TRANSITION FROM MANUAL TO AUTOMATIC RUTTING MEASUREMENTS:
Effect on Pavement Serviceability Index Values

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Outline:

- Objectives and motivation of this research project
- Rutting definition and measurements
- Pavement distress surveys in New Mexico
- NMDOT’s Pavement Serviceability Index (PSI)
- State of Practice survey
- Transverse profiles and rut depth comparisons
- Statistical analyses and results
- Conclusions and recommendations
- Acknowledgements
- Contact information
Objectives of the Research Project:

- Develop and recommend a procedure for the New Mexico Department of Transportation (NMDOT) to replace rutting ratings from manual surveys with automated rut depth data.

- The recommended procedure should introduce the smallest possible error to NMDOT’s PSI values and to the overall condition ratings of the New Mexico highway network.
The motivation of NMDOT to implement this change:

- Increase the safety of distress survey crews and traveling public by eliminating the need for performing manual rut depth measurements in the roadway.
- Avoid duplication of efforts resulting from collecting rut depth data by two different methods (in manual surveys and with profilometers).
- Pavement condition data allow NMDOT to assess the overall condition of the state’s highway network.
What is rutting?

A rut is a longitudinal depression that can occur on the surface of asphalt pavements along the wheelpaths. Ruts are permanent deformations of the pavement structure.
How does NMDOT measure rutting?

NMDOT collects automated pavement roughness and rutting data annually with two K. J. Law’s Dynatest T6600 Inertial High Speed Profilometers.

- These are 3-point profilometers, with 3 infrared displacement laser sensors and 2 precision accelerometers.
- Automated rut depth data are collected at 6 in. intervals and are reported (and averaged) at 0.1 mile intervals.
- The automated rut depth data are not currently used by NMDOT.
NMDOT collects surface distress data from manual (walk) surveys along 15,500 lane miles of state-maintained pavements.

- Currently, NMDOT contracts out the distress surveys to New Mexico State University (NMSU) and the University of New Mexico (UNM).
- Test sections are 0.1 mile long located at each milepost.
- Manual distress surveys include rutting ratings.
- More than 97% of the pavements in New Mexico are flexible (asphalt) pavements.
NMDOT’s Distress Ratings for Flexible Pavements

Distresses are defects that appear on the surface of a pavement and are indicators of problems in the pavement structure and/or materials. They affect the performance of the pavement and its duration.

Distresses rated by NMDOT:

1. Raveling and weathering
2. Bleeding
3. Rutting and shoving
4. Longitudinal cracks
5. Transverse cracks
6. Alligator cracks
7. Edge cracks
8. Patching
Rutting Ratings in Manual Surveys

- Rut depth is assessed by sliding a straightedge across the wheelpaths, perpendicular to the direction of traffic.

- The rut depth is the greatest vertical distance between the 4-ft rut bar and the pavement surface in the rut.

- Severity and extent of rutting are rated and reported.

**Rut bar check:**

- Rutting along the wheelpaths

---

**Asphalt layer**

**Base layer**
Severity and Extent Ratings for Rutting in Manual Surveys

Severity rating criteria:

Rating = 0: Rut depth less than 0.25 in.
Rating = 1 (Low severity): Rut depth between 0.25 in. and 0.5 in.
Rating = 2 (Medium severity): Rut depth between 0.5 in. and 1.0 in.
Rating = 3 (High severity): Rut depth greater than 1.0 in.

Extent rating criteria:

Rating = 0: Severity rating for rutting and shoving is 0.
Rating = 1 (Low extent): From 1% to 30% of the test section.
Rating = 2 (Medium extent): From 31% to 60% of the test section.
Rating = 3 (High extent): 61% of the test section or more.
How are the pavement condition data used by NMDOT?

NMDOT computes a **Pavement Serviceability Index (PSI)** using:

1. Pavement distress ratings, including rutting, and
2. Pavement roughness, expressed as the International Roughness Index (IRI) (inches/mile).

