NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT **308**

PAVEMENT ROUGHNESS AND RIDEABILITY FIELD EVALUATION

TRANSPORTATION RESEARCH BOARD
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REPLY TO: Robert J. Reilly
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September 9, 1988

TO: CHIEF ADMINISTRATIVE OFFICERS
STATE HIGHWAY AND TRANSPORTATION DEPARTMENTS

Subject: National Cooperative Highway Research Program Report 308, "Pavement Roughness and Rideability - Field Evaluation," the Final Report on Project 1-23(2) of the FY '87 Program

I am enclosing one copy of the final report resulting from research administered by the National Cooperative Highway Research Program. The research was conducted by JMJ Research of Newton, Pennsylvania. In accordance with the selective distribution system of the Transportation Research Board, all persons who have selected the transportation mode(s) and subject area(s) listed below will receive copies of this document.

The NCHRP staff has provided a foreword that succinctly summarizes the scope of the work and indicates the personnel who will find the results of particular interest. This will aid in the distribution of the report within your department and in practical application of the research findings. The report presents a validated new method of assessing pavement roughness represented by a value called the pavement rideability number (RN), which is presented for consideration for adoption as an AASHTO standard

Mode(s)	Area(s)
Highway Transportation	Planning Pavement Design and Performance Maintenance

Sincerely,

Thomas B. Deen
Executive Director

Enclosure

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT **308**

PAVEMENT ROUGHNESS AND RIDEABILITY FIELD EVALUATION

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JMJ Research
Newtown, Pennsylvania

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:

Planning
Pavement Design and Performance
Maintenance
(Highway Transportation)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. JULY 1988

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP REPORT 308

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NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation officials, or the Federal Highway Administration, U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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FOREWORD

By Staff
Transportation Research Board

This report describes the results of a field evaluation to validate a new method for assessing pavement roughness developed in an earlier study and documented in *NCHRP Report 275,* "Pavement Roughness and Rideability." The pavement rideability number (RN) is predicted from the physical measurement of the pavement profile by means of a transform or relationship between the profile measurement and subjective ratings of the pavement rideability. Also included in the report are models to determine the need for pavement repair based on the RN computed from the pavement profile. An accurate, valid, and uniform measure of pavement surface ride characteristics is presented for consideration for adoption as an AASHTO standard. The findings will be of particular interest to highway personnel responsible for pavement management, rehabilitation, and reconstruction; for collection, analysis, and reporting data on pavement surface characteristics; and for testing and research activities.

The roughness and rideability of pavements are embodied in a concept called serviceability developed during the AASHO Road Test in the late 1950s. Serviceability is defined as the ability of a pavement to serve the traveling public. During the road test, a pavement serviceability rating panel rated many sections of pavements; this was followed by field measurements of variations in profiles, as well as cracking and patching. Correlation of the subjective and objective data produced a formula whereby pavement measurements could be used to compute a Present Serviceability Index (PSI). Currently, the PSI is generally derived from measurements made with response-type road roughness measuring systems. However, the PSI correlates only approximately with the original panel rating concept and often considers pavement defects as well as rideability. For pavement management, both at the network and project levels, it is desirable to have separate measures for rideability and surface defects. Therefore, there is a need for a valid method of assessing pavement roughness that correlates well with the subjective panel rating or the public's perception of rideability.

A previous NCHRP research project produced a tentative method for converting objective measures of pavement roughness (longitudinal profiles) to subjective measures of the public's perception of rideability (mean panel ratings) expressed as the rideability number (RN). Through algorithms developed, NCHRP Project 1-23 researchers found that longitudinal roughness as measured with a profilometer in the band of frequencies between 0.125 and 0.630 cycles per foot correlates well with the mean panel rating for all pavement types. The results of that earlier project were published as *NCHRP Report 275,* "Pavement Roughness and Rideability."

The objective of this field-evaluation project (NCHRP Project 1-23(2)) was to validate the form and accuracy of the relationships developed in the previous project, which were based on data from only one state (Ohio), by extending the process to four additional states.

Panel rating data and profiles were collected on 282 pavement sections in New Jersey, Michigan, New Mexico, and Louisiana—as well as those in Ohio. The results documented in this report are based on combined data from all five states. These findings show the relationships between physical profile measurements and the subjective panel ratings of rideability, between Mays Ride Meter measurements and the panel ratings, and between panel ratings and subjective appraisals of a pavement's need for repair. RN, which is defined as the rideability number, is computed from transforms that predict rideability from profile index measurements. These transforms were initially developed under NCHRP Project 1-23 and refined during this project. The transforms recommended for use in determining pavement RN are shown to be accurate and valid over a wide range of roughness and can be used for any paved surface.

The validated procedure described in this report can be used to assess the ride characteristics of pavements, assisting highway agencies to (1) evaluate newly constructed pavements, (2) measure and report totally comparable rideability and roughness data, and (3) provide information for decisions on pavement rehabilitation or reconstruction. This procedure is recommended for consideration by AASHTO as a standard for measuring pavement rideability number (RN), similar to the standard previously adopted for measuring the friction number of pavement surfaces.

CONTENTS

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The research reported herein was performed under NCHRP Project 1-23(2) by JMJ Research; Michael S. Janoff was the principal investigator. Dr. Gordon F. Hayhoe, D & S Consulting, performed the analyses on the profile data. Mr. Lawrence E. Decina, KETRON, Inc., assisted with the state planning process, including site selection and marking and route formation and logistics, and with report preparation. Mr. Elson Spangler, Surface Dynamics, Inc., performed the analyses on the Ohio and Texas models and directed the profilometry work in Michigan, using the Minnesota Profilometer, and PSU collected the profile data in New Jersey, New Mexico, and Louisiana, using their profilometer.

Grateful acknowledgment and appreciation is made to the transportation departments of New Jersey, Michigan and Ohio, the New Mexico Highway Department and the Louisiana Department of Transportation and Development for their cooperation and assistance in supplying data, material and equipment, for performing many of the measurements and providing extensive staff assistance, and to the Minnesota Department of Transportation for allowing us to use their profilometer in Michigan. Appreciation is also made to Richard Wood and Ricardo Barros of the New Jersey DOT, and Dr. Alan Sockloff of Temple University, for their suggestions and assistance in performing the multitude of statistical analyses.

PAVEMENT ROUGHNESS AND RIDEABILITY
FIELD EVALUATION

SUMMARY

During the AASHO Road Test, serviceability was defined as the ability of a pavement to serve the traveling public. The most commonly used objective measure of serviceability, the Present Serviceability Index (PSI), is derived from measurements made with response-type road roughness measuring systems (RTRRMS). However, this index only approximates the original panel rating concept and is recognized as having shortcomings. Whether the public's perception of serviceability is the same today as it was 25 years ago is questionable; vehicles, highway characteristics, and travel speeds have changed, and serviceability is not exclusively a measure of pavement rideability or ride quality, but is confounded by the inclusion of factors for surface defects.

For management of pavement inventory it would be better to have separate measures of rideability and surface defects. Therefore, there is a need to develop a new pavement rating scale to ensure that objective pavement evaluations are directly and reasonably related to the public's perception of rideability.

The objectives of NCHRP Project 1-23 were to develop such a rating scale, develop transforms that relate pavement profiles to this scale and show how roughness statistics produced by various RTRRMS relate to this scale.

The major result of that study, based on data from one state—Ohio, was that for all paved surfaces, longitudinal roughness measured with a profilometer in the band of frequencies between 0.125 and 0.630 c/ft (10 to 50 Hz at 55 mph) was found to be highly correlated with mean, subjective panel ratings (MPR) measured on a scale of 0 to 5. The regression equation that related MPR to these profile measurements accounted for over 88 percent of the variance. The longitudinal roughness measure, PI, is defined as the square root of the mean square of the profile height in the specified frequency band.

For bituminous surfaces, MPR was also found to be highly correlated with Mays meter measurements (MRM), but for other surfaces the correlations were generally found to be poor to fair. The MPR of a given surface was also found to be an accurate predictor of the public's perception of whether a surface needs repair. The effects of vehicle size, vehicle speed, panel regionality, and surface type were also determined.

NCHRP Project 1-23(2) was conducted to validate the results found in Project 1-23 (*NCHRP Report 275*) by extending the study methodology to four additional states. The objectives of this project included panel studies in the four states, designed and conducted following the same methodology developed in Project 1-23, to verify the form and accuracy of the transforms developed in the former study; further evaluation of the effects of surface type, road class, panel regionality, and vehicle size on these transforms; and comparison of alternative models of profile roughness, including a model based on one wheelpath instead of two wheelpaths to predict MRP.

To meet these objectives six tasks were performed. In the first, the additional states were selected in four different areas of the United States. In the second task, planning

was accomplished in each state to select and mark sites, form a route, and select and schedule the rating panel. The participating state personnel were also trained. In the third task the panel rating studies were performed and profiles were measured on each test section.

The fourth task included data analysis to derive MPR and PI for each test section; determine the band of frequencies where MPR and PI are most highly correlated; develop transforms between MPR and PI for each state separately and all five combined for this frequency band (including Ohio from Project 1-23); develop transforms between MRM measurements and MPR and between MPR and the need for repair ratings (NR); determine the effect of surface type, road class, vehicle size, and panel regionality on these transforms; and compare the alternative models of roughness, including the one wheelpath model, with PI.

The fifth task was concerned with deriving the results, conclusions, and recommendations, including the preferred transforms between PI and MPR, between MRM and MPR, and between MPR and NR. The effects of vehicle size, surface type, road class, panel regionality, and alternative roughness models were used to develop recommended uses, potential applications, and suggestions for further research. The final (sixth) task included preparation of all reports.

The major conclusions of this research are that subjective appraisals of pavement rideability (MPR) can be accurately predicted from physical measurements of the pavement's profile made in a specific frequency band, and the transform that predicts rideability from these profiles measurements is accurate and valid for any paved surface in any state. The transform accounts for 86.5 percent of the variance and is applicable to all three surface types (bituminous concrete, portland cement concrete, and composite) and both classes of road (interstate/other). It is based on measurements made in five different and diverse states on 282 pavement sections spanning a range of rideability from 0.4 to 4.5 on a 0 to 5 scale.

RN, which is defined as the rideability or ride number of a pavement section, and is computed from this transform, is an approximation of the true MPR. RN therefore equals MPR plus a small error term resulting from this approximation. MPR and RN are comparable to PSR and PSI, respectively, from the original AASHO road tests.

The equation for computing RN, the approximation of true MPR, from PI can be derived in two different forms; a linear equation

$$\mathrm{RN} = -1.47 - 2.85\log(\mathrm{PI}) \quad (= \mathrm{MPR} + \text{error}) \tag{1}$$

and a nonlinear equation

$$\mathrm{RN} = 5e^{-11.72\mathrm{PI}^{0.89}} \quad (= \mathrm{MPR} + \text{error}) \tag{2}$$

both of which are accurate and valid within the range of the data collected in this study. The nonlinear equation extends the prediction to the entire range of roughness, although it is no more accurate or valid than the linear equation within the range of our data, which encompasses nearly all paved surfaces.

Other important conclusions were that the band of frequencies where roughness is most highly correlated with subjective appraisals of rideability was found to be the same for all five states: 0.125 to 0.630 c/ft (10 to 50 Hz at 55 mph); there was no effect of surface type, road class, or vehicle size on the transforms between PI and MPR; and the effect of regionality on these transforms was found to be very small, especially when comparing the preferred transform between PI and MPR, based on the combined data from all five states, to each of the individual state transforms between PI and MPR.

Furthermore, PI derived from profiles measured in one wheelpath can be used as accurately as PI derived from two wheelpaths to predict MPR; therefore, it appears desirable to develop an instrument that would measure profiles only in one wheelpath in this same band of frequencies, derive PI and compute RN, and, thereby, provide an efficient method for obtaining accurate and totally comparable rideability data in all states.

Finally, the transforms between MRM measurements and MPR are generally accurate and valid only for bituminous surfaces—for other surface types and all types combined, the accuracy often falls to low levels; the alternative models of profile roughness either are equivalent to PI or are not as accurate as PI in predicting MPR; and the public's subjective perception of whether a specific road section needs repair (NR) can be accurately predicted from MPR (or alternatively from RN) using the transform:

$$NR = 131.7 - 33.9RN \tag{3}$$

or from PI using the transform

$$NR = 181.5 + 96.6\log(PI) \tag{4}$$

therefore, based only on longitudinal roughness measures (PI), one can compute RN (i.e., predict MPR—from Eqs. 1 or 2) and determine the exact percentage of the driving public that thinks the road should be repaired (NR from Eq. 3). This last transform, however, is sensitive to surface type, road class, and extreme economic conditions existing in a specific state.

The major applications of these conclusions include (1) the proposed use of the preferred transforms as a uniform method for reporting rideability data, derived from profile measurements of longitudinal roughness for all paved surface types and all road classes in all states, that can be directly used by highway agencies to assist them to determine when existing pavements should be repaired and to evaluate newly constructed pavements; (2) the proposed development and potential use of a profile index or ride quality meter that would measure profiles in only one wheelpath, accurately derive PI and compute RN, and be much less expensive than a profilometer and far simpler and more efficient to use; and (3) the use of the transform between MPR and NR to assist highway agencies to determine the point at which specific road sections require improvement.

Suggested further research includes the development of a user's manual for implementing the PI concept, and development and testing of the single wheelpath instrument for measuring profiles, deriving PI, and computing RN.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

BACKGROUND

During the AASHO Road Test, serviceability was defined as the ability of a pavement to serve the traveling public. The most commonly used objective measure of serviceability, the Present Serviceability Index (PSI), is derived from measurements made with response-type road roughness measuring systems (RTRRMS). However, this index only approximates the original panel rating concept and is recognized as having shortcomings. Whether the public's perception of serviceability is the same today as it was 25 years ago is questionable; vehicles, highway characteristics, and travel speeds have changed, and serviceability is not exclusively a measure of pavement rideability, but is confounded by the inclusion of factors for surface defects.

For management of pavement inventory it would be better to have separate measures of rideability and surface defects. Therefore, there is a need to develop a new pavement rating scale to ensure that objective pavement evaluations are directly and reasonably related to the public's perception of rideability.

The overall objective of NCHRP Project 1-23 was to develop such a rating scale. The specific goals of that study were to: (1) develop a scale that accurately reflects the public's perception of pavement roughness, (2) develop transforms that relate pavement profiles to this scale, and (3) show how roughness statistics produced by various response-type road roughness measuring systems relate to this scale (*1*, p. 3)

The major result of Project 1-23 was that longitudinal roughness, measured with a profilometer, in the band of frequencies between 0.125 and 0.630 c/ft (10 to 50 Hz at 55 mph) is highly correlated with mean, subjective panel ratings of rideability (MPR), measured on a scale of 0 to 5, for all three surface types. The transform (regression equation) that relates longitudinal roughness in this frequency band to MPR accounts for more than 88 percent of the variance. RN, defined as the rideability, or ride, number of a pavement section, which is computed from this regression equation, is an approximation of the true MPR. RN, therefore, equals MPR plus a small error term resulting from the approximation. The equation for computing RN—the approximation of true MPR—from profile roughness measurements was found to be:

$$RN = -1.74 - 3.03\log(PI)\ (= MPR + error) \quad (1)$$

where PI, or profile index, is defined as the square root of the mean square of the profile height in the specified frequency band (*1*, p. 2). MPR is similar to PSR (Present Serviceability Rating) because they are both derived from panel ratings and RN is comparable to PSI because they are both derived from regression equations that relate physical roughness measures to panel ratings. However, RN is not equivalent to PSI because RN excludes measures of surface defects.

For bituminous surfaces, MPR was also found to be highly correlated with MRM measurements, but for portland cement or composite surfaces, or all three surfaces combined, the correlations were found to be poor to fair.

The MPR, or RN approximation, of a given surface is also an accurate predictor of the public's subjective perception of whether a surface needs repair. The percentage of the driving public that believes a given surface requires repair was found to be:

$$NR = 132.6 - 33.5\ RN \quad (2)$$

Therefore, based only on longitudinal roughness measures (i.e., PI), one can compute both RN and NR.

