High-Speed Inertial Profiler Precision Study

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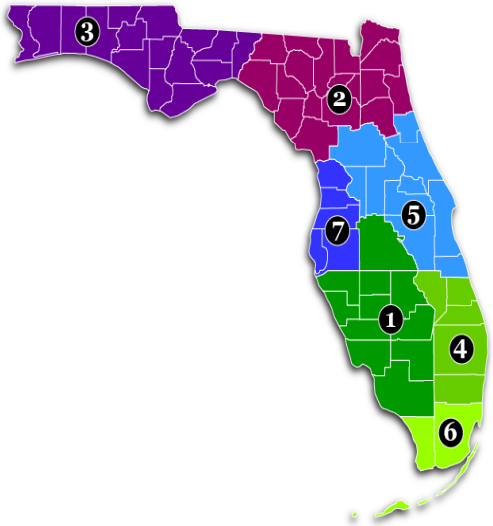
Presentation Outline

- Background
- Objectives
- Field experiment
- Analysis results
- Findings summary
- Conclusions

Background

- ~ 43,000 lane-miles surveyed annually
- ~2,000 lane-miles resurfaced annually
- 80% state roadways must be in good condition (92% in 2012)
- **Accurate, repeatable and reproducible results are critical** !

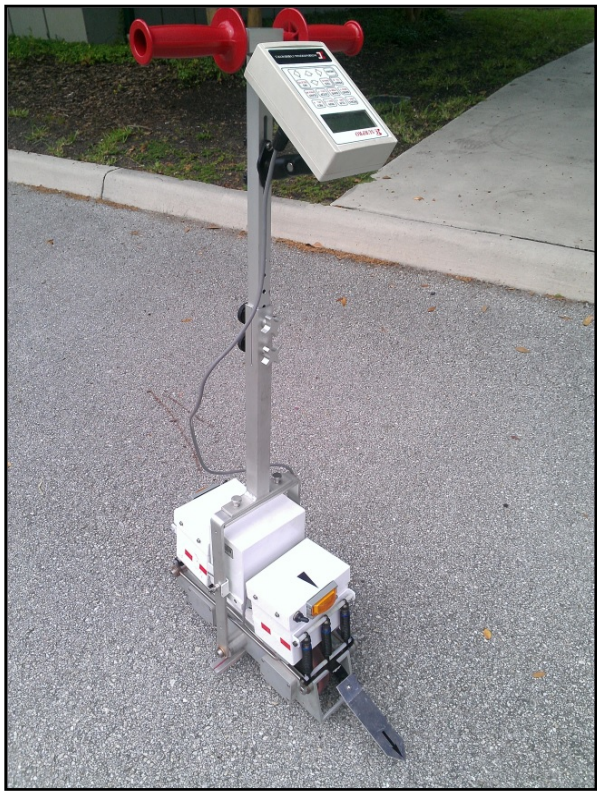


Objectives

- SurPRO 3500 repeatability
  - ✓ Distance accuracy
  - ✓ IRI, RN
  - ✓ Profile Cross-Correlation (CC)
- HSIPs' repeatability, accuracy, reproducibility
  - ✓ Distance
  - ✓ IRI,RN
  - ✓ Profile CC

Field Experiment

- **Equipment**
  - ✓ SurPRO 3500
    - ➢ Reference
    - ➢ Upgrade to SurPRO 2000
    - ➢ 1 inch sampling interval
    - ➢ 6 passes per wheelpath



Field Experiment

- **Equipment**
  - ✓ 8 High Speed Inertial Profilers (HSIPs)
    - ➢ 3 single-point sensors, 32 KHz
    - ➢ 2 accelerometers
    - ➢ 0.7 to 1.0 inch sampling interval
    - ➢ 10 passes at posted speed (40 to 60 mph)

Field Experiment

HSIP	Sampling Interval (inch)	Vehicle				Sensor Age (years)		
		Year	Make	Model	Years in Service	LWP	Center	RWP
1	1.003	2009	Ford	E-350	3	3	3	3
2	0.874	2011	Ford	E-150	1	2	2	2
3	0.698	2010	Ford	E-150	2	5	2	2
4	0.873	2010	Ford	E-150	2	14	2	14
5	0.895	2008	Ford	E-150	4	4	4	4
6	0.738	2007	Ford	E-150	5	4	4	4
7	0.766	2003	Ford	E-350	8	1	1	1
8	0.815	2004	Ford	E-150	8	1	1	1

