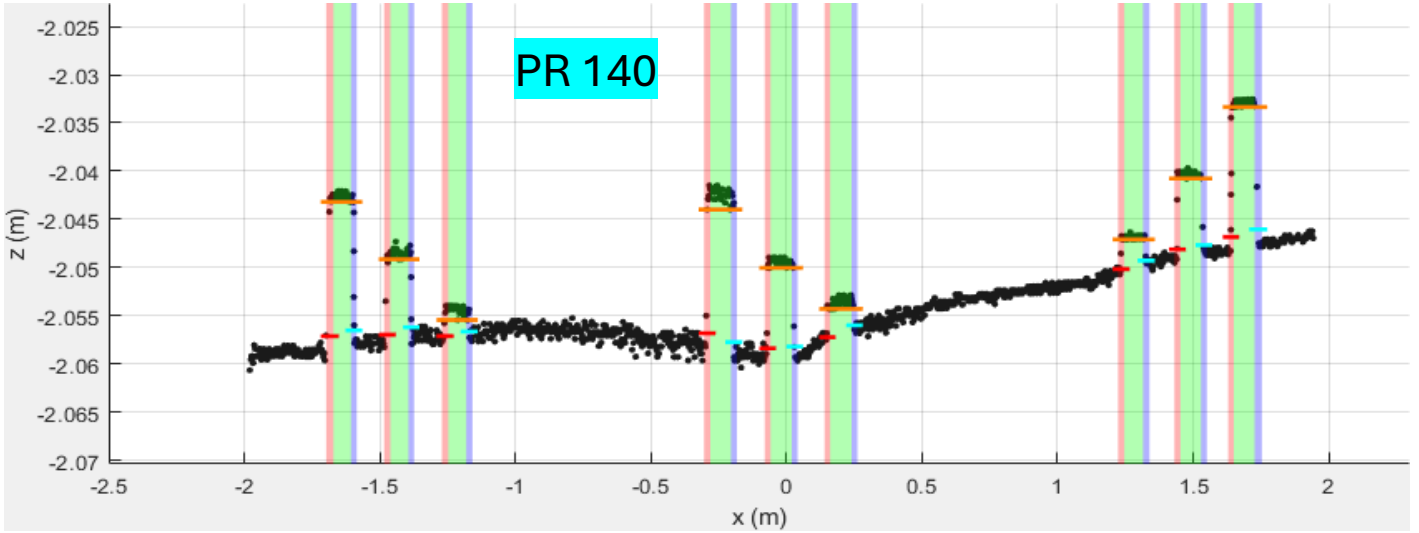
GAUGE BLOCK SETTINGS

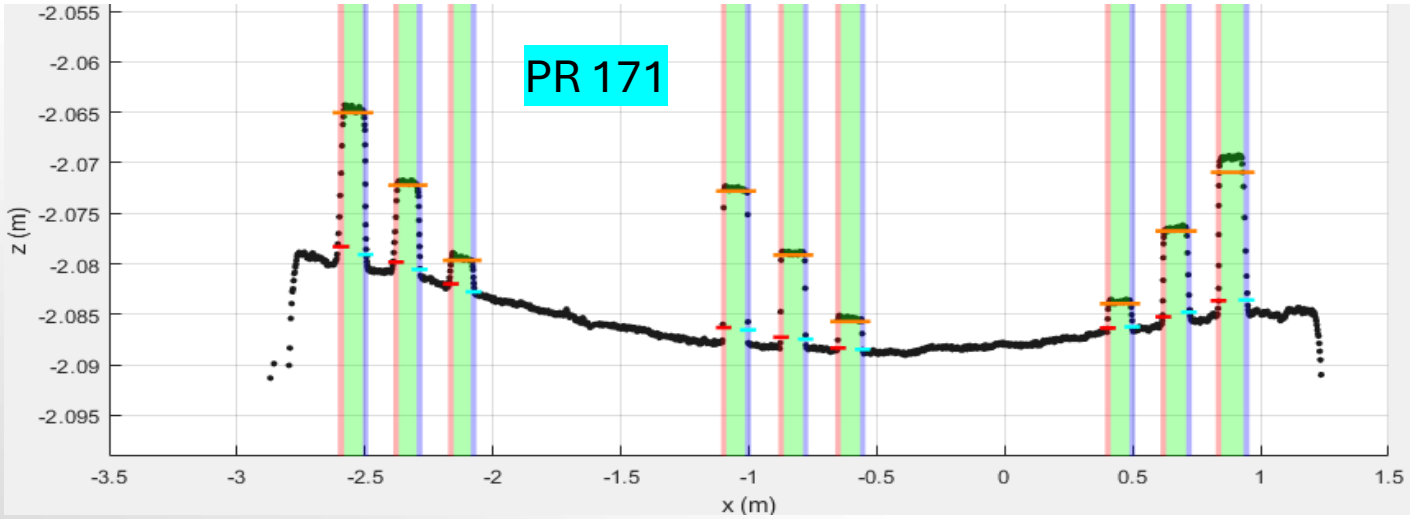
Block Width (metres): 0.09525 — same for all blocks

Block Heights (metres) — one value per block

Block 1	0.015875 m	Block 2	0.009525 m	Block 3	0.003175 m
Block 4	0.015875 m	Block 5	0.009525 m	Block 6	0.003175 m
Block 7	0.003175 m	Block 8	0.009525 m	Block 9	0.015875 m

Run Analysis





LESSONS LEARNED FROM PP 106 STATIC TEST

Analysis Result: Manual vs. Automated Process

Transverse Measurement Error

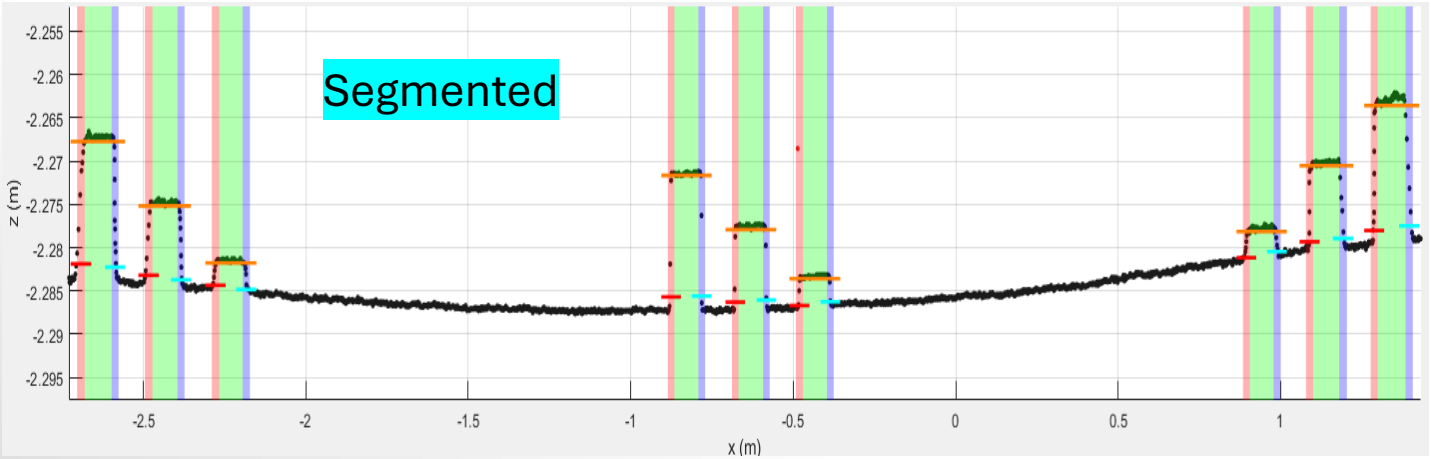
	Vehicle	5th (-7.5 mm)	25th (-5 mm)	75th (5 mm)	95th (7.5 mm)
QES-User1	PR140	-6.1	-4.4	1.7	4.4
	PR171	-4.3	-1.7	3.0	7.4
TTI-User1	PR140	-11.7	-4.0	3.6	10.0
	PR171	-4.9	-1.2	2.7	7.9
TTI-User2	PR140	-9.8	-1.7	1.0	9.6
Automated	PR140	-9.6	-5.9	-0.09	5.4
	PR171	-4.3	-2.8	0.34	7.4