A number of recommendations resulted from NCHRP Project 1-23:

1. The need for the collection and analysis of profile and panel rating data from more than one state to validate the form and accuracy of the preceding equations for a wider area of the United States (the results of Project 1-23 were based on data collected in only one state, Ohio).
2. The use of a broader range of vehicle types for evaluation of rideability (only two vehicle sizes were used in Project 1-23).
3. Additional analyses to determine if the profile from only one wheelpath can be used instead of the profile from two wheelpaths to compute RN and, hence, predict the true MPR.
4. Further analyses of the effect of regionality or panel residence to determine if one equation for computing RN from PI can be applied on a national basis or if each state or area will require its own equation.

OBJECTIVES OF NCHRP PROJECT 1-23(2)

Based on the results of Project 1-23, the recommendations for further research that arose from that project, and recent research in Ohio (*2*), Texas (*3*), and Michigan (*4*), the objectives of NCHRP Project 1-23(2) were formulated to include:

1. Additional panel studies in 3 to 5 other states.
2. Further evaluation of panel regionality.
3. Use of a broader range of vehicles.
4. Comparison of PI derived from one wheelpath with PI derived from two wheelpaths in computing RN, and predicting MPR.
5. Comparison of alternative models of pavement roughness (Ohio, Texas, and Michigan models) with PI.

RESEARCH APPROACH

To meet the objectives of the study, a research plan was formulated and adopted which consisted of six tasks. In the first task the objective was to select four states in four different areas of the United States in which panel rating studies were to be conducted exactly the same as the one conducted in Project 1-23.

The second task consisted of state planning for each of the four states and included (1) site selection and marking, RTRRMS measurements, route formation and preparation of driving instructions; (2) selection and scheduling the rating panel; (3) selection and training of drivers and selection of vehicles; (4) training of state personnel; and (5) selection of a central meeting facility and addressing all the miscellaneous tasks required for the panel rating experiments. Additional effort included planning for the profilometry.

The third task included conducting the panel rating experiments and collecting the profile data, following the exact same procedures that were used in Project 1-23.

The fourth task consisted of analysis of the panel rating data to obtain MPR's; analysis of the profile data to derive PI's, identify the most important frequency bands, and derive the alternative model formulations of roughness; development of statistical transforms between PI and MPR, between MRM and MPR, and between MPR and NR; and evaluation of alternative model formulations, one versus two wheelpaths, alternative vehicle sizes, regionality, and the effect of pavement type and road class.

In the fifth task the results, conclusions, and recommendations were derived, including: preferred transforms between PI and MPR, between MRM and MPR, and between MPR and

NR; effects of vehicle size on MPR; effect of panel regionality on the form, accuracy, and validity of the transforms between PI and MPR and between MPR and NR; effect of one versus two wheelpaths on the form, accuracy and validity of the transforms between PI and MPR; comparative effectiveness of the alternative models in predicting MPR from roughness and the relationships between the models; effect of surface type and road class on the transforms between PI and MPR, between MRM and MPR, and between MPR and NR; recommended uses; and suggested further research.

The last task consisted of the preparation of all reports: monthly, quarterly, working plan, draft final and final, and preparation of responses to panel comments on any of these reports.

State Selection

The objective of this task was to select four states in which panel rating studies were to be performed, based on: (1) willingness of the state to provide technical assistance, panel members, drivers, vehicles, meeting facilities, and data; (2) availability and quality of pavement roughness inventory data; (3) availability of a sufficient number of roadway sections of all three surface types, spanning a wide range of roughness, within a well-defined geographic region; and (4) location, climate, topography, population density, and so forth, of the state.

A survey questionnaire was designed to solicit the required information, and states were selected from all regions of the United States and were contacted by telephone to obtain the required information.

State Planning

There were three primary objectives of this task: (1) assist (train) state in selecting sites, route, panel, drivers and vehicles; and develop a data collection schedule; (2) prepare data collection forms and instructions; and (3) finalize site selection, route formation, panel selection and scheduling, driver and vehicle selection, data collection schedule and driver training.

Each of the four states (plus the other states that were contacted) were asked to send samples of their inventoried roughness data and maps of their state so that preliminary site selection and route formation could be started.

The planning and data collection for each individual state was quite similar and will be described only once.

A preliminary visit was made by the Principal Investigator to obtain additional roughness data and maps locating the potential test sections, brief the individual state staff members on the project objectives, and drive over many miles of roadway to assess the types, locations and roughness levels of potential test sections. A large number of preliminary test sections were selected, including all three surface types, within a radius of about 100 miles of the state capital. The individual states then continued the planning process.

A second trip was made to further select test sections, begin marking the test sections, and begin forming a preliminary test route. Vehicles were selected, work began on selecting the panel members, a meeting facility was identified for giving panel instructions, and drivers were selected and given preliminary training and instructions. The individual states then completed the planning process and a final trip was made to each of the four states to check the route; finalize the data collection schedule, maps and driving instructions; prepare panel rating instructions and rating forms; and complete all logistical details. Profilometry was also scheduled.

Data Collection

The experimental design and protocol followed the same procedures as those employed in Project 1-23. The design included the following: (1) Thirty-six test subjects were selected who were all employees of the state and had a wide range of driving experiences. An additional 12 test subjects were used in New Jersey for the vehicle size experiment. (2) Four identical vehicles were used—K-cars in all but Michigan, where Chevrolet Cavaliers were used. A full-size Ford LTD was used in New Jersey for the vehicle size experiemnt. (3) Sixty-five to 89 test sections, spanning a wide range of roughness and including all three surface types (bituminous concrete—BC, portland cement concrete—PCC, and composite—comp), were marked at the beginning, end, and 0.2 miles upstream with paint, tape, or wooden stakes. (4)The Weaver/AASHO rating scale was selected, including the secondary needs repair rating. (5) Uniform instructions were given to both the drivers and the panel.

The experimental protocol, or data collection procedures, included the following:

1. Raters met with experimenters at the central site.
2. Rater forms were distributed—precoded and ordered by route.
3. Panel instructions were read and questions were answered uniformly by the Principal Investigator.
4. Teams were formed (three raters and one driver).
5. Seat positions were assigned—fixed for all ratings.
6. Raters were driven to the first site.
7. Speed for the site was set by the driver.
8. Site was rated.
9. Forms were collected after the site was rated.
10. Steps 7, 8, and 9 were repeated for each additional site.
11. Breaks were taken as necessary (at least every 2 hours).
12. Raters returned to the central site when the route was completed and the forms were collected.
13. The second day repeated the first except no panel instructions were given.

The panel rating forms were compiled on a daily basis and checked for completeness. The data were reduced by measuring the distance to the nearest $\frac{1}{10}$ in. of the rating mark from the bottom of the scale. The data on each form were then entered into the computer for further analysis.

Profiles were measured by the PSU profilometer, except in Michigan where the Minnesota instrument was used because it was available at little cost to the research team. MRM measurements were made in New Jersey and Louisiana.

Data Analysis

The following analyses were planned:

1. Reduction of the panel rating data to derive MPR's and NR's for each test section.

2. Analysis of the profile and RTRRMS data to derive PI in each one-third octave (frequency) band, PI in all possible combined, continuous frequency bands, and MRM indexes.
3. Correlation of PI with MPR for the individual one-third octave bands and for the continuous combinations of one-third octave bands to determine where the correlation between PI and MPR is highest in each state.
4. Derivation of transforms relating PI to MPR for the bands of highest correlation in each state and in the five states combined (including Ohio).
5. Derivation of transforms relating MRM to MPR in each of the three states individually (Ohio, New Jersey, Louisiana) and all three states combined.
6. Derivation of transforms relating MPR to NR for each state and for the data from all states combined.
7. Determination of the effect of vehicle size on MPR in one state.
8. Determination of the effect of surface type and road class on the transforms relating PI to MPR, MPR to NR, and MRM to MPR.
9. Determination of the effect of regionality or panel residence on the transforms relating PI to MPR and MPR to NR.
10. Determination of the relationships, differences, and similarities between alternative roughness models and PI.
11. Determination of the effect of the use of one wheelpath instead of two on the analyses in steps 2, 3, and 4, in one state.

CHAPTER TWO

FINDINGS

STATE SELECTION

The states contacted included:

1. NE: Connecticut (CN), Massachusetts (MA), New Jersey (NJ).
2. SE: Alabama (AL), Georgia (GA), Florida (FL), Louisiana (LA).
3. SW: Arizona (AZ) and New Mexico (NM).
4. NW: Oregon (OR) and Washington (WA).
5. NC: Michigan (MI), Wisconsin (WI), Missouri (MO).

Each state provided the information described in the survey found in Appendix A. The responses are summarized in Table 1.

Based on these responses, New Jersey, Michigan, New Mexico, and Louisiana were selected as the best (primary) states. Of the remaining states, Florida, Alabama, Oregon, Massachusetts, and Arizona have primarily bituminous surfaces and were considered only as secondary choices. Missouri does not collect roughness data, Wisconsin conducted its own study—including as one facet an analysis of rideability and roughness—and Washington was not interested in participating. Connecticut and Georgia both appeared able to provide most of the necessary information and assistance, but New Jersey and Louisiana still seemed to be better choices for the experiments in the northeast and southeast regions of the United States.

The four primary states selected represented: four diverse areas of the United States; four very different climates (ranging from hot to cold, dry to humid, and including both rain and snow and a range of freeze-thaw cycles); four different topographies, ranging from flat through rolling to mountainous; and four different population densities, ranging from very high to very low; each also had much interest in participating in the study.

Four additional states were selected as backup states in case one of the primary states was unable to participate at a later time or was unable to fully meet the state selection criteria summarized in Chapter One. These backup states included Connecticut (NE), Georgia (SE), Arizona (SW), and Oregon (NW).

Table 1. State summary.

ITEM	STATE													
	NJ	CT	MA	LA	GA	FL	AL	NM	AZ	MI	WI	OR	WA	MO
COOPERATE	Y	?	?	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	
PROF.HELP	Y	Y	?	Y	Y	Y	Y	Y	Y	Y		Y		
PANEL	Y	?	?	Y	?	N	?	Y	Y	Y		Y		
DRIVERS	Y	Y	?	Y	?	Y	?	Y	Y	Y		Y		
VEHICLES	Y	Y	Y	Y	?	?	?	Y	Y	Y		Y		
DEF.MAINT	Y	Y	Y	Y	?	Y	?	Y	N	NC		NC		
SURFACES														
BC	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y		
PCC	Y	Y	F	Y	Y	F	N	Y	F	Y		F		
COMP	Y	Y	Y	Y	Y	F	N	Y	F	Y		F		
DATA	S	S	S	S	S	S	S	A	S	S		S		N
METER	R	R	R,O	R	R	R	R	O	R	P		R,O		
COSTS	N	?	?	N	N	N	?	N	N	N		N		
PROBLEMS	N	Y	Y	N	Y	Y	Y	N	Y	N	*	Y		Y

*Conducting their own panel rating study.

Notes: Y = yes, N = no; ? = unknown; F= few; NC = not if contracted; S = state; A = all; R = RTRRMS; P = profilometer; O = other.

STATE PLANNING

The planning process, described in Chapter One, was successfully implemented in each of the primary states. No problems were encountered other than minor schedule changes.

Panels of 36 persons were scheduled (48 in New Jersey—including the vehicle size experiment) for the following time periods: New Jersey—May/June; Michigan—July/August; New Mexico—September/October; and Louisiana—November/December.

Two day routes were developed for each state, beginning and ending on both days at the state transportation offices. The routes consisted of test sections of all three surface types, as described in Table 2.

The panel rating form and panel rating instructions are included in Appendix B, and examples of route maps, driving instructions, and the necessary details for conducting a panel rating study are included in Appendix E.

In New Jersey, it was possible to compare the distribution of roughness in the sample of selected test sections with the distribution of roughness in the entire state highway network (defined in terms of Mays meter measurements). As illustrated in Figure 1, the test sample is a valid representation of the entire state highway system. Similar comparisons were not possible in the other states.

Table 2. Description of test sections.

STATE	NUMBER OF SECTIONS BC	PCC	COMP	TOTAL	RANGE OF ROUGHNESS (MPR)
NJ	22	26	22	70	1.05 - 4.25
MI	24	38	24	86	1.11 - 4.33
NM	55	19	14	89	0.40 - 4.45
LA	19	27	19	65	1.20 - 4.47

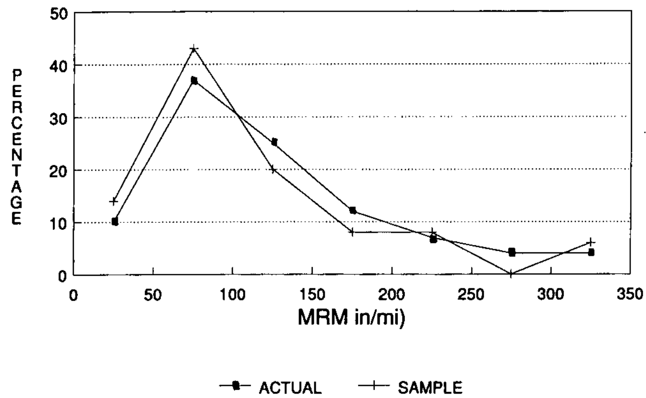


Figure 1. New Jersey data.

DATA COLLECTION

Based on the experimental design and protocol described in Chapter One, panel ratings, need-repair ratings, and profiles were collected in each state. In addition, Mays meter measurements were made in New Jersey and Louisiana, and quarter-car indexes (simulated MRM) were computed in Michigan.

The raw data for each of the four states, plus Ohio, are presented in Appendix C. A number of test sections were lost in each state because of road maintenance, missing or covered site markings, sun glare, dirt or debris on the road, and other minor problems. The actual data available for analysis—including MPR, NR, and profiles—for test sections in each state were:

1. NJ: 46 (18 BC, 18 PCC, 10 Comp)
2. MI: 68 (21 BC, 27 PCC, 20 Comp)
3. NM: 64 (41 BC, 10 PCC, 13 Comp)
4. LA: 52 (14 BC, 24 PCC, 14 Comp)
5. OH: 52 (17 BC, 18 PCC, 17 Comp)

The mean panel rating data in each state were generally similar in range, except for the one very rough section in New Mexico (MPR = 0.4) (see Table 2).

The results of NCHRP Project 1-23 were derived from profiles measured by the Ohio profilometer, which is exactly the same as the Minnesota profilometer used in Michigan. However, the profiles in the remaining states were collected using the Pennsylvania State University (PSU) instrument outfitted with lasers as the measuring device. It was, therefore, necessary to correlate the PSU unit with the Ohio unit to ensure that the roughness data (i.e., PI) collected in the five states were comparable.

This was accomplished by measuring the profiles of 12 different test sections in Ohio, using both the PSU and Ohio instruments, and then performing a linear regression analysis on the two sets of PI values derived from the two sets of profiles. The regression equation derived from this analysis:

$$\text{OHIO} = 0.817\text{PSU} \qquad (r = 0.94) \qquad (3)$$

was used to adjust the PI data from New Jersey, New Mexico, and Louisiana to enable making direct comparisons between the five states, retaining the form of the transforms between MPR and PI developed in Project 1-23 (the actual equation was OHIO $= -0.0001 + 0.8169*$PSU, which was rounded to two decimal places for the analyses).

DATA ANALYSIS

The analyses described in Chapter One are reported here, except for the first two items, derivation of NR, MRM, quarter-car index, and PI, the results of which are given in the tables of Appendix C.

Mean Panel Ratings

The mean panel ratings, MPR, for each test section were derived by adding the individual panel ratings and dividing the total by the number of panel raters. Standard deviations were also computed, scatter graphs were prepared for many of the individual test sections, and outliers (very few) were identified and deleted from further analyses.

In general, the standard deviations for each test section were small in comparison to the MPR for that test section, indicating good agreement between the raters. In addition there were no obvious differences between states for test sections with similar MPR's.

