NEW INDICATORS OF RIDING COMFORT BASED ON VEHICLE DYNAMICS

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CONTENT

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• Methods
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BACKGROUND & PROBLEM

• Longitudinal unevenness of a road is one of key condition variables included in the Finnish RAMS since late 1980’s

• IRI (International Roughness Index) calculated into 100 m intervals has been the index representing the longitudinal unevenness

• Many studies propose that IRI is not the best index concerning riding comfort (Loizos 2007, Kim et a. 2011, Nair et al 2011, Múčka et al 2016)

• The practical experiences in the Finnish Transport Agency support those statements.
  1. Rutting (60%)
  2. Cracks (30%)
  3. IRI (10%)
BACKGROUND & PROBLEM

• Typical statements have been that
  • it does not represent the riding comfort of pavements well enough and
  • it cannot show where the bad sections locate or
  • what the type of roughness is.

• A need/wish to a better index exists.
METHODS

• Root Cause Analysis
  • What could be the problem?

• Improving indexes (Simulations)
  • Improving the simulation model by increasing the DOF of the model and calculating new indexes

• Validation of results (MPR & ROC)
  • Analysing the goodness of an index by comparing the simulated outcomes to information from Mean Panel Rating

• Recommending better indicators if any to represent the riding comfort on a road
ROOT CAUSE ANALYSIS

A. Road:
1. Road is represented by one longitudinal profile only.
2. The wavelength of longitudinal profile data is filtered to cover wavelengths between 0.5 and 50 m.
3. Simulated using a constant speed 80 km/h.

B. Model:
1. Quarter car model can handle only one dimension of movement.
2. Different suspension parameters than a typical European or Japanese car or a truck.
3. The suspension system of the driver’s seat is not included in the quarter car simulation model.
ROOT CAUSE ANALYSIS

C. Outcome:

1. IRI represents the vertical movement of a car chassis which is not the best source for searching factors causing discomfort. ISO 2631 uses vertical accelerations.

2. The reporting interval of 100 m is too long to locate poor road sections accurately.

3. It also averages the outcome too much and important transients in roughness cannot be recognized.
**IMPROVEMENTS**

<table>
<thead>
<tr>
<th>Source data</th>
<th>Model</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1, A2</td>
<td>80</td>
<td>IRI</td>
</tr>
<tr>
<td>60, 80</td>
<td>100, 120</td>
<td>B1</td>
</tr>
<tr>
<td>C1, C2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Source data: A1, A2, 60, 80, 100, 120
- Model: 80
- Outcome: IRI

**Source data**

- A1, A2
- 60, 80
- 100, 120

**Model**

- 80

**Outcome**

- IRI

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**European Road Profile User’s Group, ERPU, Madrid, Spain 18-19 October 2018**
## LOTS OF OUTCOMES

### Table 2. Indexes

<table>
<thead>
<tr>
<th>Type of displacement</th>
<th>Displacement</th>
<th>Velocity</th>
<th>Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bounce of body</td>
<td>mean, std, max</td>
<td>mean, std, max</td>
<td>mean, std, max</td>
</tr>
<tr>
<td>Roll of body</td>
<td>mean, std, max</td>
<td>mean, std, max</td>
<td>mean, std, max</td>
</tr>
<tr>
<td>Pitch of body</td>
<td>mean, std, max</td>
<td>mean, std, max</td>
<td>mean, std, max</td>
</tr>
<tr>
<td>Combined acceleration of seat including bounce, roll and pitch</td>
<td></td>
<td></td>
<td>rms, std, max</td>
</tr>
<tr>
<td>ESAL (Equivalent Standard Axle Load)</td>
<td>mean, std, max</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LTR (Load Transfer Ratio)</td>
<td>mean, std, max</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy used in shocks (J/10m)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
METHODS – SIMULATIONS – MPR - VALIDATION