**Distress Rate:**

\[
DR = \sum_{i=1}^{n} (\text{Severity Rating}_i \times \text{Extent Factor}_i \times \text{Weight Factor}_i) = \sum_{i=1}^{n} (\text{DR}_i)
\]

**Interim Value X:**

\[
X = 100 - \left(\frac{0.6(\text{IRI} - 25) + (0.4\text{DR})}{2.9}\right)
\]

**Pavement Serviceability Index:**

\[
\text{PSI} = 0.041666 \times X, \quad \text{if } X \leq 60
\]

\[
\text{PSI} = [0.0625(X - 60)] + 2.4999, \quad \text{if } X > 60
\]
### Factors to Calculate Pavement Serviceability Index and Distress Rate

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Weight Factor</th>
<th>Extent Rating for Rutting and Shoving</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raveling and Weathering</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bleeding</td>
<td>2</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Rutting and Shoving</td>
<td>14</td>
<td>2</td>
<td>0.8</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>20</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>Transverse Cracking</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Edge Cracking</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patching</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### NMDOT’s Pavement Serviceability Index (PSI) Ranking for New Mexico Highways

<table>
<thead>
<tr>
<th>PSI Range</th>
<th>Condition Ranking</th>
<th>Interstate Highways</th>
<th>Non-Interstate Highways</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0 ≤ PSI ≤ 5.0</td>
<td>Very Good</td>
<td>Non-deficient</td>
<td>Non-deficient</td>
</tr>
<tr>
<td>3.0 ≤ PSI &lt; 4.0</td>
<td>Good</td>
<td>Non-deficient</td>
<td>Non-deficient</td>
</tr>
<tr>
<td>2.5 ≤ PSI &lt; 3.0</td>
<td>Fair</td>
<td>Deficient</td>
<td>Non-deficient</td>
</tr>
<tr>
<td>1.0 ≤ PSI &lt; 2.5</td>
<td>Poor</td>
<td>Deficient</td>
<td>Deficient</td>
</tr>
<tr>
<td>0.0 ≤ PSI &lt; 1.0</td>
<td>Very Poor</td>
<td>Deficient</td>
<td>Deficient</td>
</tr>
</tbody>
</table>
State DOTs that participated in the survey: 22 (all responded).

All state DOTs surveyed reported collecting some type of rutting data (automated or visual/manual).

Agencies used rutting data or ratings in many different ways and levels in their pavement management systems.

No consistency was found regarding the type or definition of the pavement condition indexes used at the network level by the surveyed agencies.

Most of the performance indexes were developed for/by the agencies to meet their own standards or requirements.
Survey Results

The survey was carried out in Fall of 2008 and Spring of 2009

Rut Depth Data Collection by State DOTs

- 18% Contractor
- 27% DOT personnel
- 55% Contractor & DOT personnel

Frequency of Rut Depth Data Collection

- Entire network annually: 40%
- Selected routes annually (generally NHS) & the rest biennially (generally non-NHS): 23%
- Entire network biennially: 32%
- Every 18 months: 5%

Methods of Rut Depth Data Collection by State DOTs

- Automated only: 76%
- Manual only: 14%
- Windshield: 5%
- Automated and manual: 5%

Survey Results
Transverse Profiles: Rut Depth Measurements and Comparisons

- Four test sections, 0.1 mile long each, in NM0185
- Located at mileposts (MP) 4.0, 5.1, 6.0 and 7.1
- Transverse profiles spaced at 7.62 m (25 ft)
- A total of 88 profiles; 22 profiles per test section
- Depth measurements every 4 in. along the profiles
12-ft Straightedges were placed on the pavement across the full width of the lane and leveled horizontally.

**Transverse Profiles**

“Measuring points” along the profiles were marked on the pavement with chalk (4 in. apart)
Depths between the straightedge and the pavement surface were carefully measured with digital calipers.

Transverse Profiles

Profile 0, Test Section NM0185 P MP4.0 (May 13, 2009)
Test Section MP 4.0 - Transverse Profiles

Transverse Profiles on Test Section NM0185 P MP4.0 (May 13, 2009)

Transverse Distance (mm)

Transverse Distance (inches)

0 m (0 ft) 7.6 m (25 ft) 15.2 m (50 ft) 22.9 m (75 ft) 30.5 m (100 ft)
38.1 m (125 ft) 45.7 m (150 ft) 53.3 m (175 ft) 61 m (200 ft) 68.6 m (225 ft)
76.2 m (250 ft) 83.8 m (275 ft) 91.4 m (300 ft) 99.1 m (325 ft) 106.7 m (350 ft)
114.3 m (375 ft) 121.9 m (400 ft) 129.5 m (425 ft) 137.2 m (450 ft) 144.8 m (475 ft)
152.4 m (500 ft) 160 m (525 ft)
Transverse Profiles on Test Section NM0185 P MP5.1 (May 14, 2009)

Transverse Distance (mm)

Transverse Distance (inches)

