2023 European Road Profiler Users' Group Conference

Relationship Between Measured Passenger Acceleration and Road Roughness on Urban and Low-speed Roadways

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UMTRI

ERPUG

NCHRP 10-93 Ride Experiment

- Related objective measurements of ride vibration on urban and low-speed roads to road roughness.
- Included 29 test sections on 6 routes.
- All sections “principal arterial - other” and “minor arterial”.

Route	Test Sections	County	Functional Class	Speed Limit Range (km/hr)
Jackson Road/Huron Street	3	Washtenaw	3	56
Grand River (M-5)	5	Wayne	3	56
Michigan Ave. (US-12)	9	Wayne	3	48-72
Fort Street (M-85)	4	Wayne	3	48-80
West Grand River	6	Livingston	4	48-88
M-52	2	Washtenaw	4	48

Karamihas, S.M., et al., “Measuring, Characterizing, and Reporting Pavement Roughness of Low-Speed and Urban Roads.” *National Cooperative Highway Research Program Report 914* (2019) 84 p.

Test Vehicles

Nissan Altima

Hyundai Tucson

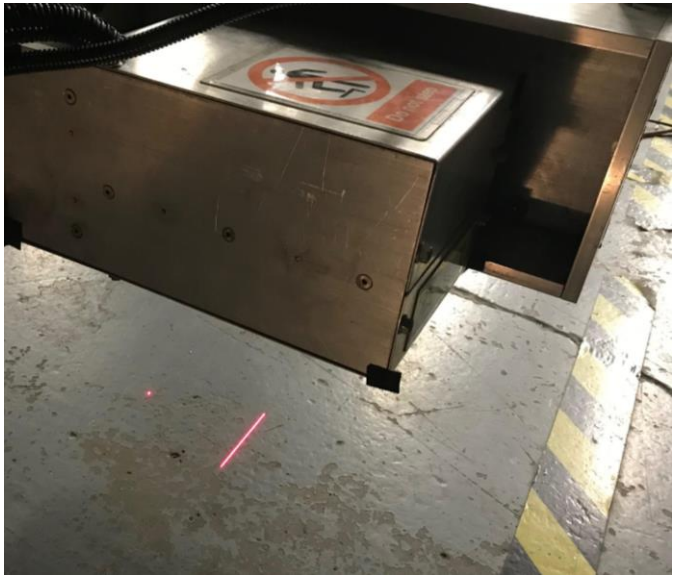
GMC Savana

Instrumentation: Ride Vibration Sensors

Seat/Back X, Y, Z
Seat/Buttock X, Y, Z, Pitch

Floor/Foot Z

Instrumentation: Profiler



Test Procedures

- 16 seconds per pass.
- 3 passes at the speed limit.
- 3 passes below the speed limit.
- Sensor pad design and mount per SAE J1013, SAE J2834.
- The same driver used throughout the experiment.
- Consistent seat position and seat back angle.
- Consistent driver posture.

IRI Generality/Other Responses

75 kg per adult
European regulation,
Bus Directive 2001/85/EC

Ride Vibration Processing: Basic (aka, “Random”)

