Dependency of Coefficient of Rolling Resistance on Pavement Surface Characteristics

Richard Sohaney, The Transtec Group
Bernard Izevbekhai, MnDOT

19 September 2013

Acknowledgements

- Transportation Pooled Fund TP-5(134)
  - Minnesota Department of Transportation
  - Texas Department of Transportation
  - Federal Highway Administration
    - Robert Orthmeyer

What is Rolling Resistance?

- The non-inertial, non-aerodynamic, and non-skidding resistance to the interaction of vehicular tire with the road surface.

Rolling resistance

Rolling direction

Percentage of Total Resistance

	Very Low Speeds	90 km/h	120 km/h
Inertial Resistance	41	–	–
Air Resistance	13	63	75
Rolling Resistance	46	37	25

[Silka W.: Energochłonność ruchu samochodu, Warszawa, WKŁ 1997]

Rolling Resistance and Fuel Consumption

- Car at 100 km/h: expends ~50% fuel to overcome RR.
- Truck at 80km/h: expends ~40% of fuel to overcome RR.
- Overall vehicle average: ~25% of fuel consumption is expended on RR.
- 10% decrease in RR results in a 2 to 3% reduction in fuel consumption.

Why Care about Rolling Resistance

- Effect of a 10% decrease in RR:
  - Energy savings –
    - 2 to 3% reduction in fuel consumption.
    - Up to $12.5 billion fuel cost savings per year.
  - Reduced emissions
    - 250,000,000 vehicles (USA)
    - CO_2 emissions reduced by 100,000 tons per day.

Objectives of this Study

- Investigate pavement surface characteristics that influence rolling resistance.

Method

- Use **test** data from MnROAD.
  - Rolling resistance study in 2011.
  - Surface characteristic data on MnROAD test cells.
- Multi-variable linear regression analyses.

Rolling Resistance Test Trailer

- One-ton
- Test tire enclosed.
- Variable load.
- Compensates for pavement smoothness and other factors.

