Accuracy and Precision of High-Speed Field Measurements of Pavement Surface Rutting and Cracking

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Introduction

- Transportation agencies use, or are transitioning to, 3D automated distress measurement systems.
- Accuracy of the automated measurements is the biggest challenge faced by developers of these systems.
- Agencies have to choose between prompt delivery and enhanced accuracy.
- Errors in distress data can lead to increased maintenance costs and inappropriate project prioritization.
Objective

Independent evaluation of the accuracy and precision of high-speed measurements of rutting and cracking in Texas highways accounting for:

- Pavement Surface Type (HMA, Surface Treatment, JCP, CRCP)
- Distress Type and Extension (rut depth, Crack type and width)
- Surface Macro-Texture (MPD)
- Level of Manual intervention (automated vs corrected)

- Phase 1: Evaluation of Rutting Measurements
- Phase 2: Evaluation of Cracking Measurements
Phase 1 - Experimental Design

• Twenty-four 550-ft long highway sections:
  – Different rut severity levels and representative of Texas highways
  – RD every 5-ft, both WP (5,328 meas) + Profiles every 25-ft (552 tr prof)
Collection of Reference Transverse Profiles

Leica Laser System transverse profile measurements
27 points per profile – total width 150”

Level aluminum beam provided reference plane
23 profiles per test section - 552 profiles total
Collection of Reference Transverse Profiles

Manual 6’ straight edge rut depth measurements
222 measurements per test section – over 5,200 measurements total
Automated Survey of Rutting
Comparison of Transverse Profiles
Comparison of Rut Depth Values

<table>
<thead>
<tr>
<th></th>
<th>Accuracy (1/16 in.)</th>
<th>Precision (1/16 in.)</th>
<th>$\beta_{RD} = \Delta R_{D_{error}} / \Delta R_{D}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAS 1</td>
<td>-0.83</td>
<td>3.14</td>
<td>0.10</td>
</tr>
<tr>
<td>CAS 2</td>
<td>-0.87</td>
<td>2.52</td>
<td>0.15</td>
</tr>
<tr>
<td>CAS 3</td>
<td>-0.99</td>
<td>2.67</td>
<td>0.09</td>
</tr>
<tr>
<td>CAS 4</td>
<td>-2.45</td>
<td>5.22</td>
<td>0.58</td>
</tr>
<tr>
<td>CAS 5</td>
<td>-3.10</td>
<td>4.37</td>
<td>0.46</td>
</tr>
</tbody>
</table>

The graph shows the relationship between the number of sensors and the rut depth error. The error is represented on the y-axis, and the number of sensors is on the x-axis. The graph includes lines for different coverage levels, indicating the quartiles and median values for each.
Phase 2 - Experimental Design

- Twenty 550-ft long highway sections:
  - Divided into eleven 50-ft subsections (220 total)
  - LTPP protocols

<table>
<thead>
<tr>
<th>Type of Pavement</th>
<th>Number of Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible</td>
<td></td>
</tr>
<tr>
<td>HMA</td>
<td>7</td>
</tr>
<tr>
<td>Surface Treatments</td>
<td>8</td>
</tr>
<tr>
<td>Rigid</td>
<td></td>
</tr>
<tr>
<td>JCP</td>
<td>2</td>
</tr>
<tr>
<td>CRCP</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>20</strong></td>
</tr>
</tbody>
</table>
Manual Distresses Surveys

• Experienced LTPP Raters
  – Distresses summarized every 50 ft
Reference Crack Maps

- Three crack width categories:
  - < 3 mm (red) / 3 mm - 6 mm (blue) / > 6 mm (green)
Automated Survey of Distresses
### Comparative Analysis

- **Summary Statistics of Cracking Measurements**
  - False Positives and Missed Cracks