Per ISO 2631, SAE 2834

- Weighted rms

$$rmsa_w = \left[\frac{1}{N} \sum_{i=1}^{N} a_w^2(i) \right]^{\frac{1}{2}}$$

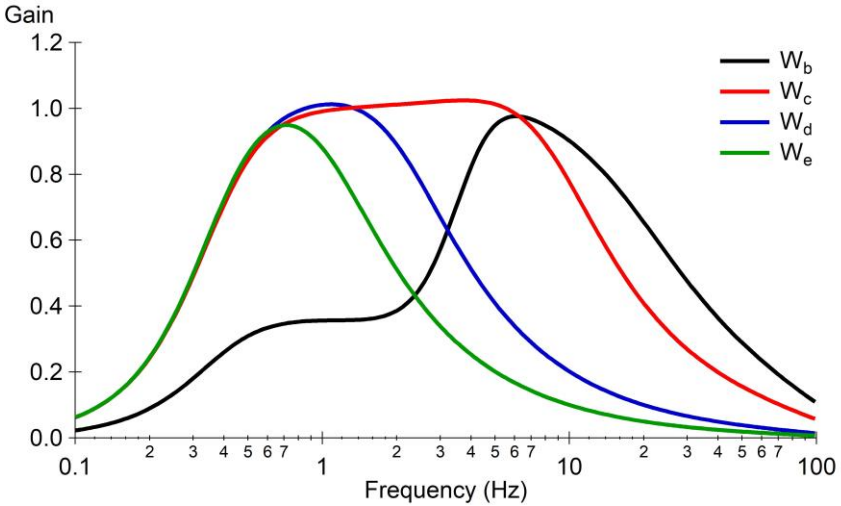
- Point vibration total

$$PV = \left(k_x^2 rmsa_{wx}^2 + k_y^2 rmsa_{wy}^2 + k_z^2 rmsa_{wz}^2 \right)^{1/2}$$

- Overall vibration total

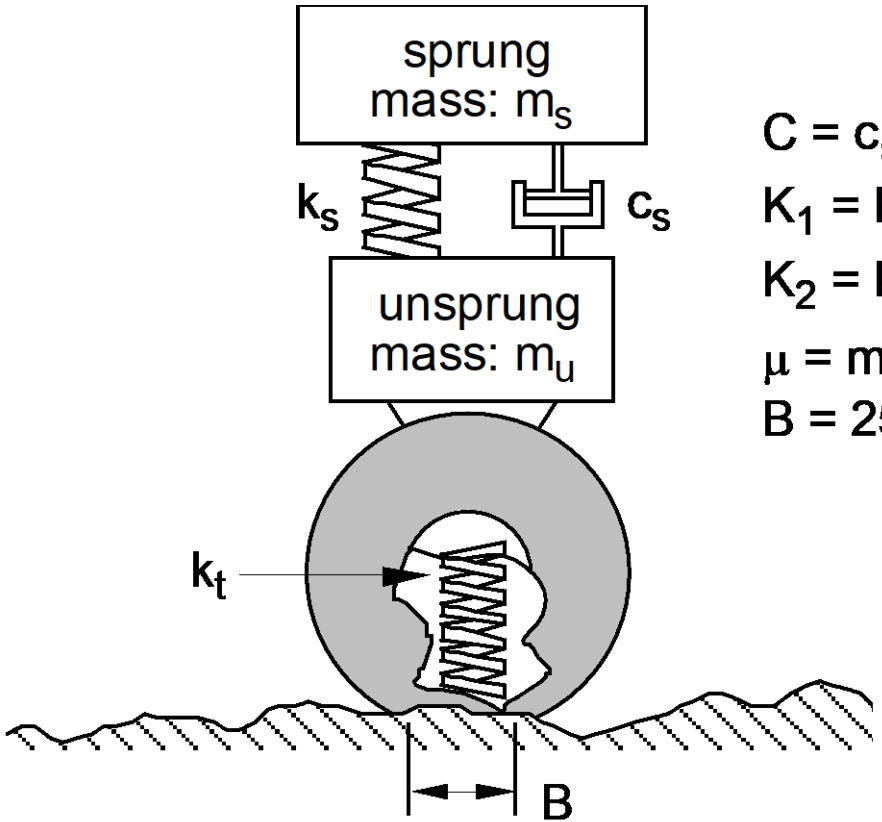
$$OVT = \left(PV_{ff}^2 + PV_{sbk}^2 + PV_{sbt}^2 \right)^{1/2}$$

Frequency Weightings



Interface	Direction	Weighting Function	Multiplying Factor
Seat/buttock	Longitudinal	W_d	1.0
	Lateral	W_d	1.0
	Vertical	W_b	1.0
	Pitch	W_e	0.4 (m/rad)
Seat/back	Longitudinal	W_c	0.8
	Lateral	W_d	0.5
	Vertical	W_d	0.4
Floor/foot	Vertical	W_b	0.4