Jerzy Ejsmont, Technical University of Gdańsk (TUG), Poland

Principle of Operation

1-frame

2-loading system

3-axis of frame and loading device

4-measuring arm

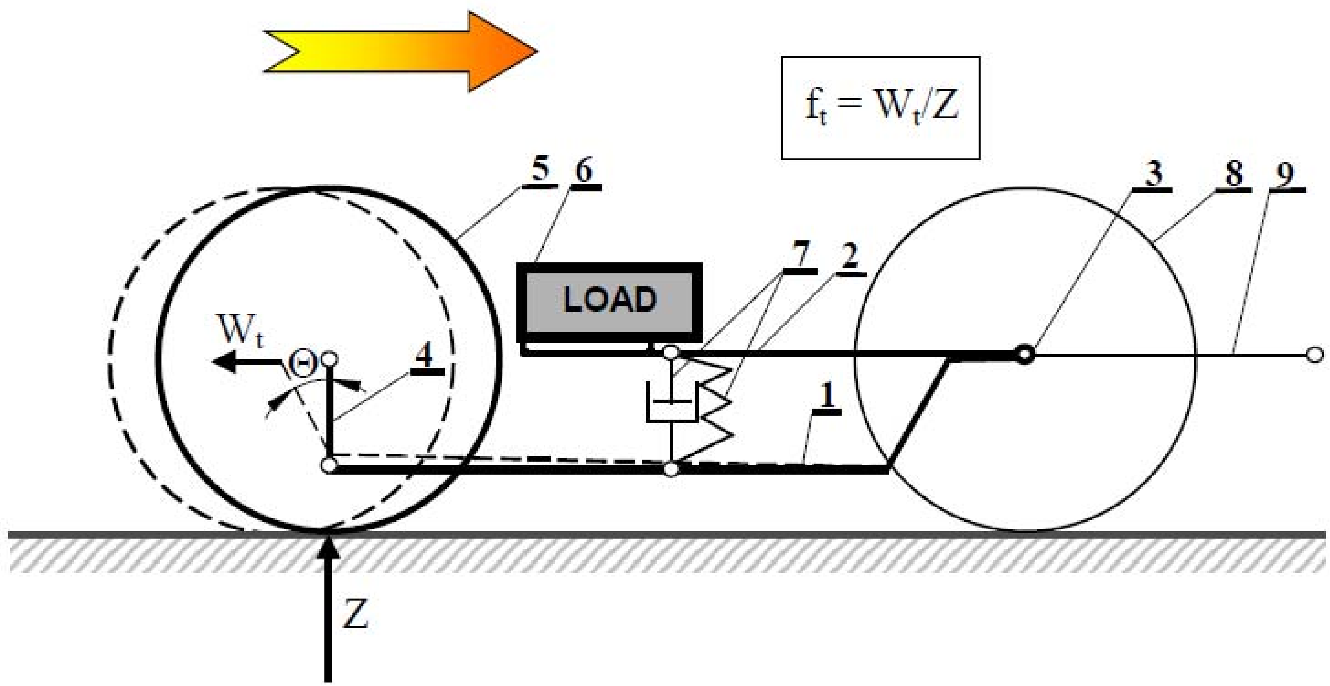
5-test wheel

6-adjustable load

7-damper and spring

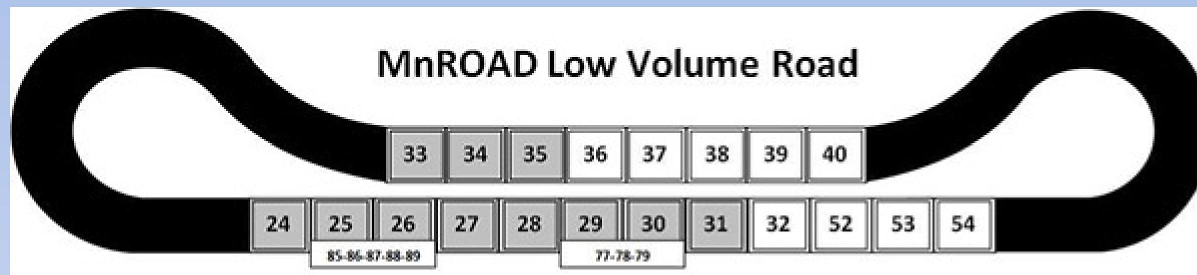
8-front wheels

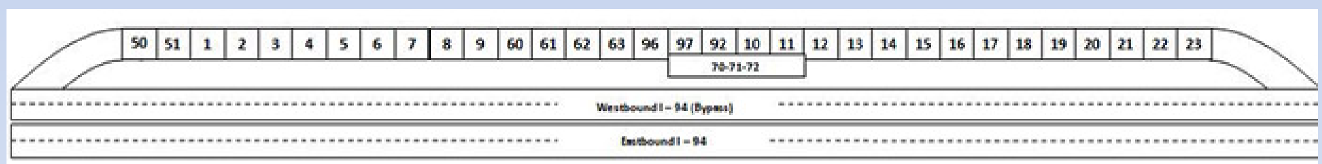
9-tow hitch



MnROAD Test Cells

- Two roads
  - 54 test cells
  - Two lanes in each cell
  - 108 data points





MnROAD Mainline

MnROAD Pavements

- Asphalt
  - Ultra thin bonded wearing course
  - Chip seal
  - 4.75 mm taconite
  - 12.5 mm dense-graded superpave
  - Porous HMA
  - Dense-grade plug fog seal
- PCC
  - Transverse and longitudinal tine
  - Broom drag
  - Artificial turf drag
  - Conventional diamond grind
  - Ultimate diamond grind
  - Innovative diamond grind
  - Pervious
  - Exposed aggregate