- 0 m (0 ft)
- 7.6 m (25 ft)
- 15.2 m (50 ft)
- 22.9 m (75 ft)
- 30.5 m (100 ft)
- 38.1 m (125 ft)
- 45.7 m (150 ft)
- 53.3 m (175 ft)
- 61 m (200 ft)
- 68.6 m (225 ft)
- 76.2 m (250 ft)
- 83.8 m (275 ft)
- 91.4 m (300 ft)
- 99.1 m (325 ft)
- 106.7 m (350 ft)
- 114.3 m (375 ft)
- 121.9 m (400 ft)
- 129.5 m (425 ft)
- 137.2 m (450 ft)
- 144.8 m (475 ft)
- 152.4 m (500 ft)
- 160 m (525 ft)
Test Section MP 6.0 - Transverse Profiles

Transverse Profiles on Test Section NM0185 P MP6.0 (May 14, 2009)
Rut depth was calculated from each transverse profile (red lines).

### Test Section MP 4.0

<table>
<thead>
<tr>
<th>Profile label</th>
<th>Rut Depth</th>
</tr>
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<tbody>
<tr>
<td>(m)</td>
<td>(ft)</td>
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<tr>
<td>(mm)</td>
<td>(in.)</td>
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<td>0</td>
<td>0</td>
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<td>7.6</td>
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<td>15.2</td>
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<td>38.1</td>
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<td>45.7</td>
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<td>53.3</td>
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<td>129.5</td>
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<td>152.4</td>
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<td>160</td>
<td>525</td>
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## Comparison of Rut Depth Data, Rutting and Shoving Ratings and Profile Data

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<tr>
<td><strong>MP 4</strong></td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
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<td>2</td>
</tr>
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<td></td>
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<td></td>
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<td>-0.15</td>
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<table>
<thead>
<tr>
<th>Test Section</th>
<th>Rater B (May 2009)</th>
<th>Rater D (May 2009)</th>
<th>Overall Equivalent Rating from Transverse Profiles</th>
<th>Averaged Automated Rut Depth</th>
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<tbody>
<tr>
<td></td>
<td>Sev.</td>
<td>Ext.</td>
<td>Sev.</td>
<td>(in.)</td>
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<tr>
<td><strong>MP 5.1</strong></td>
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<td>3</td>
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<td>(in.)</td>
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<td></td>
<td></td>
<td></td>
<td>2</td>
<td>(in.)</td>
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<td>(in.)</td>
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<td>2007</td>
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<td></td>
<td>1</td>
<td>1.0</td>
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</table>
## Comparison of Rut Depth Data, Rutting and Shoving Ratings and Profile Data

<table>
<thead>
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</thead>
<tbody>
<tr>
<td>MP 6</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test Section</th>
<th>Rater C (May 2009)</th>
<th>Rater D (May 2009)</th>
<th>Overall Equivalent Rating from Transverse Profiles</th>
<th>Averaged Automated Rut Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>MP 7.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Challenges of this Research

- Distress ratings from manual surveys and automated rut depth are very different types of data.
- Very large number of data available for the analyses.
- Quality and format of NMDOT data varied significantly throughout the years.
- Available documentation and details of current formulation and factors of performance indexes were limited.
Statistical Analysis – This Research

- Statistical analyses were carried out in terms of PSI.
- Analyses used NMDOT’s historic PSI and IRI data, automated rut depth data, and distress ratings.
- Three approaches were evaluated:
  1. Modify the interim value $X$ used to calculate PSI.
  2. Modify the extent factors and/or the weight factor for rutting in the total distress rate (DR).
  3. Convert automated rut depth data into equivalent severity and extent ratings for rutting, and maintain the current formulation unchanged.
Recommended Approach (Approach A)

- It preserves the current PSI formulation and the equation of the interim X value.

- The values of the Extent Rating Factors and Weight Factor $W_{Rut} (= 14)$ remained unchanged.

