A Case Study:

Smoothness Profiling in an Urban Setting

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Pat Kennedy

Angie Hager

City and County of Denver
Public Works Street Maintenance
Outline

• Profiling / IRI Description
• Unique Urban Influences
  – Data Collection
  – Measurements
• Denver Case Study: Uses of Profiling Data
  – Before / After Repaving
  – Contracting Specifications
Profiling Description

- Travelling Public Perception
  - Public does not care about pavement defects that do not affect ride quality!
  - Public cares about smoothness
Profiling Description

Pavement Roughness Incentive/Disincentives by State

Source: http://www.smoothpavements.com
Profiling Description

Pavement Roughness Incentive/Disincentives by State

Source: http://www.smoothpavements.com
Profiling Description
International Roughness Index (IRI)

- Measurement Metric (in/mi, mm/km)
- Common Use
  - Highways
  - Two-Lane Rural Roadways
Alternative Profilometric Indices

- International Roughness Index (IRI)
- Half-Car Ride Index (HRI)
- Michigan Ride Quality Index (RQI)
- CalPro Simulation Model
- Straightedge / Rolling Straightedge
- The Ride Number
- The Performance Index
International Roughness Index

- Developed in 1986
- Provides a Unified Analysis Tool for Pavement Roughness
- Commonly Used in Financial Incentive/Disincentive Programs for Contractors
- Indirect Profilometric Index
International Roughness Index

\[ IRI = \frac{1}{L} \int_{0}^{x/v} (z_s - z_u) \, dt \]

Where:
- \( IRI \) = International Roughness Index (in/mi or mm/km).
- \( L \) = length of the section (ft or m).
- \( V \) = speed of the quarter car model (in/sec or mm/s).
- \( X \) = longitudinal distance of segment (in or mm).
- \( z_s \) = vertical speed of the sprung mass in the quarter-car model diagram (in/sec).
- \( z_u \) = vertical speed of the unsprung mass in the quarter-car model diagram (in/sec).
- \( dt \) = the time increment (sec).
International Roughness Index

Derivation of the IRI
Quarter-Car Model

\[
IRI = \frac{1}{L} \int_{0}^{x/V} \left( \frac{z_s}{V} - \frac{z_u}{V} \right) dt
\]
Sample IRI Calculation

- Roadway Length \((L)\): 1.0 mi
- Profiler Speed \((v)\): 10 mi/hr = 176 in/sec
- Segment Length \((x)\): 0.01 in
- Unsprung Mass \((z_u)\): 15 mi/hr = 264 in/sec
- Sprung Mass \((z_s)\): 25 mi/hr = 440 in/sec

\[
IRI = \frac{1}{L} \int_0^{x/v} |z_s - z_u| \, dt
\]
International Roughness Index

Sample IRI Calculation

\[ IRI = \frac{1}{1.0 \text{mi}} \int_0^{0.000057 \text{sec}} 440 \frac{\text{in}}{\text{sec}} - 264 \frac{\text{in}}{\text{sec}} \, dt \]

1) \[ IRI = \frac{1}{1.0 \text{mi}} \int_0^{0.000057 \text{sec}} 176 \frac{\text{in}}{\text{sec}} \, dt \]

2) \[ IRI = \frac{1}{1.0 \text{mi}} \left[ 176 \frac{\text{in}}{\text{sec}} \cdot t \right]_0^{0.000057 \text{sec}} \]

3) \[ IRI = \frac{1}{1.0 \text{mi}} \ast [0.01 \text{ in}] \]

\[ IRI = 0.1 \text{ in/mi} \]
Literature Review

• Supporting Research on Traditional Applications of the IRI
• Standards & Practices for IRI Usage
• Concrete & Asphalt Variations in the Usage of the IRI
• IRI Applications on Urban Roadway Facilities
International Roughness Index

Research Supporting UIRI

• “Urban Considerations for Using Road Roughness to Manage Road Networks” (Reggin, Et. Al, 2008)

\[
\text{Network IRI} = \frac{(\text{IRI})(L) - (1.5 \text{ m/km})(d)(n)}{(L)}
\]

Where:

- IRI = International Roughness Index (m/km)
- L = Length of Segment (km)
- d = Average Length of Railroad Crossings (km)
- n = Number of Railroad Crossings in Segment
Recommended Threshold Values

FHWA Recommended IRI Threshold Values for Highways & Rural Roadways:

- **GOOD** < 95 in/mi
- **ACCEPTABLE** < 170 in/mi
- **UNACCEPTABLE** ≥ 170 in/mi
Denver, Colorado
Factors Influencing IRI Data Collection on Urban Roadways
- Traffic Signals / Stop Signs
  - Frequent Start / Stops
  - Lower Speeds
High-Speed Profilier
Low-Speed Profilier
Urban Influences

[Graph showing data with labels ODS 1 and ODS 2, indicating elevation in inches over time from 1 to 21 hours.]

- ODS 1 IRI: 209.23 (in/mi)
- ODS 2 IRI: 222.39 (in/mi)
- Average Speed: 10.77 mph
- Distance: 0000+00.000 to 0022+55.358 [2255.36 ft.]
Urban Influences

• Factors Influencing **IRI Values** on Urban Roadways
  – Drainage Infrastructure
    • Cross Pans
    • Inlets
  – Utility Access Panels
    • Manhole Covers
    • Traffic Signal Panels
  – Cross Street
    • Cross-Crown Effect
    • Cross-Street Rutting
  – Other Infrastructure
    • Railroad Tracks
Urban Influences

• 2 Options to Account for Urban Influences
  – Adjustment Factors
    • Blanking Bands (Surface Roughness)
    • Appurtenances (Manholes, Train Tracks, etc.)
    • Intersection (Cross-crown)
  – Establish Unique Urban IRI Threshold Values
“Urban Considerations for Using Road Roughness to Manage Road Networks” (Reggin, Et. Al, 2008)

Network $IRI = \frac{(IRI)(L) - (1.5 \frac{m}{km})(d)(n)}{(L)}$

Where:

$IRI = \text{International Roughness Index (m/km)}$
$L = \text{Length of Segment (km)}$
$d = \text{Average Length of Railroad Crossings (km)}$
$n = \text{Number of Railroad Crossings in Segment}$
Adjustment Factors
Approach

- Infrastructure Influence
  - Elimination of Cross Street Access
  - Elimination of Manhole Covers
  - Test Site Improvement: 13%

- Ignore Function in Profiler Software
• High Pass Filter for Reducing Cross Street Impact
  – Default Setting: 0.00 ft
  – Test Setting: 70.0 ft (average cross street intersection width)
  – Average Improvement of 4-6%

• Start/Stop Condition Control For Short Segment Lengths
  – Remove First/Last 20 ft of Test Run
  – Average Improvement of 2-3%
Urban Influences

- 2 Options to Account for Urban Influences
  - Adjustment Factors
  - Establish Unique Urban IRI Threshold Values
Recommended Threshold Values

FHWA Recommended IRI Threshold Values for Highways & Rural Roadways:

- **GOOD** < 95 in/mi
- **ACCEPTABLE** < 170 in/mi
- **UNACCEPTABLE** ≥ 170 in/mi

Project Recommended IRI Threshold Values for Urban Roadways in the CCD:

- **GOOD** < 150 in/mi
- **ACCEPTABLE** < 220 in/mi
- **UNACCEPTABLE** ≥ 220 in/mi
Case Study: Denver Profiling

- Equipment
- Repeatability Study
- Before and After Repaving
  - % Improvement
  - By Pavement Treatment
  - Established UIRI Threshold Value
- Contract Specifications
  - DTC Blvd
  - Martin Luther King Parkway
Case Study: Denver Profiling

- Low Speed Pavement Profiler
  - Laser Inertial Surface Analyzer (LISA) 6500 Pavement Profiler by Ames Engineering
  - Dual Laser Track
- Lead & Lag Vehicle For Safety
- Four-Person Data Collection Teams (3 drivers, 1 operator)
Project Scope