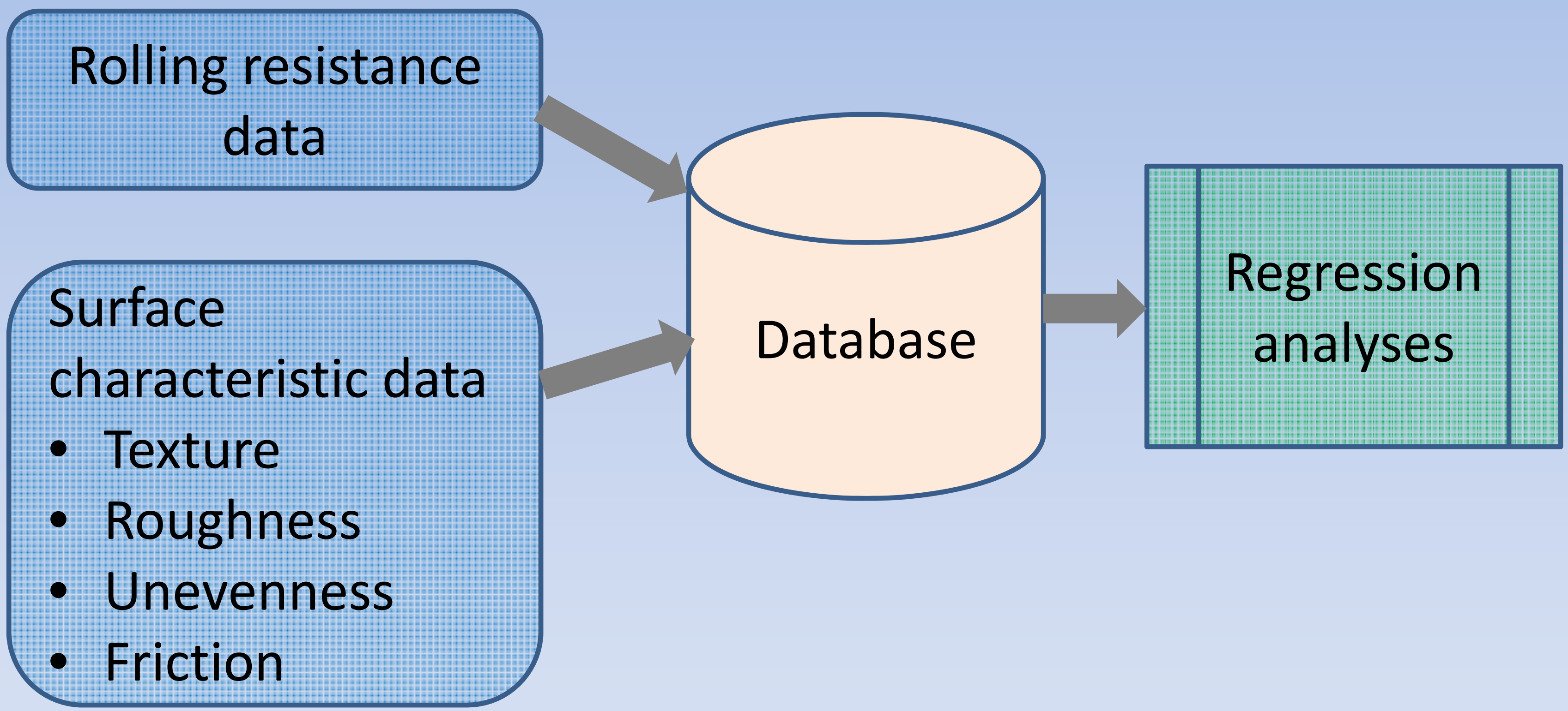
MnROAD Surface Characteristics

- Texture
  - Profile depth
- Roughness
  - IRI, ASTM E-950
- Friction
  - ASTM E-247

Additional Surface Characteristics

- Texture variables – **105 total**
  - RMS, Skew, Max peak/valley/height
  - Bearing ratio curve: Rpk, Rk, Rvk, Rktotal
  - 3rd octave wavebands from 3.15 to 160 mm
  - Lumped spectral bands
  - Statistical: 10th, 50th, 90th percentile
- Unevenness – **31 total**
  - 3rd octave wavebands from 0.08 to 25 meters
  - Lumped wavebands

Database


Rolling resistance data
Surface characteristic data
• Texture
• Roughness
• Unevenness
• Friction
Database
Regression analyses

Multi-Variable Linear Regression

- General equation

$$CRR = C_1 \times Variable_1 + C_2 \times Variable_2 + C_3 \times Variable_3 + C_4$$

  - Where
    - $Variable_i$ = texture, unevenness, or friction
    - C_i = coefficients