<table>
<thead>
<tr>
<th>Cracking Type</th>
<th>System</th>
<th>False Positives</th>
<th>B&amp;A effect</th>
<th>Missed Cracks</th>
<th>B&amp;A effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before</td>
<td>After</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td># (%)</td>
<td># (%)</td>
<td></td>
<td># (%)</td>
</tr>
<tr>
<td><strong>Fatigue</strong></td>
<td>INO LCMS 1</td>
<td>23 (26%) **</td>
<td>20 (23%) **</td>
<td>40 (52%) **</td>
<td>44 (57%) *</td>
</tr>
<tr>
<td></td>
<td>INO LCMS 2</td>
<td>33 (38%) *</td>
<td>34 (39%) *</td>
<td>36 (47%) **</td>
<td>25 (32%) ***</td>
</tr>
<tr>
<td></td>
<td>PaveVision</td>
<td>12 (14%) ***</td>
<td>12 (14%) ***</td>
<td>-</td>
<td>36 (47%) **</td>
</tr>
<tr>
<td><strong>Longit.</strong></td>
<td>INO LCMS 1</td>
<td>81 (74%) **</td>
<td>45 (41%) ***</td>
<td>49-13</td>
<td>22 (20%) **</td>
</tr>
<tr>
<td></td>
<td>INO LCMS 2</td>
<td>83 (75%) **</td>
<td>69 (63%) **</td>
<td>18-04</td>
<td>08 (07%) ***</td>
</tr>
<tr>
<td></td>
<td>PaveVision</td>
<td>64 (58%) ***</td>
<td>64 (58%) **</td>
<td>-</td>
<td>41 (37%) *</td>
</tr>
<tr>
<td><strong>Transv.</strong></td>
<td>INO LCMS 1</td>
<td>90 (63%) **</td>
<td>11 (08%) ***</td>
<td>81-02</td>
<td>17 (22%) **</td>
</tr>
<tr>
<td></td>
<td>INO LCMS 2</td>
<td>97 (67%) **</td>
<td>79 (55%) *</td>
<td>18-00</td>
<td>04 (05%) ***</td>
</tr>
<tr>
<td></td>
<td>PaveVision</td>
<td>27 (19%) ***</td>
<td>27 (19%) **</td>
<td>-</td>
<td>11 (14%) **</td>
</tr>
</tbody>
</table>

**Notes:**

- *** highest ranked; ** middle ranked; and * lowest ranked
- Underlined cells indicate statistically significant worsened effect
## Comparative Analysis

- **Summary Statistics of Cracking Measurements**
  - **Quantification of Measurement Errors**

<table>
<thead>
<tr>
<th>Crack Type</th>
<th>System</th>
<th>Quantification Errors</th>
<th>B&amp;A effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td></td>
<td></td>
<td>avg</td>
<td>sd</td>
</tr>
<tr>
<td>Fatigue</td>
<td>INO LCMS 1</td>
<td>-11.76 m² **</td>
<td>9.34 m²</td>
</tr>
<tr>
<td></td>
<td>INO LCMS 2</td>
<td>-6.56 m² ***</td>
<td>11.31 m²</td>
</tr>
<tr>
<td></td>
<td>PaveVision</td>
<td>-13.88 m² *</td>
<td>8.62 m²</td>
</tr>
<tr>
<td>Longit.</td>
<td>INO LCMS 1</td>
<td>1.09 m ***</td>
<td>9.86 m</td>
</tr>
<tr>
<td></td>
<td>INO LCMS 2</td>
<td>4.41 m **</td>
<td>10.70 m</td>
</tr>
<tr>
<td></td>
<td>PaveVision</td>
<td>7.24 m **</td>
<td>23.73 m</td>
</tr>
<tr>
<td>Transv.</td>
<td>INO LCMS 1</td>
<td>-15.54 m *</td>
<td>23.75 m</td>
</tr>
<tr>
<td></td>
<td>INO LCMS 2</td>
<td>-8.36 m ***</td>
<td>17.41 m</td>
</tr>
<tr>
<td></td>
<td>PaveVision</td>
<td>-12.79 m **</td>
<td>15.94 m</td>
</tr>
</tbody>
</table>

