Identifying Deficient Pavement Sections using an Improved Acceleration-based Metric

Huanghui Zeng  University of Virginia
Agenda

- Introduction
- Data Collection
- Data Analysis Results
  1. Acceleration-based metric
  2. Identification of deficient pavements
- Conclusions
Introduction - Background

- Measuring pavement roughness is essential for pavement management
- Currently one of the most commonly used roughness measurements is the International Roughness Index (IRI)
- Collection of network level roughness data requires significant resources with accurate profiler
Connected Vehicle Environment

- A connected, data-rich transportation system thanks to the development of sensor and wireless communication techniques
- Acceleration, GPS location, Vehicle Speed, etc…
- How can this new data be used to improve pavement assessment and management?
Introduction - CVI-UTC Project

- “Pavement Assessment and Management Applications Enabled by the Connected Vehicles Environment- Proof-of-Concept”
- To use data collected from “probe” vehicles to extract information that could be used to remotely and continuously monitor pavement health
Introduction - Challenges

- Root Mean Squared Acceleration = IRI?

- Acceleration-only metric may not be good enough
Introduction - Objectives

- An acceleration-based metric by incorporating speeds
- Identify deficient pavement sections

Serve as a supplemental method for current IRI practice- network screening.
Data Collection System

- RoLine profiler
- Smartphone data (50 Hz) 3-way accelerations
- GPS location, and speed
- IRI and RMS aggregated at 0.1-mile interval
Data Collection Routes

- Three types of roadways
- 50-mile in total
- Speed limit range from 30 to 70 mph

<table>
<thead>
<tr>
<th>Route</th>
<th>IRI Summary (in/mile)</th>
<th>Speed (mph)</th>
<th>Number of Sites</th>
<th>Length (mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS-64E</td>
<td>75.5</td>
<td>45.5</td>
<td>256.8</td>
<td>65.9</td>
</tr>
<tr>
<td>IS-64W</td>
<td>76.9</td>
<td>37.3</td>
<td>267.5</td>
<td>64.8</td>
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<tr>
<td>US-15</td>
<td>82.6</td>
<td>63.4</td>
<td>125.5</td>
<td>52.4</td>
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<tr>
<td>SR-616</td>
<td>124.7</td>
<td>86.1</td>
<td>172.0</td>
<td>45.4</td>
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<tr>
<td>SR-600</td>
<td>121.2</td>
<td>85.7</td>
<td>219.3</td>
<td>40.8</td>
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<tr>
<td>SR-799</td>
<td>87.4</td>
<td>123.9</td>
<td>228.5</td>
<td>39.3</td>
</tr>
<tr>
<td>SR-676</td>
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<td>151.8</td>
<td>248.2</td>
<td>40.5</td>
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<tr>
<td>Total</td>
<td>85.0</td>
<td>37.3</td>
<td>267.5</td>
<td>64.8</td>
</tr>
</tbody>
</table>
An Acceleration-based Metric

- Finding from previous studies (Ahlin and Granlund, 2002)
  \[
  \frac{vib}{IRI} = 0.16(v/80)^{(n-1)/2}
  \]

- Recommended format: indicates the vibration level that a vehicle is expected to experience at 50 mph (80 km/h).
  \[
  NRMS = (80/v)^w a_{z,RMS}
  \]

Where:
- \( vib \) = vehicle vibration responses;
- \( v \) = vehicle speed, km/h;
- \( a_{z,RMS} \) = RMS vertical acceleration;
- \( NRMS \) = normalised RMS acceleration; and
- \( n, w \) = exponent values that are related to pavement wavelength, and \( w = (n-1)/2 \).
An Acceleration-based Metric

- Scatter plots of IRI Vs. RMS/NRMS ($w = 0, 0.5, 1, 1.5$)

- For network screening, what’s the optimal value of $w$?
An Acceleration-based Metric