One-Third Octave Analysis

The results of the one-third octave analyses are presented in Figure 2 for each of the five states for all surfaces combined. Similar figures for the individual surface types are presented in

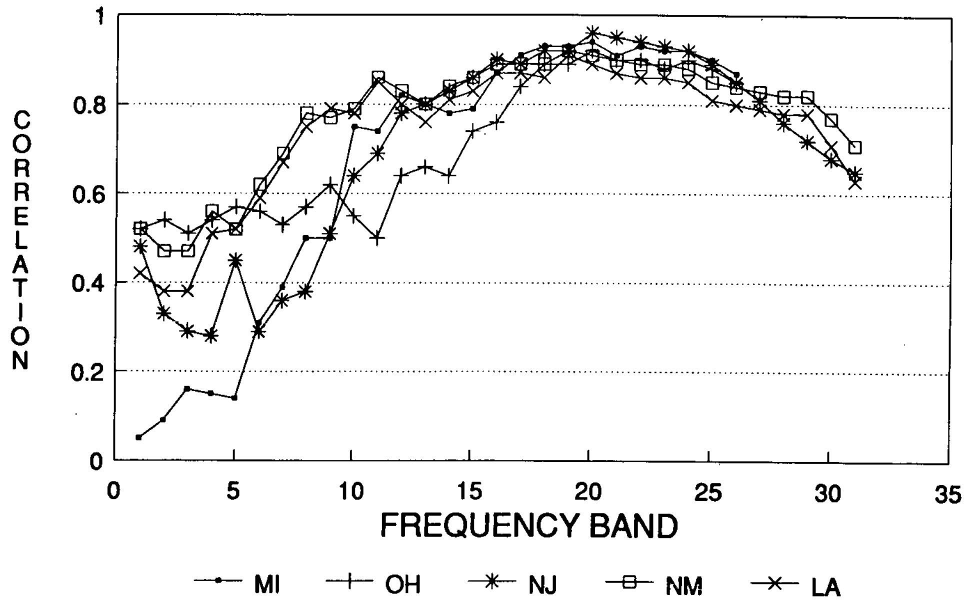


Figure 2. MPR vs. PI; one-third octave bands for five states.

Figures D-1 through D-5 of Appendix D. The one-third octave analysis will be described here only for all surfaces combined. The effect of surface type on this analysis will be covered in the section of this chapter dealing with surface type and road class.

On the basis of the results shown in Figure 2, the region of highest correlation between PI and MPR appears to be the band of frequencies found to be best for Ohio in Project 1-23: 0.125 to 0.630 c/ft (frequency (c/ft) = 1/wavelength (ft)) (*1*, p. 2). Outside of this band the correlations between MPR and PI fall off to low values, indicating little relationship between the two variables. The differences between the five states in the one-third octave frequency bands below 0.125 c/ft (i.e., below band 18), as shown in Figure 2, are caused by these poor correlations and the resulting large variations.

This graphic analysis was corroborated by a series of regression analyses that related PI in all continuous, combinations of one-third octave frequency bands, with MPR and found that the correlation did not significantly improve if any other band was chosen. For example, Figure 2 shows that for New Jersey the band of frequencies where the correlation between PI and MPR is better than 0.85 (present study criteria) is slightly larger than the band identified in Project 1-23 (actually including two additional one-third octave bands). However, if PI is correlated with MPR for this slightly larger band, the correlation coefficient does not improve significantly (the increase in r is only 0.03 percent). Similar results were found in the other states. Therefore, for all further analyses relating PI to MPR, the frequency band 0.125 to 0.630 c/ft is used.

Table 3. PI vs. MPR; all surfaces combined.

STATE	TRANSFORM	CORRELATION COEFFICIENT
OH	MPR = -1.74 - 3.03Log(PI)	-.94
	MPR = $5e^{-12.51PI^{0.91}}$	----
NJ	MPR = -1.76 - 3.15Log(PI)	-.97
	MPR = $5e^{-12.65PI^{0.94}}$	----
MI	MPR = -1.85 - 3.15Log(PI)	-.95
	MPR = $5e^{-14.73PI^{0.94}}$	----
NM	MPR = -1.59 - 2.77Log(PI)	-.96
	MPR = $5e^{-13.36PI^{0.88}}$	----
LA	MPR = -1.60 - 2.96Log(PI)	-.90
	MPR = $5e^{-15.60PI^{0.97}}$	----
ALL 5 STATES COMBINED	MPR = -1.47 - 2.85Log(PI)	-.93
	MPR = $5e^{-11.72PI^{0.89}}$	----

* Correlation coefficients for the non-linear regression equations (actually, for the underlying linear equations used to derive the coefficients in the non-linear equations) are normally the same as the correlation coefficents for the linear regression equations. Differences occur only in the second decimal place, and are typically less than 0.01.

PI vs. MPR

Table 3 summarizes the results of this analysis for all surface types combined for each of the five states individually and all five states combined for two different forms of regression: linear and nonlinear. Table D-1 of Appendix D presents the transforms for the individual surface types. The linear form is that employed in Project 1-23 (*1*, p. 2): MPR $= a + b\log$ (PI), and the nonlinear transform is MPR $= ae^{bPI^{c}}$, where $a = 5$ and b and c are derived by a nonlinear regression method suggested by Richard Weed of the New Jersey Department of Transportation, and described in Ref. 5.

The reasons for including this nonlinear technique in the present study are that the linear transform will not be accurate for very rough (MPR < 0.5) or very smooth (MPR > 4.5) roads, and the linear transform does not pass through the "correct" boundary conditions: PI = 0, MPR = 5 and PI infinitely large, MPR = 0.

This nonlinear technique forces the transform to go through the "correct" boundary conditions, and thus, from an engineering viewpoint, the transform behaves in the correct manner for all values of PI.

However, the technique does not improve the correlation between PI and MPR, nor does it provide a better prediction of MPR from PI within the range of the data of interest (i.e., MPR from about 0.4 to almost 4.5). In addition, within the range of MPR values most important, MPR = 2 to MPR = 3, where the decision to repair is made, it provides no advantages. It does, however, force the MPR to be between the values 0 and 5 no matter what value of PI is inserted in the transform, thus removing a possible type of error which could occur if very large or very small PI values were found and MPR was predicted using the linear transform.

It will be seen on the figures relating PI to MPR that in the range of roughness values of most importance the two types of transforms agree quite well, and predict almost the exact same values of MPR for a given value of PI.

Figure 3 shows the linear and nonlinear transforms for the Ohio data, and Figures 4, 5, 6 and 7 show the same results for New Jersey, Michigan, New Mexico, and Louisiana, respectively. Figure 8 illustrates the linear and nonlinear transforms for the five states combined. Appendix D presents scatter plots to illustrate the fit of the regression equations to the raw data.

It is obvious from Figures 3 to 8 that there is little practical difference between the linear and nonlinear transforms for each state separately or all five states combined. The differences between the two types of transforms are minimal, especially within the range of data, never exceeding 0.2 MPR units except at very high or very low roughness levels, normally of less importance. This is within the accuracy of the experiment itself, which is about 0.2 to 0.3 MPR units (*1*. p. 39). Both provide excellent fits of the raw data for each individual state or for all five states combined.

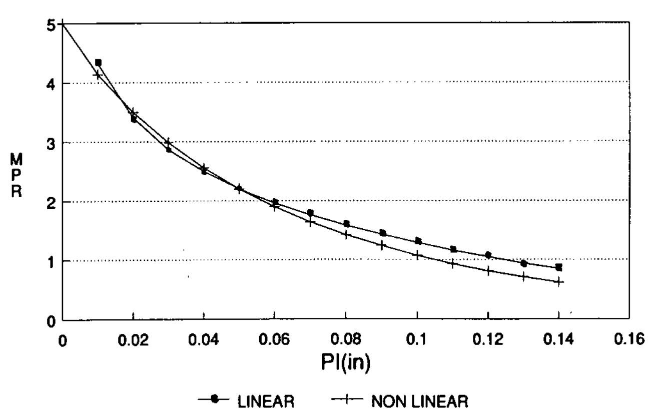


Figure 3. PI vs. MPR for Ohio.

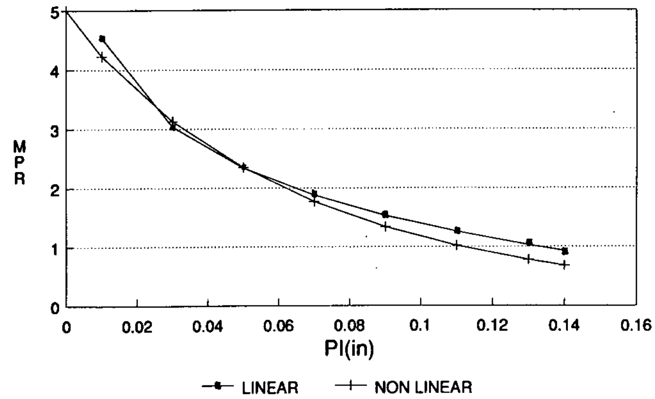


Figure 4. PI vs. MPR for New Jersey.

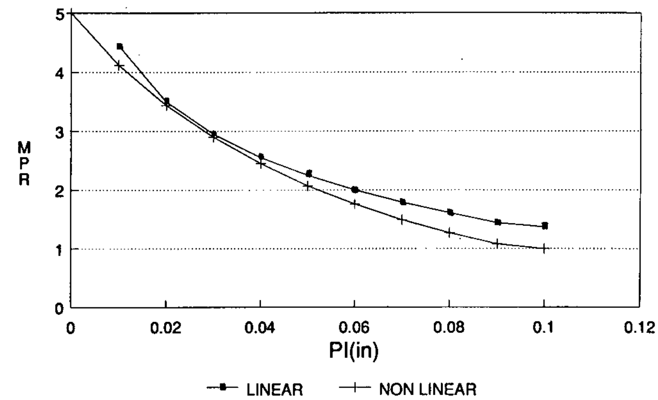


Figure 5. PI vs. MPR for Michigan.

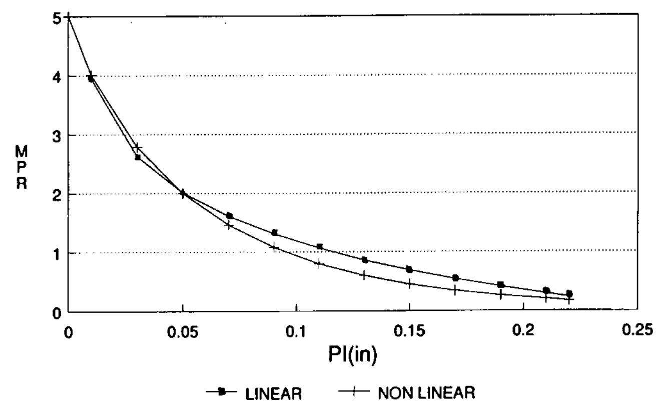


Figure 6. PI vs. MPR for New Mexico.

An analysis of the actual differences between states, and between the combined state data and each individual state, is provided in the section of this chapter dealing with regionality.

Confidence limits were computed for the linear transform for all five states combined. For a 1 percent alpha level the limits were at most ± 0.026 MPR units for roughness within the range of data (0.01 < PI < 0.22). This is much less than the error of the panel experiment.

MRM vs. MPR

In Ohio, New Jersey, and Louisiana, Mays meters were employed to measure the roughness of each of the test sections, and in Ohio and Michigan quarter-car indexes, or simulated MRM measures, were derived from the profilometer outputs for each test section. This part of the report compares the results obtained when MPR was statistically related to the MRM measurements. The results for the quarter-car simulations are very similar and are given in Table D-3 of Appendix D.

The Mays meters were those owned by the three states and were each calibrated before the measurements were made. The three meters, however, were not correlated against each other.

The statistical transforms were the same as those used for the MPR versus PI analyses: the linear regressions relating MPR to log (MRM), and the nonlinear regression relating MPR to MRM. Table 4 summarizes the results for the Mays meter for each individual state and for the combined data from the three states, for BC surfaces only. The results for other surfaces, and all surfaces combined, are summarized in Table D-2 of Appendix D, and described in the section of this chapter dealing with the effects of surface type.

Figures 9 and 10 illustrate the linear and nonlinear transforms for each of the three states and all three states combined for BC surfaces. It is quite obvious that on either of these figures the differences between the transforms are negligible and that the combined transform closely approximates either one of the other three individual state transforms. The maximum deviations between the combined transform and either individual state transform are only on the order of 0.3 MPR (at MPR < 1) and in the range of greatest interest (2 < MRP < 3) are at most 0.1 MPR unit.

PI and MRM values were correlated for the data from the three states combined, yielding a correlation coefficient of 0.88, indicating reasonably good agreement for the BC surfaces.

MPR vs. NR

The objective of this analysis was to determine the relationship between MPR and the percentage of the driving public that believes a given road section should be repaired (NR). A linear regression analysis was performed for each state separately and for four of the states combined. The effects of surface type and road class are discussed in the section of this chapter dealing with surface type and road class. Table 5 summarizes the results of these analyses for all surfaces combined.

Table 4. MRM vs. MPR; bituminous concrete surfaces.

STATE	TRANSFORM	CORRELATION COEFFICIENT
OH	$MPR = 8.66 - 2.70Log(MRM)$	-.92
	$MPR = 5e^{-0.012MRM^{0.76}}$	----
NJ	$MPR = 7.74 - 2.26Log(MRM)$	-.96
	$MPR = 5e^{-0.017MRM^{0.68}}$	----
LA	$MPR = 7.50 - 2.19Log(MRM)$	-.86
	$MPR = 5e^{-0.017MRM^{0.70}}$	----
All 3 STATES COMBINED	$MPR = 7.86 - 2.35Log(MRM)$	-.92
	$MPR = 5e^{-0.016MRM^{0.71}}$	----

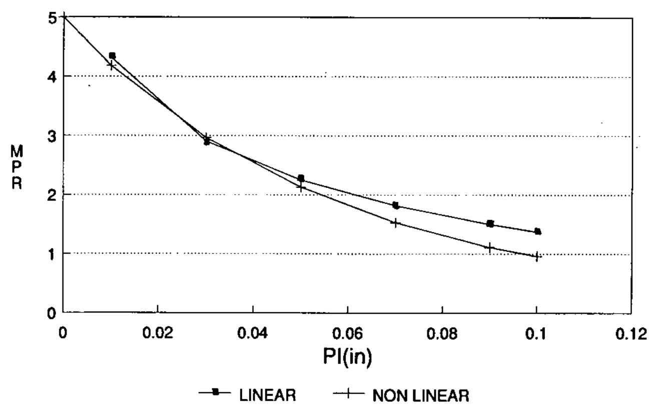


Figure 7. PI vs. MPR for Louisiana.

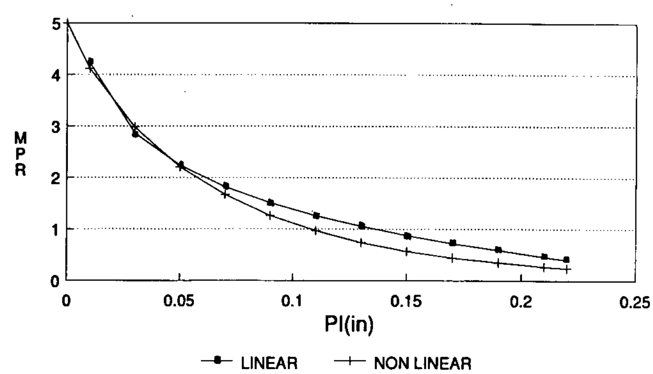


Figure 8. PI vs. MPR for five states.