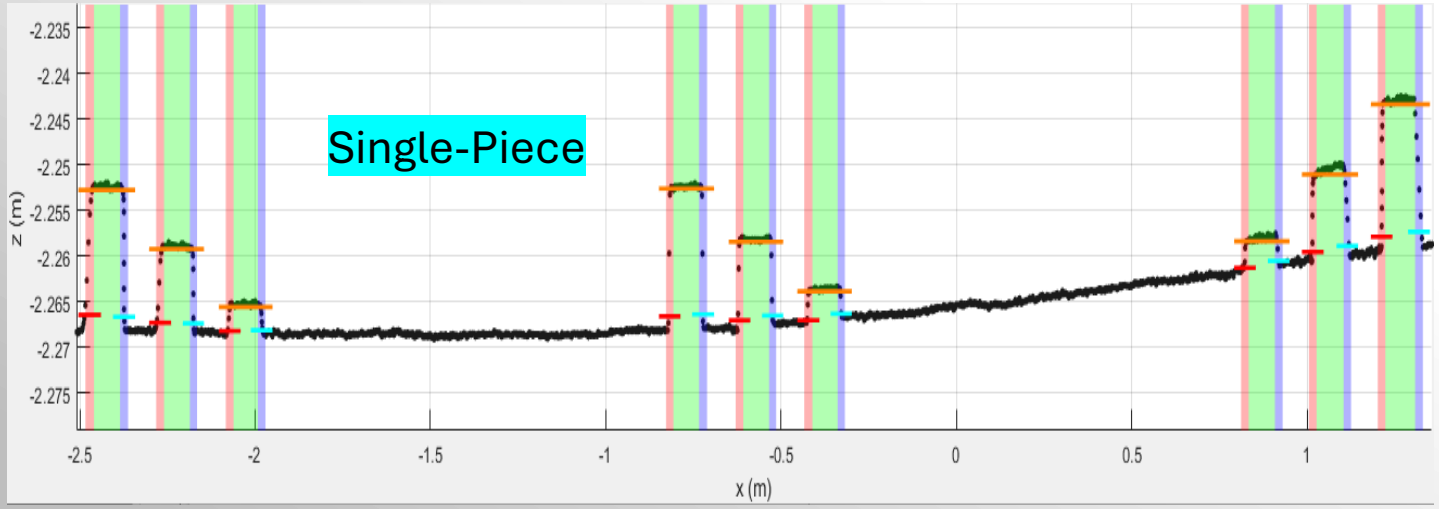
Straightness Error

Vehicle	5th (-2.5 mm)	25th (-1 mm)	75th (1 mm)	95th (2.5 mm)
PR140	-2.7	-0.7	1.0	1.9
PR171	-2.5	-1.2	0.6	3.1
PR140	-2.0	-0.5	0.6	1.5
PR171	-0.9	-0.3	0.3	1.2
PR140	-1.0	-0.4	0.4	1.0
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	5th (-7.5 mm)	25th (-5 mm)	75th (5 mm)	95th (7.5 mm)
Segmented	-2.0	-0.1	6.1	7.8
Single-Piece	-5.5	-2.5	0.72	6.1

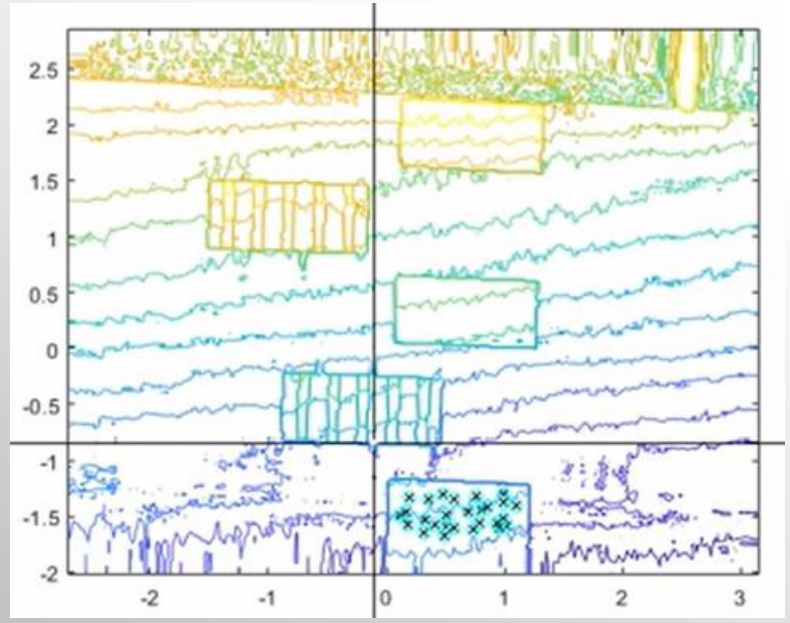
Straightness Error

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

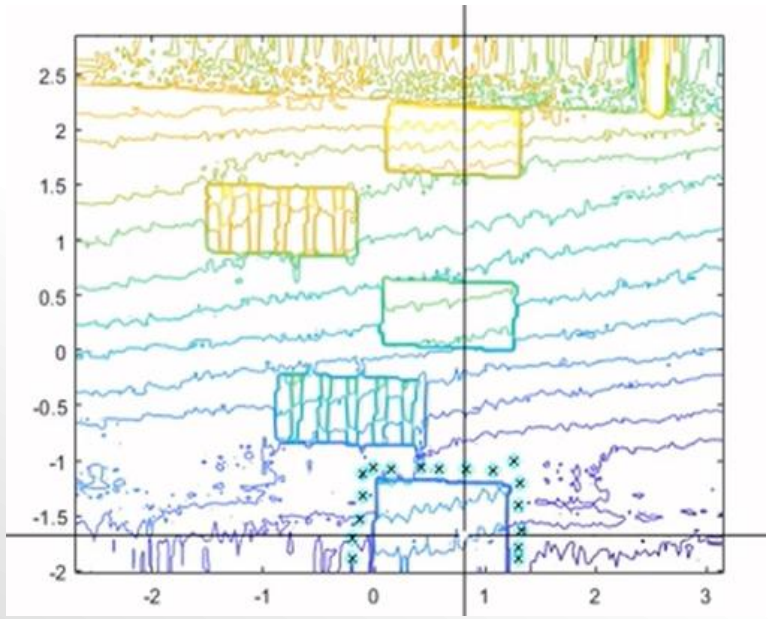
LESSONS LEARNED FROM PP 107 BODY MOTION TEST

Manual Object Identification Process

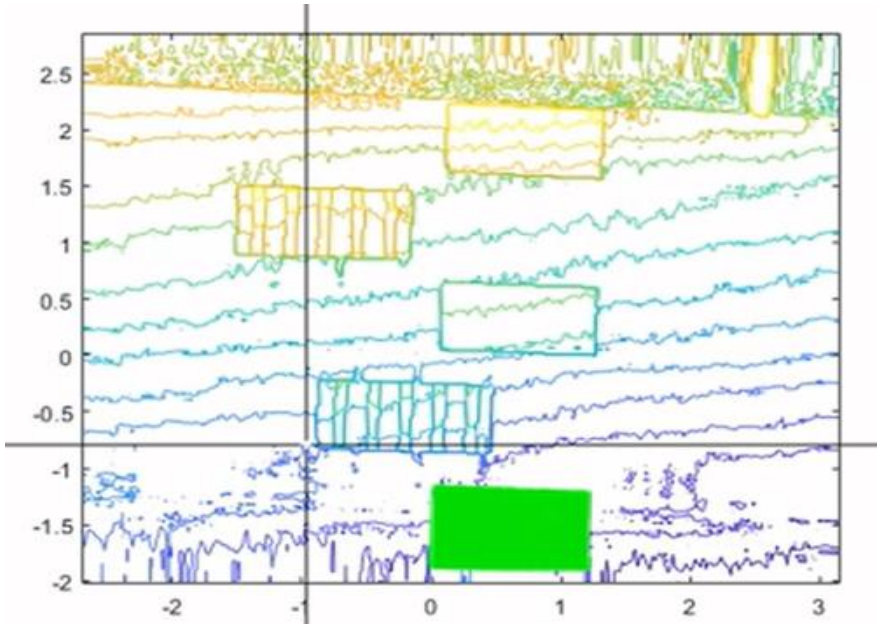
- Contour plot represents a 3D surface on a 2D (XY) plane
- Uses contour lines connecting equal-value (Z) points
- Dense contour lines indicate sharp changes (possible edges); *Not true object edges*



