3D Sensor Based Longitudinal Profiling: Issues and Status

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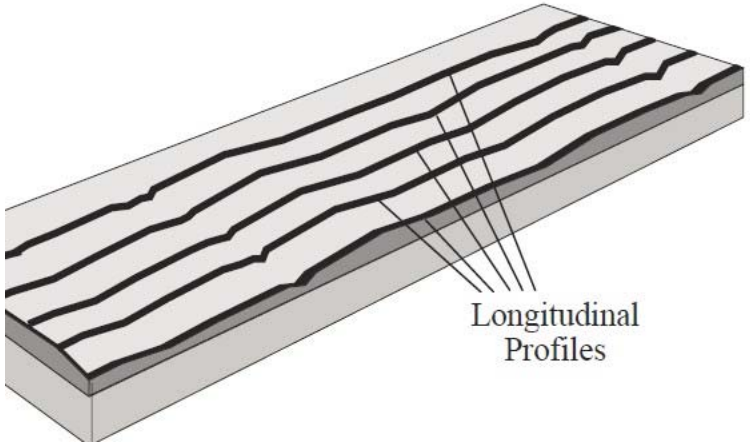
OUTLINE

- Introduction
- PaveVision3D Ultra
- Profiler Hardware
- Profiler Software Interface
- Software Algorithms
- Profiler Field Validation
- Conclusions

Longitudinal Profiles

- Definition
  - A Profile is A Two-Dimensional Slice of the Road Surface, Taken Along an Imaginary Line.
- Importance
  - Driving Experience
  - Road Safety
  - Vehicle Operating Costs



- Measurements
  - Manual Method (Rod and Level, Walking Profiler)
  - Profilographs
  - Light-weight Profilers
  - High-speed Inertial Profilers

Image Reference: M.W. Sayers and S.M. Karamihas, *The Little Book of Profi*ling

Components of Inertial Profiler

- Accelerometer
- Laser Height Sensor
- Distance Measuring Instrument

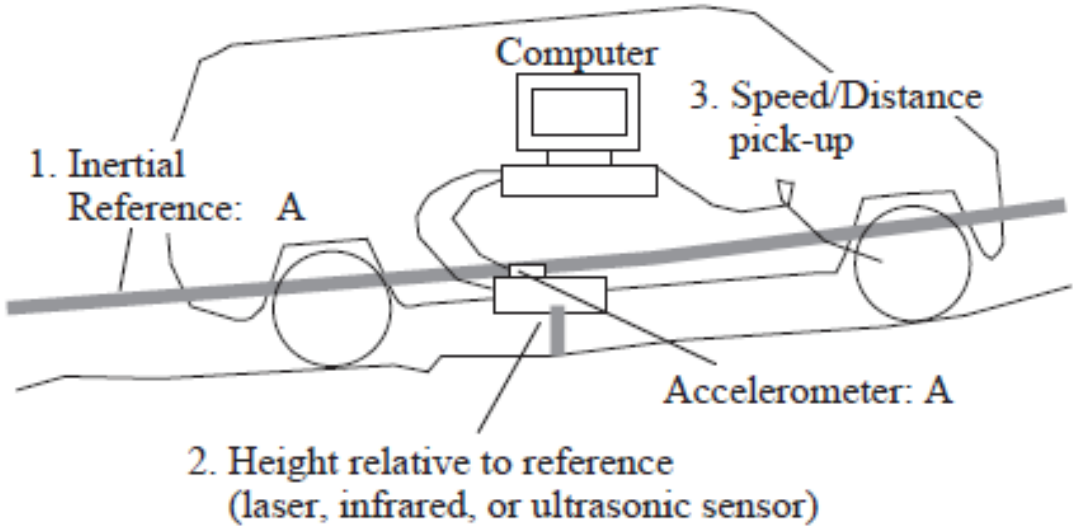
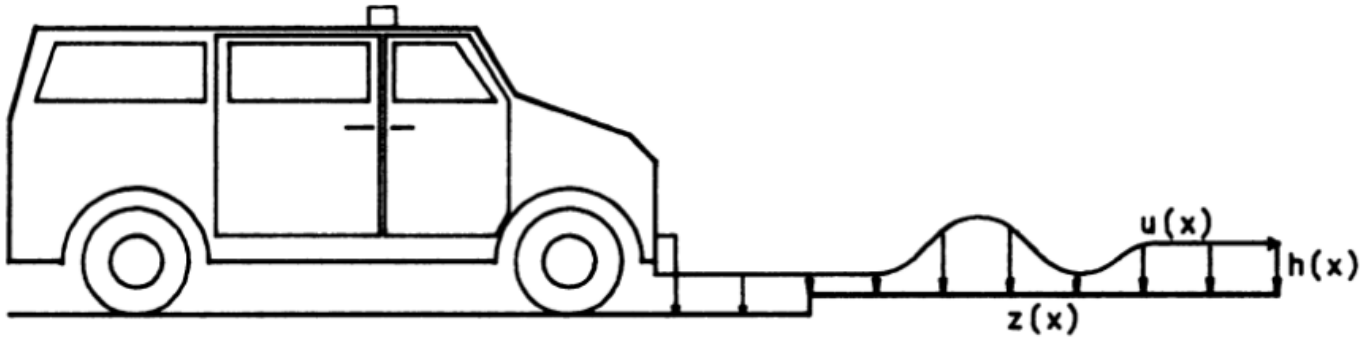