Criteria for Good Fit

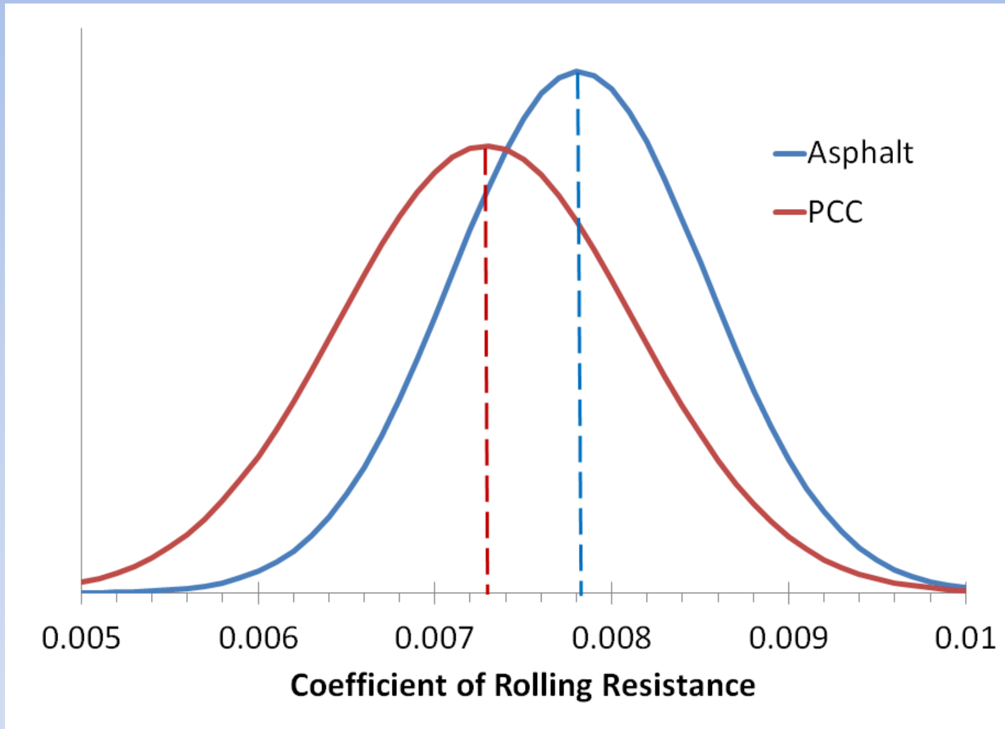
- R-squared large.
- Valid results:
  - P-values (significance level) ≤ 0.05.
  - Sign of coefficients meets engineering expectations.

Analyses by Groups

- By pavement type (separate analyses)
  - Asphalt
  - PCC, non-grind
  - PCC, grind
- By road (using qualitative variable)
  - Mainline
  - Low Volume Road

CRR Distributions

- Asphalt
  - Mean CRR = 0.00781
- PCC
  - Mean CRR = 0.00729



Variable Combinations

- Single variable
- Two variable
  - Traditional MPD and IRI
  - Texture and unevenness
  - Texture and friction
  - Two texture variables
- Three variable
  - Texture, unevenness, and friction
  - Two texture and one unevenness

