



High-Speed Inertial Profiler Precision Study

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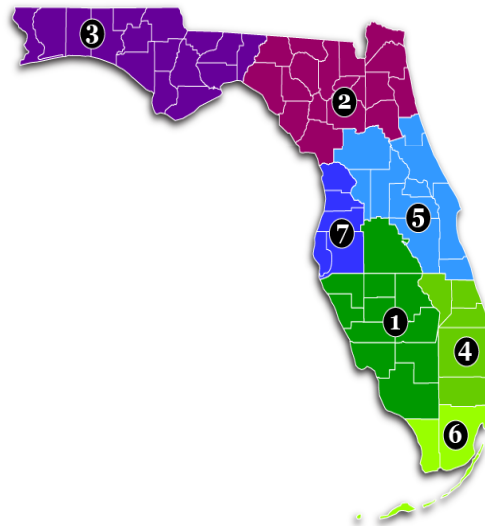
Presentation Outline

- ◆ 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
- ◆ **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 device
 - Upgrade to SurPRO 2000
 - 1 inch sampling interval
 - 6 passes per wheelpath



Field Experiment

◆ Equipment

✓ 8 HSIPs

- 3 height sensors, 32 KHz single-point lasers
- 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



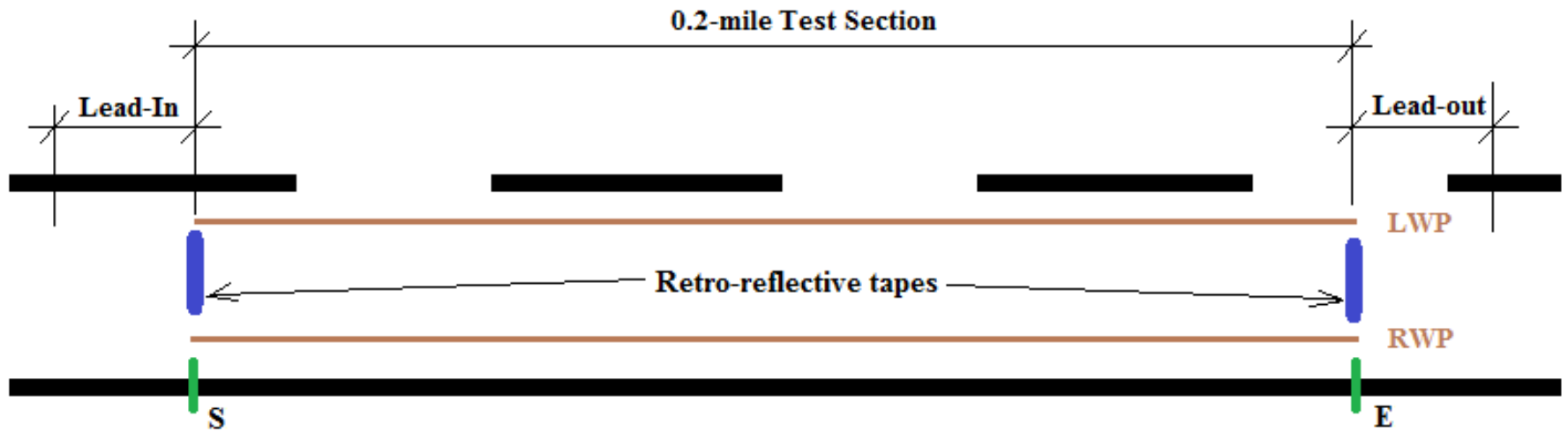
SR 24 OG Smooth



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 | <i>0.7</i> | <i>0.01</i> | <i>1.5</i> | <i>0.02</i> | <i>0.3</i> | <i>0.01</i> | <i>0.6</i> | <i>0.01</i> | <i>0.5</i> | <i>0.00</i> | <i>0.5</i> | <i>0.01</i> |
| 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 | <i>1.2</i> | <i>0.01</i> | <i>0.5</i> | <i>0.01</i> | <i>0.2</i> | <i>0.01</i> | <i>1.0</i> | <i>0.00</i> | <i>0.3</i> | <i>0.01</i> | <i>0.5</i> | <i>0.01</i> |