Image Reference: M.W. Sayers and S.M. Karamihas, *The Little Book of Profi*ling

Profile Measurement Principle



h(x) – Vehicle Height Above Pavement

u(x) – Vehicle Position

z(x) – Vertical Road Profile

Profile = z(x) = u(x) – h(x)

Image Reference: *Description and Evaluation of the South Dakota Road Profiler (Huft 1989)*

PaveVision3D Ultra (3D Ultra)

WayLink Inertial System (WIS) Hardware Platform

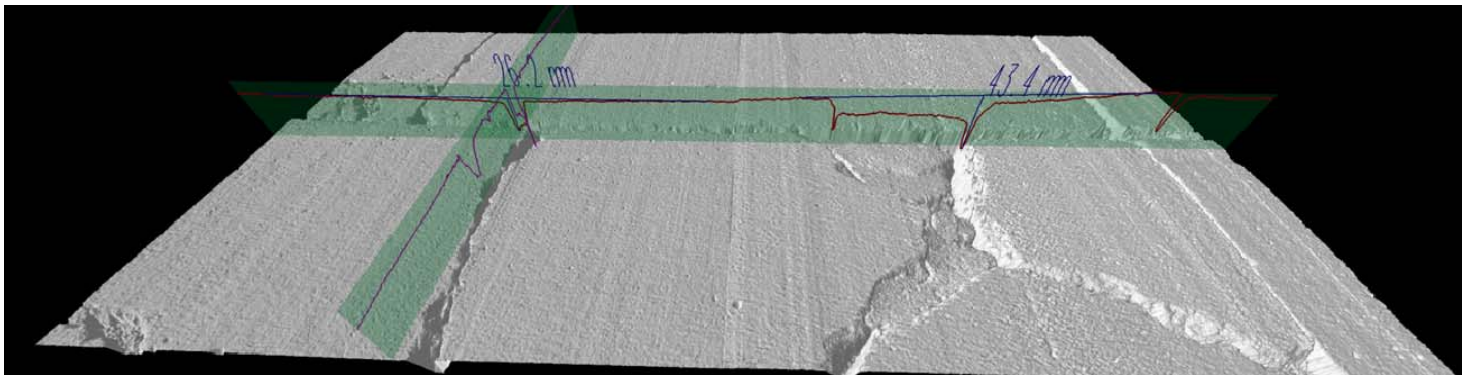
- PaveVision 3D Ultra
  - Vertical Resolution: 0.3 mm
  - 30KHz: 1mm Res in Longitudinal Direction at 60 MPH)
  - Full-Lane Coverage (4-Meter Width): 4000 3D Transverse Points
  - Total system power consumption: 500 Watts
  - Data collection: continuous collection for several hours at 1 to 2GB/lane-mile data
- Accelerometer: Micro-g Resolution
- Sampling Device: Multi-Channels Simultaneously Sampling
- Distance Measuring Instrument
  - 2048 Pulses/Revolution

Accelerometer and DMI for WIS

- Integration: Critical for Accelerometers; Power, Filtering
- 3D Points in the Center of Wheel-Paths for Height Data

Pavement 3D Capture

- Acquire 1mm 3D Pavement Surface Data
- Provide Longitudinal Height Information for Profiler