User selects points inside the plate



User selects points outside the plate to define a polygon boundary

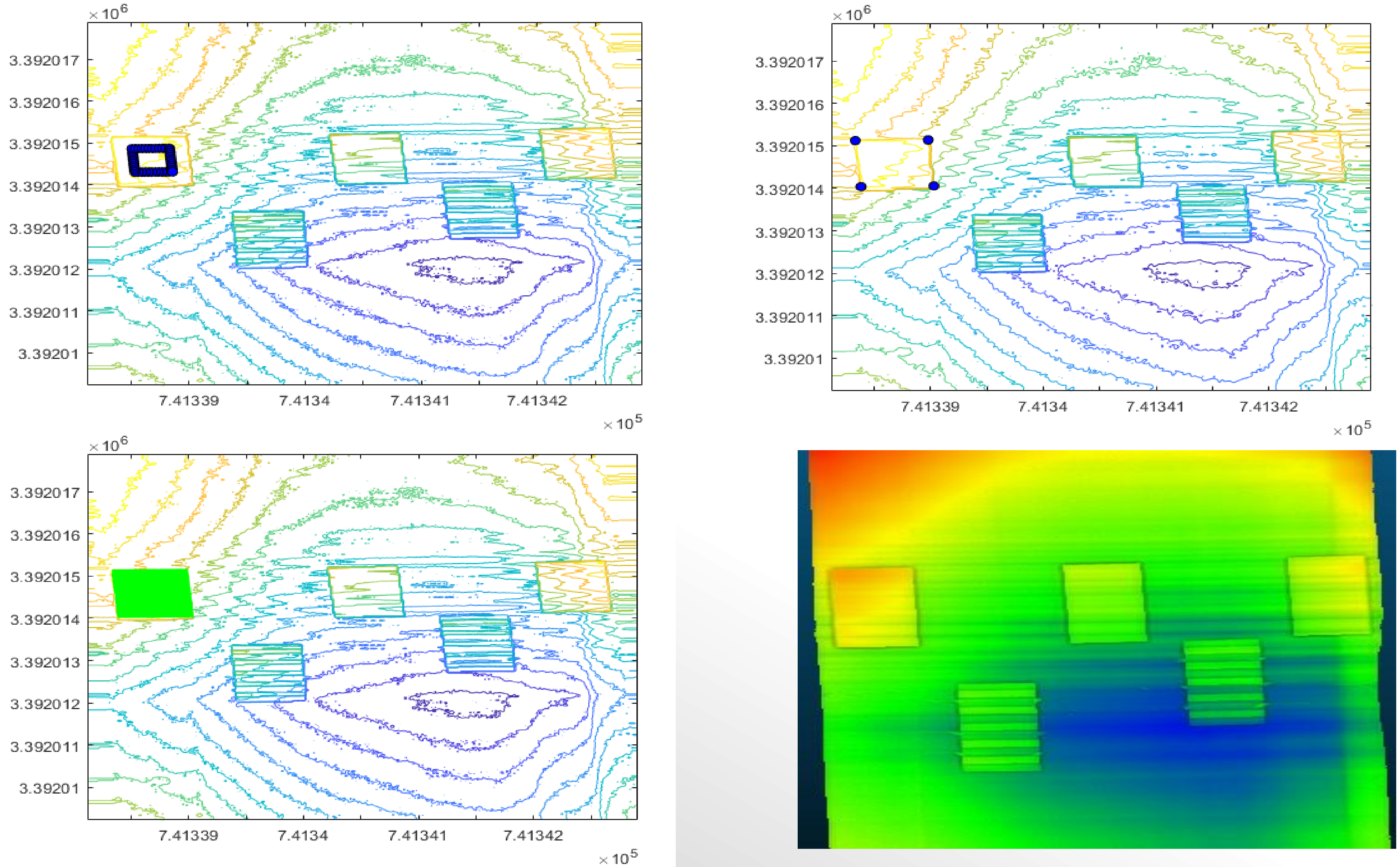


- Fits a plane from inside points
- Computes distances of polygon points to the plane
- Classifies points below a threshold as surface points (green)

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

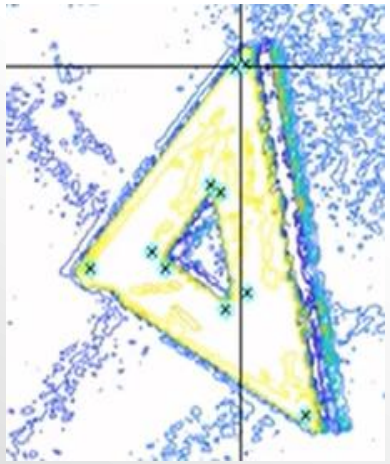
	Vehicle	5th (-8 mm)	25th (-5 mm)	75th (5 mm)	95th (8 mm)
QES-User1	PR140	-7.5	-2.2	2.7	4.7
	PR171	-3.8	-1.8	1.7	4.1
TTI-User1	PR140	-8.9	-3.5	3.8	6.4
	PR171	-3.9	-1.8	1.8	4.1
TTI-User2	PR140	-9.4	-3.8	4.0	6.5
	PR171	-4.0	-1.8	1.8	4.1
Automated	PR140	-6.0	-1.6	2.1	3.9
	PR171	-3.5	-1.7	1.7	3.8

Vehicle Body Motion Error – for Edge/Curb Analysis

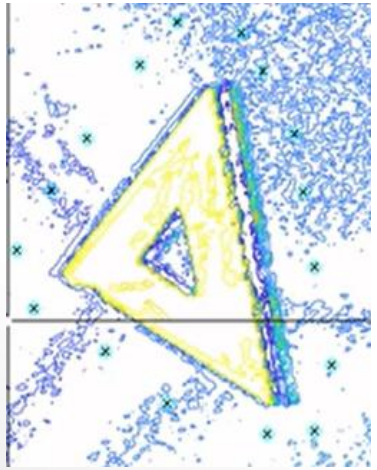
Vehicle	5th (-4 mm)	25th (-2.5 mm)	75th (2.5 mm)	95th (4 mm)
PR140	-8.4	-2.3	2.9	5.8
PR171	-4.1	-1.7	1.6	4.3
PR140	-9.4	-2.9	3.5	6.7
PR171	-4.4	-1.8	1.6	4.8
PR140	-9.7	-3.5	3.7	7.1
PR171	-4.5	-1.8	1.7	5.1
PR140	-6.0	-1.3	2.0	3.7
PR171	-3.6	-1.6	1.4	3.7