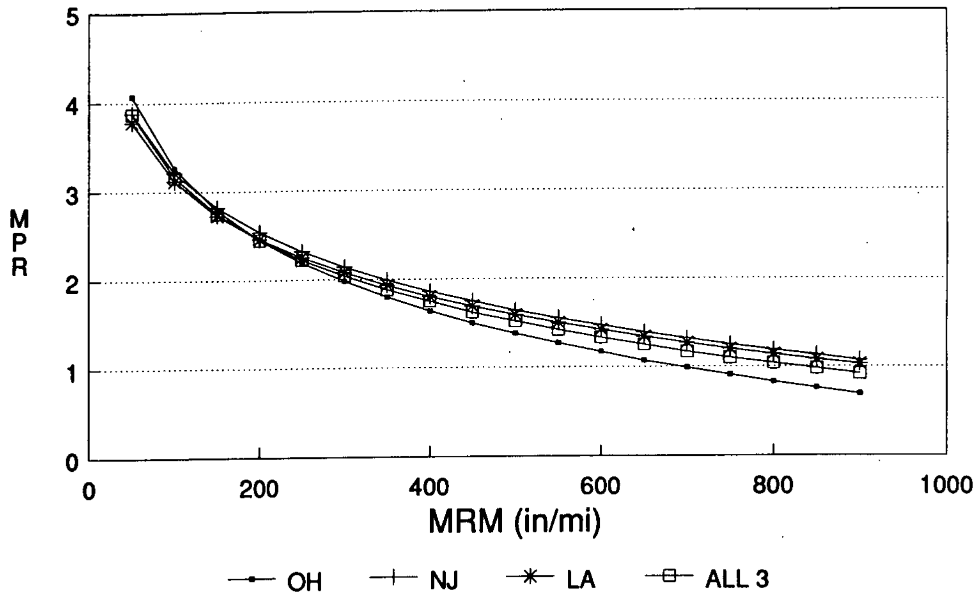


Figure 9. MRM vs. MPR for BC surfaces—linear transform.

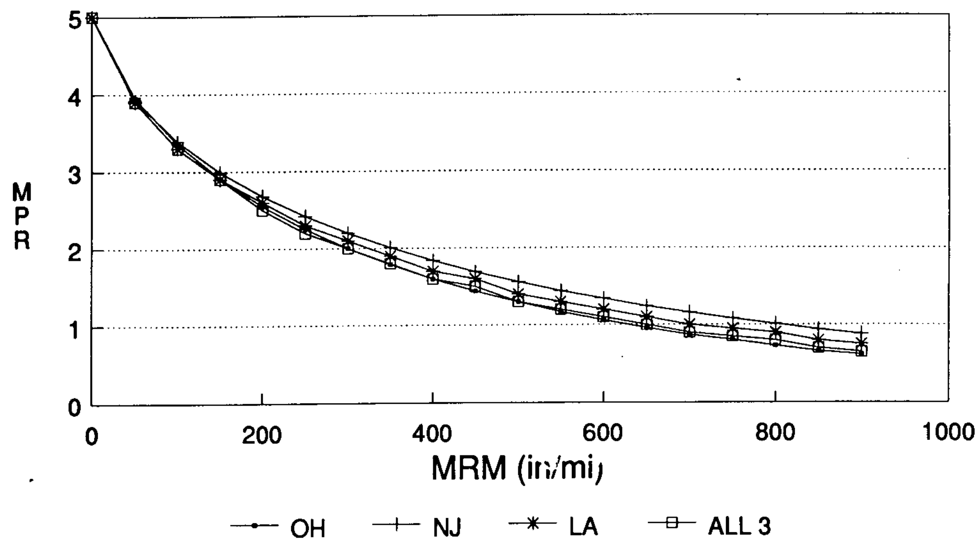


Figure 10. MRM vs. MPR for BC surfaces—nonlinear transform.

For Ohio, New Jersey, Michigan, and New Mexico, the transforms are nearly identical and are closely approximated by the transform for the four states combined. This is illustrated in Figure 11. Table 6 gives the values of MPR for NR percentages from 0 to 100 for the combined transform. The 50 percent point is approximately 2.4 (i.e., at this MPR, 50 percent of the driving public thinks the road should be repaired). The maximum deviation between the transform for the combined data and the four individual transforms (at NR = 50 percent) is about 0.1 MPR unit and between any two individual state transforms is about 0.2 MPR units. At lower MPR values the deviation is slightly less, while at larger values of MPR the deviation increases slightly. These deviations are less than the error of the panel rating experiment. The Louisiana data, however, yielded a transform that is quite different from the other four states. The Louisiana transform agrees with the other transforms for smooth roads but on rough roads the Louisiana panel provided NR ratings that were much lower than the other states. This is shown in Figure 12. The Louisiana data indicated that no road was ever rough enough to yield a 100 percent NR rating.

Table 5. Needs repair vs. MPR; all surfaces combined.

STATE	TRANSFORM	CORRELATION COEFFICIENT
OH	NR = 132.6 - 33.5MPR	-.93
NJ	NR = 129.6 - 34.6MPR	-.94
MI	NR = 126.9 - 33.5MPR	-.93
NM	NR = 134.1 - 33.1MPR	-.93
LA	NR = 92.8 - 23.5MPR	-.90
OH, NJ, MI & NM COMBINED		
-LINEAR	NR = 131.7 - 33.9MPR	-.92
-LOGISTIC	$NR = \frac{100\exp(5.96-2.49MPR)}{1+\exp(5.96-2.49MPR)}$	——

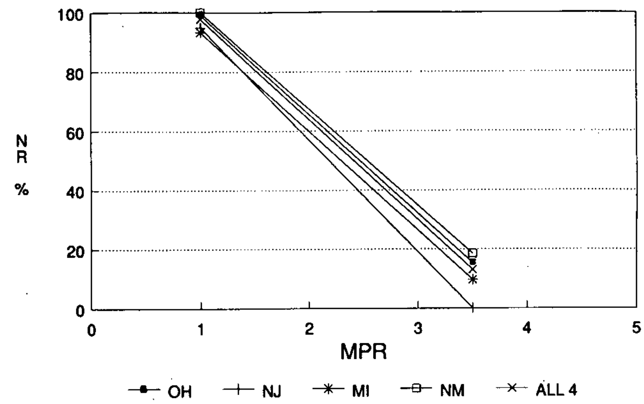


Figure 11. MPR vs. NR for four states.

Table 6. NR vs. MPR; Ohio, New Jersey, Michigan, and New Mexico combined.

NR	MPR
0	3.9
10	3.6
20	3.3
30	3.0
40	2.7
50	2.4
60	2.1
70	1.8
80	1.5
90	1.2
100	0.9

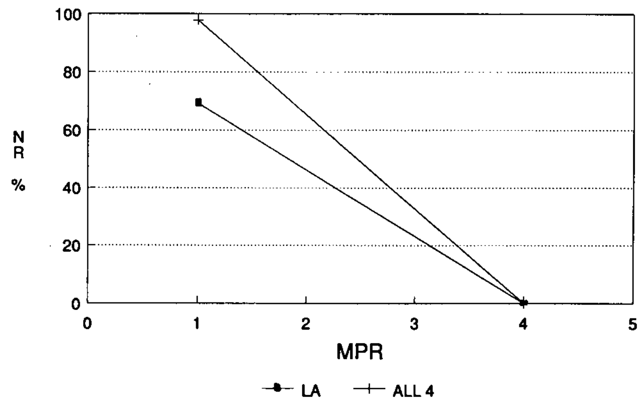


Figure 12. MPR vs. NR for four states vs. Louisiana.

The 50 percent point for Louisiana is 25 percent below that of the other four states, and the 70 percent point (the limit of the Louisiana data) is nearly 50 percent below that of the other states.

An explanation for this difference between Louisiana and the other four states can be found by considering the economic conditions existing in Louisiana at the time of this experiment. Because of the great decrease in oil prices during 1985 and 1986, considerable revenue was lost by the State of Louisiana. As a result, the State implemented many cost reductions, including reduced staff and reduced road expenditures. A topic of conversation during the time of the panel rating experiment in Louisiana was the economic conditions and the resulting effect on LADOT&D, the agency from which the panel members were obtained. It is believed that the NR ratings are a direct reflection of these conditions. In addition, the NR ratings may also reflect the panel's recognition of the special problem's by La's weak soils and high water table. The other results in Louisiana (e.g., PI vs. MPR and MRM vs. MPR) agree with the results found in other states.

Based on the work of the New Jersey Department of Transportation (*5*), a nonlinear regression technique was also applied. This technique employs the logistic response function to fit the data relating MPR to NR. Reference 6 describes this technique. Its usefulness is in deriving a functional relationship between MPR and NR that not only fits the data well but also passes through the correct boundary points: MPR = 0, NR = 100 percent and MPR = 5, NR = 0 percent. The linear functions derived previously are only valid within the ranges of the MPR data (e.g., for the data from the four states combined the transform is only valid between about MPR = 0.94 (NR = 100) and MPR = 3.88 (NR = 0)) and do not pass through the correct boundary points, while the nonlinear function maintains its validity for all values of MPR. Figure 13 illustrates the two different techniques for the data from the four states combined.

By combining the transform between NR and MPR for the four states combined:

$$NR = 131.7 - 33.9MPR \tag{4}$$

with the linear transform relating PI to MPR:

$$MPR = -1.47 - 2.85\log(PI) \tag{5}$$

a transform between PI and NR is obtained:

$$NR = 181.5 + 96.6\log(PI) \quad (6)$$

which can be used to determine NR directly from PI measures. Similar transforms can be derived by combining either the linear or nonlinear transforms between PI and MPR with either the linear or nonlinear transforms between MPR and NR.

Vehicle Size

A full-size car was used to determine mean panel ratings for a group of raters, and these mean panel ratings were statistically compared to those that were derived using the compact car.

The procedures employed to obtain the mean panel ratings for the large car were exactly the same as those employed in Project 1-23 and were accomplished in conjunction with the panel ratings in New Jersey. A Ford LTD instead of the Chrysler K-car was used to derive the mean panel ratings, and only 12 panel members were used with the Ford as opposed to the 36 that were used with the K-car. One other difference between the vehicles, other than size, is that the Ford is a front engine, rear drive car, whereas the K-car is a front engine, front drive car.

Only the bituminous surfaces were used for this analysis, the same as in Project 1-23. There were 18 of these sections and they spanned a very wide range of rideability—from 1.05 to 4.25. Figure 14 shows both sets of mean panel rating data plotted as a function of increasing physical roughness (MRM).

From Figure 14 it can be observed that each of the 18 pairs of ratings is in high agreement. A two-way analysis of variance revealed no statistically significant effect of either vehicle size or interaction between vehicle size and roughness.

The relationship between the two sets of ratings is linear with a slope almost equal to 1.0 and a y-intercept almost equal to 0. The equation relating MPR(LG), the mean panel rating for the large car, to MPR, the mean panel rating for the compact car is:

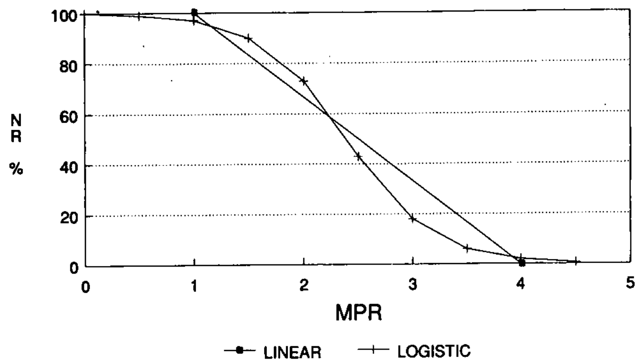


Figure 13. MPR vs. NR—linear and logistic.

$$MPR(LG) = -0.12 + 1.02\ MPR \quad (7)$$

(It is noted that if all test sections were employed in the large versus compact experiment the resulting equation changes slightly (the new equation is MPR(LG) = −0.39 + 1.09MPR) and the maximum deviation increases to 0.3 MPR unit, but this is still within the error of the experiment itself. Only the results for BC surfaces are reported to retain comparability with the former study of subcompact versus compact, which only employed BC surfaces.)

A perfect statistical relationship would be in the form MPR(LG) = MPR, and the one derived from the data in this research differs from that by a negligible amount. The correlation coefficient for the preceding equation is 0.98.

The maximum deviation between ratings for the large and compact car occurs at MPR = 1, where the deviation is only 0.1 MPR unit, far below the error of the experiment itself, which is between 0.3 and 0.5 MPR units for a panel of 12 members (*1*, p. 39).

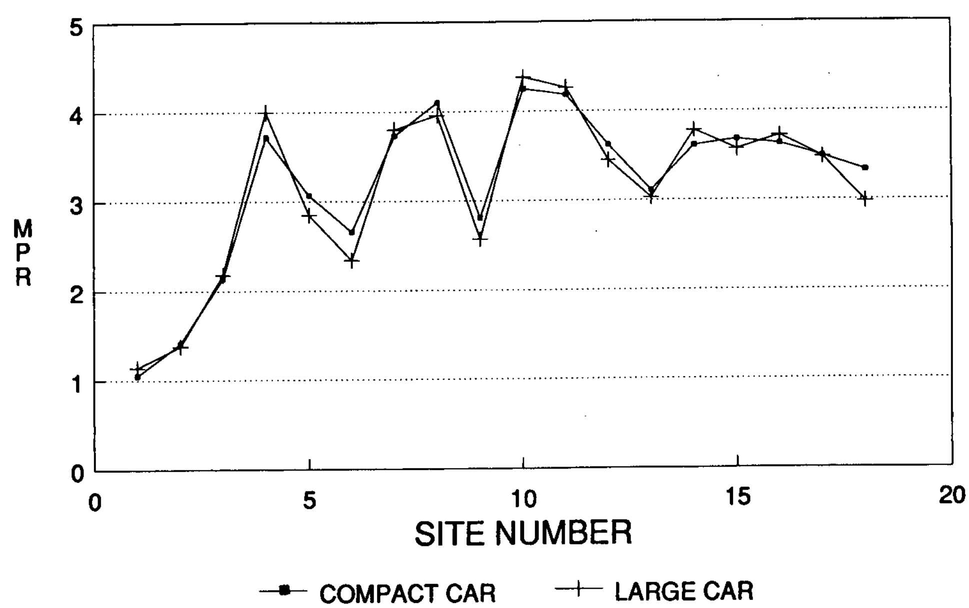


Figure 14. MPR vs. MPR (large car).

The relative effects of a compact and subcompact car on rideability were evaluated as part of Project 1-23. The results were similar to the results noted above—no effect of vehicle size. The resulting regression equation for the subcompact car was:

$$\text{MPR(SML)} = 0.07 + 1.02\ \text{MPR} \quad (8)$$

with a correlation coefficient of 0.97, and a maximum deviation of 0.15 MPR units, very similar to the results relating the large and compact car (*1*, p. 12).

Table C-1 in Appendix C includes the raw data for these experiments, and Table C-6 presents a description of the three vehicles used to collect the panel rating data.

Surface Type and Road Class

The intent of these analyses was to determine the effect of surface type (BC, PCC, composite) and road class (interstate, other) on a number of the previous results.

Surface Type

The effects of surface type on the one-third octave analysis, PI vs. MPR, MRM vs. MPR, and MPR vs. NR analyses were determined.

One-Third Octave Analysis. Figures D-1 through D-5 in Appendix D illustrate the differences between road surfaces for each of the five states. In general, the band of highest correlation (r better than -0.85) is wider for BC surfaces and narrower for PCC and composite surfaces. However, using the different band of frequencies for the individual surfaces (e.g., the larger one for the BC surfaces) does not significantly improve the correlation between PI and MPR from that obtained when all surfaces are combined and the standard band of frequencies is used (i.e., 0.125 to 0.630 c/ft).

PI vs. MPR. The results obtained when PI was correlated with MPR for the three different surfaces for each individual state and all five states combined are presented in Table D-1 of Appendix D. There is normally no significant improvement in the transforms between PI and MPR from that obtained when all surfaces are combined. In each of the states, as well as for the five states combined, the transforms for BC surfaces have correlation coefficients better than -0.94; for PCC surfaces the correlation coefficients are between -0.52 and -0.93; and for composite surfaces are typically better than -0.91. In comparison, the correlation coefficients for all surfaces combined range from -0.90 to -0.97.