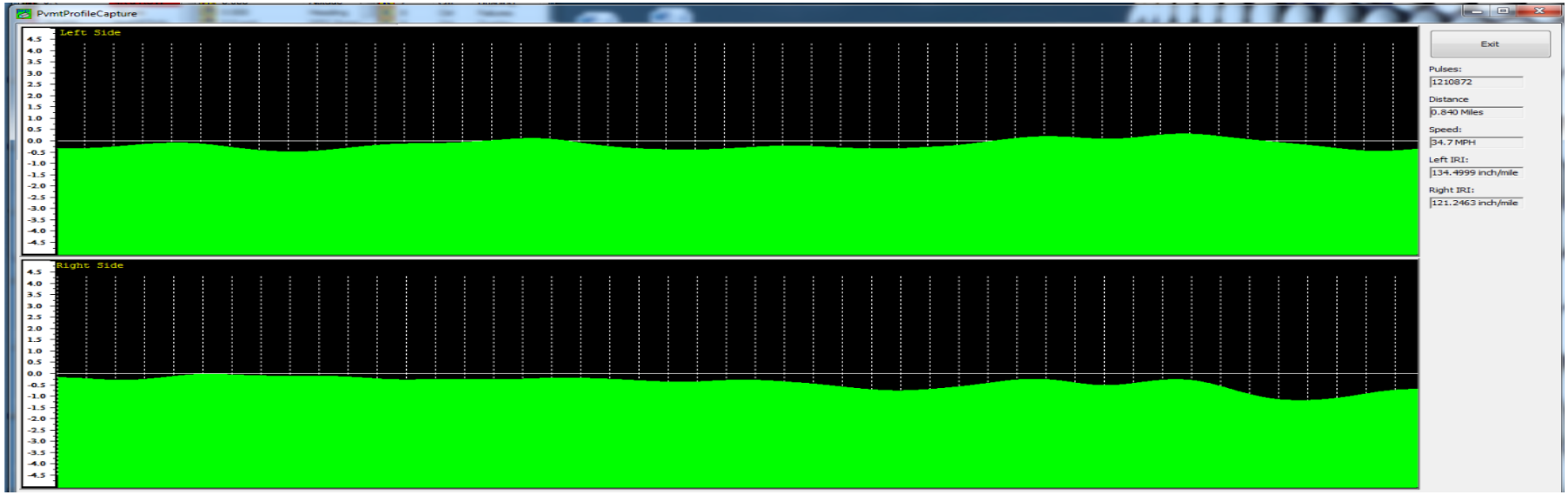


Profiler Software

- Software Capabilities
  - Data Collection
  - Profile View

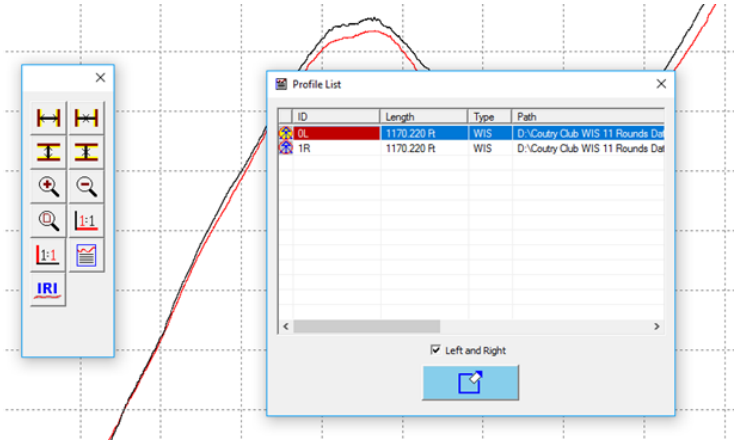
Profiler Software

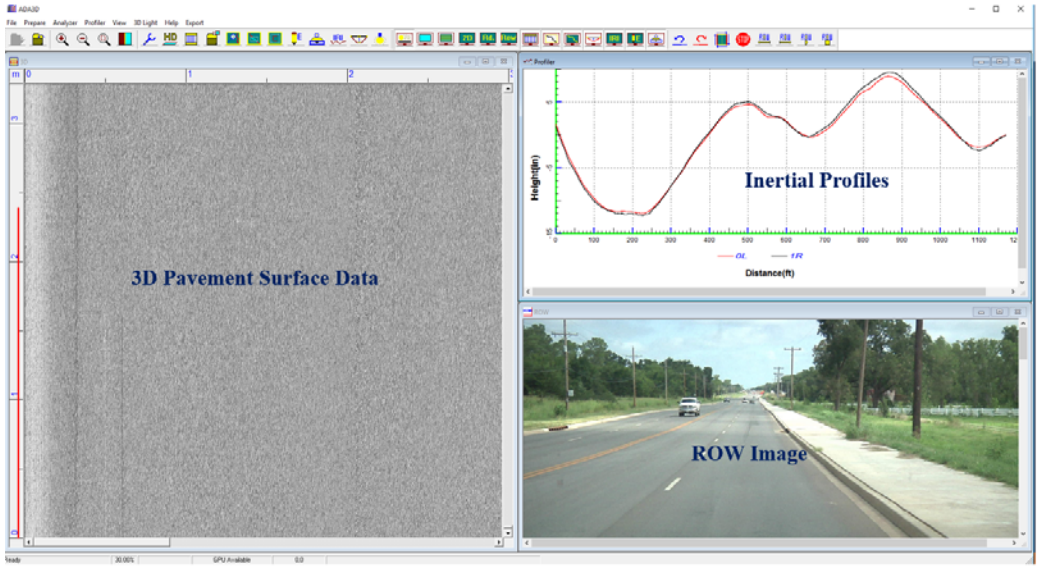
- Data Collection
  - Display Distance Traveled and Speed
  - Display Pavement Profile in Real Time
  - Display IRI values for LWP and RWP



