User perceptions of highway roughness

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Background

- States invest millions of dollars annually measuring the physical condition of their highways.
- Such measurements are used to allocate resources for repair and reconstruction.
  - Are the correct factors being measured?
  - How do physical measurements correspond to public perceptions?
Factors usually measured:

- Rutting
- Faulting
- Cracking
- Patching
- Spalling
Rutting
(surface deflection in wheel path):
Alligator (fatigue) Cracking:
Slippage Cracking:
Traverse Thermal Cracking:
Patching:
Spalling:
Faulting:
International Roughness Index (IRI)

- Widely accepted measure of pavement condition
- IRI procedures were developed by the World Bank in Brazil
- Measures suspension movement over some longitudinal distance (in/mi)
- IRI correlates with vertical passenger acceleration and tire load
International Roughness Index (IRI)
IRI and pavement quality

- **Very good** (<60 in/mi),
- **Good** (61-94 in/mi),
- **Fair** (95-119 in/mi for Interstates, 95-170 in/mi for other roads),
- **Mediocre** (120-170 in/mi for Interstates, 171-220 in/mi for other roads) and
- **Poor** (>170 in/mi for Interstates, >220 in/mi for other roads)
Present Serviceability Index (PSI) and IRI

- **Excellent** (4.1– 5.0) ~ (IRI<60 in/mi),
- **Good** (3.1– 4.0) ~ (61-94 in/mi),
- **Fair** (2.1– 3.0) ~ (95-170 in/mi for Interstates, 95-220 in/mi for other roads),
- **Poor** (1.1– 2.0) ~ (>170 in/mi for Interstates, >220 in/mi for other roads)
- **Very Poor** (0 – 1.0)
PSI in pavement design
PSI in pavement design

- Initial and terminal PSI used in pavement design equations
- Terminal PSI is critical in determining Load Equivalency Factors to get $W_{18}$
PSI in pavement design

- **Flexible pavements:**

\[
\log_{10} W_{18} = Z_R S_o + 9.36 \left[ \log_{10} (SN + 1) \right] - 0.20 + \frac{\log_{10} [\Delta PSI / 2.7]}{0.40 + \left[ 1094 / (SN + 1)^{5.19} \right]} + 2.32 \log_{10} M_R - 8.07
\]

- **Rigid pavements**

\[
\log_{10} W_{18} = Z_R S_o + 7.35 \left[ \log_{10} (D + 1) \right] - 0.06 + \frac{\log_{10} [\Delta PSI / 3.0]}{1 + \left[ 1.624 \times 10^7 / (D + 1)^{8.46} \right]} + (4.22 - 0.32 TSI) \log_{10} \left( \frac{S'_c C_d [D^{0.75} - 1.132]}{215.63 J [D^{0.75} - \left[ 18.42 / (E_c / k)^{0.25} \right]}} \right)
\]
Study Motivation

- To determine how user perceptions of pavement roughness (the intent of PSI) relate to the IRI and other factors
What makes a road feel rough?
Factors likely to determine roughness opinion

- Socioeconomic (age, income, etc.)
- Type of vehicle driven
- Interior noise level
- Passenger expectations when driving from one pavement condition to the next
- Physical measures of pavement condition
Study approach:

- Have 56 individuals drive a variety of vehicles (mid-sized sedan, sport-utility vehicle, pick-up truck, minivan)

- Individuals drive over a circuit of Seattle freeways that includes 40 segments with detailed data from pavement databases (IRI, Pavement structural condition, patching, pavement type, etc.)
Study approach (continued):

- In addition to physical pavement measurements, on the 40 sections data are collected on:
  - 1 (smooth) to 5 (rough) scale of roughness impression
  - Interior vehicle noise
  - Vehicle speed
  - Weather conditions
  - Pavement surface (wet or dry)
Ratings of roadway roughness on a scale from one to five – with one being the smoothest and five being the roughest.

Use an ordered probit model. Define an unobserved variable $z$ for each observation $n$

$$z_n = \beta X_n + \epsilon_n$$

where:

- $X$ is a vector of variables determining the discrete ordering for observation $n$,
- $\beta$ is a vector of estimable coefficients, and
- $\epsilon$ is a random disturbance.
Observed ordinal data are defined:

\[ y_n = 1 \quad if \quad z_n \leq \mu_0 \]
\[ = 2 \quad if \quad \mu_0 < z_n \leq \mu_1 \]
\[ = 3 \quad if \quad \mu_1 < z_n \leq \mu_2 \]
\[ = 4 \quad if \quad \mu_2 < z_n \leq \mu_3 \]
\[ = 5 \quad if \quad z_n > \mu_3 \]

where:

\( \mu \)'s are estimable thresholds that define \( y_n \)
Figure 14.1: Illustration of an ordered probability model with $\mu_0 = 0$. 
Figure 14.2: Illustration of an ordered probability models with an increase in $\beta X$ (with $\mu_0 = 0$).
Random effects:

- To account for repeat observations (56 subjects) (40 opinions for each person) a random effects model is used:

  \[ z_{ic} = \beta X_{ic} + \epsilon_{ic} + \varphi_i \]

- Where:

  \( I \) denotes an individual (1 to 56);
  \( c \) denotes roadway segments (1 to 40) and,
  \( \varphi_i \) is an individual specific error term that is normally distributed.
General results (midsized vehicle)

Measured IRI (in/mi)

Percent of Observations

- Rank 5 (Rough)
- Rank 4
- Rank 3
- Rank 2
- Rank 1 (Smooth)

Poor (170in/mi)
General results (SUV)

Measured IRI (in/mi)

Percent of Observations

Rank 5 (Rough)
Rank 4
Rank 3
Rank 2
Rank 1 (Smooth)

Poor (170in/mi)
General results (pickup truck)

Measured IRI (in/mi)

Percent of Observations

Rank 5 (Rough)
Rank 4
Rank 3
Rank 2
Rank 1 (Smooth)

Poor (170in/mi)
General results (minivan)

Poor (170 in/mi)
Summary data:

- Percent of male/female respondents: 64.5/35.5
- Avg. household size: 2.7
- Average household annual income category (US dollars): 55,000 – 64,999
- Avg. respondent age category (years): 41 – 45
Summary data (continued):

- Avg. test segment IRI measurement (in/mi) 122.75 (fair/mediocre)
- Avg. roadway segment surface age (years) 17.43
- Pavement structural condition (PSC) index of roadway 90.78
- Percent of segments by surface type: rigid/flexible 35.1/64.9
Interpretation of results: Marginal effects

- Marginal effects give the change in category probabilities (1=smooth, 2, 3, 4, 5=rough) resulting from a one unit change in the variable.

- Obtained by integrating the probability density function.
Figure 14.2: Illustration of an ordered probability models with an increase in $\beta X$ (with $\mu_0 = 0$).
**Results: Socioeconomics**
*(1=smooth, 5=rough)*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Marginal Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[ ( y = 1 ) ]</td>
</tr>
<tr>
<td>Gender indicator</td>
<td></td>
</tr>
<tr>
<td>(1 if participant was female,</td>
<td>0.0451</td>
</tr>
<tr>
<td>0 if male)</td>
<td></td>
</tr>
<tr>
<td>Older age indicator</td>
<td></td>
</tr>
<tr>
<td>(1 if participant was over age</td>
<td>0.0620</td>
</tr>
<tr>
<td>55, 0 otherwise)</td>
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</tbody>
</table>
## Results: Pavement condition (1=smooth, 5=rough)

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( y = 1 )</td>
</tr>
<tr>
<td>IRI measurement (in/mi) of roadway segment</td>
<td>-0.0008</td>
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<tr>
<td>Age of roadway segment surface (years)</td>
<td>-0.0017</td>
</tr>
<tr>
<td>Patch indicator (1 if the segment appeared to have patch work, 0 otherwise)</td>
<td>-0.0363</td>
</tr>
<tr>
<td>Pavement structural condition (PSC)</td>
<td>0.0017</td>
</tr>
</tbody>
</table>
## Results: Vehicle

**(1=smooth, 5=rough)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Marginal Effects</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>[ y = 1 ]</td>
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<tr>
<td>Noise (dB) inside test vehicle during evaluation</td>
<td>-0.0085</td>
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<tr>
<td>Noise increase indicator</td>
<td>-0.0410</td>
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<tr>
<td>(1 if the noise inside test vehicle during evaluation increases by 3 dB or more between two adjacent test segments, 0 otherwise)</td>
<td></td>
</tr>
<tr>
<td>Speed (km/h) of test vehicle during evaluation</td>
<td>0.0011</td>
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</tbody>
</table>
## Results: Vehicle (continued)
*(1=smooth, 5=rough)*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Marginal Effects</th>
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</thead>
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<tr>
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<td>( y = 1 )</td>
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<tr>
<td>Sport-utility test vehicle indicator</td>
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<tr>
<td>(1 if sport utility was test vehicle type, 0 otherwise)</td>
<td>0.0530</td>
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<tr>
<td>Minivan test vehicle indicator</td>
<td>0.0530</td>
</tr>
<tr>
<td>(1 if minivan was test vehicle type, 0 otherwise)</td>
<td>0.0530</td>
</tr>
</tbody>
</table>
Summary

- Physical measurements of the pavement are correlated to public perceptions, but many other factors are significant.
- Must consider more than IRI in determining pavement condition.