Figure 15 shows the linear transforms for each of the individual surface types and for all surface types combined. The differences between the transforms are negligible, never greater than 0.17 MPR units. The difference between either of the individual surface transforms and the transform for all surfaces combined is less than 0.13 MPR units. The regression equations are presented in Table D-4 of Appendix D.

MRM vs. MPR. The transforms relating MRM to MPR are accurate only for BC surfaces. Correlation coefficients drop to as low as -0.24 for other surfaces, and the resulting transforms are not considered to be valid predictors of MPR. In addition, the correlation between PI and MRM drops to 0.79 for composite surfaces and down to 0.62 for PCC surfaces.

There are certain exceptions to these results, as can be seen in Tables D-2 and D-3 of Appendix D. However, these exceptions are normally the result of a limited range of roughness and no very rough test sections for the specific surface type (e.g., composite in Michigan; PCC in New Jersey). When the range of roughness is large and includes very rough test sections, the accuracy of the transforms drops off, except for BC (e.g., PCC in Ohio or Michigan; composite in Ohio or New Jersey) as does the correlation of PI with MRM.

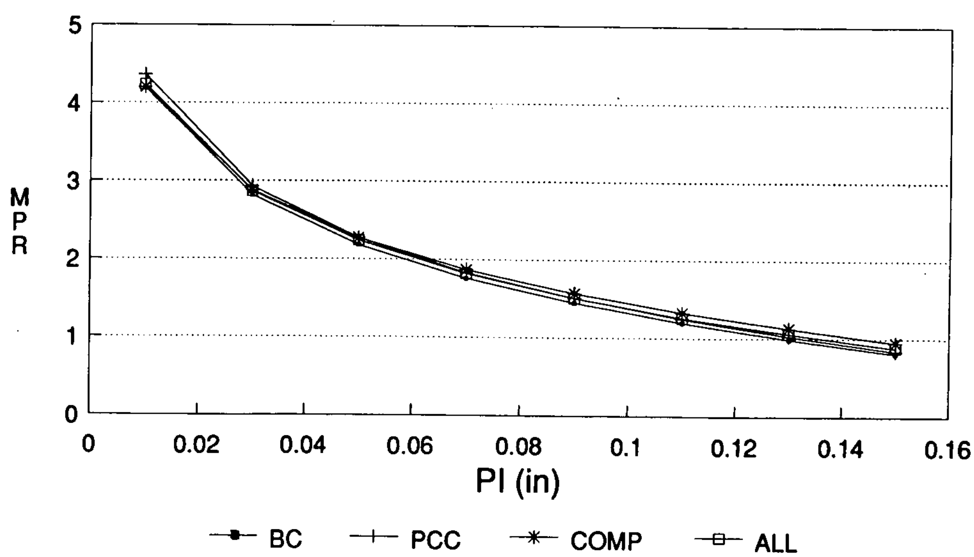


Figure 15. PI vs. MPR by surface type.

MPR vs. NR. For all four states combined (excluding Louisiana), the relationship between NR and MPR was found to be the same for BC and composite surfaces, as shown in Figure 16. However, for PCC surfaces the resulting transform was found to be different. The transform for PCC is also shown in Figure 16.

For smooth surfaces the three transforms agree, but at the 50 percent NR rating the MPR for BC and composite surfaces was found to be 2.3 while for PCC surfaces the MPR was found to be 2.6, approximately 13 percent higher. At NR = 100 the difference is greater: MPR = 0.8 for BC and composite and 1.4 for PCC—75 percent greater. It appears that subjects will tolerate more roughness in BC or composite surfaces in comparison to PCC ones before they indicate that repair is needed. Conversely, subjects feel that PCC surfaces require repair much sooner (i.e., at higher MPR) than those of BC or composite. This same result was found for each of the individual states. The regression equations are given in Table D-5 of Appendix D.

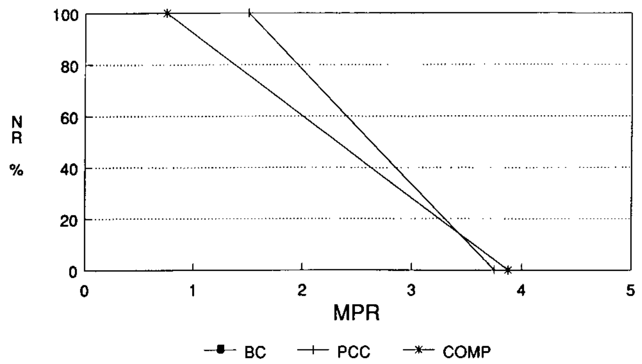


Figure 16. MPR vs. NR by surface type.

Road Class

The effects of road class on the PI vs. MPR and MPR vs. NR analyses were determined.

PI vs. MPR. Data from New Jersey, Michigan, and New Mexico were classified by surface type and interstate/noninterstate to determine if there were differences in the relationship between PI and MPR for the two highway classes for each of the three surface types. Figures 17 and 18 show the results for BC and PCC surfaces respectively (there was insufficient composite interstate data for this analysis). There is almost no difference between the interstate and noninterstate transforms for either the BC or PCC surfaces; the maximum difference for BC is less than 0.15 MPR units and the maximum difference for PCC is less than 0.3 MPR units, indicating no effect of road class on the transform between PI and MPR. The regression equations are given in Table D-4.

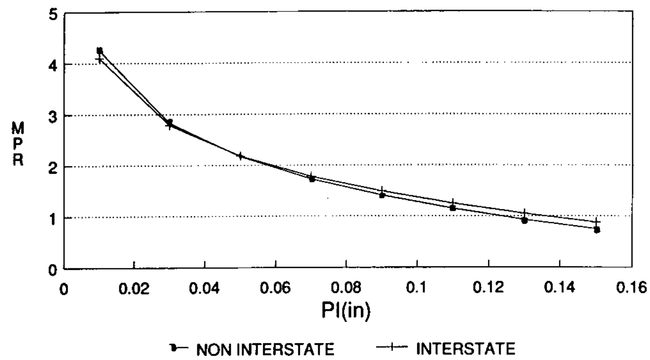


Figure 17. PI vs. MPR for BC surfaces, by road class.

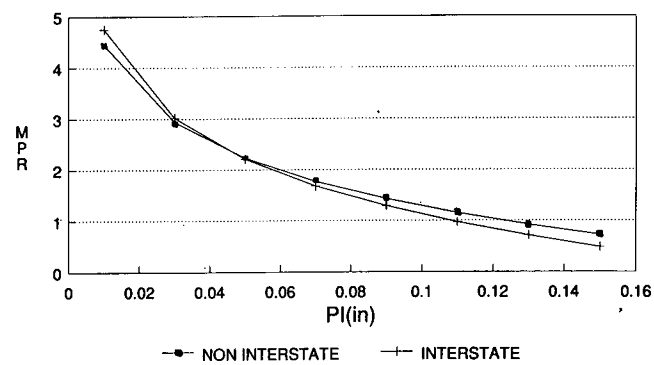


Figure 18. PI vs. MPR for PCC surfaces, by road class.

MPR vs. NR. Data from New Jersey, Michigan, and New Mexico were classified by surface type and interstate/noninterstate to determine if there were differences in the relationship between NR and MPR for the two highway classes for each of the three surface types. Figure 19 shows the transforms for interstate and noninterstate highways for BC surfaces, and Figure 20 for PCC surfaces (there was insufficient composite interstate data for this analysis). It is obvious from Figure 19 that subjects feel that bituminous interstate highways require repair sooner than bituminous noninterstate highways. The difference ranges from 8 percent at NR = 0 to 60 percent at NR = 100. However, for PCC surfaces there is only a slight difference between the transforms, approximately 0.1 MPR unit.

The result for BC surfaces is not unexpected because the instructions given each rating panel (App. B) point out that the NR rating should consider the nature and type of the road, as well as the roughness. That the PCC surfaces do not reflect this difference may be attributed to the fact that the PCC surfaces already indicate repair needed at MPR levels higher than BC, and the further classification by highway type causes no further change in transform. In fact, the transform for BC interstate highways is quite similar to the PCC highways for both interstate and noninterstate. Finally, if one considers the BC noninterstate as the basic transform (it is quite close to the one for all surfaces combined for all four states), then either a change of surface type (e.g., to PCC) or a change in highway class (e.g., to interstate) will result in a similar change in transform: to one that indicates repair needed at about 60 percent higher MPR at NR = 100 percent. The regression equations are given in Table D-5.

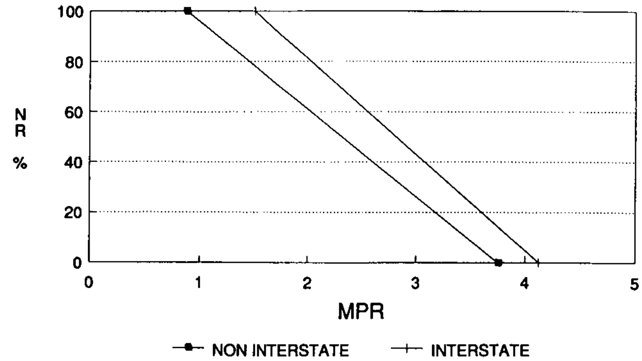


Figure 19. MPR vs. NR for BC surfaces, by road class.

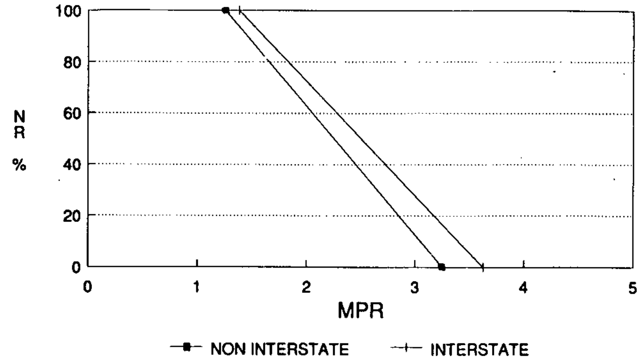


Figure 20. MPR vs. NR for PCC surfaces, by road class.

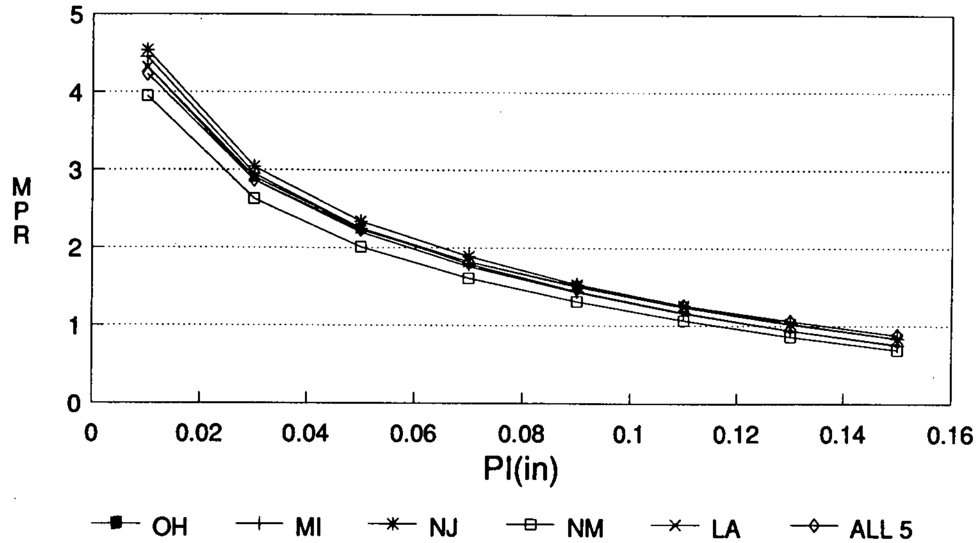


Figure 21. PI vs. MPR; five states, 6 linear transforms.

Regionality

The intent of this analysis was to compare the transforms relating PI to MPR for each state individually and all five combined. Figure 21 illustrates the six linear transforms. Figure 22 illustrates the differences between the transforms in predicting MPR from PI.

From Figure 21 it is obvious that all 6 transforms are quite similar in both shape and amplitude. In fact, only the New Mexico data, illustrated by the lowest curve in Figure 21, exhibit any significant difference in amplitude; all of the other transforms are nearly identical. (A statistical test to analyze the differences between the various regression equations indicated that the NM regression equation was significantly different from the other four state regression equations. This test is described in the text: "Linear Statistical Inference and Its Applications," John Wiley, N.Y., N.Y. 1965.)

For the linear transforms, the maximum difference in predicted MPR between any two states ranges from 0.15 MPR units at PI = 0.15 up to 0.59 MPR units at PI = 0.01, as illustrated in Figure 22. In comparison, the nonlinear transforms exhibit a maximum difference that ranges from 0.20 MPR units at PI = 0.15 up to 0.43 MPR units at PI = 0.05, dropping to 0 at PI = 0. Almost all of the difference is the result of the somewhat lower predicted MPR in the New Mexico transform.

When comparing the five-state transform with the individual state transforms, the maximum difference for the linear transform is always less than 0.31 MPR units, as seen in Figure 22, while the maximum difference for the nonlinear transform never exceeds 0.3 MPR units. The error of the panel rating experiment itself is on the order of 0.2 to 0.3 MPR units, quite similar to the differences between the individual state transforms and the combined transform, for both the linear and nonlinear cases.

A last consideration was the fact that the transform for the five states combined was slightly biased by the different number of test sections in each of the five states, ranging from a low of 46 in Louisiana to a high of 68 in Michigan. A further analysis derived a transform for the combined state data without this bias or weighting by sample size. The resulting transform was, however, found to be almost exactly the same as the previous one, never differing by more than 0.01 MPR units from the linear, five-state transform within the roughness range of interest.

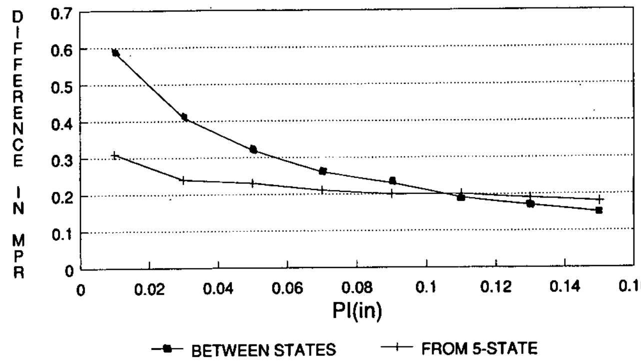


Figure 22. Linear transform differences.

Alternative Roughness Models

The objective of this analysis was to compare the PI formulation of roughness, as developed in Project 1-23, with three alternative roughness models; referred to as the Ohio model (OHPI), the Michigan model (RQI), and the Texas model (TX). OHPI is discussed in Ref. 2, RQI is discussed in Ref. 4, and TX is discussed in Ref. 3.

Two analyses were accomplished for each model: (1) compare the alternative model with PI in its accuracy in predicting MPR, and (2) investigate the statistical relationship between PI and the alternative model to determine if it can be accurately predicted from PI, or can predict PI.

Ohio Model

Using the data collected in Project 1-23 in Ohio, both PI and OHPI were related to MPR using both linear and log transformed linear regression techniques. For all surface types, the log transform always improved the correlations between MPR and PI or OHPI. For OHPI the correlation for all surfaces was −0.91 while for PI it was −0.94, an improvement of 3 percent. The individual surface types yielded similar results, with correlation coefficients between either PI or OHPI and MPR typically better than −0.9.

When the two models were subjected to a linear regression analysis to determine their statistical relationship, a correlation coefficient of 0.93 was found for the log transformed data, and only slightly lower (0.9) for the untransformed data. This relationship is illustrated in Appendix D. Clearly, either model can be accurately predicted from the other, but PI does slightly better in predicting MPR.

Michigan Model

The PI and RQI values were derived from a subset of the data collected in Michigan by the Minnesota profilometer. (Three data points were deleted from the total of 68 because the three RQI values were obvious outliers when inspected on a scatergram of RQI vs. MPR. The inclusion of these three points would weaken the relationships between RQI and MPR and between RQI and PI.)