Golden Car Model



$C = c_s/m_s = 6.0\ sec^{-1}$

$K_1 = k_t/m_s = 653\ sec^{-2}$

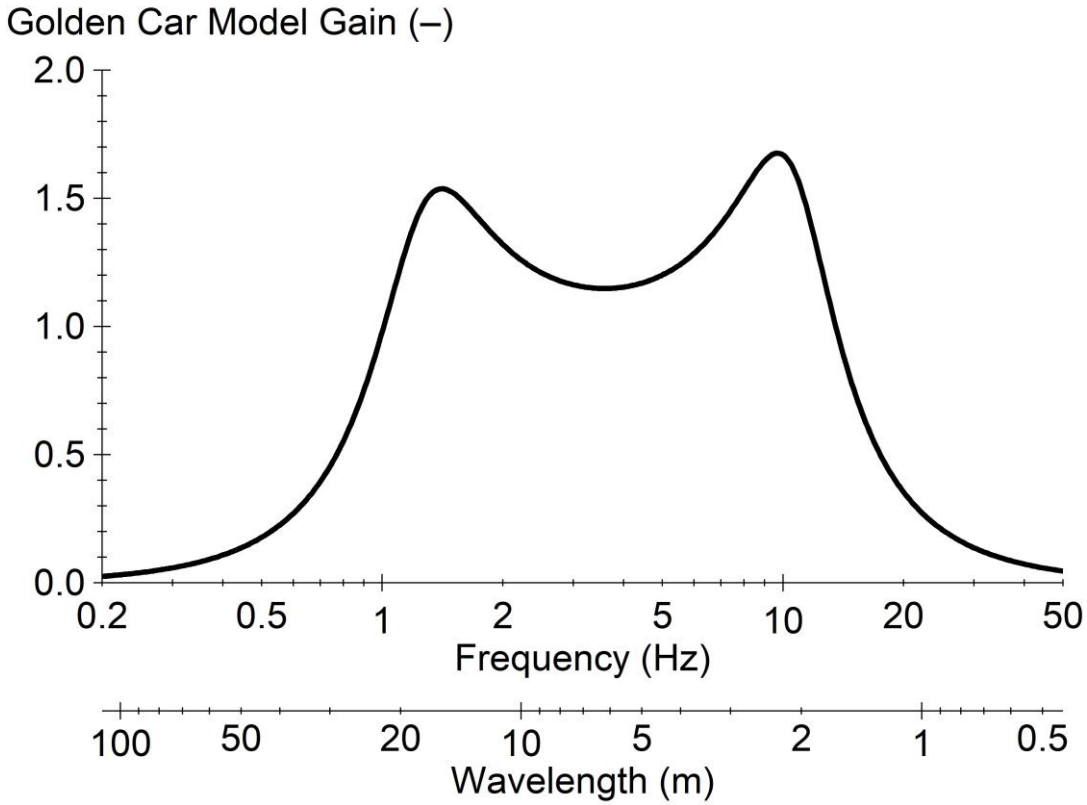
$K_2 = k_s/m_s = 63.3\ sec^{-2}$

$\mu = m_u/m_s = 0.15$

$B = 250\ mm$

Sayers, M. W., "On the Calculation of International Roughness Index from Longitudinal Road Profile." *Transportation Research Record 1501* (1995) pp. 1-12.