LESSONS LEARNED FROM PP 108 NAVIGATION DRIFT TEST

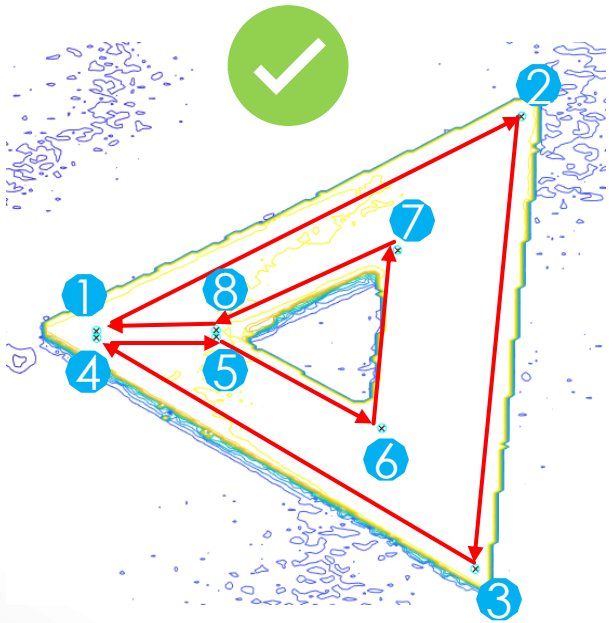
Manual Object Identification Process

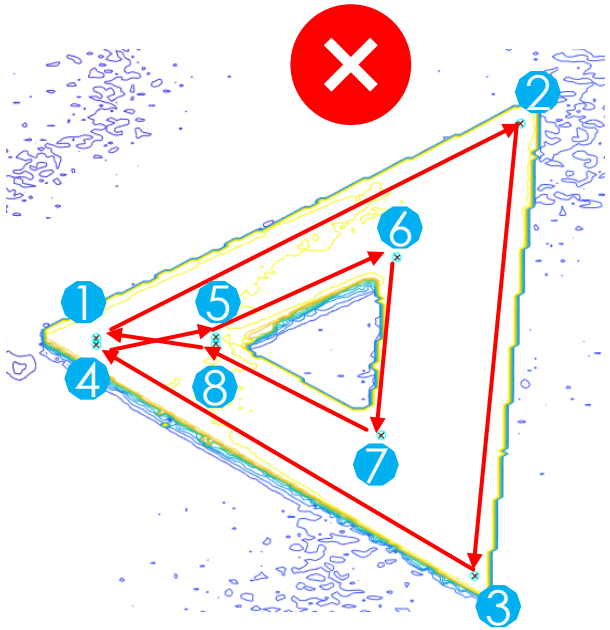


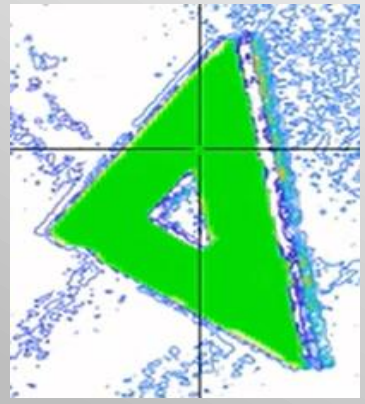
User selects points inside the plate



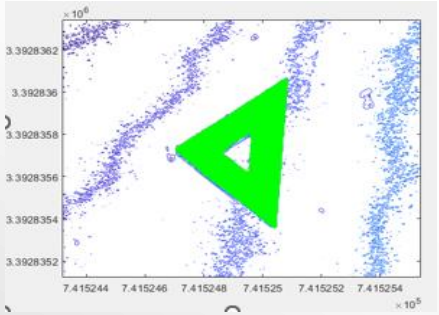
User selects points outside the plate

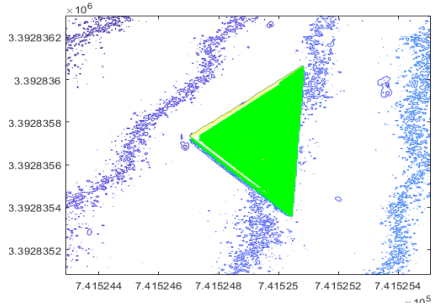






- Fits a plane
- Computes distances
- Identifies surface points

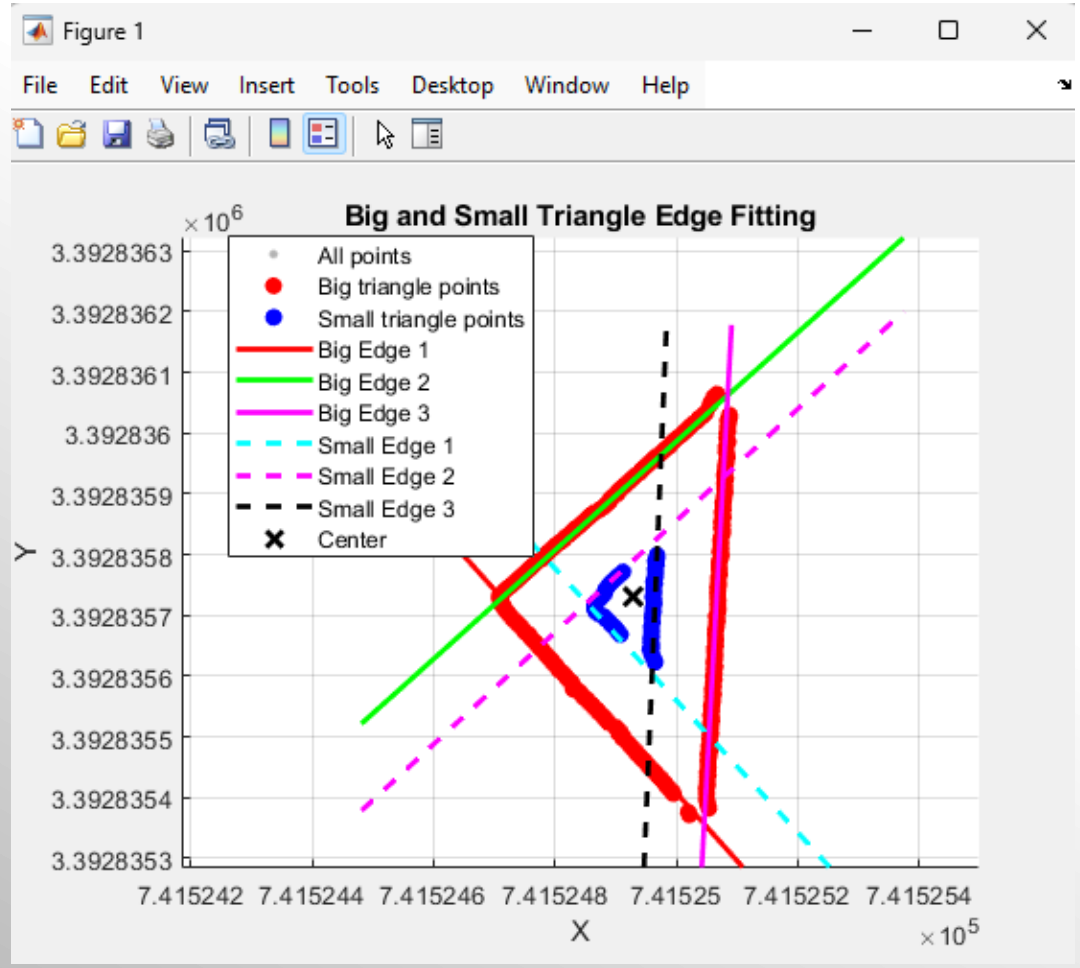


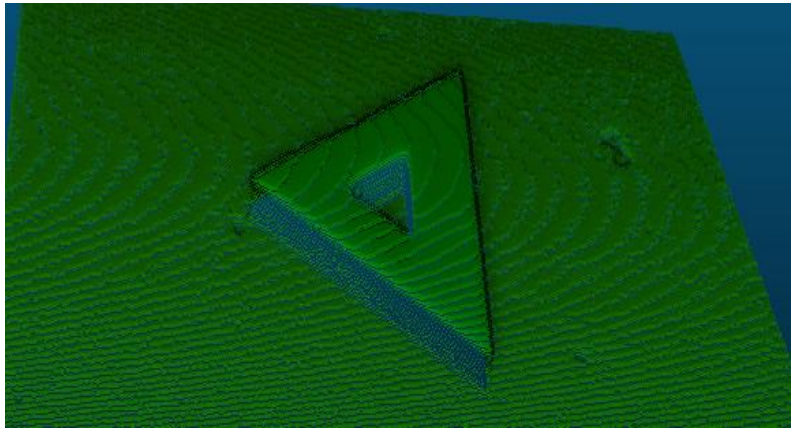


Each profiler: 5 repeat runs, 2 files/run; Repeat 10 times.