For this data set RQI predicts MPR very well for all surfaces combined, $r = -0.93$; for BC surfaces, $r = -0.95$; for PCC surfaces, $r = -0.91$; and for composite surfaces, $r = -0.92$. In comparison, PI (log transformed) predicts MPR very well for all surfaces, $r = -0.95$; for BC surfaces, $r = -0.99$; for PCC surfaces, $r = -0.90$; and for composite surfaces, $r = -0.93$. The differences between these correlations are minimal, with PI having a 2 percent improvement in correlation for all surfaces combined.

When the two models were subjected to a linear regression analysis to determine their statistical relationship a correlation coefficient of 0.96 was obtained for all surfaces combined, and even higher for the individual surfaces. This relationship is illustrated in Appendix D. Either model can thus be accurately predicted from the other.

Texas Model

Using 55 of the Michigan test sections, both PI and TX were computed. For all surface types combined the PI (log transformed) predicted MPR with a correlation coefficient of −0.95 and the TX model predicted MPR with a correlation coefficient of 0.88 (the TX model computes a value between 0 and 5—similar to PSI—therefore, the correlation coefficient is positive). A log transform did not improve the correlation between TX and MPR.

For BC surfaces, both models predicted MPR with correlation coefficients better than 0.97; for PCC surfaces, the correlation dropped to about 0.85 for PI but fell to 0.65 for the TX model; and for composite surfaces, the correlation for PI was 0.95 and for TX it was 0.91.

TX and PI were found to be highly related, with a correlation coefficient of −0.95. This is illustrated in Appendix D. Either model can thus be derived from the other but PI does a somewhat better job in predicting MPR; an 8 percent improvement in correlation coefficient was mainly attributed to the better performance of PI for PCC surfaces.

One vs. Two Wheelpaths in Predicting MPR from PI

The objective of this analysis was to determine if the PI derived from one wheelpath could be used to predict MPR, and what loss in accuracy would result if one wheelpath were used instead of two wheelpaths. Two separate analyses were performed: comparison of the results of the one-third octave analysis using one wheelpath with the results obtained when using two wheelpaths, and comparison of the transforms relating PI to MPR for one wheelpath to the transform relating PI to MPR for two wheelpaths. Data from New Jersey were used for all analyses.

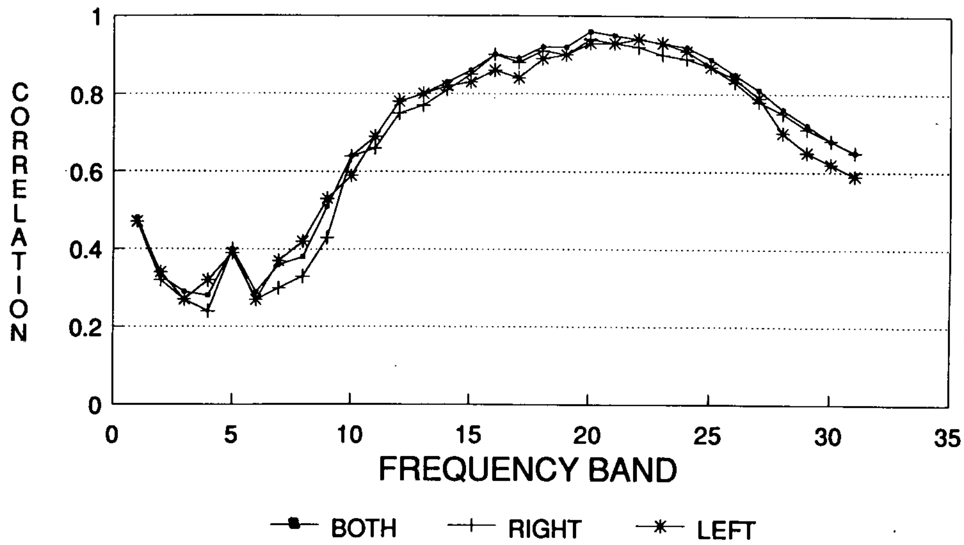


Figure 23. MPR vs. PI; one-third octave bands for both wheelpaths vs. each individually.

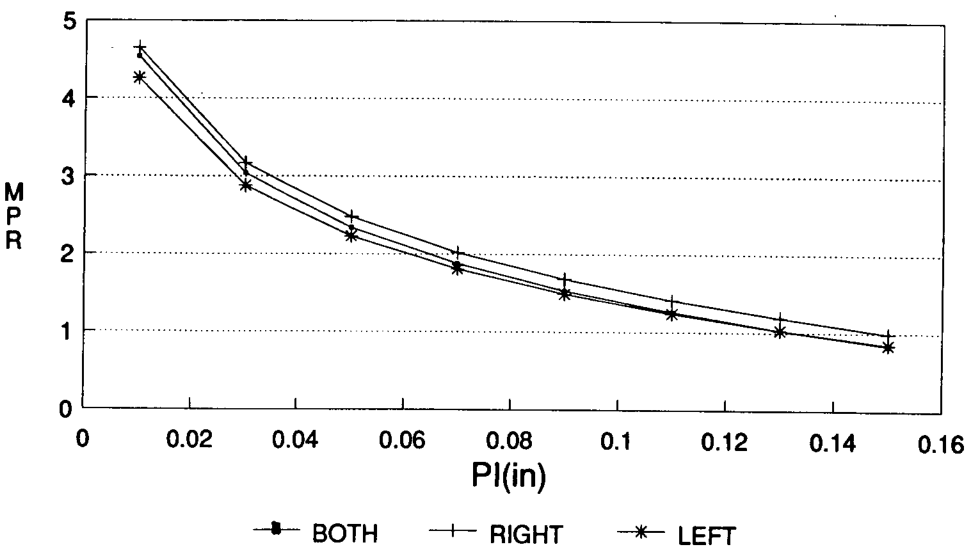


Figure 24. PI vs. MPR for New Jersey—two wheelpaths, together vs. each separately.

One-Third Octave Analysis

The results of the one-third octave analysis are shown in Figure 23. This figure shows the correlations between PI and MPR for each of the 31, one-third octave bands of frequencies for all three surfaces combined for both wheelpaths, the right wheelpath, and the left wheelpath. It is evident that all three graphs are nearly identical and that the relationships between PI and MPR for each of the three cases should be very similar.

Transforms Between Pi and MPR

Figure 24 illustrates the transforms obtained when PI was used in the linear regression analysis to predict MPR for both wheelpaths combined and each separately. It is again obvious that either of the individual wheelpaths can be used to predict MPR from PI with as much accuracy as the two wheelpaths combined.

The transforms and correlation coefficients are:

Both wheelpaths: $MPR = -1.76 - 3.15\log(PI)$ $r = -0.97$ (9)
Right wheelpath: $MPR = -1.57 - 3.11\log(PI)$ $r = -0.96$ (10)
Left wheelpath: $MPR = -1.54 - 2.90\log(PI)$ $r = -0.97$ (11)

The correlation coefficients are almost identical and the differences in predicted MPR, shown in Figure 25, never exceed 0.3 MPR units, within the error of the panel experiment. In fact, excluding the lowest level of PI (<0.02, of little importance) the differences are always less than about 0.15 MPR units.

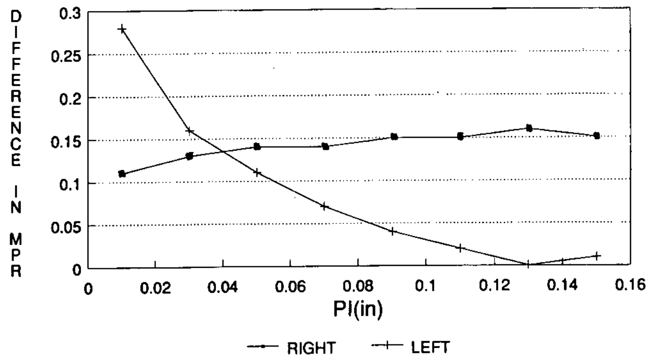


Figure 25. Difference in predicted MPR using left or right wheelpath vs. both wheelpaths.

CHAPTER THREE

INTERPRETATION AND APPLICATION

INTRODUCTION

This chapter provides an interpretation of the results of Chapter Two and discusses their implications and applications. The areas of interest include the following:

1. The preferred transforms between physical profile measures of roughness and subjective panel ratings of rideability, their accuracy, and their validity.
2. The generalizability of these transforms and their potential use as a uniform method for predicting subjective panel ratings of rideability from profile measures of pavement roughness.
3. The effect of vehicle size, surface type, road class, panel regionality, and one versus two wheelpaths on these transforms.
4. The use of these transforms, and related methodology, to assist highway agencies to determine when existing pavements should be repaired and to evaluate newly constructed pavements.
5. The possible transforms between response-type roughness measures and subjective panel ratings of rideability, their limitations and uses, and performance specifications for a simpler meter based on profile-type roughness measured by one wheelpath in a specific frequency band.
6. The preferred transforms between subjective need repair ratings and subjective panel ratings of rideability or physical profile measures of roughness, their uses, and their limitations.
7. The comparative effectiveness of alternative models of physical profile roughness in predicting subjective panel ratings of rideability, and the similarities and differences between these models.

PREDICTION OF SUBJECTIVE APPRAISALS OF RIDEABILITY FROM PROFILE MEASUREMENTS OF PAVEMENT ROUGHNESS

The preferred linear equation that computes RN, the approximation of true subjective, mean panel ratings of rideability, from physical profile measures of roughness, PI, is:

$$RN = -1.47 - 2.85\log(PI) \tag{12}$$

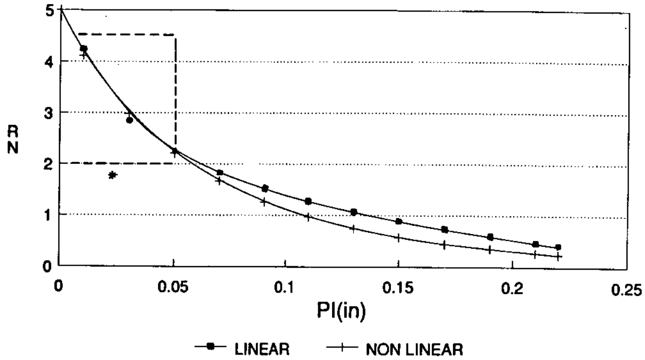
and the preferred nonlinear equation is:

$$RN = 5e^{-11.72PI^{0.89}} \tag{13}$$

for profile frequencies between 0.125 and 0.630 c/ft. These equations are based on data collected on 282 test sections, in five different and diverse states, spanning a range of rideability from 0.4 to 4.5, and a range of PI roughness of 0.009 to 0.220 in.

The linear equation is considered to be statistically valid within the rideability range of 0.4 to 4.5, spanning the vast majority of all paved surfaces found in the United States. Roads with rideability over 4.5 are of little importance from a practical or maintenance viewpoint, and rideability less than 0.4 is rarely found on paved roads, especially on Federal or State designated highways, and obviously requires some type of repair.

The accuracy of the linear equation is very high within the range of roughness described above. The correlation coefficient



* REGION OF GREATEST IMPORTANCE

Figure 26. PI vs. RN for five states.

is −0.93, and the equation accounts for 86.5 percent of the variance.

The nonlinear equation is valid, from an engineering viewpoint, over the entire range of roughness; however, it is no more accurate than the linear equation within the range of roughness described above. Its advantage is that it allows the prospective user to compute RN, and thus predict MPR, from any value of physical roughness. Both of these equations are valid for all surface types and all classes of road.

These transforms can be directly used by agencies that are able to compute PI in the band of frequencies from 0.125 to 0.630 c/ft (i.e., those that have access to a profilometer). RN is computed directly from either of the two transforms after PI is derived from the profiles. Figure 26 illustrates these equations. In the region of greatest importance (($RN > 2$), covering the vast majority of roads), identified in Figure 26, the two are nearly identical.

The preferred linear and nonlinear equations generally differ from the five individual state, linear and nonlinear equations between RN and PI by less than 0.3 RN units, within the margin of error of the 36-member panel rating experiment. Therefore, use of these equations by any state to compute RN from PI, instead of the use of any specific individual state transform, will result in a valid and accurate prediction of subjective panel ratings of rideability for any paved road surface.

By employing these equations nationwide, a uniform method of predicting subjective panel ratings of rideability from profile measures of physical roughness will be available which is accurate and valid for all paved surfaces. The use of these equations will thus provide a method for making direct comparisons between the rideability of different state highway systems with the assurance that the data are uniformly reported and totally comparable. In addition, the equations, and related methodology for deriving PI, provide a method for assisting highway agencies to determine when existing pavements should be repaired (e.g., $NR >$ some predefined value) and to evaluate newly constructed pavements (e.g., $RN >$ some predefined level).

The effect of vehicle type—large, compact, and small—on the subjective panel ratings of rideability is not significant. Drivers provide equivalent panel ratings using either size car. Therefore, the use of either of these size cars in panel rating studies of rideability will result in equivalent transforms.

There is no significant effect of either surface type or road class on the preferred equations. The differences between the preferred equations and the equations derived for each surface separately (BC, PCC, composite) never exceed 0.17 RN units, smaller than the error of the panel experiment. For road class the differences between the preferred equations and the equations for each of the two road classes separately (interstate/other) are always less than 0.15 RN units. Therefore, use of the individual road surface or road class equations provide no more accuracy or validity than use of the preferred equations for all surfaces and both classes combined.

The five individual state, linear equations exhibit differences in computed RN that range from 0.15 RN units to 0.48 RN units (excluding the smoothest roads, of little importance) and as high as 0.43 RN units for the nonlinear equations. Therefore, there are small regional differences in the subjective panel ratings of rideability between the individual states. The use of any one state transform by a prospective user could thus lead to a small error in computing RN from PI (except, of course, if the state equation is based on the same states' data). By using the preferred equation, based on the data from all five states combined, these differences are greatly reduced, the RN data are totally comparable, and the effect of regionality is minimized. Hence, for reporting and comparing RN data on a nationwide basis, the transform derived from the combined data from all five states is clearly preferred.

However, a state wishing to use RN as an input into their own pavement management system may want to derive their own transform between PI and MPR (or RN) instead of employing the five-state transform. This would account for the small differences between local perceptions of roughness as reflected by the small differences between the five individual state transforms described earlier.

The three equations between PI and RN derived from the New Jersey data—one using profiles from two wheelpaths and the other two from the profiles of the individual wheelpaths—exhibit minimal differences as described in Chapter Two, and it is thus feasible to use PI derived from one wheelpath to compute RN instead of using the entire profile to compute RN.

PREDICTION OF SUBJECTIVE APPRAISALS OF RIDEABILITY FROM MRM MEASUREMENTS OF PAVEMENT ROUGHNESS

In general, accurate and valid transforms between MRM measurements and subjective panel ratings of rideability were developed only for BC surfaces. For other surface types the accuracy of the transforms often falls to very low levels (correlation coefficients as low as −0.24). Exceptions are discussed in Chapter Two and illustrated in Appendix D, Tables D-2 and D-3.

For BC surfaces the preferred linear equation for computing RN from MRM measurements is:

$$RN = 7.86 - 2.35 \log (MRM) \tag{14}$$

and the preferred nonlinear equation is:

$$RN = 5e^{-0.016\,MRM^{0.71}} \tag{15}$$

The linear equation has a correlation coefficient of −0.92 and is as accurate for BC surfaces as the preferred linear equation that computes RN from PI within the range of rideability from 1.01 to 4.25 (MRM values between 17.5 and 669 in./mi).

The nonlinear equation is valid, again from an engineering viewpoint, over the entire range of roughness; however, it is no more accurate than the linear equation within the range of roughness described in the preceding paragraph. It does, however, allow the user to compute rideability ratings from any MRM value for all BC surfaces. These equations are illustrated in Figure 27. In the region of greatest importance (RN > 2, covering the vast majority of roads), identified in Figure 27, the two are nearly identical.

Either of these equations between MRM measurements of roughness and RN can be directly used by agencies that employ Mays meters to measure roughness. For BC surfaces the equations provide an interim method for computing RN from MRM measurements of roughness that yield RN data that are comparable to the RN data computed from PI. A later conversion to the PI-based methods would thus provide continuity and compatibility of the RN data for BC surfaces.

