PAVEMENT SMOOTHNESS INDICES

RESEARCH BRIEF

by

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INTRODUCTION

BACKGROUND

Many in the asphalt industry believe that initial pavement smoothness directly relates to pavement life. Public perception of smoothness is also important. Oregon is interested in determining the appropriate method of measurement to quantify smoothness in terms of performance and public perception. Several smoothness indices exist, however, they need to be compared and evaluated for application in Oregon.

PROCESS

A literature search was undertaken to identify publications having information on indices and equipment used to measure the pavement smoothness. The majority of sources identified were contained in the National Cooperative Highway Research Program Project 1-31, *Smoothness Specifications for Pavements,* published in March 1997. Project 1-31, therefore, became the primary source of report information.

EVALUATION OF INDICES

INDICES AVAILABLE

Four types of indices may be used to measure pavement roughness (NCHRP 1-31, 1997):

- Subjective rating indices (PSR: Present Serviceability Rating),
- Mechanical filter-based indices (MRN: Mays Ride Number, PI: Profile Index, SV: Slope Variance),
- Profile-based indices—mechanical system simulation (RARV: Reference Average Rectified Velocity, RARS: Reference Average Rectified Slope, IRI: International Roughness Index, HRI: Half-car Roughness Index, RN_{Sayers}: Sayers Ride Number, TRS: Telescoped Rolling Straightedge),
- Profile-based indices—filtered and weighted (RQI: Michigan DOT Ride Quality Index, RN_{Janoff}: Janoff Ride Number, $RN_{Spangler}$: Spangler Ride Number, MO: Mays Meter Output Function of RMSVA).

Subjective ratings, where participants are driven over a variety of road surfaces, are expensive and time-consuming. In addition, confounding factors such as vehicle size and type, panel size, and participant training may affect the repeatability and bias of the rating.

Mechanical filter-based indices include response-type road roughness measuring (RTRRM) systems and rolling straightedge systems. RTRRM systems measure the cumulative relative displacement between the axle and the vehicle body and average those displacements over some distance of the roadway (mm/km). Response type systems (Mays Ride Meter, PCA Roadmeter, and BPR Roughometer) generate summary statistics calibrated to a profile. RTRRMs are reported to not correlate well with user response to roadway roughness. An example of a rolling straightedge system is the profilograph that generates the profile index (PI). The PI, expressed in mm/km represents the total accumulated profile highs and lows. The maximum acceptable accumulation of highs and lows can be reduced by specifying a band width (an allowable range of roughness).

Profile-based indices—mechanical system simulation numerics are generally obtained by either simulating the response of an RTRRM system as it traverses the profile or by filtering and weighting the spectra of wavebands that make up the road surface profile. Profile-based indices—filtered and weighted numerics are based on a different filtering method which also requires separating and weighting the waveband spectra that make up the roadway surface.

The correlation of measured index with user response was reviewed to identify promising indicators. Indices commonly used as a numerical indication of pavement smoothness are shown in Table 1 along with their reported correlation with user response.

The ride index chosen for use must reflect what the travelling public senses as the smoothness or roughness of the pavement. And, in fact, the indices presently in wide use, and those being proposed, do appear to correlate well with a driver's subjective response. The NCHRP Project 1-31 Report summarizes this by saying: "Based on the correlations and level of use, the IRI, PI, RN_{Sayers}, RQI, and RN_{Janoff} were all rated very highly. The IRI and PI (5.1 mm blanking band) were rated as moderate to good in correlation with user response, while the other three indices were rated good to excellent. No information was available relating user response to PI determined using a 2.5 or 0 mm blanking band but studies in Kansas and Michigan indicate that pavement roughness omitted by the 5.1 mm blanking band can be disturbing to highway users."

Table 1. Common indices and correlation with user response.

Mechanical Filter-Based Indices	**$R^{2\ (A)}$**	**Profile-Based Indices—Mechanical System Simulation**	**R^2**	**Profile-Based Indices—Filtered and Weighted**	**R^2**
MRN: Mays Ride Number	0.55-0.62	RARV: Reference Average Rectified Velocity	NA	RQI: Michigan DOT Ride Quality Index	0.21 - 0.86
PI: Profile Index (measured with a profilograph)	0.705 – 0.742$^{(B)}$	RARS: Reference Average Rectified Slope	NA	RN_{Janoff}: Janoff Ride Number	0.86-0.90
SV: Slope Variance	NA	IRI: International Roughness Index	0.62-0.72	$RN_{Spangler}$: Spangler Ride Number	0.83

Mechanical Filter-Based Indices	R^{2} (A)	Profile-Based Indices—Mechanical System Simulation	R^2	Profile-Based Indices—Filtered and Weighted	R^2
		HRI: Half-car Roughness Index	NA	MO: Mays Meter Output Function of RMSVA	NA
		RN_{Sayers}: Sayers Ride Number	0.85-0.88		
		TRS: Telescoped Rolling Straightedge[(C)]	NA		

[A] R^2 value is the measured correlation of the listed index with respect to user response on all types
of pavements. R^2 =1.0 indicates perfect correlation; R^2 = 0.0 indicates no correlation.
[B] The higher correlation was obtained when the blanking band was reduced.
[C] Correlation with rider comfort not expected to be better than IRI or RN.