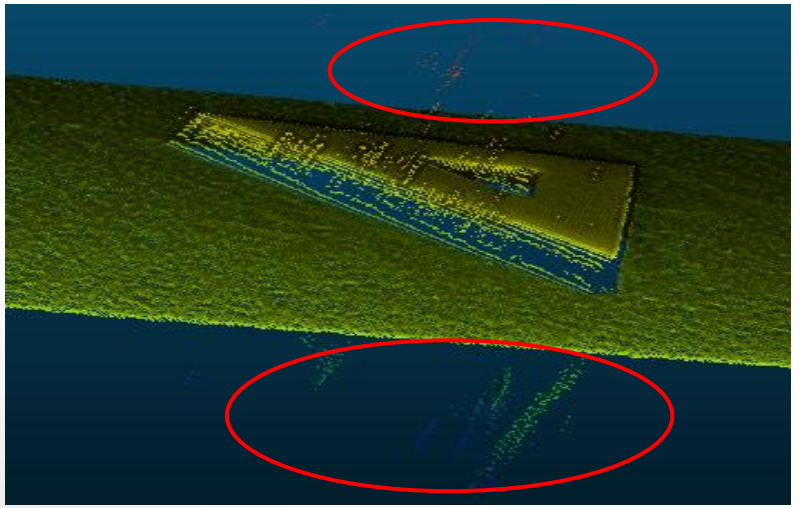
LESSONS LEARNED FROM PP 108 NAVIGATION DRIFT TEST

Automated Process





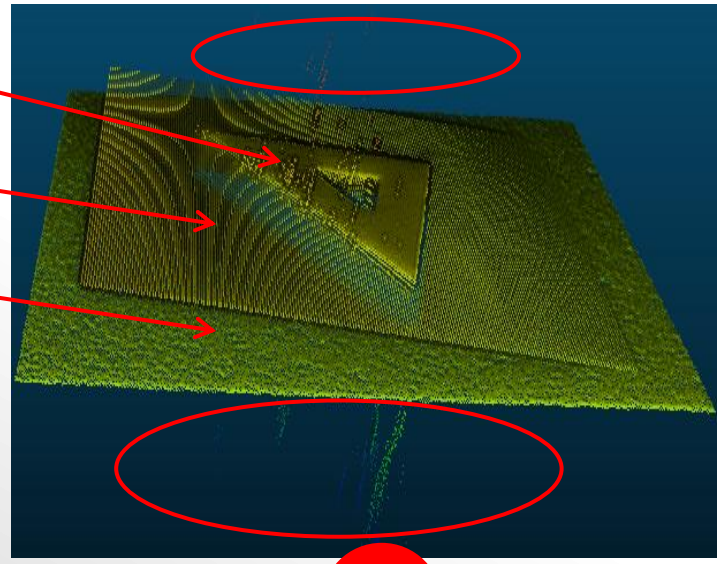
Clean Data

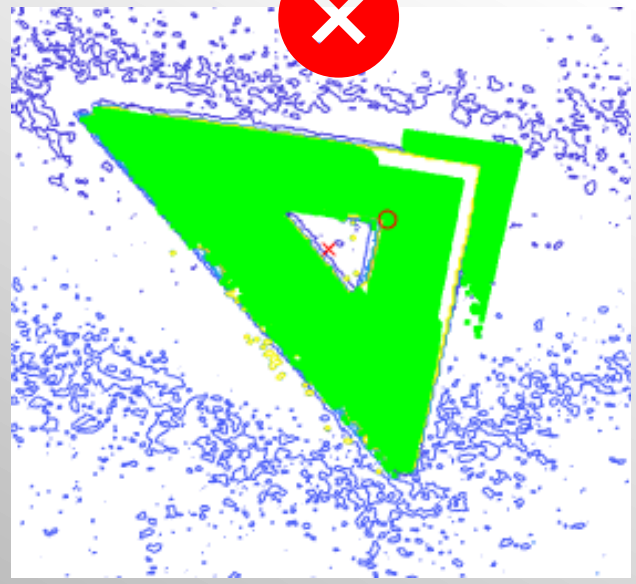


Data with outliers, PR160, Montana, 2025

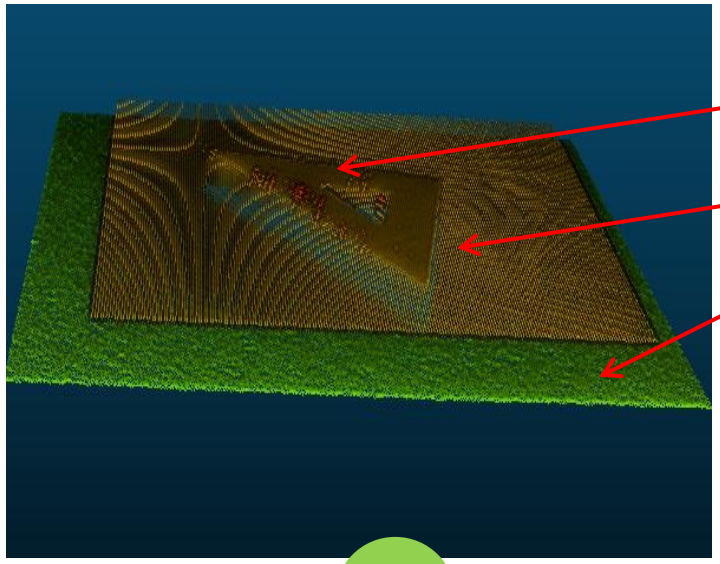
LESSONS LEARNED FROM PP 108 NAVIGATION DRIFT TEST

Before Outlier Removal: Misfitted Plane



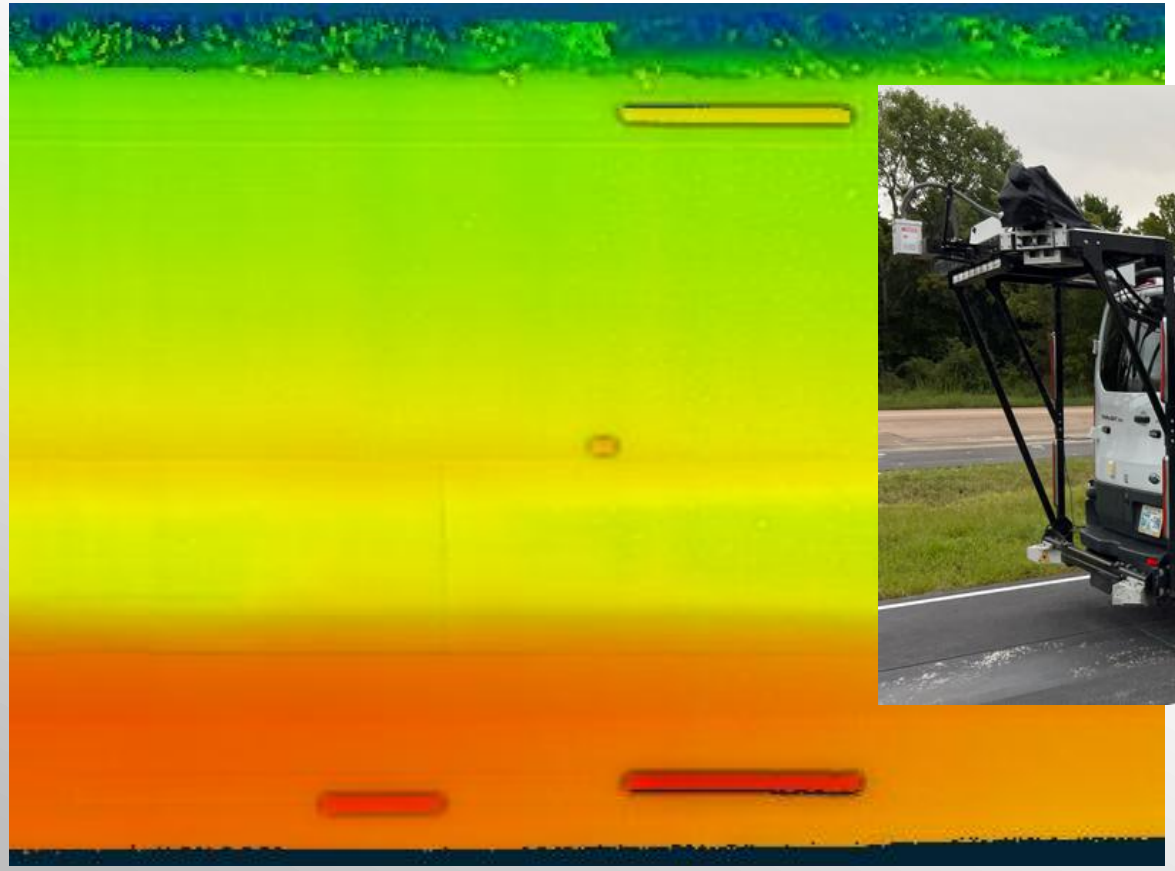


After Outlier Removal: Properly Fitted Plane



LESSONS LEARNED FROM PP 109 HIGHWAY PERFORMANCE TEST

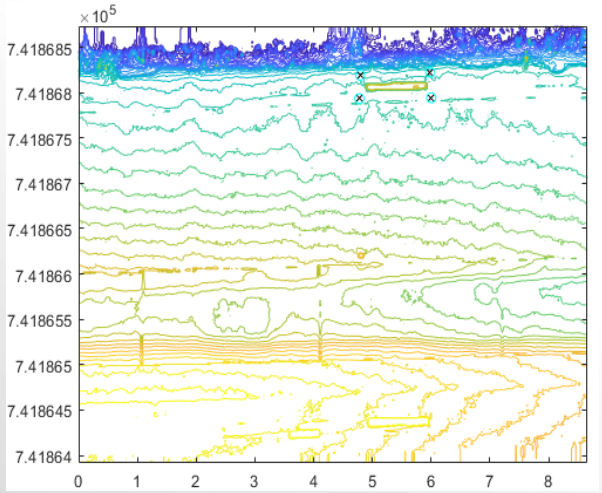
PR171, 20 mph, Run1, 2024 TTI Test Track