Use of the equations described in Appendix D, Table D-2, for computing RN from MRM measurements on other types of surfaces, or all surfaces combined, can lead to large errors. This is because response-type meters, such as the MRM, respond only to frequencies from about 0.013 to 0.150 c/ft, while panel ratings are highly correlated with frequencies between 0.125 and 0.630 c/ft, except for BC where the range extends downward to much lower frequencies (e.g., see Figs. D-1 through D-5 in Appendix D).

Prospective users of the equations between MRM measurements and RN should also be cognizant of the results found by Gillespie and described in *NCHRP Report 228,* pertaining to the problems associated with response-type measuring systems and necessary calibration procedures (*7*).

PERFORMANCE SPECIFICATIONS FOR A PROFILE INDEX OR RIDE QUALITY METER

It would be extremely beneficial to be able to use a meter that is simpler than a profilometer to measure roughness. This was the impetus for the analysis that compared the use of one and two wheelpaths to measure profiles, derive PI and compute RN.

The almost identical forms of the three equations between PI and RN—one using profiles from two wheelpaths and the other two derived from the profile of each individual wheelpath—lead to preliminary performance specifications for an instrument, referred to as a Profile Index meter (or, alternatively, a Ride Quality meter), that measures profile-type roughness in only one wheelpath, derives PI for a specific band of frequencies, and computes RN.

The performance specifications are:

1. The instrument should measure profile-type roughness in only one wheelpath.
2. The instrument should derive PI for the frequency band between 0.125 and 0.630 c/ft.
3. The instrument should be calibrated against a profilometer to ensure that it is responding accurately to the roughness in the specified frequency band.
4. The instrument should, preferably, be independent of the host vehicle.

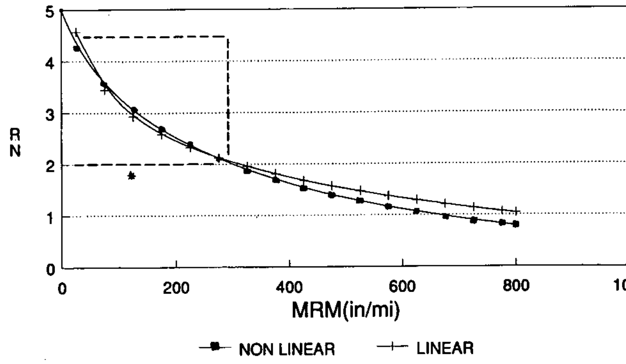


Figure 27. MRM vs. RN for three states.

5. The recommendations provided in *NCHRP Report 228* should be considered.

Either wheelpath can be used to derive PI and compute RN, but the right one is preferred because it tends to be somewhat rougher on many roads.

The use of such an instrument, which would be far simpler and much less costly than a profilometer, would allow state agencies to efficiently and economically collect roughness data that could be used to accurately derive PI and compute RN. These data could be used to assist states to determine when to repair existing pavements, to evaluate newly constructed pavements and to report uniform, totally comparable rideability and roughness data.

PREDICTION OF SUBJECTIVE APPRAISALS OF NEED FOR REPAIR FROM SUBJECTIVE APPRAISALS OF RIDEABILITY OR PROFILE MEASUREMENTS OF ROUGHNESS

The preferred equation for computing the percentage of the driving public that thinks a specific pavement section should be improved from subjective panel ratings, or RN their approximation, is:

$$NR = 131.7 - 33.9RN \qquad (16)$$

This equation is valid over the same range of rideability as the preferred equation between PI and RN and has a correlation coefficient of 0.92. It thus accurately predicts the driving public's subjective appraisal of the need for repair of a given pavement section. It can be used directly by highway agencies to assist them in determining the point at which road improvements are necessary. For example, 50 percent of the driving public believes that a road should be improved at a RN of 2.4 (see Table 6).

This equation, however, is sensitive to both surface type and road class; the NR for equivalent RNs will be different for different surface types and different road classes. In addition, extreme economic conditions in a particular state can significantly affect the actual rating of NR for a specific level of rideability and thus change this equation.

If the preceding equation between NR and RN is combined with the preferred linear transform between PI and RN, one obtains an equation:

$$NR = 181.5 + 96.6\log(PI) \quad (17)$$

which can be accurately used to compute the need for repair directly from profile measures of roughness. Equivalent nonlinear transforms can be developed, having similar validity and limitations as the linear equation.

ALTERNATIVE MODELS OF PHYSICAL PROFILE ROUGHNESS

Four alternative formulations or models of profile roughness were compared: the Profile Index model, developed in NCHRP Project 1-23, the Ohio model, the Michigan RQI model, and the Texas model.

The Profile Index, Michigan, and Ohio models were found to be equivalent because either one can be used to predict subjective, mean panel ratings of rideability with almost the same accuracy (PI 2 to 3 percent better) and either one can be derived from PI by means of a statistical transform with high correlation coefficient. As a result, the profile roughness data or computations of RN generated by all three models are comparable. Data reported in the Ohio model format, for example, can easily and accurately be converted into PI format.

The Texas model was also found to be highly correlated with PI, but somewhat poorer in its prediction of MPR.

CHAPTER FOUR

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

The two major conclusions of this research are that (1) subjective appraisals of pavement rideability can be accurately predicted from physical measurements of the pavement's profile made in a specific frequency band and (2) the equation that computes RN, the approximation or prediction of true subjective mean panel ratings of rideability, from profile measurements of roughness is applicable to any paved surface, in any state.

This equation is based on measurements made in five different and diverse states on 282 pavement sections spanning an extremely wide range of roughness; five rating panels of 36 drivers spanning a wide range of driving experience; and the AASHO/Weaver rating scale with explicit instructions.

The equation between rideability and profile measurements can be derived and used in two different forms; a linear equation

$$RN = -1.47 - 2.85\log(PI) \quad (= MPR + error) \quad (18)$$

and a nonlinear equation

$$RN = 5e^{-11.72PI^{0.89}} \quad (= MPR + error) \quad (19)$$

both of which are accuate and valid within the rideability range of our data: 0.4 to 4.5 on a 0 to 5 scale. The nonlinear equation extends the validity to the entire range of roughness, although it is no more accurate or valid than the linear equation within the range of our data, which encompasses nearly all paved surfaces.

Other important conclusions are as follows:

1. The specific band of frequencies where profile measured roughness is most highly correlated with subjective appraisals of rideability is 0.125 to 0.630 c/ft (10 to 50 Hz at 55 mph), for all five states.

2. Three different vehicle sizes had no effect on the subjective appraisal of rideability.

3. Neither surface type nor road class had any effect on the foregoing equations between RN and PI.

4. The effect of panel regionality or residence on the foregoing equations is very small. The differences between each of the five individual state equations and the equation based on the data from all five states combined is less than the error inherent in the panel study, for either the linear or nonlinear form.

5. PI values derived from measurements made by only one wheelpath of the profilometer in the same band of frequencies can be used as accurately as PI derived from both wheelpaths to compute RN.

6. It appears desirable to develop a profile index (Ride Quality) meter that would measure profiles only in one wheelpath, in the same band of frequencies, and which could provide an efficient method for deriving accurate and totally comparable roughness (PI) or rideability (RN) data in all states.

7. For all paved surfaces, the equations that compute need for repair, NR, from RN or PI are:

$$NR = 131.7 - 33.9RN \quad (20)$$

$$MR = 181.5 + 96.6\log(PI) \quad (21)$$

These equations provide a method for determining the exact level of rideability at which the driving public believes improvements should be made. However, these equations are sensitive to type of surface, class of road, and extreme economic conditions existing in a specific state.

8. For bituminous surfaces, equations that compute RN from MRM measurements can be derived in two forms; a linear form

$$RN = 7.86 - 2.35\log(MRM) \quad (22)$$

and a nonlinear form

$$RN = 5e^{-0.016\,MRM^{0.71}} \quad (23)$$

both of which are valid and accurate within the range of the data, and the nonlinear form extends the validity to all values of MRM measurements of roughness.

9. For portland cement and composite surfaces, and all three surfaces combined, MRM measures do not accurately predict rideability.

10. Alternative formulations or models of profile roughness were found to be either equivalent to PI, in that either one could be computed from the other and both could be used to accurately predict rideability, or that PI was found to be a better predictor of rideability.

The key conclusions of this research are that it is possible to develop transforms between profile measurements of pavement roughness and subjective panel ratings of pavement rideability that are accurate and valid over a wide range of roughness, can be applied in all states on all surfaces, and can be simplified to be based on profile-type roughness measured in only one wheelpath by a far simpler and less costly instrument than a profilometer.

It is thus possible to implement a method for reporting roughness or rideability data that is efficient and inexpensive, which would provide accurate, valid, and totally comparable data from all states, and which can greatly assist highway agencies to determine when existing pavements should be repaired and to evaluate newly constructed pavements.

RECOMMENDATIONS FOR FURTHER RESEARCH

The primary need is to develop a user's manual for implementing the profile index methodology. This manual should include a complete description of the procedures for computing PI from the profiles collected with either the K. J. Law profilometer (e.g., Ohio or Minnesota), or the PSU instrument in either of its two forms (lasers, wheels); sample computations of PI for both the recommended frequency band (0.125 and 0.630 c/ft) and for individual one-third octave frequency bands; and copies of the software necessary for computing PI from profiles. At present, this software is available from either the present research contractor or NCHRP, but detailed instructions have not been prepared for widespread use.

The manual should also include descriptions of the statistical analyses necessary for relating PI to MPR and deriving the equations for computing RN from PI, thus complementing the instructional manual for conducting panel rating studies included as Appendix E of this report.

Other suggested research includes further investigation of the use of one wheelpath instead of both to derive PI and compute RN—the analyses conducted in the present study were based on data from only one state; the development and testing of the profile index (or Ride Quality) meter that would derive PI and compute RN based on the profile of only one wheelpath; further analyses of the relationships between the alternative models of profile roughness in order to develop transforms that would allow the data derived from different models to be comparable; the effect of vastly different vehicles, such as trucks, on the subjective appraisals of rideability; and the time stability of the PI/RN methodology and its potential use for evaluating the long-term performance of pavements.

REFERENCES

1. JANOFF, M. S. ET AL., "Pavement Roughness and Rideability." *NCHRP Report 275* (Sept. 1985) 69 pp.
2. MCQUIRK, J. and SPANGLER, E., "Use of the Inertial Profilometer in the Ohio DOT Pavement Management System." ASTM Committee E-17 Symposium, Columbus, Ohio (June 1985).
3. SUKUMAR, K. N. and HUDSON, W. R., "Serviceability Prediction from User-Based Evaluations of Pavement Ride Quality." *Transportation Research Record 1084* (1986).
4. State of Michigan Model for Predicting Ride Quality Indexes from Profiles. (No published report)
5. WEED, R. M. and BARROS, R. T., "Discussions of Paper: 'Methodology for Computing Pavement Ride Quality from Pavement Roughness Measurements,'" by M. S. Janoff, *Transportation Research Record 1084* (1986).
6. NETER, J. and WASSERMAN, W., "Applied Linear Statistical Models—Regression, Analysis of Variance and Experimental Design." Richard D. Irwin, Inc. (1974).
7. GILLESPIE, T. D., ET AL., "Calibration of Response-Type Road Roughness Measuring Systems." *NCHRP Report 228* (Dec. 1980) 81 pp.

APPENDIX A

RIDE QUALITY SURVEY

NCHRP 1-23(2) RIDE QUALITY SURVEY

Part I GENERAL INFORMATION

Name of state ____

Name of respondent____

Address____

____

Telephone Number (___)__________

(DESCRIBE GENERAL OBJECTIVES OF THE STUDY AND DETERMINE IF THE STATE IS INTERESTED IN COOPERATING. ADDRESS THE ISSUES OF: ASSISTANCE - IN TERMS OF MANPOWER, VEHICLES AND FACILITIES; COLLECTION AND PROVISION OF DATA; USE OF STATE FACILITIES; DEFERRING ROAD MAINTENANCE; AND COSTS TO THE RESEARCH TEAM)

General Cooperation yes ___ no ___

Part II ROAD SECTIONS

1. What type of roughness data do you collect?

   1.1 RTRRMS yes___ no___ Type of equipment ___________

   1.2 Profilometer yes___ no ___ type of unit _________

   1.3 Other yes___ no___ explain ____________________

2. How is the data stored? computer_____ hard copy_____

3. What are the section lengths?

   less than 1/2 mile___ greater than or equal to 1/2 mile___

   other___ explain ______________________________________

4. How often is the roughness data collected?

   annually ___ other ___ explain ________________________

5. Could you provide roughness data for every section of road in a 50-60 mile radius circle of a major city?

   yes___ no___ cities ____________________________________

   Would there be any costs? yes___ no___ explain____________

6. Do you construct roads using all three surface types?

   BC____ PCC____ composite____

Part III TEST PANEL

1. Could you provide 36-48 persons to serve as panel raters during a 2 week test period? Each person must be a licensed driver and be available on two consecutive weekdays. Ages should range from 20 to over 60 years; DOT or non-DOT persons are both acceptable.

   yes___ no___ explain______________________________

2. Would there be any costs associated with the above?

   explain____

Part IV FACILITIES

1. Could you provide a central meeting facility (eg. conference room) where 10-15 persons could meet and be given instructions?

yes___ no___

2. Could you provide 3-5 compact sedans of similar size and age to be used for up to 2 weeks for the panel rating sessions?

yes___ no___ number___

2.1 Would a full-size sedan also be available?

yes___ no___

3. Could you provide drivers for these vehicles for a 2 week period?

yes___ no___

4. Would there be any costs associated with 1-3 above?

yes___ no___ explain________________________________

Part V ASSISTANCE

1. Could you provide 1 or 2 persons to assist the research team select test sections, mark test sections, measure roughness of selected test sections and form a test route?

yes___ no___ explain________________________________

1.1 Types of persons: technicians___ civil engineers___

other(type______________)_______

Such persons should be available for 2-3 weeks for test site selection and 1-2 weeks for the panel ratings.

2. Would you allow us to temporily mark the test sections with small paint markings, temporary road marking tape or reflectant tape on signs, guardrails or utility poles?

yes___ no___ restrictions___________________________

3. Could you insure that road maintenance would be deferred on all test sections between selection and panel ratings? (up to 3 months).

yes___ no___ explain________________________________

4. Would there be any costs associated with 1-3 above?

yes___ no___ explain________________________________

Part VI OTHER

1. When does the daytime temperature in your area stay consistently

below 32f.______ above 90f._______?

2. Is there a predominantly inclement weather period (eg. rain, snow, fog, low/high temperatures) in your area?

yes___ no___ when_________ describe____________________

3. Have you ever performed a panel rating study of pavement ride quality?

yes___ no___ when______

3.1 Would you please send us a copy of your methods and results?

4. Would you like the research team to train one or more members of your staff to perform panel rating studies of pavement ride quality? (there is no cost to you for this service).

yes___ no___

5. If your state is selected to participate in this study do you prefer any specific time period during 1986?

yes___ no___ when_________

6. Would you allow the research team to measure the profiles of the selected test sites?

yes___ no___ restrictions___________________________________

7. If your state is not selected to participate in this study would you be interested in performing such a study at a future time?

yes___ no___ when______ who should be contacted____________

8. Do you have any comments or questions?

yes___ no___ explain______________________________________

Thank you for your assistance.

Michael S Janoff
JMJ RESEARCH
P.O. Box144
Newtown, PA 18940
215/968-6486

STATE SURVEY SUMMARY

State____

Cooperation____

Professional help____

Panelists____

Drivers____

Automobiles____

Defer maintenance____

Surfaces: BC______________________________
PCC______________________________
Comp______________________________

Data____

Meter____

Range of roughness____

Potential Problem areas____________________________________

____

Costs____

Comments____

APPENDIX B

PANEL INSTRUCTIONS AND RATING FORM

Panel Instructions

HIGHWAY IMPROVEMENT STUDY

Purpose: To survey typical drivers in order to determine what they think of the quality of the ride provided by the roads in the State. DOT will use this information to help decide which roads they should improve first with the limited funds available to make highway improvements.