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**Notes:** *** highest ranked; ** middle ranked; and * lowest ranked
Phase 1 - Conclusions

• Transverse Profiles (hardware capabilities)
  – All five systems tested were capable of capturing surface transverse profiles with the necessary accuracy

• Rut Depth values (both hardware and software capabilities)
  – Three of four systems (INO LRMS sensors attached to the survey vehicle) produced similar RD values to the manually measured ones for all practical purposes
  – All showed a high dispersion of their measurements errors
  – Data processing algorithms can be further improve to improve accuracy and precision for roadways in Texas.

• Impact on TxDOT Pavement Management System Scores
  – Moving from a 5-point system to a continuous system will result in improved accuracy and higher levels of rutting (Condition Score dropped significantly, approx. 19 points)
Phase 2 – Conclusions (1/2)

• Accuracy Before Manual Post-Processing:
  – Both systems using INO LCMS sensors performed similarly. They tended to overestimate the number of sections with cracking.
  – Although PaveVision system slightly outperformed the other two for some error types, all systems showed poor overall accuracy and precision, which highlights the importance of manual intervention.
  – None of the systems outperformed the others on the quantification of cracking for all cracking types. All of them largely underestimated fatigue and transverse cracking, and overestimated long cracking.
Phase 2 – Conclusions (2/2)

• Effect of Manual Post-Processing:
  – Both INO LCMS systems significantly improved their accuracy after manual intervention for most cracking types
  – However, the amount of reported false positives was still large (>30%) for several combination of vendors and crack types
  – Manual corrections were more effective at removing cracks incorrectly detected than at adding cracks missed by their algorithm
  – None of the vendors’ measurement precision improved after applying manual post-processing
  – Several types of distresses, such as patching, punchouts, spalling, and joint damage, were reported only after manual post-processing of the crack maps
Thanks for your attention
Extra Slides
Laser distancemeter – DISTO D8
Leica System – Data collection on section 23
- Bias
- Precision
- MSE
- Average SSE
- Correlation
### Station 525 TxDOT Dynatest

<table>
<thead>
<tr>
<th></th>
<th>TxDOT</th>
<th>Dynatest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean abs Error (mm)</td>
<td>1.51  0.95</td>
<td>1.02  0.64</td>
</tr>
<tr>
<td>(SSE/n)^2 (mm)</td>
<td>1.89  1.19</td>
<td>1.22  0.77</td>
</tr>
</tbody>
</table>

- **Z** Axis [mm]
- **X** Axis [mm]

**Graph:**
- Blue line: TxDOT
- Red dots: CTR
- Green line: Dynatest
Phase 2 - Automated Surveys

• Data delivery time-frames analyzed in this study:
  
  – **Before** manual post-processing,
    • for data delivered within 2 business days
    • Faster results without manually correct the results produced by their system’s algorithms.
  
  – **After** manual post-processing,
    • for data delivered within 4 weeks.
    • Detailed manual inspection and corrections of their algorithm’s results, producing their most accurate results.
Manual Crack Map

PaveVision
Manual Crack Map

INO LCMS 1 (after)
Manual Crack Map

INO LCMS 2 (after)
Manual Crack Map

PaveVision
Manual Crack Map

INO LCMS 2 (before)
Manual Crack Map

INO LCMS 2 (after)
Crack Maps Gral Observations

• The number of missed cracks was larger for the cracks < 3 mm wide

• The system using PaveVision sensor did not misidentify transverse and longitudinal joints as cracks whereas the other two did

• None of the systems presented large amount of false positives on PFC surface

• None of the systems was able to capture the very fine cracks on Jointed Concrete Pavement sections

• Significant improvement after manual intervention for both INO LCMS systems