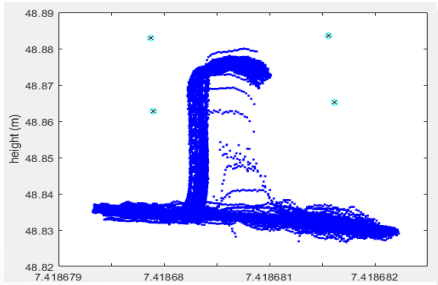
PR 136, 35 mph, Run1, 2024 TTI Test Track

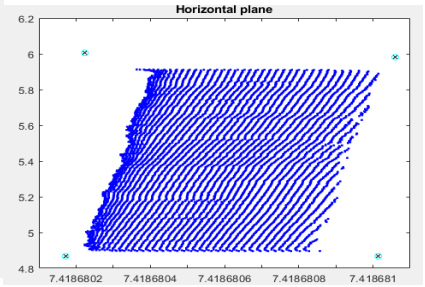
LESSONS LEARNED FROM PP 109 HIGHWAY PERFORMANCE TEST

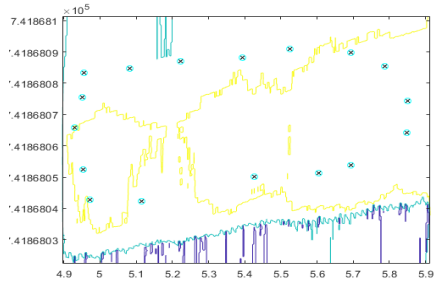
Manual Object Identification Process

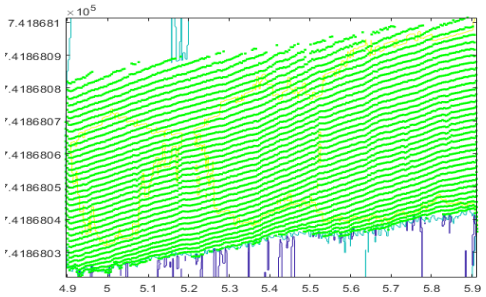


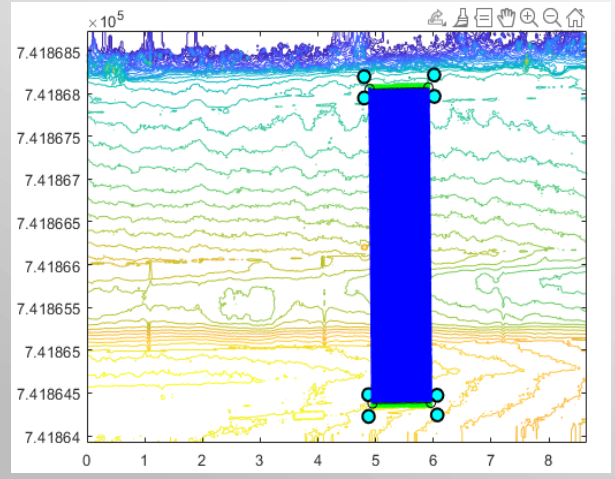
Left Beam Top Point Selection (Top View → Side View → Top View Again)