Field Experiment

- **Equipment**
  - ✓ 100 ft steel tape

Field Experiment

- **Test Sections**
  - ✓ Six 0.2 mile sections
    - ➢ 3 Open-Graded (OG) - Smooth, Medium, Rough
    - ➢ 3 Dense-Graded (DG)- Smooth, Medium, Rough
    - ➢ Marked wheelpaths
    - ➢ Minimum of 528 ft lead-in and lead-out
    - ➢ Automatic triggering

Field Experiment

Surface Type	Surface Smoothness	IRI Range Criteria	Posted Speed Limit [mph]
OG	Rough	> 100	60
	Medium	60 – 80	60
	Smooth	< 50	50
DG	Rough	> 120	40
	Medium	90 – 110	50
	Smooth	< 60	50

Field Experiment

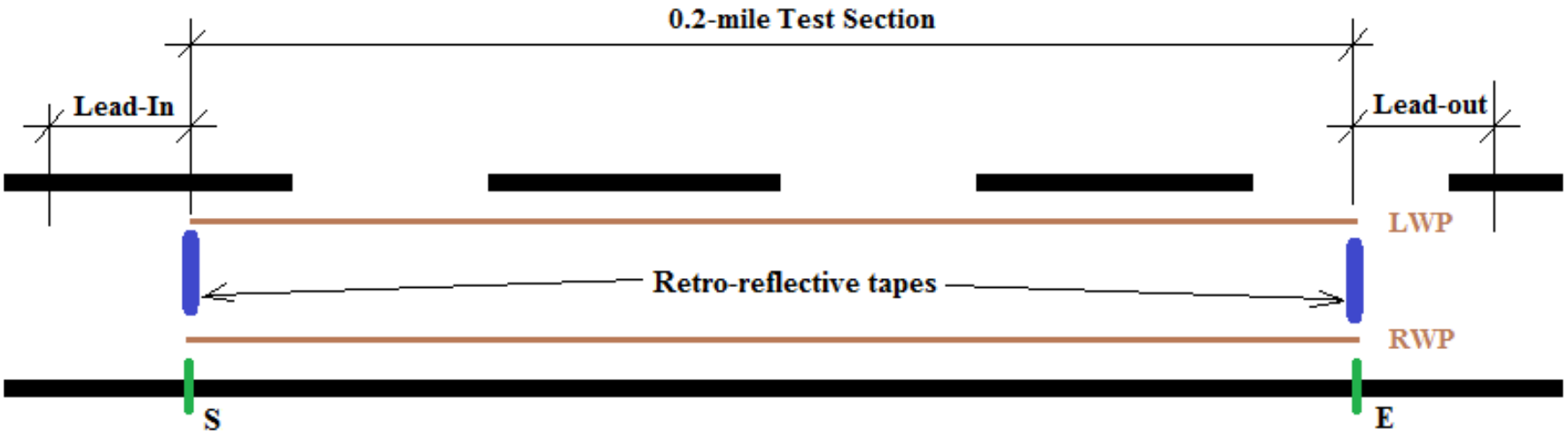
SR 500 OG Rough

SR 222 DG Smooth

SR 24 OG Smooth

NW 59 Drive DG Rough

Field Experiment



Analysis Results

Wheel Path	Surpro Distance Error (%)			
	St.Dev	Average	Max	Range
Left	0.02	-0.03	-0.06	0.07
Right	0.02	-0.03	-0.06	0.04

Analysis Results

Wheel Path	Statistics	SurPRO 3500 IRI and RN Repeatability											
		OG						DG					
		Rough		Medium		Smooth		Rough		Medium		Smooth	
		IRI	RN	IRI	RN	IRI	RN	IRI	RN	IRI	RN	IRI	RN
LWP	Average	88.9	3.90	88.0	3.37	34.9	4.57	188.4	2.72	98.4	3.84	49.7	4.39
	St. Dev	*0.7*	*0.01*	*1.5*	*0.02*	*0.3*	*0.01*	*0.6*	*0.01*	*0.5*	*0.00*	*0.5*	*0.01*
RWP	Average	120.5	3.05	72.7	3.84	34.0	4.54	170.3	2.85	89.3	3.98	48.4	4.37
	St. Dev	*1.2*	*0.01*	*0.5*	*0.01*	*0.2*	*0.01*	*1.0*	*0.00*	*0.3*	*0.01*	*0.5*	*0.01*