- “Equivalent” severity and extent ratings were estimated from the automated rut depth data for the entire length of each section.
### Criteria to Convert Automated Rut Depth into Equivalent Severity and Extent Ratings

<table>
<thead>
<tr>
<th>Rating</th>
<th>Criteria</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Severity (Modified Criteria)</td>
<td>Extent (NMDOT’s criteria)</td>
</tr>
<tr>
<td>0</td>
<td>Rut depth less than 0.20 in.</td>
<td>Severity rating is 0</td>
</tr>
<tr>
<td>1</td>
<td>Rut depth between 0.20 in. and 0.28 in.</td>
<td>From 1% to 30% of the test section</td>
</tr>
<tr>
<td>2</td>
<td>Rut depth between 0.28 in. and 0.36 in.</td>
<td>From 31% to 60% of the test section</td>
</tr>
<tr>
<td>3</td>
<td>Rut depth greater than 0.36 in.</td>
<td>61% or more of the test section</td>
</tr>
</tbody>
</table>
Recommended Approach A

- 2006-2009 Data
- 18,114 Sections

**Statistical indicators:**
- \( \text{SSE} = 86 \) \( R^2 = 0.993 \)
- \( t = 1.917 \) \( S_p^2 = 0.664 \)

**Mean values of the sets:**
- \( \text{PSI}_{\text{Man.Rut}} = 3.594 \)
- \( \text{PSI}_{\text{Auto.Rut}} = 3.610 \)

**Data comparisons:**
- 30.8% \( \text{PSI}_{\text{Man.Rut}} > \text{PSI}_{\text{Auto.Rut}} \)
- 10.1% \( \text{PSI}_{\text{Man.Rut}} < \text{PSI}_{\text{Auto.Rut}} \)
- 59.2% \( \text{PSI}_{\text{Man.Rut}} = \text{PSI}_{\text{Auto.Rut}} \)

SSE: Sum of square residuals
\( R^2 \): Coefficient of determination
\( t \): t-Test value
\( S_p^2 \): Pooled sample variance
Recommended Approach A

Evaluating the Results - Condition Ranking:

- 813 Sections (4.49%) would have been rated, based on their PSI, in a pavement condition level that was either higher or lower than the one in which they would have been ranked with the current formula and manual ratings were used.

- Of these 813 sections, 209 sections (25.7%) fell in a higher (better) condition level; 604 sections (74.3%) fell in a lower (worse) condition level. The rest of the sections (17,301 or 95.51%) were rated in the same condition level.
The interim X value to calculate PSI was modified to:

\[
X = 100 - \left[ 0.6 \frac{(IRI - 25) + (0.4 \cdot DR)}{2.9} + k_1 \exp^{k_2 (Auto.Rut)} \right]
\]

\[k_1 = 0.73311 \quad k_2 = -2.80284\]

Distress Rate (DR) is calculated with the other 7 distresses.
**Alternative Approach B**

- **2003-2009 Data**
- **27,453 Sections**

**Statistical indicators:**
- $\text{SSE} = 120 \quad R^2 = 0.994$
- $t = 0.293 \quad S_p^2 = 0.699$

**Mean values of the sets:**
- $\text{PSI}_{\text{Man.Rut}} = 3.496$
- $\text{PSI}_{\text{Auto.Rut}} = 3.488$

**Data comparisons:**
- $61.6\% \ \text{PSI}_{\text{Man.Rut}} > \ \text{PSI}_{\text{Auto.Rut}}$
- $38.4\% \ \text{PSI}_{\text{Man.Rut}} \leq \ \text{PSI}_{\text{Auto.Rut}}$
Alternative Approach B

Evaluating the Results - Condition Ranking:

- 1,594 Sections (5.8%) would have been rated, based on their PSI, in a pavement condition level that was either higher or lower than the one in which they would have been ranked with the current formula and manual ratings were used.

- Of these 1,594 sections, 919 sections (58%) fell in a higher (better) condition level; 675 sections (42%) fell in a lower (worse) condition level. The rest of the sections (25,859 or 94.2%) were rated in the same condition level.
Conclusions

1. The transverse profiles confirmed that rutting ratings from manual surveys are in very good agreement with the actual rutting in the test sections. However, the automated rut depth data were not consistent with the transverse profiles.

2. The automated rut depth data showed a tendency to underestimate the actual rut depth. The reason of the large percentage of “negative” rut depth data (interpreted as “no rutting”) should be investigated further.
3. The **Recommended Approach** does not require modifications of the current PSI formulation and can be implemented relatively easily. It converts the automated rut depth into equivalent ratings of severity and extent of rutting.

4. The implementation of **Alternative Approach B** is also feasible, but it would require modifications of the PSI formulation in TIMS.
Recommendations

1. Perform systematic quality control checks, including rut bar checks, and calibration of the NMDOT-owned 3-point profilometers in an annual basis.

2. As new data become available, evaluate the performance of the proposed approaches and rating criteria, and adjust or refine them as necessary.

3. Assess if (and how much) the implemented changes will affect the overall condition rankings of the NM highway network (based on PSI) in the medium term (for example, two cycles following the implementation).
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