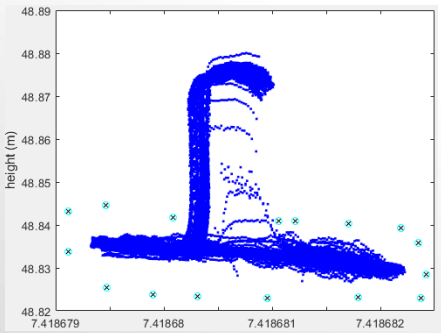


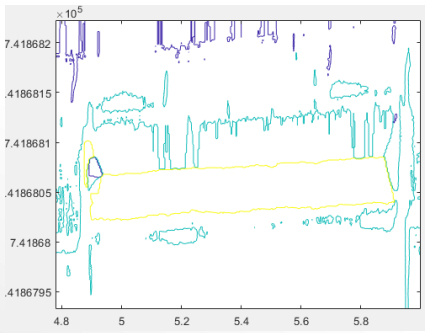


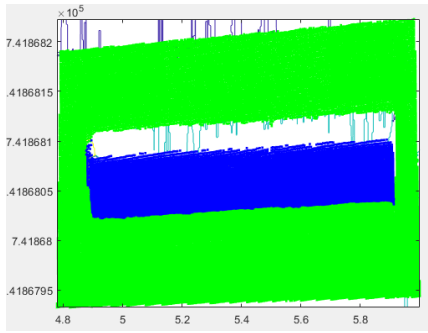




Left Beam Bottom & Road Point Selection



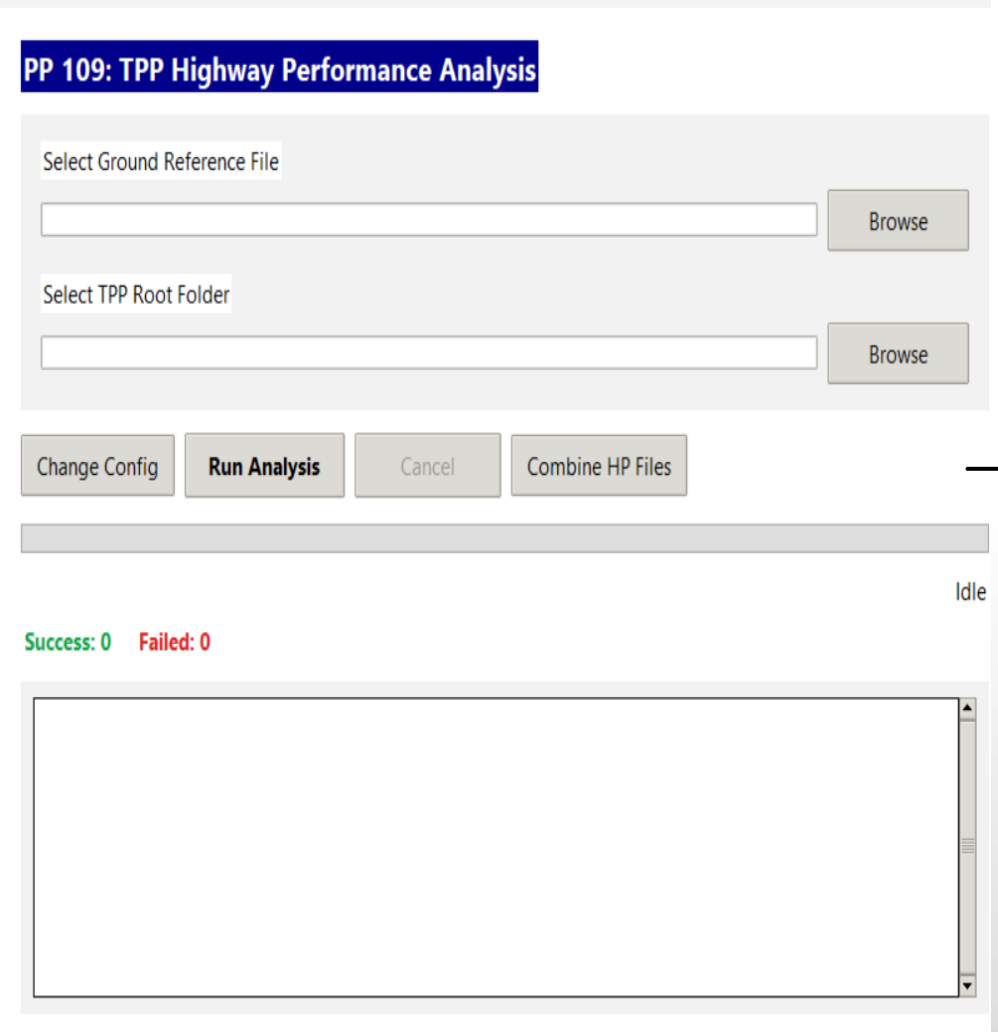


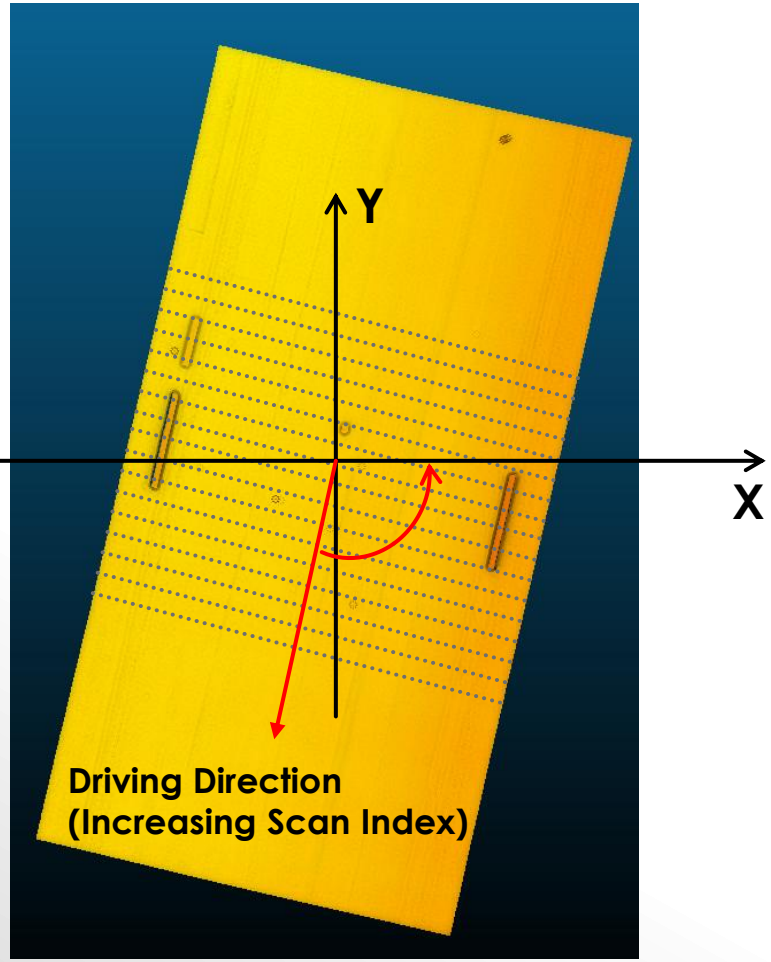


Each profiler: 9 files (3 speeds × 3 runs); each file has 2 beams and 1 block → Repeat 27 times.

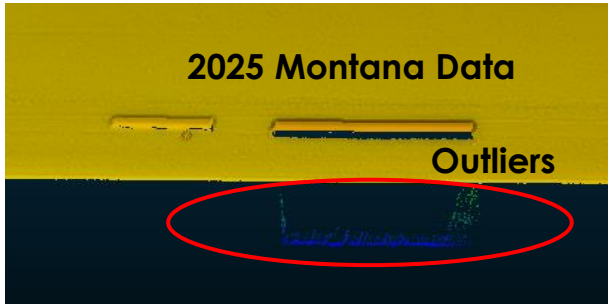
LESSONS LEARNED FROM PP 109 HIGHWAY PERFORMANCE TEST

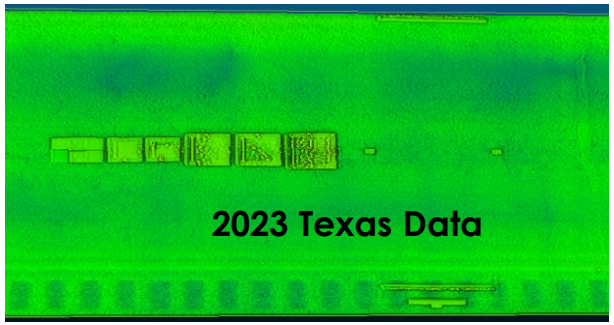
Automated Process





Auto Rotation





LESSONS LEARNED FROM PP 109 HIGHWAY PERFORMANCE TEST

Algorithm for Rut Depth and Cross Slope Calculation

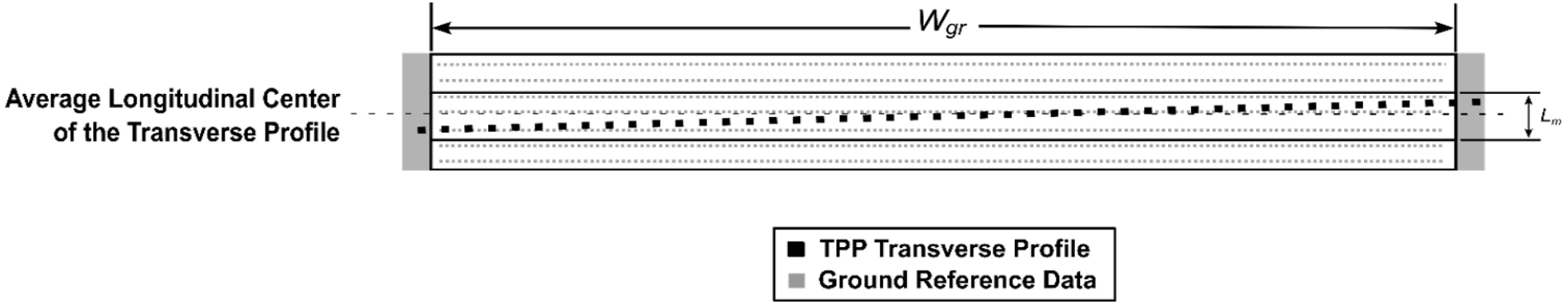
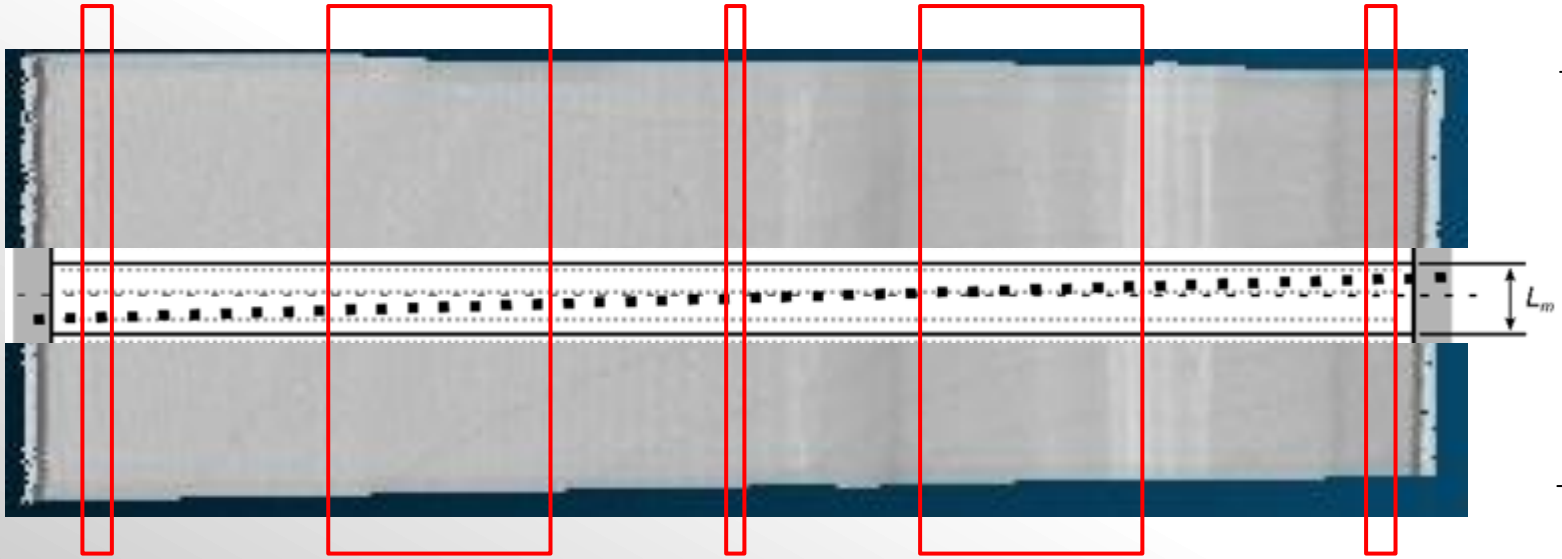