Profiler Software

- Profile View
  - Display Profile Data
  - Display Basic Data Collection Information
  - Calculate IRI Values, Export .ERD or .CSV File





ProfileData-both Sides.erd - Notepad

File Edit Format View Help

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ERDFILEV2.00
    2,    76288,    -1,    1,    5,    0.004676,    -1,
SHORTNAMLElev.  RELev.
LONGNAMELeft Elevation                    Right Elevation
RIGIBODYLeft                              Right
UNITSNAMinch      inch
XLABEL  Distance
XUNITS  m
END
 1.691148 1.232380
 1.688422 1.229952
 1.685730 1.227414
 1.683066 1.224874
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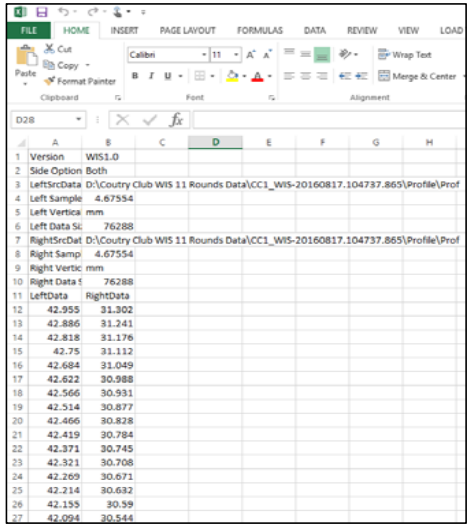


Profiling Data View

Software Algorithms

- Low Pass Filter (Anti-Aliasing Filter): Remove High Frequency Noise
- Double Integration: Calculate the Vertical Bouncing Distance
- Butterworth Band Pass Filter: Preserve Useful Waveform, Filter the Unwanted Waveform
- IRI Calculation Based on Quarter-Car Model

Validation Tests

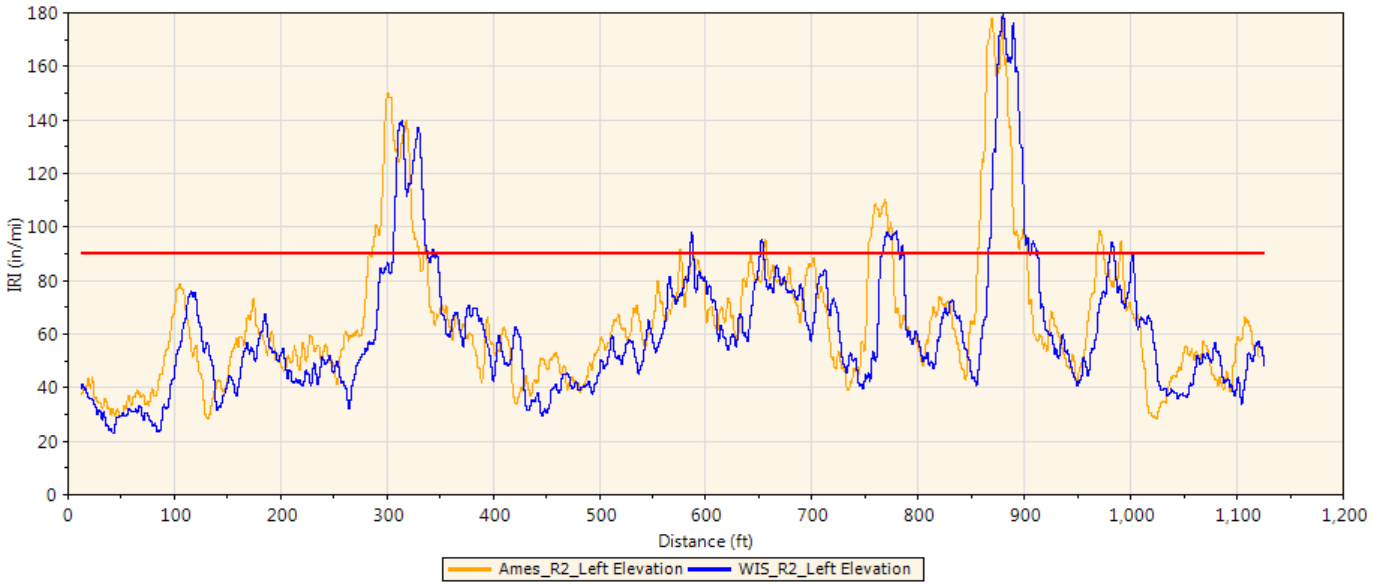
- Field Test
  - Three Asphalt Test Roads: 1100 ft, 1100 ft, 1700 ft with Lead-In and Lead-Out tested at 30 mph, 40 mph, and 60 mph respectively
  - Automatic Triggering for Consistent Start & End of Data Collection
  - 10 Repeating Passes for Each Site