Analysis Results

SurPRO 3500 Average Cross Correlation(%)						
Texture	Smoothness	Wheelpath	Wavelenght			
			IRI	Long	Medium	Short
OG	Rough	LWP	98	99	98	94
		RWP	98	97	97	96
	Medium	LWP	94	98	94	92
		RWP	98	99	96	95
	Smooth	LWP	94	99	92	87
		RWP	95	99	93	80
DG	Rough	LWP	99	99	99	97
		RWP	99	99	99	97
	Medium	LWP	99	100	98	95
		RWP	99	100	99	96
	Smooth	LWP	92	99	88	89
		RWP	90	99	81	90
Critical Profiler Accuracy Requirements			98	98	98	94

Analysis Results

HSIP	HSIP Distance Error (%)			
	St.Dev	Average	Max	Range
1	0.04	0.04	0.10	0.08
2	0.04	0.07	0.13	0.09
3	0.02	0.05	0.09	0.09
4	0.07	0.07	0.14	0.14
5	0.07	0.09	0.18	0.14
6	0.02	0.05	0.09	0.08
7	0.02	0.04	0.07	0.07
8	0.01	0.04	0.09	0.08

Analysis Results

Roughness Index	Surface Type	Smoothness	Average	Pooled Standard Deviation		Overall Pooled Standard Deviation		d2s limit	
				Within Unit	Between Units	Within Unit	Between Units	Within Unit	Between Units
IRI	OG	Rough	104.3	3.8	4.9	2.8	3.7	**7.8**	**10.4**
		Medium	83.5	2.9	4				
		Smooth	39.7	0.7	1.1				
	DG	Rough	176.4	2.8	6.1	1.9	4.1	**5.5**	**11.5**
		Medium	96.2	0.7	1.2				
		Smooth	51.8	1.7	3.4				
RN	OG	Rough	3.4	0.07	0.09	0.06	0.07	**0.17**	**0.21**
		Medium	3.5	0.07	0.08				
		Smooth	4.3	0.03	0.04				
	DG	Rough	2.7	0.03	0.07	0.02	0.05	**0.07**	**0.18**
		Medium	3.8	0.01	0.02				
		Smooth	4.3	0.03	0.05				

Analysis Results

Surface Type	Smoothness	Wheelpath	HSIPs Repeatability Based on Average Profile Cross-Correlation (%)			
			IRI	Long	Medium	Short
OG	Rough	LWP	83	**99**	89	33
		RWP	71	**97**	77	44
	Medium	LWP	55	**98**	62	36
		RWP	70	**98**	74	34
	Smooth	LWP	70	**99**	81	13
		RWP	67	**99**	77	14
DG	Rough	LWP	90	**98**	***93***	72
		RWP	85	**96**	89	68
	Medium	LWP	**94**	**99**	**96**	63
		RWP	**96**	**99**	**97**	69
	Smooth	LWP	88	**99**	90	56
		RWP	83	**99**	85	54
AASHTO R-56 / CPAR			*92* /94	NA/94	NA/94	NA/88

Analysis Results

Surface Type	Smoothness	HSIPs Accuracy			
		IRI Difference		RN Difference	
		Average	95% CI	Average	95% CI
OG	Rough	-0.7	-1.8, 0.4	0.14	0.12 , 0.16
	Medium	3.5	2.6, 4.4	0.09	0.07 , 0.11
	Smooth	5.6	5.4, 5.8	-0.26	-0.26 , -0.25
DG	Rough	-3.2	-4.5, -1.9	0.09	0.07, 0.10
	Medium	2.2	1.9, 2.4	-0.03	-0.03, -0.03
	Smooth	2.6	1.9, 3.3	-0.04	-0.03, -0.06

Analysis Results

Surface Type	Smoothness	Wheel Path	HSIPs Accuracy Based on Average Profile Cross Correlation (%)			
			IRI	Butterworth Waveband		
				Long	Medium	Short
OG	Rough	LWP	82	97	88	24
		RWP	64	95	72	35
	Medium	Left	57	97	64	31
		Right	70	98	75	27
	Smooth	Left	67	91	78	6
		Right	64	92	76	7
DG	Rough	Left	79	94	85	50
		Right	74	92	79	45
	Medium	Left	87	98	91	38
		Right	88	96	91	42
	Smooth	Left	79	97	79	36
		Right	72	96	73	36
Overall Average Cross-Correlation			74	95	79	32
AASHTO R-56/CPAR			90/94	NA*/94	NA*/94	NA*/88

