National Cooperative Highway Research Program

RESEARCH RESULTS DIGEST

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Subject Area: IIB Pavement Design, Management, and Performance

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Methodology to Improve Pavement-Investment Decisions

An NCHRP digest of the findings from the final report on NCHRP Project 1-33, "Methodology to Improve Pavement Investment Decisions," conducted by Washington State University. Dr. A. T. Papagiannakis served as Principal Investigator.

INTRODUCTION

This digest describes a methodology for conducting life-cycle cost analysis, developed under NCHRP Project 1-33, that could be incorporated into the pavement-investment decision processes currently used by state departments of transportation and other agencies.

There is consensus among those involved in managing the nation's highway systems that pavement-investment strategies must consider both user and agency measures of pavement quality. Conventional user-oriented measures of pavement serviceability are based on automobile-occupant reaction to pavement roughness. Currently available measures of pavement roughness do not reflect the full range of vehicle classes, and their relationship to user costs for U.S. conditions is not well defined. A more useful measure would summarize pavement roughness attributes that affect the user costs for all vehicle classes. User costs consist of vehicle-operating costs for the full range of vehicle classes (automobiles, buses, and light and heavy trucks); costs of delays due to construction/maintenance work zone activities; costs of transporting goods over the full spectrum of pavements; and costs attributable to driver and passenger discomfort. Therefore, there is a need to develop an improved pavement-investment decision methodology that incorporates user costs, condition measures, and agency inputs and that can also be integrated into pavement management systems. NCHRP Project 1-33 was conducted to address this need.

The research was conducted under NCHRP Project 1-33, "Methodology to Improve Pavement-Investment Decisions," by Washington State University. The research, completed in 1999, presented on a CD-ROM a method for conducting life-cycle cost analysis that incorporates relationships between pavement roughness and user costs. This digest provides a summary of the work performed in this research. The materials in this digest are extracted from the final report on NCHRP Project 1-33.

FINDINGS

As part of this project, relationships between user costs and pavement roughness reported in the literature were identified, a new index for summarizing pavement roughness was developed, and relationships between pavement roughness and truck or car repair and maintenance costs and between pavement roughness and truck tire costs were established. Also, a life-cycle cost analysis methodology that considers pavement roughness and user costs was presented.

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USER COSTS AND PAVEMENT ROUGHNESS

User costs include both vehicle operating and non-vehicle operating costs. Vehicle operating costs include costs related to fuel and oil consumption, tire wear, repair and maintenance, and depreciation. Non-vehicle operating costs include costs incurred because of cargo damage, speed reduction, and passenger discomfort attributed to pavement roughness.

The majority of studies dealing with the effects of roughness on user costs were conducted in developing countries where pavement roughness varies over a much wider range than the range encountered in the United States. These studies showed that vehicle operating costs vary substantially for vehicles operating on pavements with different surface types (e.g., bituminous, gravel, and earth), but not necessarily for paved roads with different roughness levels. Vehicle repair, maintenance, and tire costs were found to be primarily influenced by pavement roughness while other cost items were influenced mainly by road geometrics and traffic congestion. Studies dealing with passenger comfort and cargo damage focused on vehicle excitation, not on pavement roughness. Vehicle speed was found to be influenced by pavement roughness only at extreme roughness levels.

DEVELOPMENT OF A ROUGHNESS INDEX

An index summarizing pavement roughness was developed in this research. The index designated RIDE (Roughness Index for Driving Expenditure) relates user-cost components to pavement roughness. This index is based on the root-mean-square (RMS) of the vertical acceleration of the body of a reference truck. RIDE is calculated by the frequency domain from the power-spectral-density (PSD) of the road profile. It expresses ride comfort for passenger cars and heavy trucks in terms of vertical vehicle acceleration as stipulated in ISO (International Standards Organization) Standard 2631, "Evaluation of Human Exposure to Whole-Body Vibration," and considers pavement roughness aspects that contribute to the dynamic loads generated by heavy trucks that lead to truck and pavement damage. The RIDE index can be measured onboard a vehicle using an accelerometer mounted on the vehicle's frame. Because of its sensitivity to pavement roughness excitation frequencies that are close to the resonant frequencies of the unsprung masses of heavy trucks (i.e., 2.5 to 3.5 Hz), the RIDE index is suited for identifying pavements that need rehabilitation.

Relationship Between RIDE and the International Roughness Index (IRI)

Based on the analysis of a large number of flexible and rigid pavements, the following relationships between RIDE (in mm/sec^2) and IRI (in m/km) were developed.