Data Collection Instruments

- AMES Profiler
  - 1 Inch Sampling Interval
- WIS
  - 0.184 Inch Sampling Interval

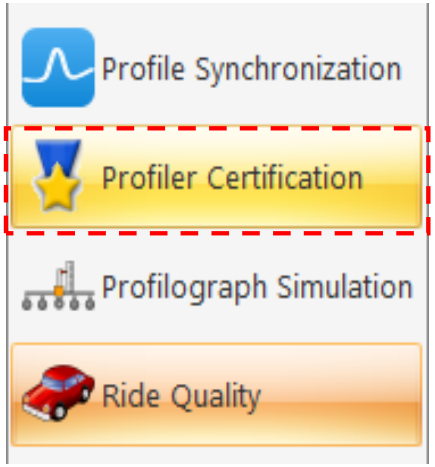
Site I: IRI Results (30 mph)

- IRI Results: Calculated for every 25 ft, While a Small Interval is Set between the Starting Points of Two Consecutive Calculations



Site I: Profiler Certification

- Reference Profile: One Pass Collected by Ames Profiler
- WIS Profiles: Nine Profiles to Analysis the Repeatability and Accuracy based on the Ames Profile as the Basis

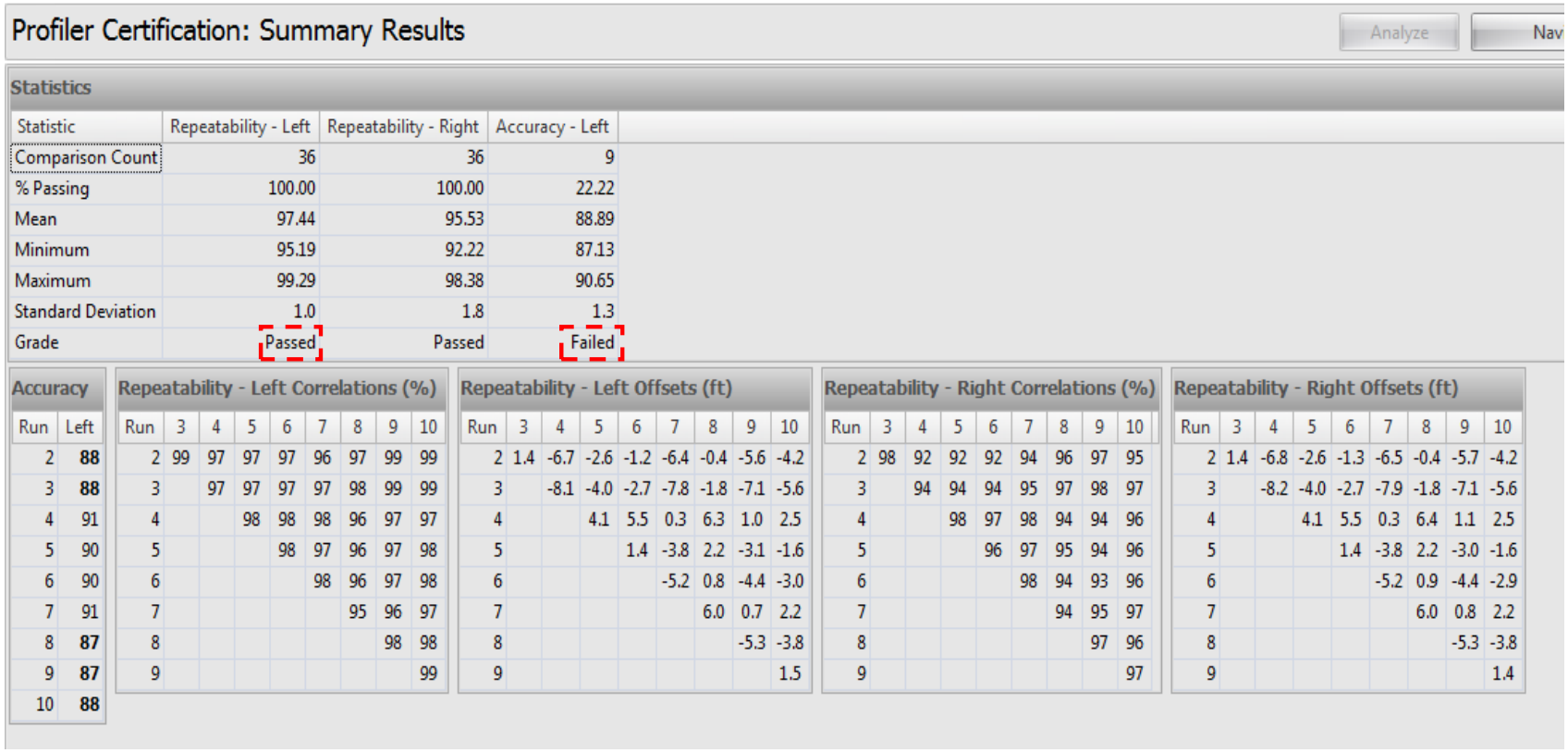


Profiler Certification

Maximum Offset (ft)	5.00
Minimum Repeatability (%)	92
Minimum Accuracy (%)	90
Basis Filter	
IRI (with 250mm Filter)	
Comparison Filter	
IRI (with 250mm Filter)	

File	Profiles	Basis	Run	Sample Interval (in)
Ames_R2	Left	☑		0.984252
WIS_R10	Left + Right	☐	2	0.184095
WIS_R12	Left + Right	☐	3	0.184095
WIS_R2	Left + Right	☐	4	0.184095
WIS_R3	Left + Right	☐	5	0.184095
WIS_R4	Left + Right	☐	6	0.184095
WIS_R5	Left + Right	☐	7	0.184095