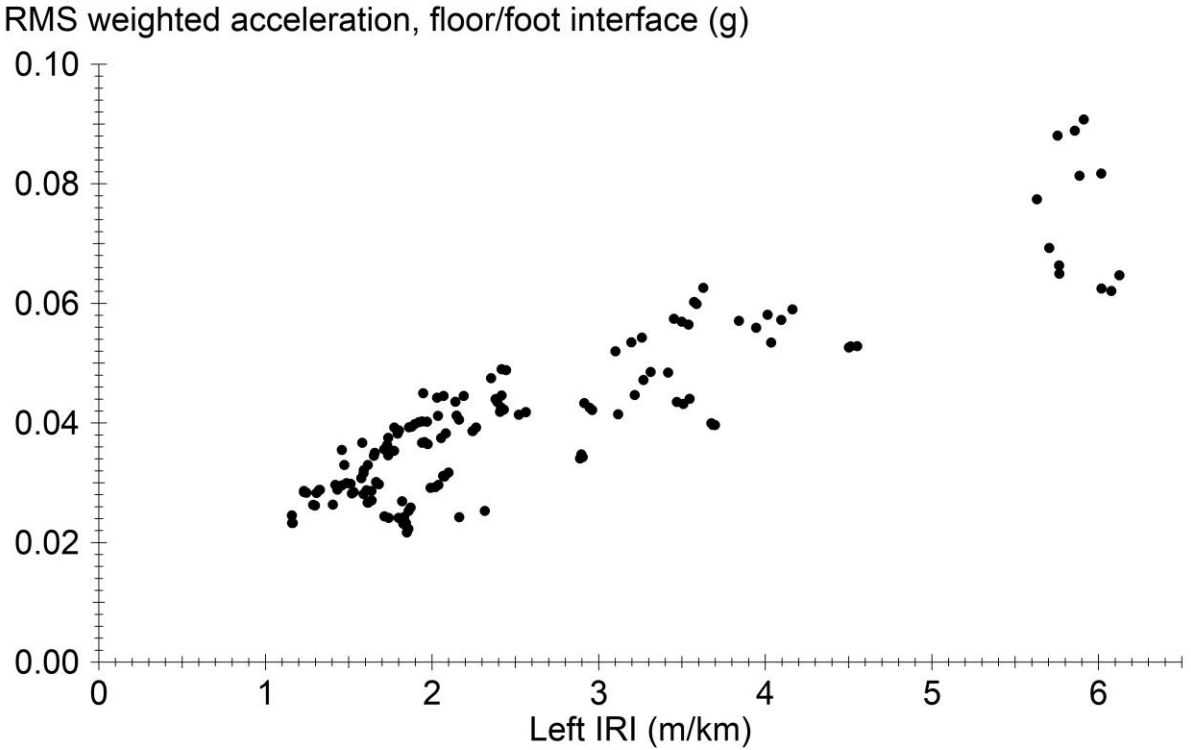
International Roughness Index (IRI) Response



Wavelength
= Speed/Frequency

Karamihas, S. M., "Golden-Car Simulation Speed and Its Implications to the Relevance of the IRI." *ASTM STP 1555* (2011).
AASHTO M328-14, "Standard Specification for Inertial Profiler."