- Classification error curve

\[ W_{optimal} = 1.3 \]

\[ NRMS = (80/v)^{1.3}a_{z,RMS} \]
Identification of Deficient Pavements

\[ Y_i = \begin{cases} 
1 & \text{If the pavement is deficient (IRI}_i \geq 140 \text{ in/mile)} \\
0 & \text{If the pavement is not deficient (IRI}_i < 140 \text{ in/mile)} 
\end{cases} \]

\[ \log(\text{Odd}) = \alpha + \beta \text{NRMS}_i \]

<table>
<thead>
<tr>
<th>Model</th>
<th>Variable</th>
<th>Coefficient</th>
<th>S.E.</th>
<th>Significant</th>
<th>Odds Ratio$^{1}$</th>
<th>Nagelkerke R Square$^{2}$</th>
<th>AIC</th>
<th>NRMS$_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Default Model</td>
<td>Intercept</td>
<td>-14.20</td>
<td>2.16</td>
<td>0.000</td>
<td>1.48</td>
<td>0.84</td>
<td>69.46</td>
<td>0.36</td>
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<tr>
<td>NRMS</td>
<td></td>
<td>39.04</td>
<td>6.16</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A pavement section will be flagged as deficient if its NRMS \( \geq 0.36 \text{ m/sec}^2 \).
Identification of Deficient Pavements

- Identify correctly 80% (24/30) of deficient pavements
- The IRIs of those mis-identified sections are close to 140 in/mile
Conclusion and Future Research

- This study developed a normalized acceleration-based metric (NRMS) that can generalize to different functional classes of highway by incorporating vehicle speed.
- Feasibility of using NRMS for the purpose of network screening
- Future Research:
  1. Identify IRI > 220 inch/mile situation
  2. Vehicle dynamic system impacts
  3. Filters to remove invalid data
  4. Prototype system using state-own vehicles
Questions?

Thank You!

Contact Information:
Brian Smith
Professor
Center for Transportation Studies
University of Virginia. Charlottesville, VA
briansmith@virginia.edu

Huanghui Zeng
PhD Candidate
Graduate Research Assistant
Center for Transportation Studies
University of Virginia, Charlottesville, VA
hz3xm@virginia.edu
## Classification Results Summary

<table>
<thead>
<tr>
<th>Model</th>
<th>Observed</th>
<th>Testing Data Predicted</th>
<th>Non-Def.</th>
<th>Deficient</th>
<th>Correct Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Default Model</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Def.</td>
<td>132</td>
<td>3</td>
<td>97.78</td>
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<tr>
<td></td>
<td>(99, 33)</td>
<td>(0, 3)</td>
<td>(100.00, 91.67)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deficient</td>
<td>6</td>
<td>24</td>
<td>80.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3, 3)</td>
<td>(13, 11)</td>
<td>(81.25, 78.57)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Shifted Model</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Def.</td>
<td>123</td>
<td>12</td>
<td>91.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(96, 27)</td>
<td>(3, 9)</td>
<td>(96.97, 75.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deficient</td>
<td>2</td>
<td>28</td>
<td>93.33</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>(1, 1)</td>
<td>(15, 13)</td>
<td>(93.75, 92.86)</td>
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<td></td>
</tr>
<tr>
<td><strong>No Speed</strong></td>
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</tr>
<tr>
<td>Non-Def.</td>
<td>133</td>
<td>2</td>
<td>98.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(98, 34)</td>
<td>(1, 1)</td>
<td>(98.99, 97.14)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deficient</td>
<td>13</td>
<td>17</td>
<td>56.66</td>
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</tr>
<tr>
<td></td>
<td>(7, 6)</td>
<td>(9, 8)</td>
<td>(56.25, 57.14)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: 1. The first value in the parenthesis indicates the number of interstate sections and the latter the number of non-interstate sections.
Classification Results - Shifted Model

![Chart showing classification results with categories: True Negative, False Positive, False Negative, True Positive.](image)
Training and Testing Dataset

FIGURE 1  Comparison of IRI, RMS and Speed Data in the Testing and Training Datasets
Fig. 4 IRI compared to RMS acceleration on US-250 E; Top: Original 0.1-mile data; Bottom: Moving average using a 1-mile window.

Fig. 3 IRI compared to RMS acceleration on I-64 W; Top: Original 0.1-mile data; Bottom: Moving average using a 1-mile window.