WIS_R6	Left + Right	☐	8	0.184095
WIS_R7	Left + Right	☐	9	0.184095
WIS_R8	Left + Right	☐	10	0.184095

Test Site I: Profiler Repeatability (30 mph)



Profiler Certification: Summary Results

Analyze | Nav

Statistics

Statistic	Repeatability - Left	Repeatability - Right	Accuracy - Left
Comparison Count	36	36	9
% Passing	100.00	100.00	22.22
Mean	97.44	95.53	88.89
Minimum	95.19	92.22	87.13
Maximum	99.29	98.38	90.65
Standard Deviation	1.0	1.8	1.3
Grade	Passed	Passed	Failed

Accuracy

Run	Left
2	88
3	88
4	91
5	90
6	90
7	91
8	87
9	87
10	88

Repeatability - Left Correlations (%)

Run	3	4	5	6	7	8	9	10
2	99	97	97	97	96	97	99	99
3		97	97	97	97	98	99	99
4			98	98	98	96	97	97
5				98	97	96	97	98
6					98	96	97	98
7						95	96	97
8							98	98
9								99

Repeatability - Left Offsets (ft)

Run	3	4	5	6	7	8	9	10
2	1.4	-6.7	-2.6	-1.2	-6.4	-0.4	-5.6	-4.2
3		-8.1	-4.0	-2.7	-7.8	-1.8	-7.1	-5.6
4			4.1	5.5	0.3	6.3	1.0	2.5
5				1.4	-3.8	2.2	-3.1	-1.6
6					-5.2	0.8	-4.4	-3.0
7						6.0	0.7	2.2
8							-5.3	-3.8
9								1.5