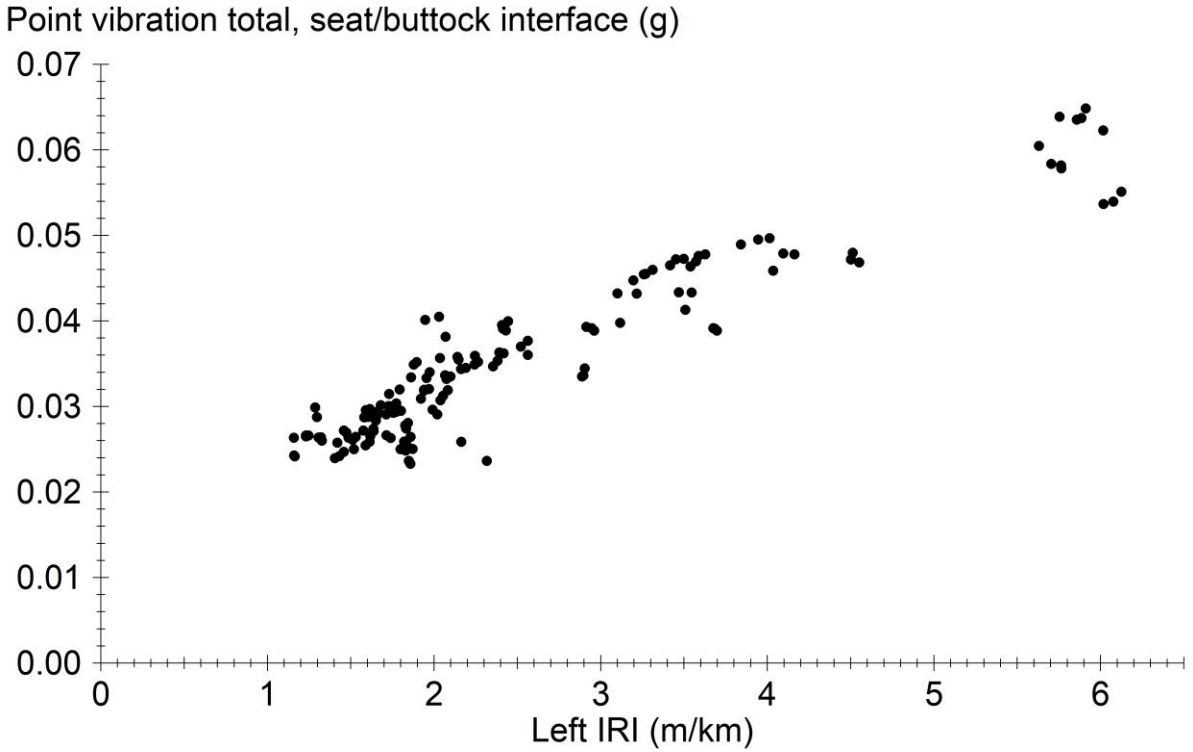
Results for IRI, Mid-Sized Sedan



SE = 0.0065 g
R^2 = 0.796

Inadequate alignment of frequency sensitivity. (spatial vs. temporal)

Results for IRI, Mid-Sized Sedan



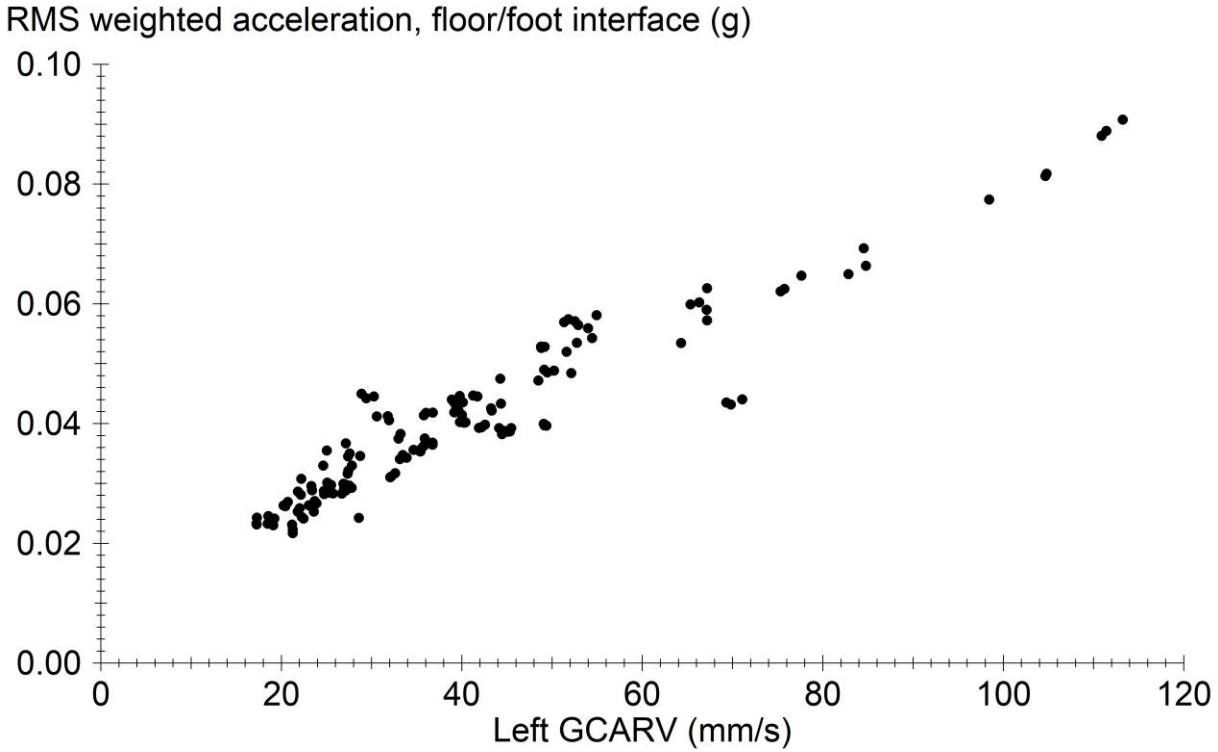
SE = 0.0033 g
R^2 = 0.891

Coincidental alignment of frequency sensitivity.

Not as good for the other vehicles.