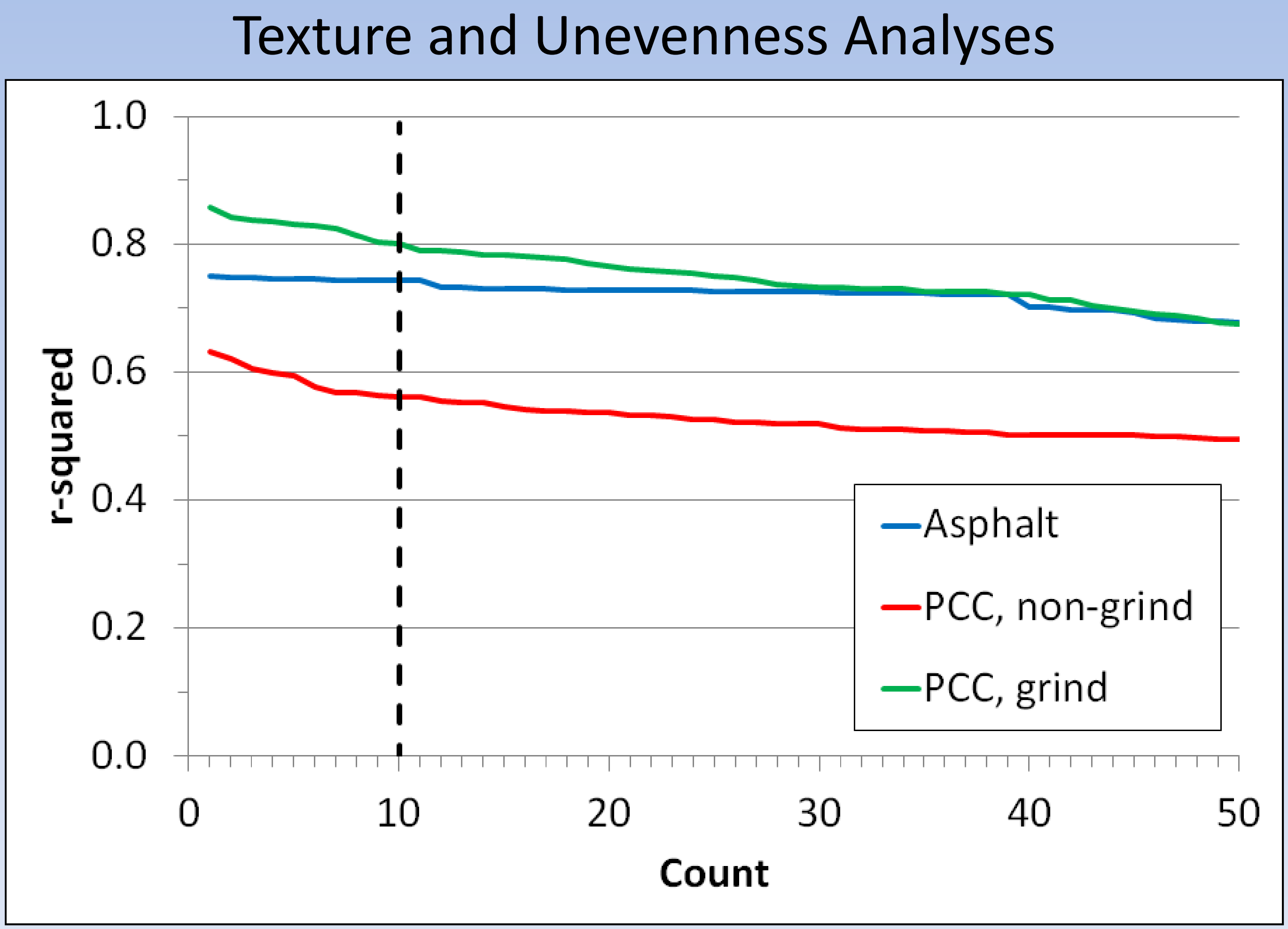
Number of Variable Combinations

- Example: 1 texture and 1 unevenness variable

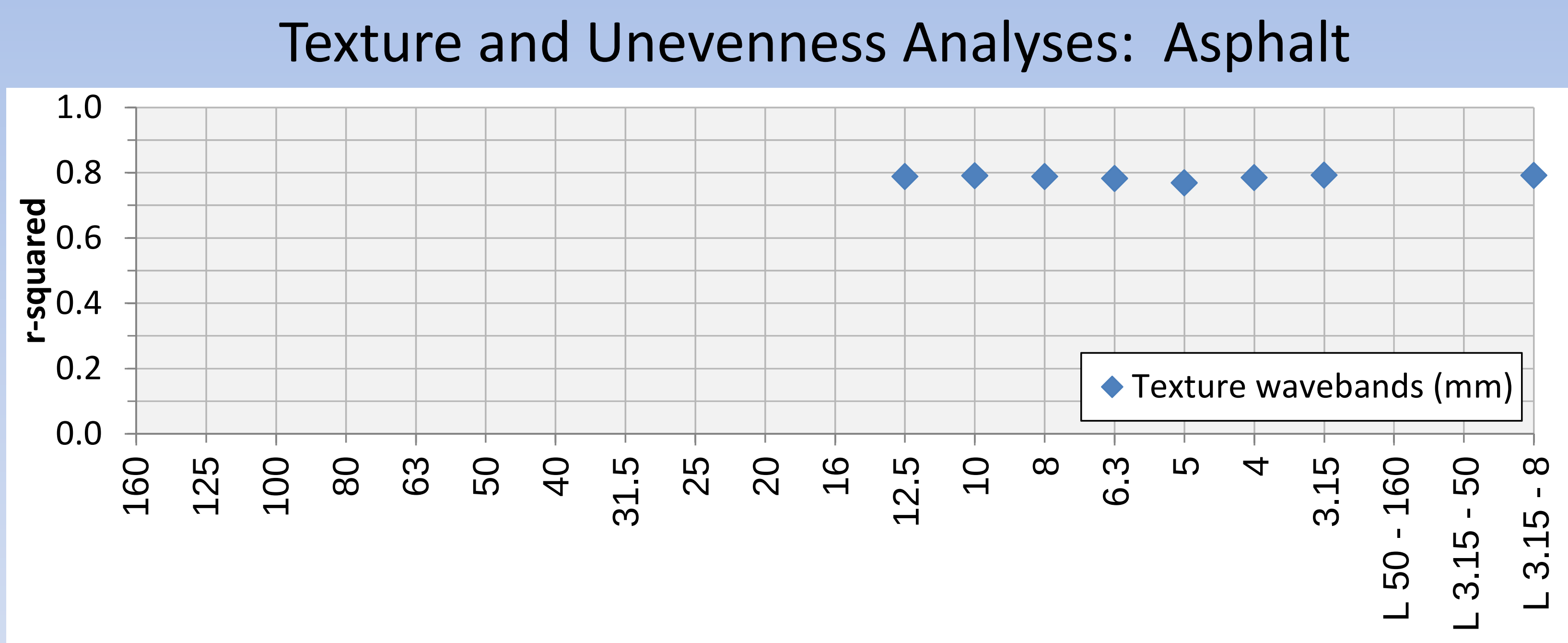
$$CRR = C_1 \times Texture_1 + C_2 \times Unevenness_2 + C_3$$