Figure 8—Identification of the Ground Reference Data Points for Calculation of Reference Cross Slope and Rut Depth

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

Too small L → insufficient points for rut calculation→ 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	5th (-2.5 mm)	25th (-1.0 mm)	75th (1.0 mm)	95th (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	5th (-2.5 mm)	25th (-1.0 mm)	75th (1.0 mm)	95th (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

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

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

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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	5th (-0.4)	25th (-0.15)	75th (0.15)	95th (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	5th (-0.4)	25th (-0.15)	75th (0.15)	95th (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

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LESSONS LEARNED FROM PP 109 HIGHWAY PERFORMANCE TEST

Other Results (Automated Process), 20 mph

Left Wheel Path Rut Depth, mm

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
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
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
PR160	8.68	7.22	1.46	0.12
PR162	8.46	7.23	1.24	0.06

Right Wheel Path Rut Depth, mm

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
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
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
PR160	5.03	3.6823	1.35	0.06
PR162	4.25	3.6796	0.57	0.08

Cross Slope, %

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
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
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
PR160	1.07	1.01	0.06	0.01
PR162	0.95	1.01	-0.06	0.00

2023 Texas Data

2025 Texas Data, Shallow Rut Section

2025 Texas Data, Deep Rut Section

2025 Montana Data

- Rut & cross slope:
  - **repeatable**
- Rut depths:
  - **meet accuracy** (assumed ±2.5 mm)
- Cross Slopes:
  - mostly **fail accuracy** (assumed ±0.4%)

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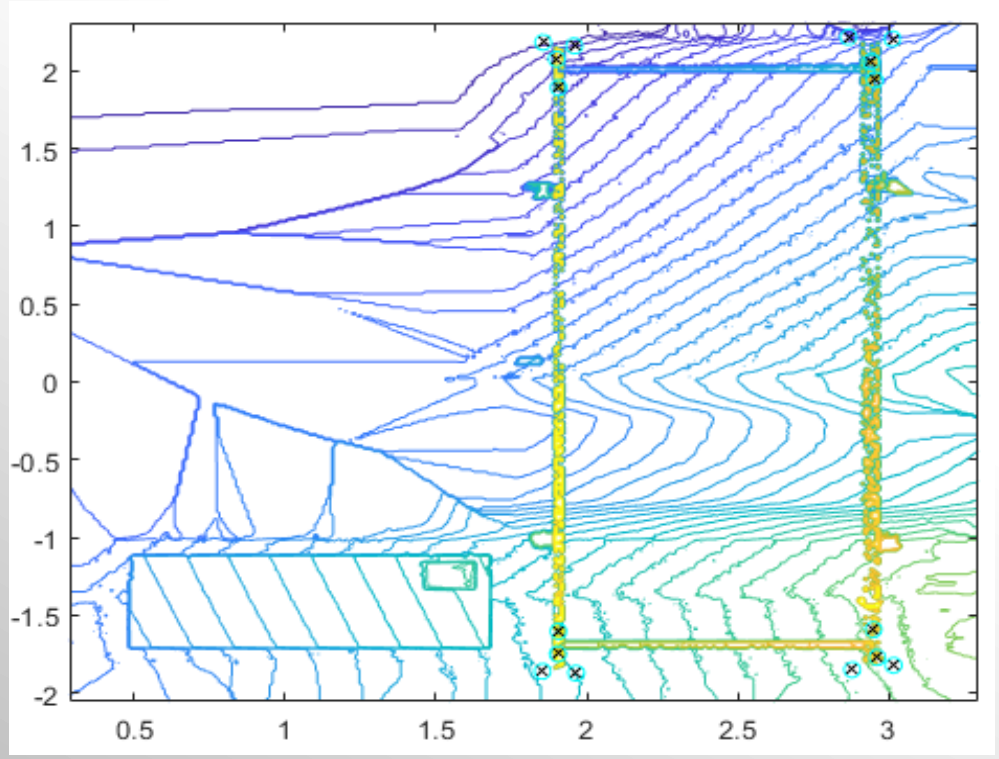
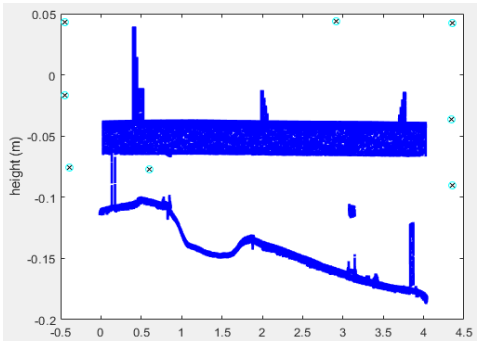
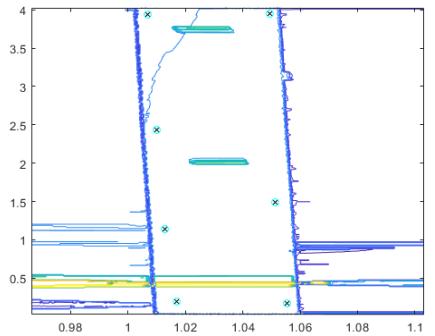
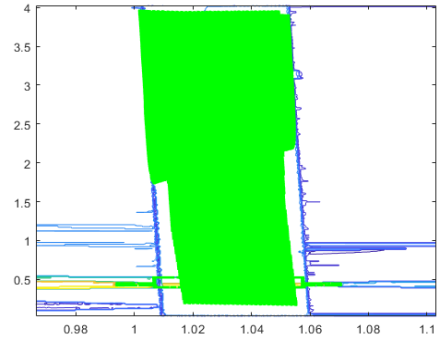
LESSONS LEARNED FROM PP 110 GROUND REFERENCE TEST

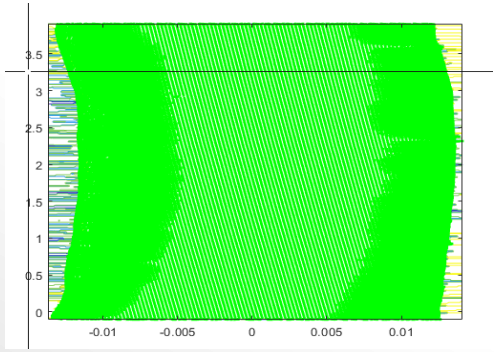
Manual Object Identification Process

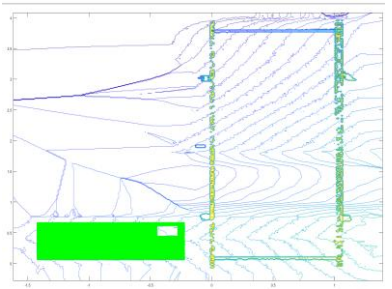


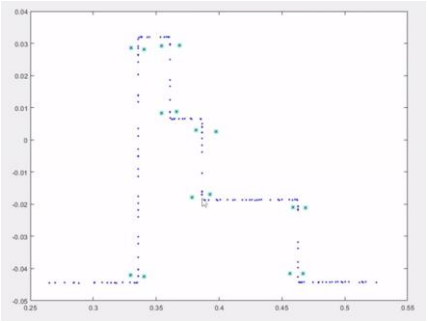












Automated process under development

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

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