Would not hold up under a wider speed range.

Results for GCARV, Mid-Sized Sedan



SE = 0.0045 g
R^2 = 0.901

Better alignment of frequency sensitivity.

Similar improvement in other vehicles.

Still limited by the use of a quarter-car model.

Ride Vibration Processing: Transient Events

Per ISO 2631, SAE J2834

- Vibration dose value (weighted rmq)

$$VDV = \left[\frac{1}{N} \sum_{i=1}^{N} a_w^4(i) \right]^{\frac{1}{4}}$$

- Maximum transient vibration value

$$rmsa_{w,T}(j) = \left[\frac{1}{M} \sum_{i=j}^{j+M-1} a_w^2(i) \right]^{\frac{1}{2}}, M = T / \Delta t$$

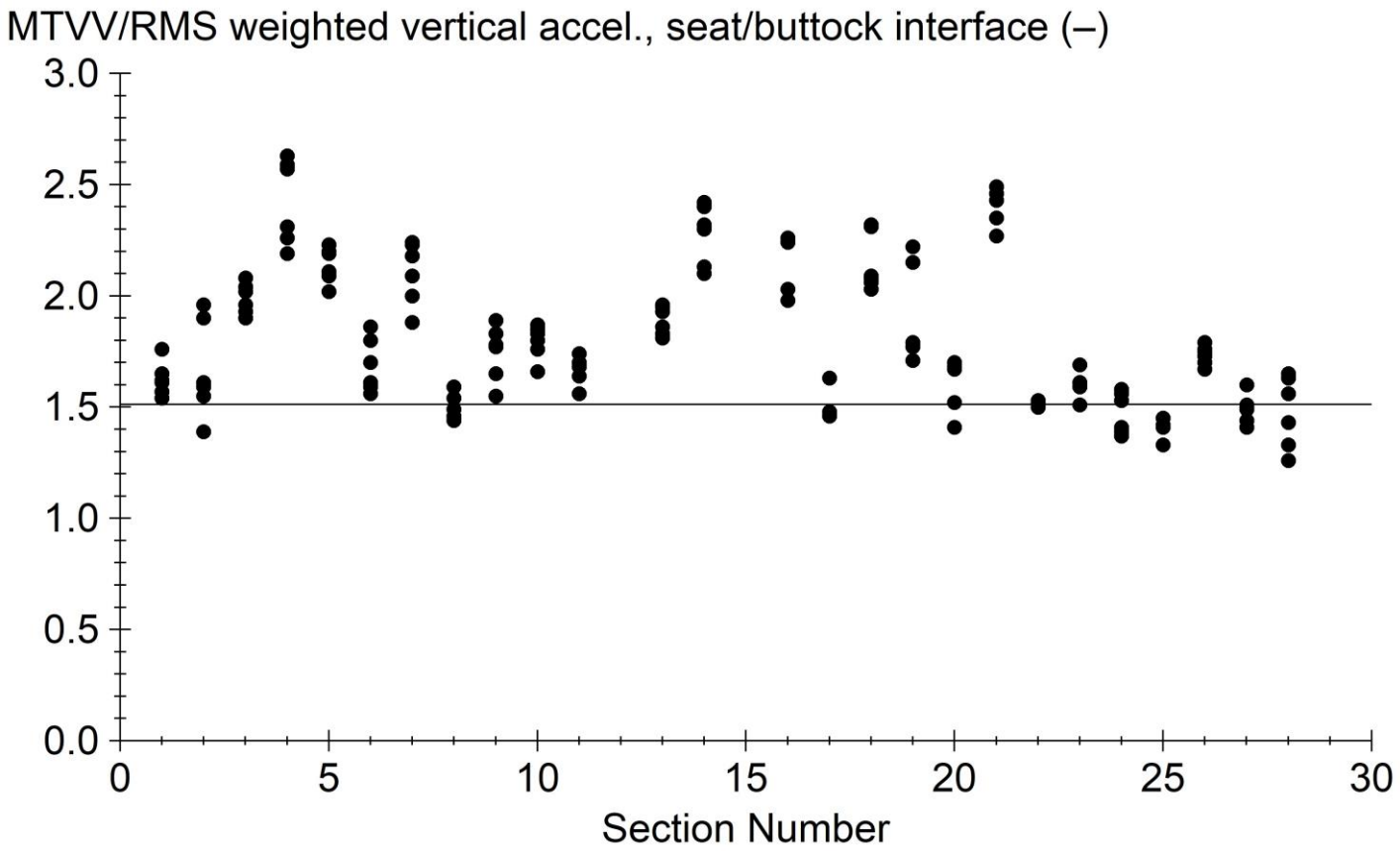
$$MTVV = \max\left(rmsa_{w,T}(j)\right), j = 1, N - M$$