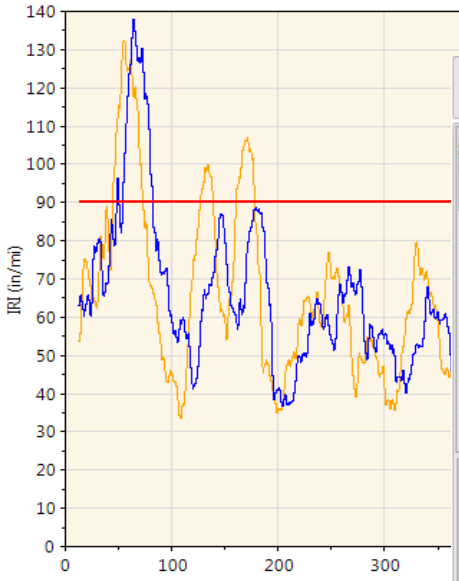
Repeatability - Right Correlations (%)

Run	3	4	5	6	7	8	9	10
2	98	92	92	92	94	96	97	95
3		94	94	94	95	97	98	97
4			98	97	98	94	94	96
5				96	97	95	94	96
6					98	94	93	96
7						94	95	97
8							97	96
9								97

Repeatability - Right Offsets (ft)

Run	3	4	5	6	7	8	9	10
2	1.4	-6.8	-2.6	-1.3	-6.5	-0.4	-5.7	-4.2
3		-8.2	-4.0	-2.7	-7.9	-1.8	-7.1	-5.6
4			4.1	5.5	0.3	6.4	1.1	2.5
5				1.4	-3.8	2.2	-3.0	-1.6
6					-5.2	0.9	-4.4	-2.9
7						6.0	0.8	2.2
8							-5.3	-3.8
9								1.4

Site II: IRI Results (40 mph)



Profiler Certification: Summary Results

Analyze | Navigate

Statistics

Statistic	Repeatability - Left	Repeatability - Right	Accuracy - Left
Comparison Count	36	36	9
% Passing	77.78	100.00	100.00
Mean	94.14	96.33	93.41
Minimum	90.97	94.51	90.38
Maximum	97.52	98.03	96.45
Standard Deviation	1.9	0.9	2.0
Grade	Passed	Passed	Passed

Accuracy

Run	Left
2	91
3	96
4	94
5	95
6	93
7	94
8	92
9	94
10	90

Repeatability - Left Correlations (%)

Run	3	4	5	6	7	8	9	10
2	**91**	94	92	94	94	**91**	93	92
3		95	98	94	96	94	96	**91**
4			96	95	96	94	96	92
5				96	96	95	97	**91**
6					96	94	95	92
7						94	96	92
8							96	92
9								**91**

Repeatability - Left Offsets (ft)

Run	3	4	5	6	7	8	9	10
2	-1.3	-1.7	0.4	2.5	-1.4	-0.6	1.0	2.9
3		-0.4	1.8	3.9	-0.1	0.7	2.4	4.3
4			2.1	4.2	0.3	1.1	2.7	4.6
5				2.1	-1.9	-1.0	0.6	2.5
6					-4.0	-3.1	-1.5	0.4
7						0.8	2.4	4.4
8							1.6	3.5
9								1.9

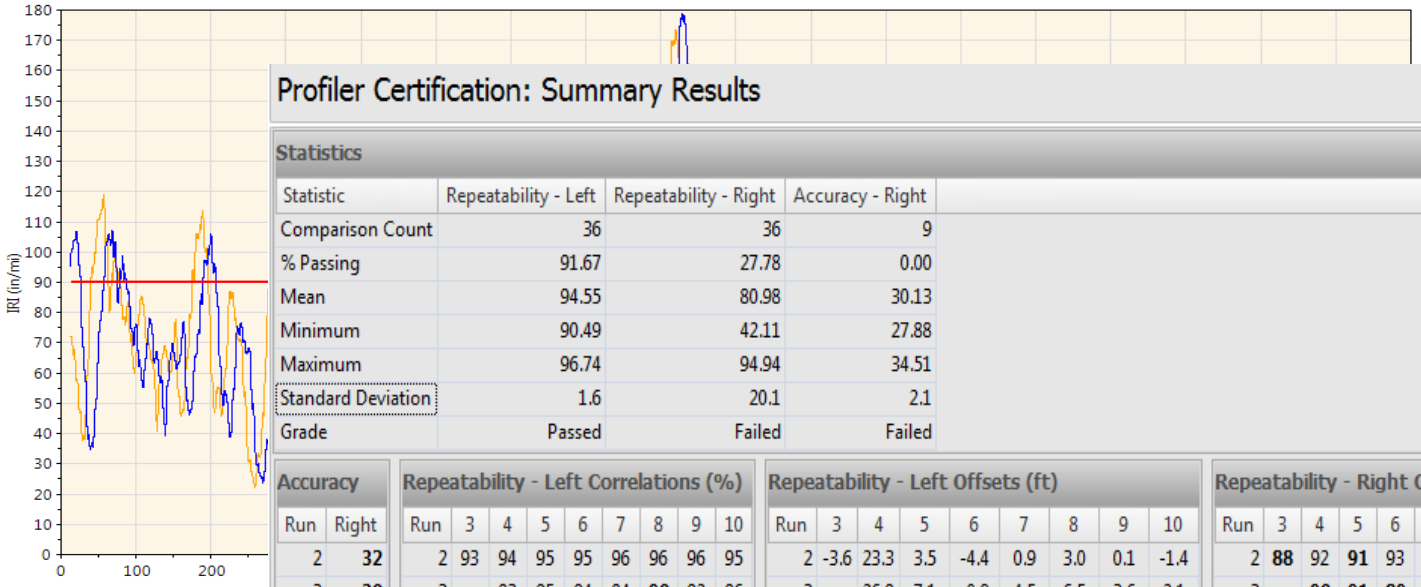
Repeatability - Right Correlations (%)