  - 105 texture variables
  - 31 unevenness variables
  - **3255** combinations; a regression analyses for each
- Number of valid results
  - Asphalt: 222
  - PCC, non-grind: 233
  - PCC, grind: 101

r-Squared Graph

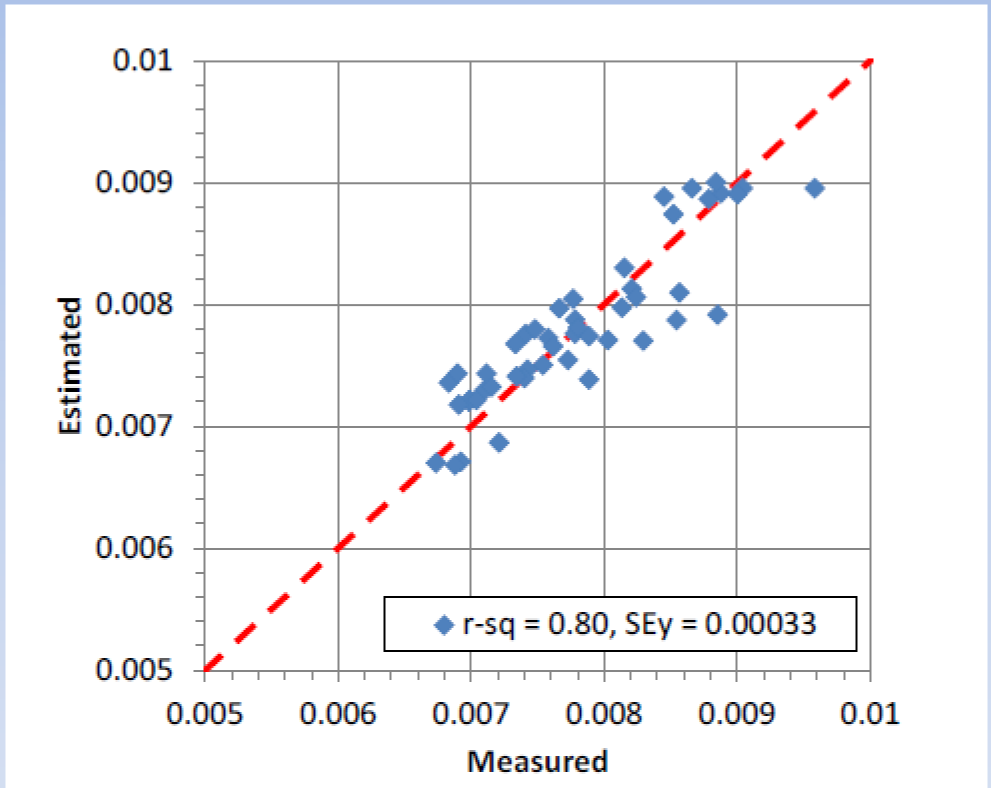


r-Squared vs. Dependent Variable



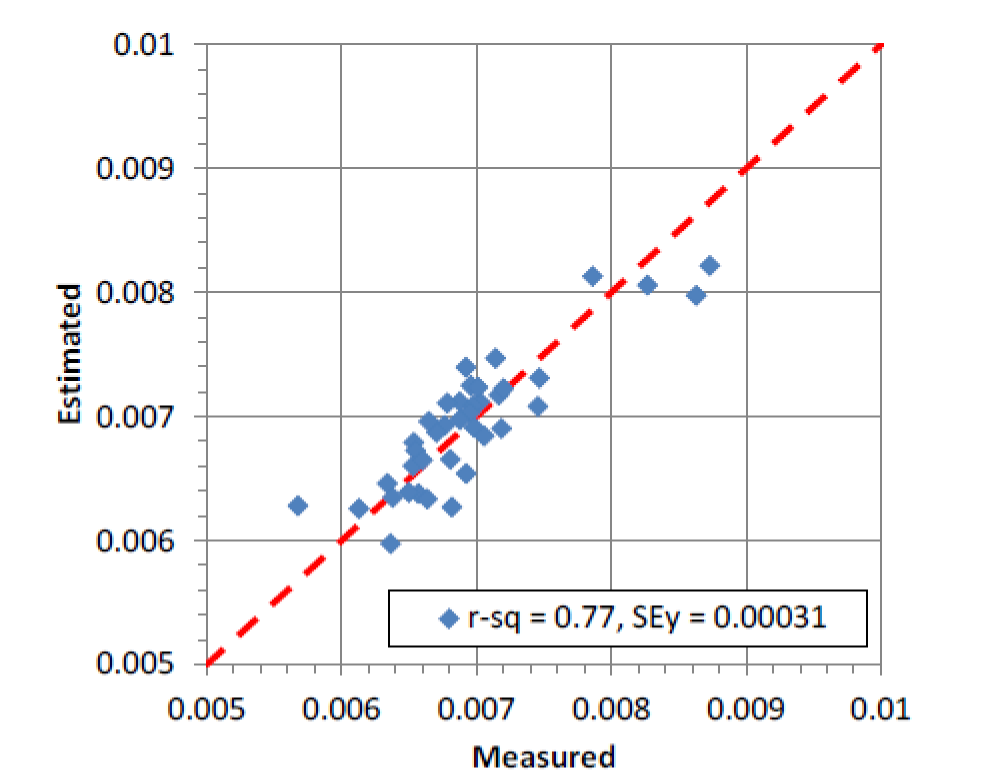