- "Transient" if

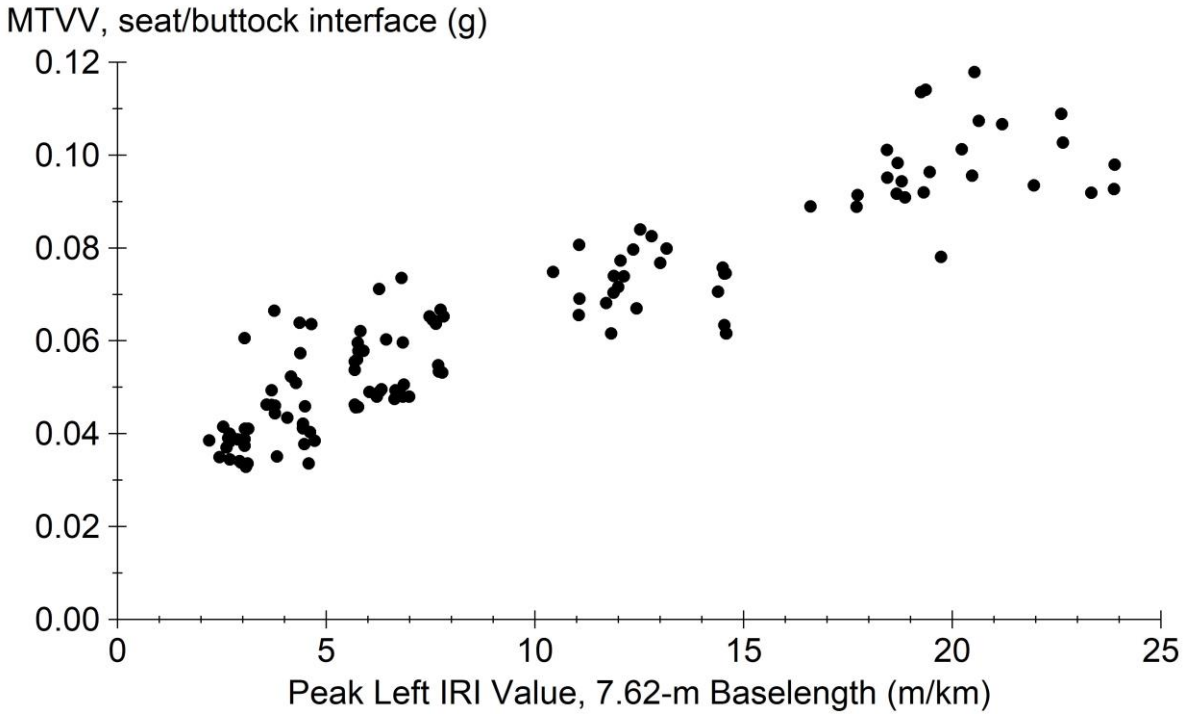
$$\frac{MTVV}{rmsa_w} > 1.5 \qquad \frac{VDV}{a_w T^{1/4}} > 1.75$$

ISO 2631-1: Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1: General requirements (1997).

Will “the basic evaluation method suffice”?



MTVV versus Peak IRI, 7.62-m Baselength



SE = 0.0084 g
R^2 = 0.854

Not adequate.

However, consistently flagged transient events.

Summary

- IRI correlated to measures of ride discomfort on low-speed and urban roadways, but better correlation is possible.
- Use of travel speed and a temporal output improved correlation.
- Optimizing correlation for limited conditions is not recommended.
- Localized roughness must be considered to quantify functional quality.
- Not covered: All results correspond to the use of lateral and longitudinal bridging.