For flexible pavements:

$$\text{RIDE} = 144.78\ e^{0.235\ \text{IRI}} \quad (1)$$

(t= 5.3, t_2= 3.65, SE= 13.03, R^2 = 0.254, n= 40)

For rigid pavements:

$$\text{RIDE} = 92.24\ e^{0.368\ \text{IRI}} \quad (2)$$

(t_1= 7.5, t_2 = 6.9, SE= 51.5, R^2= 0.39, n= 80)

These relationships are shown in Figures 1 and 2 for flexible and rigid pavements, respectively. The poor correlation between RIDE and IRI illustrated in these figures is attributed to the sensitivity of each index to different parts of the pavement profile spectrum.

Relationship Between RIDE and the Pavement Serviceability Index (PSI)

The relationship between RIDE and PSI was determined from Equations 1 and 2 by substituting the following relationship between PSI and IRI as developed by Paterson (*1*):

$$\text{PSI} = 5.0\ e^{-0.18\ \text{IRI}} \quad (3)$$

Thus, for flexible pavements:

$$\text{PSI} = 5.0\ e^{-0.7657\ \ln(\text{RIDE}/144.78)} \quad (4)$$

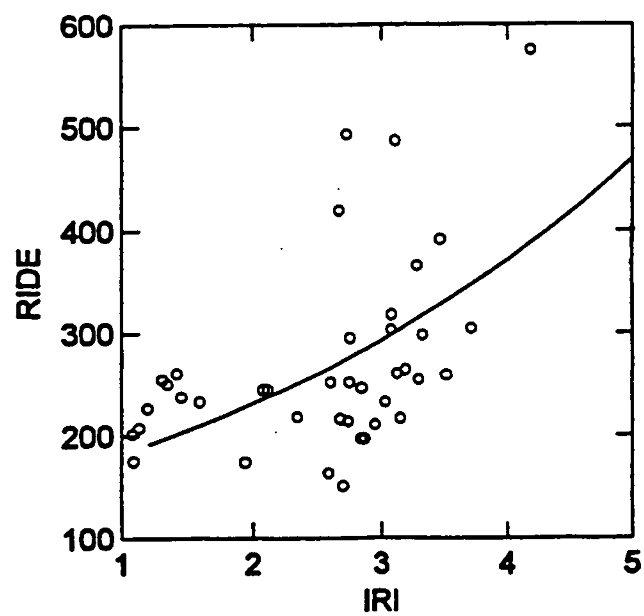

Figure 1. Relationship between RIDE (in mm/sec^2) and IRI (in m/km) for flexible pavements.

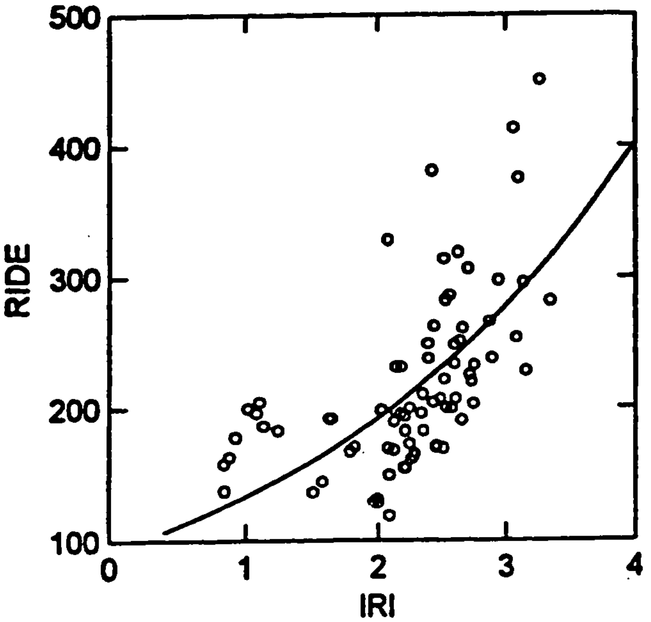

Figure 2. Relationship between RIDE (in mm/sec²) and IRI (in m/km) for rigid pavements.