<table>
<thead>
<tr>
<th>Road/section</th>
<th>Number</th>
<th>Class</th>
<th>Speed limit</th>
<th>Length m</th>
</tr>
</thead>
<tbody>
<tr>
<td>vt 1 sec 6</td>
<td>1</td>
<td>Main</td>
<td>120</td>
<td>4909</td>
</tr>
<tr>
<td>vt 1 sec 7</td>
<td>2</td>
<td>Main</td>
<td>120</td>
<td>7229</td>
</tr>
<tr>
<td>vt 1 sec 8</td>
<td>3</td>
<td>Main</td>
<td>120</td>
<td>5150</td>
</tr>
<tr>
<td>vt2 sec 1</td>
<td>4</td>
<td>Main</td>
<td>120</td>
<td>3953</td>
</tr>
<tr>
<td>vt2 sec 2</td>
<td>5</td>
<td>Main</td>
<td>100/80</td>
<td>2186</td>
</tr>
<tr>
<td>vt 25 sec 24</td>
<td>6</td>
<td>Main</td>
<td>80</td>
<td>4505</td>
</tr>
<tr>
<td>vt 25 sec 25</td>
<td>7</td>
<td>Vantaa</td>
<td>80</td>
<td>4788</td>
</tr>
<tr>
<td>mt 120 sec 7</td>
<td>8</td>
<td>Secondary</td>
<td>60</td>
<td>5363</td>
</tr>
<tr>
<td>mt 120 sec 6</td>
<td>9</td>
<td>Secondary</td>
<td>60</td>
<td>7727</td>
</tr>
<tr>
<td>mt 120 sec 5</td>
<td>10</td>
<td>Secondary</td>
<td>60</td>
<td>2318</td>
</tr>
<tr>
<td>yt 11337 sec 2</td>
<td>11</td>
<td>Local</td>
<td>50</td>
<td>6692</td>
</tr>
<tr>
<td>yt 11337 sec 1</td>
<td>12</td>
<td>Local</td>
<td>50</td>
<td>6544</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>61364</td>
</tr>
</tbody>
</table>
Mean Panel Rating
- 11 passengers in a car one by one
- 9 passengers in a truck one by one

Car
- The average number of bad sections varied according to the site from 1 to 14.

Truck
- The average number of bad sections varied according to the site from 2 to 21.
- Raters in truck gave 60% more bad (uncomfortable) sections than raters in car.
VALIDATION – GRAPHICAL SELECTION

Road VT 1/007 Probability of discomfort based on MPR

Distance (m)

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

2000 2500 3000 3500 4000 4500 5000 5500 6000 6500 7000

- Truck panel
- Car panel
Preliminary selection of indicators according to graphs

- Best indicators were selected as bounce, roll and pitch, comb acc
- Best statistical indicators were selected as std of accelerations
VALIDATION – GRAPHICAL SELECTION

Road 1 section 7, STD of vertical acceleration

Distance (m)

0 10 20 30 40 50 60 70 80

0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6

m/s²/10m

KA 90 km/h
Truck panel

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Receiver operating characteristic curve, i.e. ROC-curve,

- Is a graphical plot that illustrates the diagnostic ability of a binary classifier system as its discrimination threshold is varied
- Horizontal axis = true positive
- Vertical axis = true negative
- Curves produced by varying threshold values from min to max
- Area under curve => goodness of indicator
  - Minimize distance from upper right corner

Goodness of indexes on Road 25

Correct not uncomfortable
Minimize

Maximize this area
Random classifier worthless

True positive (correct uncomfortable)
**ROC-CURVES – BEST INDEXES**

<table>
<thead>
<tr>
<th>Road</th>
<th>VERT_A_STD</th>
<th>ROLL_A_STD</th>
<th>PITCH_A_STD</th>
<th>COMB_A_RMS</th>
<th>COM_A_STD</th>
<th>IRI_10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>25</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>120</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>11337</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Average</td>
<td>4.4</td>
<td>4</td>
<td>3.8</td>
<td>1.2</td>
<td>2</td>
<td>5.6</td>
</tr>
</tbody>
</table>
• The riding comfort was rated **more critically in a truck** (than in a car).
• The best indexes able to distinguish “poor” sections from “not poor” sections were **RMS** and **STD** of combined acceleration.
• The STD of **vertical** acceleration, **roll** acceleration, and **pitch** acceleration (for a 10 m section) were also good indexes and additionally they gave information about what type of roughness caused the discomfort.
• The indexes worked best for high standard roads.
  • For a low standard poor condition road it didn’t matter so much what index was used.
• The IRI-index was the worst among selected 6 indexes to distinguish “poor” sections from “not poor” sections.
CONCLUSIONS

• High speed monitoring produces **3D data** of the road pavement which is not very effectively used in IRI-model.

• **Full car model** uses 3D data and gives more information of the driving comfort on a road than IRI.

• Riding comfort is lower in a **truck** than in a car.

• Simulated **accelerations** correlate better with the riding comfort than simulated displacements do.

• Simulated **variation of acceleration** or RMS (on a 10 m section) locate the mileposts in poor condition better than simulated averages do.

• Simulation speeds should be taken from **actual speed limits**.
FURTHER ACTIONS

• New indexes are calculated and added to the data delivered from high speed monitoring.
  • IRI + RIDE-sim. (RIDE definition available)
  • Truck:
    • STD’s of vertical accelerations, roll accelerations, pitch accelerations
    • STD & RMS of combined accelerations (ISO 2631)
    • STD of ESALS & LTR,
    • Energy used in shock absorbers
  • Car:
    • Energy used in shock absorbers
• Several field surveys give promising results
  • Classification of indexes ongoing