Run	3	4	5	6	7	8	9	10
2	95	96	95	95	95	95	96	95
3		96	98	97	97	98	98	96
4			96	97	96	96	97	96
5				97	96	98	98	96
6					97	97	97	96
7						97	96	96
8							98	95
9								95

Repeatability - Right Offsets (ft)

Run	3	4	5	6	7	8	9	10
2	-1.3	-1.7	0.4	2.5	-1.4	-0.6	1.0	2.9
3		-0.4	1.7	3.8	-0.1	0.7	2.3	4.2
4			2.1	4.2	0.3	1.1	2.7	4.6
5				2.1	-1.8	-1.0	0.6	2.5
6					-4.0	-3.1	-1.5	0.4
7						0.8	2.5	4.3
8							1.6	3.5
9								1.9

Site III: IRI Results (60 mph)



Profiler Certification: Summary Results

Analyze | Navigate

Statistics

Statistic	Repeatability - Left	Repeatability - Right	Accuracy - Right
Comparison Count	36	36	9
% Passing	91.67	27.78	0.00
Mean	94.55	80.98	30.13
Minimum	90.49	42.11	27.88
Maximum	96.74	94.94	34.51
Standard Deviation	1.6	20.1	2.1
Grade	Passed	Failed	Failed

Accuracy

Run	Right
2	**32**
3	**30**
4	**29**
5	**29**
6	**29**
7	**31**
8	**28**
9	**35**
10	**29**

Repeatability - Left Correlations (%)

Run	3	4	5	6	7	8	9	10
2	93	94	95	95	96	96	96	95
3		93	95	94	94	**90**	92	96
4			94	92	**91**	93	96	93
5				97	95	96	96	96
6					97	94	95	97
7						94	94	97
8							97	95
9								94

Repeatability - Left Offsets (ft)

Run	3	4	5	6	7	8	9	10
2	-3.6	23.3	3.5	-4.4	0.9	3.0	0.1	-1.4
3		26.9	7.1	-0.8	4.5	6.5	3.6	2.1
4			-19.8	-27.7	-22.4	-20.3	-23.2	-24.7
5				-8.0	-2.6	-0.6	-3.5	-5.0
6					5.3	7.4	4.5	3.0
7						2.0	-0.9	-2.4
8							-2.9	-4.4
9								-1.5

Repeatability - Right Correlations (%)

Run	3	4	5	6	7	8	9	10
2	**88**	92	**91**	93	93	93	**43**	**91**
3		**90**	**91**	**89**	**90**	**87**	**44**	**91**
4			**91**	**91**	**90**	**90**	**42**	92
5				94	92	92	**45**	95
6					92	92	**45**	94
7						**91**	**45**	93
8							**44**	92
9								**45**

Repeatability - Right Offsets (ft)

Run	3	4	5	6	7	8	9	10
2	4.3	23.3	-4.4	-4.4	0.9	2.9	-0.1	-1.5
3		19.0	-8.7	-8.7	-3.4	-1.4	-4.4	-5.8
4			-27.7	-27.7	-22.4	-20.4	-23.4	-24.8
5				-0.1	5.3	7.3	4.3	2.9
6					5.3	7.3	4.4	2.9
7						2.0	-1.0	-2.4
8							-3.0	-4.4
9								-1.4

Conclusions

- WIS Integrated into 3D Ultra Sensors
- Repeatable Results (Uncontrolled Roadway Sections)
  - Multiple Passes
  - Various Speeds
  - Various Road Conditions/Geometry without Traffic Control
- What is next?
  - Actual Profiler Certification