SELECTION CRITERIA

Selection of a smoothness index should be made on the basis of correlation to user response, correlation with other statistics and consideration of current smoothness statistics so that specification limits can be easily developed. NCHRP Project 1-31 recommended the PI as the initial pavement smoothness statistic since no index stands out as the most appropriate. The IRI does not provide an improved user-response correlation over PI and the expense required for changing to the statistic noes not appear justified. RN_{Sayers}, RQI, and $RN_{Janoff\ provide}$ promise as the smoothness indicators of the future based on user correlations. There currently is not enough experience with the indices, however, to develop specifications.

ROAD SMOOTHNESS MEASURING DEVICES

The Appendix provides information on cost, operating, and data reporting characteristics for most of the commercially available equipment. The equipment information was selected to address the following items:

- Accuracy & repeatability (precision),
- Initial cost,
- Size/portability/dependability,
- Ease/cost of use and

- Versatility (Can it measure more than one index?).

Road smoothness measuring devices fall into four general categories:

- Profilograph,
- Response-Type,
- Inertial and
- Inclinometer.

PROFILOGRAPH

The California-style profilograph (there are several manufacturers) is the most widely used smoothness-measuring device for use on newly constructed pavements. As the unit moves along the pavement, the vertical movement of a wheel is recorded as a tracing on a roll of paper or as data in a computer file. Purchase prices run from $14,000 (simplest model) to $30,000 (computer-equipped devices). Most profilograph units are pushed along the roadway by the operator; however, some equipment is designed to be towed. Most units are disassembled for transport, although one manufacturer is producing a towed unit that incorporates highway travel capability. At least one manufacturer produces a profilograph with a slightly different design. This unit produces a different profile tracing than the other manufacturers' units. At best, the precision of all of these devices is only fair.

RESPONSE-TYPE DEVICES

Response-type smoothness measuring devices can be mounted in a vehicle or trailer. The devices measure the movement of an axle with respect to the vehicle or trailer frame. The Mays Ride Meter is the most common unit of this type. The "Mays" is generally mounted in a small trailer and the cost is approximately $14,000. Response-type devices require frequent calibration and are greatly affected by the speed and mechanical characteristics of the vehicle or trailer. This type of device should not be used for initial quality acceptance.

INERTIAL DEVICES

Inertial smoothness measuring devices are vehicle-mounted. They employ accelerometers and vertical-distance measuring devices (acoustic, light, infrared, or laser). In effect, the accelerometers offset the movement of the vehicle while the distance-measuring device measures the distance to the pavement. Inertial systems are generally mounted in van-type vehicles and are most often used for system-wide data collection for pavement management work. At least two manufacturers are producing units mounted on small all-terrain or golf-cart type vehicles. These lighter weight units are suitable for use on newly placed pavements. The smaller units cost about $46,000. Van equipped units, depending upon the sophistication, may cost $200,000. This type of device offers a high degree of precision.

INCLINOMETER DEVICES

Inclinometer smoothness measuring devices measure the slope from one point to the next as the unit is moved along the pavement. These are generally small devices moved along by a walking operator. The devices are very accurate but time consuming to use. The units cost about $20,000.

RECOMMENDATIONS

In accordance with Project 1-31 recommendations, because of the lack of proven replacement, the profile index (PI), notwithstanding its limitations, is the recommended index for portland cement concrete (PCC) and asphalt concrete (AC) pavements initial smoothness measurements. However, it is recommended that the blanking band be eliminated and PI statistics be computed from surface profiles measured using inertial-based systems. The inertial based equipment will provide a faster, more versatile, and accurate system to measure profiles. In addition, the profiles can be used to generate other smoothness indices besides the PI. The recommended equipment specifications are shown in Table 2.

Table 2: Summary of recommended properties for smoothness-measuring equipment.
(NCHRP, Project 1-31, 1997)

Property	**Recommended Requirements**
Measured Profile Wavelengths	0.37 - 30.5 m (1.2’ - 100’) up to 88 km/hr (55 mi/hr)
Sampling Interval	24.4 mm (1”) if digital antialiasing used 51.8 mm (2“) if analog antialiasing used
Distance Accuracy	0.1%
Vertical Elevation Accuracy Static Precision/Bias Dynamic Precision/Bias	 0.125 mm/0.125 mm ($\pm$ 0.005”/$\pm$0.005”) 0.38 mm/1.25 mm ($\pm$ 0.015”/$\pm$0.05”)
Other Considerations	Lightweight Rapid sampling speed Ease of use Identify must-grinds Horizontal positioning Rapid availability of survey data results Automated calibration, analysis, reporting

Steve Karamihas from the University of Michigan Transportation Research Institute, author of *Estimation of Rideability by Analyzing Longitudinal Road Profile* (Transportation Research Record No. 1536) and other smoothness related papers, was contacted regarding the information presented in Table 2. He is in general agreement with the recommended requirements for data gathering equipment and with the suggestion that inertial profilers be specified. Mr. Karamihas is partly responsible for development of the ride number (RN) ride index. He suggested any device chosen or specified should, at the very least, generate the international roughness index (IRI) because of the Federal Highway Administration (FHWA) reporting requirements. Also, the device chosen or specified should employ laser or infrared, distance-measuring instruments. Mr. Karamihas was confident that software is available to generate a number of ride indices from the profile data gathered by any of the equipment available. The vendor supplying profiler equipment or doing the data gathering would be requested to supply results in whatever indices are desired.

APPENDIX

SMOOTHNESS MEASURING DEVICES