Sample Analysis – Asphalt

- Single variable
  - "Lumped" texture level in the 3.15 to 50 mm bands
- R-squared = 0.80



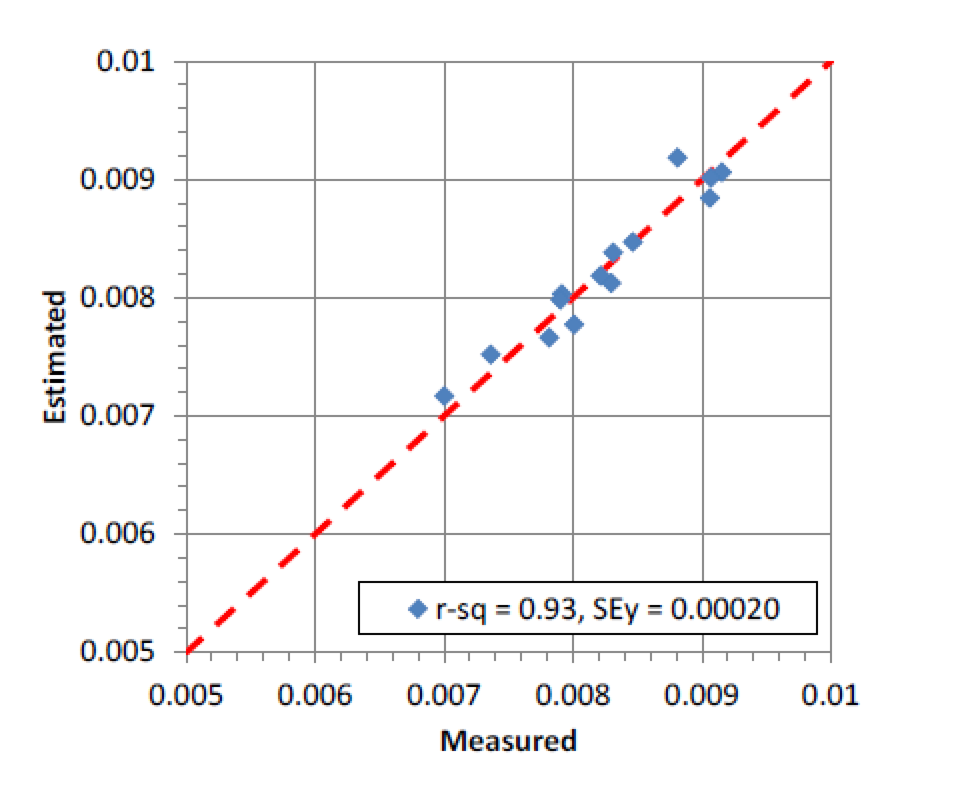
Sample Analysis – PCC, Non-Grind

- Three variables:
  1. “Lumped” texture level in the 50 to 160 mm bands.
  2. Transverse skew.
  3. Unevenness level in the 1.25 m band.
- R-squared = 0.77