• Test Sites Spanned 66.9 Lane Miles in the CCD (134 segments)
  – 55.4 mi of **Before Repaving** Condition (79 segments)
  – 39.3 mi of **After Repaving** Condition (55 segments)
  – 27.15 mi of **Both Before & After** Condition (33 segments)
  – Average Segment Length: 0.69 mi
Repeatability Study

- Minimum of Two Drivers Used on All Data Collection Runs in All Directions
- Examination of Two Data Collection Sites for Repeatability
  - Five Profiler Drivers' Results were Examined; Percent Difference Values Were Derived and Averaged:

<table>
<thead>
<tr>
<th>Track</th>
<th>Average IRI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(in/mi)</td>
</tr>
<tr>
<td>ODS1</td>
<td>232.50</td>
</tr>
<tr>
<td>ODS2</td>
<td>247.00</td>
</tr>
<tr>
<td>AVG</td>
<td>237.42</td>
</tr>
<tr>
<td>ODS1</td>
<td>154.33</td>
</tr>
<tr>
<td>ODS2</td>
<td>200.69</td>
</tr>
<tr>
<td>AVG</td>
<td>182.57</td>
</tr>
<tr>
<td>ODS1</td>
<td>231.67</td>
</tr>
<tr>
<td>ODS2</td>
<td>236.48</td>
</tr>
<tr>
<td>AVG</td>
<td>234.08</td>
</tr>
<tr>
<td>ODS1</td>
<td>227.62</td>
</tr>
<tr>
<td>ODS2</td>
<td>242.11</td>
</tr>
<tr>
<td>AVG</td>
<td>234.87</td>
</tr>
<tr>
<td>ODS1</td>
<td>219.06</td>
</tr>
<tr>
<td>ODS2</td>
<td>260.11</td>
</tr>
<tr>
<td>AVG</td>
<td>239.59</td>
</tr>
<tr>
<td>ODS1</td>
<td>227.62</td>
</tr>
<tr>
<td>ODS2</td>
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<tr>
<td>ODS2</td>
<td>260.11</td>
</tr>
<tr>
<td>AVG</td>
<td>239.59</td>
</tr>
</tbody>
</table>

- From / To: E. 8th Ave. / Steele St., Harrison St.
  - Segment Length: 0.40 mi / 0.64 km

- From / To: E. 8th Ave. / Downing St., York St.
  - Segment Length: 0.68 mi / 1.09 km
Before & After Study

• Study included 27.15 mi (33 segments) of Data Collected both Before & After Repaving
• Data Collection Planned as Close to the Repaving Date as Possible
• Infrastructure Conditions Varied Widely by Site
Before & After Study

- Average IRI Values Weighted by Segment Length:
  - Before Repaving: 375.28 in/mi (5922.97 mm/km)
  - After Repaving: 170.53 in/mi (2691.44 mm/km)
  - Percent Improvement: 36.3%
**UIRI Threshold Values**

- Before & After Data In FHWA Threshold Standards:

<table>
<thead>
<tr>
<th></th>
<th>Pre-Repair</th>
<th>Post-Repair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Acceptable</td>
<td>0</td>
<td>55.14%</td>
</tr>
<tr>
<td>Not Acceptable</td>
<td>100%</td>
<td>44.86%</td>
</tr>
</tbody>
</table>

- Before & After Data In New UIRI Threshold Standards:

<table>
<thead>
<tr>
<th></th>
<th>Pre-Repair</th>
<th>Post-Repair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>0</td>
<td>31.64%</td>
</tr>
<tr>
<td>Acceptable</td>
<td>8.84%</td>
<td>61.62%</td>
</tr>
<tr>
<td>Not Acceptable</td>
<td>91.16%</td>
<td>6.74%</td>
</tr>
</tbody>
</table>

**URBAN ROADWAYS**

- **GOOD** < 150 in/mi
- **ACCEPTABLE** < 220 in/mi
- **UNACCEPTABLE** ≥ 220 in/mi

**Average Pre-Repair IRI:**

- 325.28 in/mi

**Average Post-Repair IRI:**

- 170.53 in/mi
Repaving Methods Used

• Mill & Overlay (M&O)
  – Road is milled (up to a depth of 3 in.)
  – New asphalt is placed atop milled surface.