For rigid pavements:

$$PSI = 5.0\ e^{-0.4891\ \ln(RIDE/92.24)} \quad (5)$$

These relationships, also shown in Figures 3 and 4 for flexible and rigid pavements, respectively, can be used to establish minimum acceptable RIDE values. For example, a RIDE value of about 500 m/sec² corresponds to a PSI value of approximately 2.0

RELATIONSHIP BETWEEN PAVEMENT ROUGHNESS AND USER COSTS

Preliminary relationships between pavement roughness, as expressed by RIDE or IRI, and user costs (i.e., truck parts for repair/maintenance and tires) were derived based on information provided by four common-carrier trucking companies for 102 tractor trailers. In terms of RIDE, these relationships are expressed by the following equations:

$$\text{Parts cost (\$/km)} = 0.012\ (RIDE/190)^{5.528} \quad (6)$$

($t_1 = 6.04$, $t_2 = 4.13$, $SE = 0.001$, $R^2 = 0.30$)

$$\text{Tire cost (\$/km)} = 7.65 \times 10^{-6}\ (RIDE) - 0.001093 \quad (7)$$

($t_1 = 3.6$, $t_2 = 2.2$, $SE = 4.76 \times 10^{-5}$, $R^2 = 0.82$)

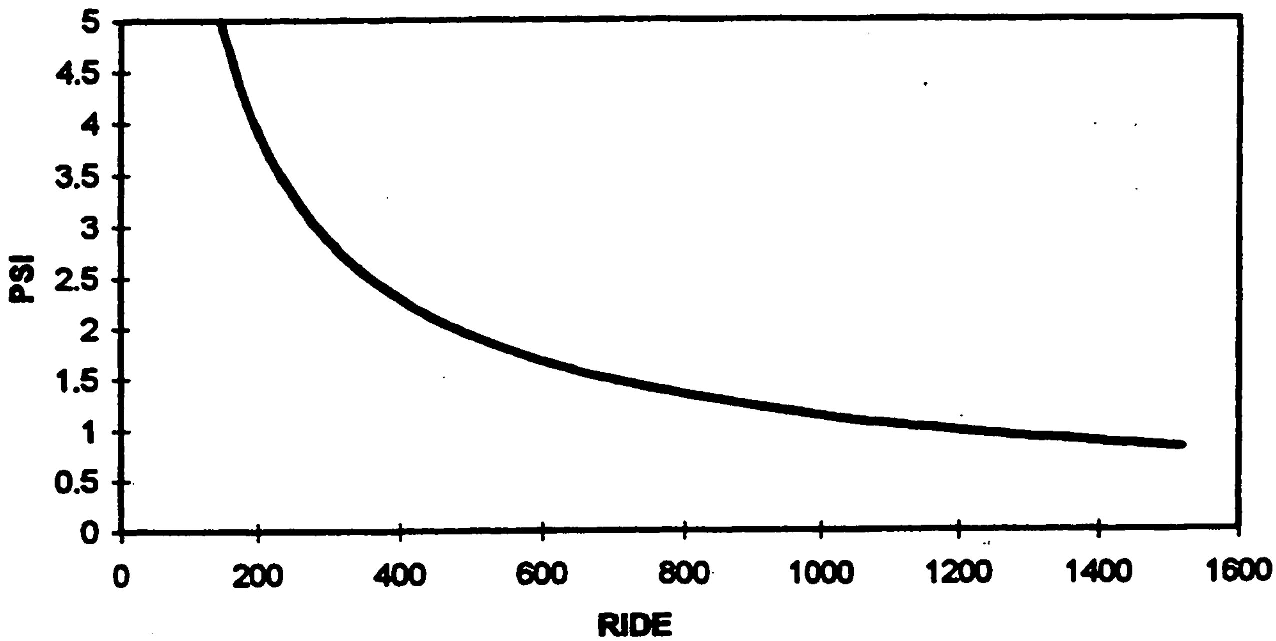

Figure 3. Relationship between RIDE (in mm/sec²) and PSI for flexible pavements.