Analysis Results

| SurPRO 3500 Average Cross Correlation(%) | | | | | | | |
|--|------------|-----------|------------|------|--------|-------|----|
| Texture | Smoothness | Wheelpath | Wavelength | | | | |
| | | | 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**

- Maximum distance error of 0.06% exceeded R-56 and CPAR criteria
- Excellent IRI and RN repeatability on all test sections
- Met or exceeded profile repeatability criteria for IRI, Long, Medium and Short wavebands on DG rough and medium-smooth sections
- Variable profile repeatability on other sections depending on surface texture, waveband, and wheelpath tested



Findings Summary

◆ **HSIP Distance Accuracy**

- ✓ Average distance error of 0.06% exceeded R-56 and CPAR criteria (Maximum distance error was 0.18%)

◆ **HSIP Smoothness Repeatability**

- ✓ **On OG surfaces**, IRI and RN from two properly conducted tests using same HSIP system on same section should not differ by more than 7.8 in/mile and 0.17 at 95% confidence level, respectively
- ✓ **On DG surfaces**, IRI and RN from two properly conducted tests using same HSIP system on same section should not differ by more than 5.5 in/mile and 0.07 at 95% confidence level, respectively.



Findings Summary

◆ **HSIP Smoothness Reproducibility**

- ✓ **On OG surfaces**, the IRI and RN from two properly conducted tests using two HSIP systems on same section should not differ by more than 10.4 in/mile and 0.21 at 95% confidence level, respectively
- ✓ **On DG surfaces**, the IRI and RN from two properly conducted tests using two HSIP systems on same section should not differ by more than 11.5 in/mile and 0.18 at 95% confidence level, respectively



Findings Summary

◆ **HSIP Smoothness Accuracy**

- ✓ **On DG surfaces**, the difference in IRI and RN ranged from -4.5 to 3.3 in/mile and -0.06 to -0.10 at 95% confidence level, respectively
 - The smallest and largest difference was on the medium-smooth and rough section, respectively
- ✓ **On OG surfaces**, the difference in IRI and RN ranged from -1.8 to 5.8 in/mile and -0.26 to 0.16 at 95% confidence level, respectively
 - The smallest and largest difference was on rough and smooth section, respectively.



Findings Summary

◆ **HSIP Profile Repeatability**

- ✓ The 92% repeatability criterion was not met on any section tested for IRI filter
- ✓ Met or exceeded CPAR criteria for the long waveband on all surface types
- ✓ Scores were the lowest in the short waveband, followed by IRI, and Medium waveband for all surfaces



Findings Summary

◆ **HSIP Profile Repeatability**

- ✓ OG sections had lower scores than DG surfaces for IRI, Medium and short wavebands. This may be attributed to the limitation of the single-point laser footprint
- ✓ Low scores in smooth DG section may be partly attributed to influence of system noise on signal response



Findings Summary

◆ **HSIP Profile Reproducibility**

- ✓ Higher scores on DG sections (especially in the short waveband) 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

- ✓ The 90% accuracy criterion was not met on any section tested for IRI filter
- ✓ Low scores in the short waveband are partly due to the difference in HSIPs' laser footprint and SurPRO tire footprint
- ✓ High scores for OG sections in long waveband and low scores in short waveband are indicative of the single-point laser limitation on these type of surfaces



Conclusions

- ◆ Results from the study prompted FDOT researchers to:
 - ✓ further investigate factors affecting HSIPs' agreement in repeatability, accuracy and reproducibility
 - ✓ conduct a follow up study to evaluate the performance of different laser sensor technologies with various footprints over pavements with different surface textures
 - ✓ evaluate effectiveness of pavement markings and tracking-aid devices in reducing vehicle wander



QUESTIONS ?