• Hot In Place Recycling (HIPR)
  – Outer edges of the street are milled (up to 1.5 in.)
  – Existing pavement is heated and scarified
  – Mix of new asphalt, existing asphalt and reconstituting agent is placed.

• Complete Reconstruction
  – Complete removal of existing asphalt
  – Placement of new asphalt
• Total After Repaving Condition Sites Include 39.3 mi (55 segments)
  – M&O: 27.61 mi (39 segments)
  – HIPR: 9.16 mi (8 segments)
  – Reconstruct: 4.12 mi (8 segments)
• Before & After Repaving Condition Sites Include 27.15 mi (33 segments)
  – M&O: 16.71 mi (21 segments)
  – HIPR: 9.16 mi (8 segments)
  – Reconstruct: 1.28 mi (4 segments)
Repaving Method Comparison Study

- **After Repaving Condition:**
  
<table>
<thead>
<tr>
<th>Resurfacing Method</th>
<th>Total Length Tested (mi) / (km)</th>
<th>Number of Segments Tested</th>
<th>Weighted Average IRI (in/mi) / (mm/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill &amp; Overlay</td>
<td>27.61</td>
<td>39</td>
<td>188.85 / 2980.58</td>
</tr>
<tr>
<td>HIPR</td>
<td>9.16</td>
<td>8</td>
<td>128.47 / 2027.62</td>
</tr>
<tr>
<td>Reconstruction</td>
<td>2.56</td>
<td>8</td>
<td>202.16 / 3190.65</td>
</tr>
</tbody>
</table>

- **Before & After Repaving Condition:**

<table>
<thead>
<tr>
<th>Resurfacing Method</th>
<th>Mill &amp; Overlay</th>
<th>Percentage Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before Repaving Condition</td>
<td>After Repaving Condition</td>
</tr>
<tr>
<td></td>
<td>Weighted Average IRI (in/mi) / (mm/km)</td>
<td>Weighted Average IRI (in/mi) / (mm/km)</td>
</tr>
<tr>
<td>Mill &amp; Overlay</td>
<td>26.89 / 443</td>
<td>21</td>
</tr>
<tr>
<td>HIPR</td>
<td>14.74 / 237</td>
<td>8</td>
</tr>
<tr>
<td>Reconstruction</td>
<td>2.06 / 33</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Percent Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>32.2%</td>
</tr>
<tr>
<td>46.6%</td>
</tr>
<tr>
<td>28.0%</td>
</tr>
</tbody>
</table>
Contract Specs
DTC Blvd

• DTC Blvd from I-225 to Belleview Ave
  – Approx 0.7 mi. centerline length (27,500 SY)
  – Divided Roadway
  – Concrete Pavement
  – Arterial

• 30% Improvement Contracted
NOTES:
1. ALL JOINTS SHALL FOLLOW CITY & COUNTY OF DENVER STANDARDS FOR JOINT PATTERNS.
Contract Specs
DTC Blvd
Contract Specs
DTC Blvd

• Fixing drainage
Contract Specs
DTC Blvd

- Full Panel Replacement
Contract Specs
DTC Blvd

• Patching
Contract Specs
DTC Blvd

- Sawing and Sealing
Contract Specs
DTC Blvd

- Grinding
Contract Specs
DTC Blvd

• Profiling
  – Contracted: 30% Improvement
  Achieved: 32% Improvement
Contract Specs
MLK Blvd

• Martin Luther King Blvd from Colorado Blvd to Quebec
  – Approx 2 miles
  – Divided Roadway
  – Concrete Pavement
  – Arterial

• 25% Improvement Contracted
Contract Specs
MLK Blvd
Intersection reconstruction
• Full Panel Replacement
• Partial Depth Repair
Contract Specs
MLK Blvd

- Profiling
  - Contracted: 25% Improvement
  - Achieved: 14% Improvement

- ACPA CO/WY Regional Award
- ACPA National Gold Medal Award
Conclusion
Statements

- IRI is a valuable tool
- Awareness of Influences
- Contractual Provisions
  - % Improvement
  - Target IRI
Acknowledgements

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