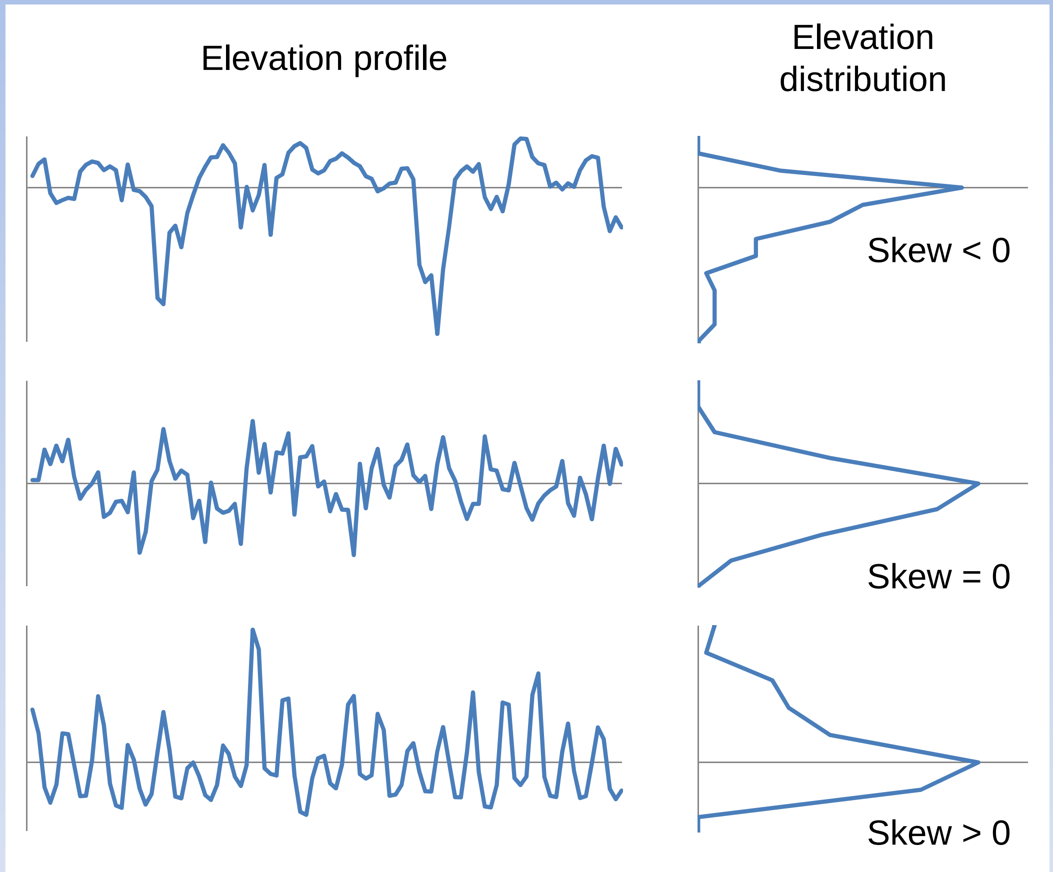
Sample Analysis – PCC, Grind

- Three variables:
  1. "Lumped" texture level in the 3.15 to 50 mm bands
  2. Transverse skew.
  3. Unevenness level in the 2.0 m band.
- R-squared = 0.93



Skew

- Statistical metric
  - 3^{rd} moment about the mean.
- Distinguishes between positive and negative oriented texture.



Regression Analysis using MPD and IRI

- Poor regression results with MPD and IRI.
  - R-squared values < 0.5
  - P-values >> 0.05
  - Negative coefficients
  - Or, some combination of these.

Conclusions

- Many combinations of surface characteristic variables can predict CRR.
- Variables that predict CRR are different between asphalt and PCC.
- Traditional texture depth (MPD) and roughness (IRI) metrics are not optimum variables to predict rolling resistance.
- TUG returning next year for additional RR measurements.

Conclusions – Asphalt

- One texture variable adequate
- R-squared up to 0.80
- Strong dependency on:
  - Macro texture in the 3.15 to 50 mm range
- Adding more variables reduced the quality of the regression analyses.

Conclusions - PCC

- Three variables provide best fits
  - Two texture + one unevenness
- R-squared values
  - PCC, non-grind: up to 0.78
  - PCC, grind: up to 0.93
- Strong dependency on:
  - Macrotexture
  - Skew