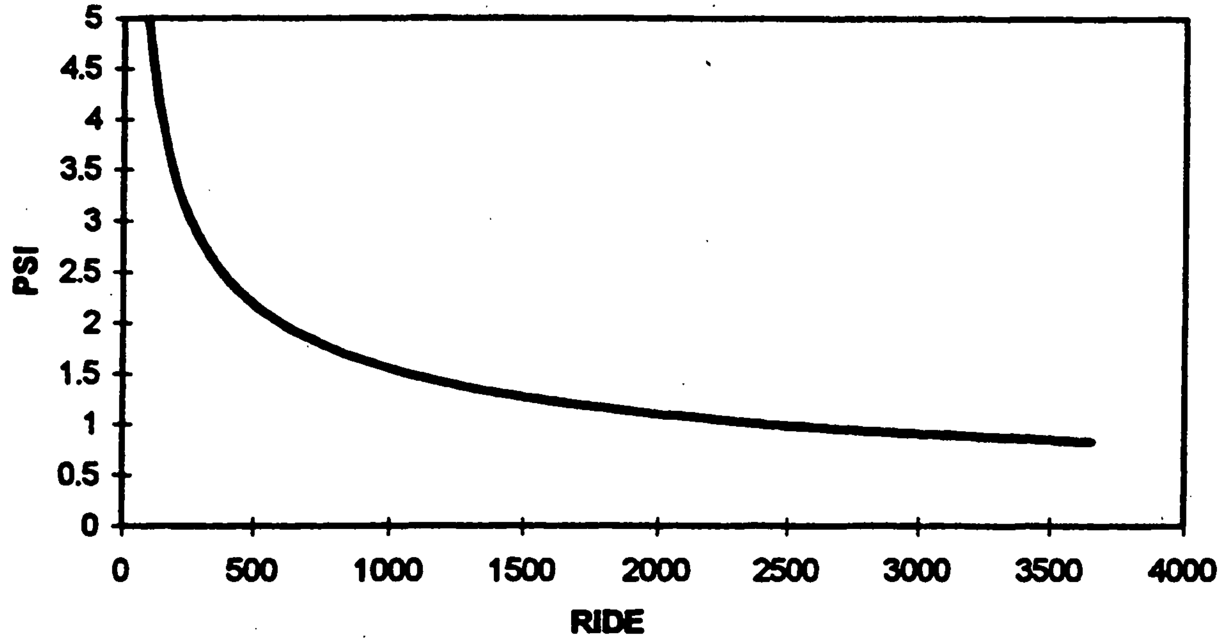

Figure 4. Relationship between RIDE (in mm/sec^2) and PSI for rigid pavements.

LIFE-CYCLE COST ANALYSIS (LCCA) METHODOLOGY

A method for conducting LCCA was developed to allow incorporation of the user-cost relationships, developed in this research, into network-level and project-level decisions. Software designated PID (Pavement Investment Decisions) was also developed to facilitate implementation of the LCCA method. The software considers user and agency costs and could accept direct input from a pavement management system. It includes several input and calculation modules and an output module. Input modules pertain to pavement management database description, pavement classification, pavement distress, new or rehabilitated pavement performance, unit costs, and economic analysis. The calculation modules estimate the costs associated with vehicle depreciation, vehicle maintenance and repair, tires, cargo damage, driver/passenger health and injury, and user delays. The output module provides information that would be useful for a network- or project-level application. For example, network-level information may identify projects requiring further analysis (e.g., because of excessive pavement distress or roughness or because of an unexpected cost/benefit ratio). Project-level information would identify all data elements needed for budgetary purposes. To facilitate its use, the LCCA method has been presented on a CD-ROM.

CONCLUSIONS

The need to develop pavement-involvement decision methodologies that incorporate user costs, condition measures, and agency inputs and can also be integrated into pavement management systems has been recognized by the state highway agencies and other organizations. This research presented on a CD-ROM a method for conducting LCCA in support of pavement-investment decisions. The method incorporates a new pavement roughness index, RIDE, that may have some advantages over the commonly used IRI. The method incorporates relationships between pavement roughness and user costs that were developed on the basis of limited data. In addition, some of the data required for the method's application may not be readily available. For these reasons, further calibration and data collection may be required to ensure validity of the procedure's outputs.

FINAL REPORT

The agency's final report, titled "Methodology to Improve Pavement Investment Decisions," gives a detailed account of the project, findings, and conclusions, including a CD-ROM for conducting the LCCA method developed under this project. The report, which was distributed to NCHRP sponsors (i.e., the state departments of transportation), is available for loan on request to the National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, DC 20418. The report and the CD-ROM can also be found at the research agency's website: www.ce.wsu.edu/cegeotechnical/gtresearch/gtresearch.htm

REFERENCE

1. Paterson, W. D. O. "International Roughness Index: Relationship to Other Measures of Roughness and Riding Quality," *Transportation Research Record 1084*. Transportation Research Board, National Research Council, Washington, D.C. (1986), p. 49–58.

ACKNOWLEDGMENTS

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These **Digests** are issued in order to increase awareness of research results emanating from projects in the CRP. Persons wanting to pursue the project subject matter in greater depth should contact the Cooperative Research Programs Staff, Transportation Research Board, 2101 Constitution Ave., NW, Washington, DC 20418.

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