Analysis Results

Surface Type	Smoothness	Wheel Path	HSIPs Reproducibility Based on Average Profile Cross-Correlation (%)			
			IRI	Butterworth Waveband		
				Long	Medium	Short
OG	Rough	LWP	78	96	86	23
		RWP	63	95	71	35
	Medium	LWP	48	96	56	28
		RWP	62	97	69	23
	Smooth	LWP	65	97	76	8
		RWP	61	98	71	9
DG	Rough	LWP	78	96	85	48
		RWP	73	92	79	46
	Medium	LWP	88	98	92	48
		RWP	92	97	94	53
	Smooth	LWP	78	98	81	39
		RWP	69	97	73	36
Average for All Sub-Sections			71	96	78	33

Findings Summary

- **SurPRO 3500**
  - 0.03% average distance error was less than R-56 and CPAR criteria
  - Achieved excellent IRI and RN index repeatability on all surfaces
  - Met or exceeded profile repeatability CC criteria for IRI, Long, Medium and Short wavebands on DG rough and medium-smooth surfaces
  - Did not meet profile repeatability CC for IRI on smooth surfaces
  - Variable profile repeatability on rest of surface types depending on texture, waveband, and wheelpath tested

Findings Summary

- **HSIP Distance Accuracy**
  - ✓ 0.06% average error was less than the 0.15% R-56 criterion
  - ✓ 0.06 % average error was less than the 0.10% CPAR criterion

Findings Summary

- **HSIP IRI Repeatability**
  - ✓ **OG surfaces –** IRI difference from two properly conducted tests using same HSIP system on same section should not exceed 7.8 in/mile at 95% confidence level
  - ✓ **DG surfaces –** IRI difference from two properly conducted tests using same HSIP system on same section should not exceed 5.5 in/mile at 95% confidence level

Findings Summary

- **HSIP IRI Reproducibility**
  - ✓ **OG surfaces –** IRI difference from two properly conducted tests using two HSIP systems on same section should not exceed 0.4 in/mile at 95% confidence level
  - ✓ **DG surfaces –** IRI difference from two properly conducted tests using two HSIP systems on same section should not exceed 1.5 in/mile at 95% confidence level

Findings Summary

- **HSIP IRI Accuracy**
  - ✓ **DG surfaces –** IRI difference ranged from - 4.5 to 3.3 in/mile at 95% confidence level
  - ✓ **OG surfaces –** IRI difference ranged from -1.8 to 5.8 in/mile at 95% confidence level

Findings Summary

- **HSIP Profile Repeatability CC**
  - ✓ R-56 IRI criterion (92%) and CPAR IRI criterion (94%) was only met on DG Medium-Smooth surface
  - ✓ CPAR criterion for long waveband (94%) was met on all surface types
  - ✓ Scores were lower on OG than DG surfaces for IRI, Medium and Short wavebands. This may be attributed to limitation of single-point laser footprint
  - ✓ Low scores on smooth surfaces may be attributed to influence of system noise on signal response

Findings Summary

- **HSIP Profile Reproducibility CC**
  - ✓ Higher scores on DG surfaces suggest OG surfaces present a challenge to single-point lasers
  - ✓ Relatively low IRI reproducibility scores appear to be due to lateral variability in profiled paths

Findings Summary

- **HSIP Profile Accuracy CC**
  - ✓ R-56 IRI criterion (90%) was not met on any surface type
  - ✓ CPAR IRI criteria were met for Long wave band (except for smooth DG surface), but not for other other surfaces and wavelengths

Conclusions

- Results from the study prompted FDOT researchers to:
  - ✓ look into reason(s) Surpro 3000 generally did not meet repeatability CC on smooth surfaces
  - ✓ further investigate factors affecting HSIPs' agreement in repeatability, accuracy and reproducibility
  - ✓ Conduct follow up study to evaluate performance of different laser sensors on pavements with different surface textures
  - ✓ evaluate effectiveness of wheelpath tracking devices in reducing lateral wander

QUESTIONS ?