Object of the Study:

We are going to drive you over a number of roads which we believe are representative of the roads as they exist throughout the State. We will then ask you to make two judgments concerning each road. First, we want you to rate the roughness or smoothness of the ride provided by each road on a scale of 0 to 5, and second, we want you to indicate whether or not you think an effort should be made to improve the ride quality of each road.

MAKING YOUR RATINGS OF RIDE QUALITY

(A facsimile of the rating scale was shown to the subjects for this section).

The first thing we want you to consider as you drive down a road is the roughness or smoothness of the ride provided by the road and then to rate it on this scale (illustrated) which ranges from 0 to 5. You will indicate your rating by placing a small mark across the vertical line of the scale at the place which you think best describes the ride provided by each road.

DEFINITIONS OF ENDPOINTS

All roads which you drive over in this survey will be between two extremes. That is, somewhere between impassable and perfect.

Impassable: A road which is so bad that you doubt that you or the car will make it to the end at the speed you are travelling--like driving down railroad tracks along the ties.

Perfect: A road which is so smooth that at the speed you are travelling you would hardly know the road was there. You doubt that if someone made the surface smoother that the ride would be detectably nicer.

Since these roads probably do not exist you will probably not consider any road to be worse than impassable or better than perfect.

In order to help you make your rating, we have included a number of words along the scale which could be used to describe how the riding sensation seems to you. For example, if you should encounter a road for which you could describe the ride as FAIR but not quite good, place your ma just below the line labeled "3" (illustrated). On the other hand, if you think the next road is still fair, but somewhat worse than the previous road, place your mark at a point which you think is the appropriate distance down in the FAIR category. To indicate small differences between the ride quality provided by the roads, you may place your mark anywhere you like along the scale.

NOTE: We are not asking you to place roads into one of five categories! You should use small differences in the position of your marks to indicate small differences between the ride quality provided by the roads. You may place your mark anywhere you like along the scale.

INDICATING THE NEED FOR THE IMPROVEMENT

After you have made your rating of the degree of ride quality provided by any particular road, we want you to check the appropriate box alongside the rating scale to indicate whether or not you think the State should improve the ride quality of the road.

When making this decision you should take into account the fact that since the State only has a certain, fixed amount of money each year to make road improvements, it must determine which roads should be improved first. Therefore, before deciding on the need for improvement, you should not only consider how rough a ride is provided by each road, but whether <u>you</u> feel the road is important enough to be placed high on the State's list of roads needing improvement. For example, you may ride across two roads which give identically rough rides but, if you had your choice, you would rather see only one of them improved because the type or character of that road seems to you to make it more worthy of improvement.

PROCEDURE FOR SURVEY

- For this survey we are going to ask you to evaluate road sections.

Panel Instructions(continued)

NOTE: You will <u>not</u> be rating an entire road for its ride quality. We have carefully selected small test sections to represent each road. It is these sections that we want you to rate for ride quality.

- As you approach each section, the driver will call out the number of the section. Be sure you have the proper numbered form.
- When the driver says START, begin concentrating on what the <u>rating of ride quality</u> should be, based on how the ride feels to you.
- It will only take about 30 seconds to drive over each section, so maintain your concentration until the driver says STOP. At that point, place your rating mark on the scale.
- Next, while taking into account both the roughness of the ride through the representative test section, as ~~well as~~ the nature and type of the entire road, indicate whether or not you think the ride quality needs to be improved by checking the appropriate box next to the rating scale.
- Since some sections are only 3-4 minutes apart, make your decisions quickly and pass your forms to the person sitting in the front right seat.
- This procedure will be repeated for each site.
- We will be driving over a predetermined course in an ordinary passenger car. The trip will take hours the first day and hours the second.

SPECIAL INSTRUCTIONS

- When making your rating of ride quality, do <u>not</u> consider any of the road before or after a test section. We are only interested in a rating for a small section of road.
- When making your decision concerning the need for improvements, assume that the ride provided by the entire road is the same as that for the test section.
- Concentrate only on the ride quality provided by the roads. Don't let the appearance of the road surface influence your ratings. Judge only how the road feels!

Panel Instructions (continued)

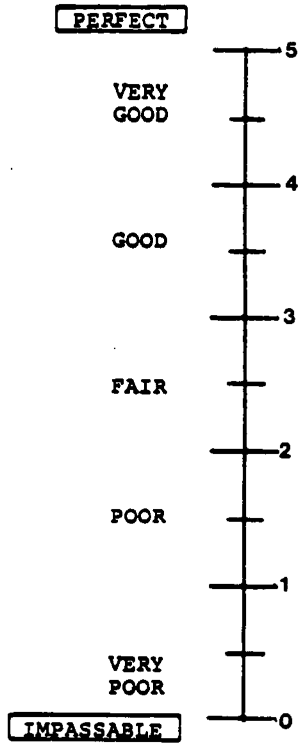
- Don't be distracted by conversations in the car or by pretty scenery.
- Don't reveal your ratings to the other raters. There is no right or wrong answer, so don't "cheat". We are interested only in <u>your</u> opinion which is as valid as anyone else's.
- Be critical about the ride quality provided by the roads. If they are not absolutely perfect as far as you are concerned, be sure to give it a rating on the scale which you think best reflects the diminished quality of the ride.
- Be aware that there are many ways that the ride could be considered less than <u>PERFECT</u>. The road could

  a) be so bumpy that it rattles your bones and makes your teeth chatter,

  b) have bumps or undulations that makes the car heave up and down as if it was a roller coaster, or

  c) have other imperfections in the surface which you think detract from the ride quality.

RATER FORM



☐ Ride quality does <u>not</u> need improvement

☐ Ride quality <u>needs</u> improvement

Site No. ________

Rater No. ________

Note: RATING LINE MUST BE EXACTLY FIVE INCHES LONG

APPENDIX C

SUPPORT MATERIAL FOR DATA COLLECTION

TABLE C-1 NJ DATA

Surface	MPR	MRM	NR	PI	MPR(Large Car)
BC	1.05	669	94.40	.147	1.14
BC	1.41	445	77.77	.112	1.51
BC	2.14	311	41.67	.079	1.99
BC	3.72	76	5.56	.022	3.74
BC	3.07	127	16.67	.028	3.41
BC	2.66	244	30.56	.049	2.65
BC	3.73	93	0.00	.023	3.68
BC	4.10	43	0.00	.020	3.87
BC	2.81	108	25.00	.047	2.70
BC	4.25*	27	0.00	.015	4.27
BC	4.18*	25	0.00	.016	4.18
BC	3.62*	63	0.00	.019	3.94
BC	3.11	129	2.78	.037	3.03
BC	3.61	58	0.00	.027	3.46
BC	3.68	73	8.33	--	3.57
BC	3.63	81	5.56	.029	3.36
BC	3.49	84	2.78	--	3.48
BC	3.33	104	8.33	--	2.98
PCC	2.57	201	44.44	--	
PCC	3.76	50	0.00	.021	
PCC	4.20*	47	0.00	.018	
PCC	3.49	56	8.33	.021	
PCC	3.43	56	8.33	.026	
PCC	3.60	78	0.00	.026	
PCC	3.60	86	2.78	.026	
PCC	3.57	92	2.78	.030	
PCC	3.61	46	0.00	.022	
PCC	1.94	183	88.89	.074	
PCC	2.24	212	75.00	.064	
PCC	3.47*	69	5.56	.025	
PCC	3.31*	74	11.11	.028	
PCC	2.89	162	30.56	--	
PCC	3.63*	88	0.00	.025	
PCC	3.34	62	0.00	.023	
PCC	3.97	68	0.00	.021	
PCC	2.64	160	55.56	.053	
PCC	2.44	246	61.11	.063	
PCC	2.61	97	41.67	.040	
PCC	2.60	174	41.67	.051	
PCC	2.79	163	27.78	.051	
PCC	3.43*	102	11.11	.033	

* Interstate

TABLE C-1 NJ DATA (Continued)

Surface	MPR	MRM	NR	PI
COMP	3.52	27	8.33	.029
COMP	3.24	131	13.89	--
COMP	3.07	103	11.11	--
COMP	3.32	81	5.56	.031
COMP	3.57	92	5.56	--
COMP	3.66	82	5.56	--
COMP	3.71	34	2.78	.025
COMP	3.33	62	0.00	.032
COMP	2.46	144	50.00	.046
COMP	3.16	82	5.56	.031
COMP	3.11	62	13.89	.035
COMP	3.97	72	0.00	--
COMP	2.48	133	52.78	.048
COMP	3.28	84	5.56	.032
COMP	3.94	50	0.00	--
COMP	3.47	53	2.78	.022

TABLE C-2 MI DATA

Surface	MPR	1/4 CAR	NR	PI	RQI
BC	3.22	138	0.0	--	62.4
BC	3.59	85	0.0	.018	56.9
BC	3.94	64	0.0	.015	47.0
BC	3.50	56	8.3	.021	36.0
BC	2.93	108	13.9	.031	52.9
BC	2.65	118	30.6	.036	44.4
BC	2.94	98	8.3	.029	45.4
BC	3.24	81	5.5	.025	41.5
BC	3.44	62	0.0	.021	42.6
BC	1.97	186	69.4	.067	77.6
BC	1.93	217	69.4	.073	80.9
BC	1.40	247	80.6	.081	93.2
BC	1.49	272	88.9	.082	91.3
BC	3.35	88	0.0	.023	52.3
BC	3.96	45	0.0	.015	28.2
BC	3.92	36	0.0	.013	30.6
BC	3.51	58	0.0	.022	30.9
BC	2.61	187	27.8	.044	78.3
BC	3.39	69	2.8	.019	54.0
BC	3.99	54	0.0	.012	38.4
BC	3.95	59	0.0	.018	43.6
BC	2.46	138	41.7	.037	65.7
PCC	2.25	154	61.1	.050	68.2
PCC	3.22*	138	11.1	.029	66.8
PCC	3.04	129	13.9	.022	64.6
PCC	3.12	147	5.5	.027	70.0
PCC	3.32	104	8.3	.022	56.2
PCC	2.98	98	19.4	.021	51.4
PCC	2.51	155	44.4	.041	74.4
PCC	2.67*	115	47.2	.032	63.3
PCC	2.69*	121	44.4	.029	70.6
PCC	2.81*	122	36.1	.029	68.3
PCC	1.93	127	72.2	.045	60.2
PCC	1.66	182	83.3	.062	72.1
PCC	2.13	203	72.2	.059	71.8
PCC	2.63	111	19.4	.030	60.6
PCC	4.08	87	0.0	.016	51.5
PCC	3.58*	124	5.5	.025	54.9
PCC	3.56*	104	5.5	.023	49.1
PCC	3.24*	117	11.1	.030	56.5
PCC	3.40*	116	8.3	.028	56.1
PCC	2.82*	139	33.3	.039	66.1
PCC	2.47	144	47.2	.037	68.7
PCC	3.48	112	5.5	.023	53.9
PCC	3.93*	69	5.5	.017	41.1
PCC	2.97*	132	22.2	.025	70.1
PCC	2.97*	98	13.9	.027	58.4
PCC	3.15	135	11.1	.027	66.4
PCC	2.23*	159	72.2	--	72.2
PCC	4.26*	78	0.0	--	38.0
PCC	2.46	138	41.7	--	41.7

* Interstate

TABLE C-2 MI DATA (Continued)

Surface	RN	1/4 CAR	NR	PI	RQI
COMP	3.11	84	19.4	.028	52.7
COMP	2.41	133	47.2	.039	70.0
COMP	4.33	70	0.0	.012	48.6
COMP	2.05	150	69.4	.039	73.6
COMP	2.15	132	58.3	.039	67.8
COMP	2.47	128	47.2	.042	63.9
COMP	4.10	63	0.0	.016	40.3
COMP	3.36	127	5.5	.030	62.0
COMP	2.89	134	16.7	.040	64.7
COMP	3.12	95	8.3	.037	53.3
COMP	3.40	78	2.8	.027	45.6
COMP	2.70	134	30.6	.040	66.6
COMP	4.01	60	0.0	.013	44.9
COMP	3.91	62	0.0	.015	42.4
COMP	4.02	46	0.0	.011	33.4
COMP	4.08	45	0.0	.012	35.0
COMP	1.11	329	97.2	.095	79.9
COMP	4.14	50	2.8	.012	36.6
COMP	4.06	50	0.0	.011	36.9
COMP	4.07	49	2.8	.010	36.6
COMP	3.37	84	5.5	--	(44.6)

TABLE C-3 NM DATA

Surface	MPR	NR	PI
BC	2.36*	73.0	.048
BC	3.41*	11.1	.015
BC	3.75*	2.8	.018
BC	3.67*	2.8	.012
BC	2.55*	64.9	.036
BC	1.83	69.4	--
BC	1.95	70.3	.070
BC	1.39	81.1	.110
BC	2.71	13.9	.040
BC	3.84*	0.0	.012
BC	3.67*	0.0	.014
BC	2.08	78.4	.064
BC	2.45	56.8	--
BC	4.22	2.8	.012
BC	2.29	63.9	.044
BC	2.34	54.1	.048
BC	4.27	0.0	.011
BC	4.30	0.0	.014
BC	4.29*	0.0	.012
BC	3.78*	5.4	--
BC	2.28	50.0	.046
BC	3.95*	5.6	.019
BC	4.19*	0.0	.009
BC	2.22*	83.3	--
BC	2.79*	48.6	--
BC	2.60	51.4	.031
BC	2.29	67.6	.037
BC	2.34	67.6	.045
BC	2.96	32.4	--
BC	3.66	2.7	.016
BC	3.83	2.7	.014
BC	2.79	27.0	.034
BC	2.02	72.9	.063
BC	2.83*	27.0	.033
BC	2.92	16.2	.038
BC	3.69	2.7	.021
BC	0.40	89.2	.269
BC	3.53	5.4	.014
BC	2.83	43.2	.033
BC	3.39*	11.1	.019
BC	2.28	56.8	--
BC	4.27*	0.0	.009
BC	1.84	97.3	.058
BC	3.95*	8.1	.011
BC	4.35*	0.0	.011
BC	4.45*	0.0	.009
BC	3.52	8.1	.027
BC	3.23	8.3	--
BC	2.77	54.1	.036

* Interstate

TABLE C-3 NM DATA (Continued)

Surface	MPR	NR	PI
PCC	2.36	64.9	.033
PCC	2.8	40.5	--
PCC	2.62	43.2	--
PCC	3.04	35.1	.033
PCC	2.77	58.3	--
PCC	2.68	54.1	--
PCC	3.04	37.8	.026
PCC	2.71	56.8	--
PCC	3.44	18.9	--
PCC	2.85	45.9	.028
PCC	2.7	52.8	.025
PCC	2.8	47.2	.026
PCC	2.97	30.6	.019
PCC	2.61	56.8	--
PCC	2.96	37.8	.023
PCC	2.86	37.8	.023
PCC	3.14	22.2	.019
PCC	3.48	16.2	--
COMP	3.32	11.1	.019
COMP	3.84	5.6	.014
COMP	3.90	5.4	.014
COMP	3.32	21.6	.019
COMP	3.55	8.3	.019
COMP	4.01	5.4	.014
COMP	4.06	0.0	.014
COMP	4.07	0.0	.012
COMP	3.84	2.7	.011
COMP	4.02	2.7	.011
COMP	3.86	5.6	.016
COMP	2.34	62.2	--
COMP	2.55	43.2	.037
COMP	2.34	64.9	.045

TABLE C-4 LA DATA

Surface	MPR	NR	MRM	PI
BC	2.42	47.2	205.0	.046
BC	4.09	0.0	55.0	.016
BC	2.51	33.3	210.0	--
BC	4.17	2.8	27.5	.010
BC	4.17	0.0	45.0	.012
BC	3.25	8.3	85.0	.022
BC	1.20	86.1	350.0	.114
BC	3.03	15.2	112.5	.027
BC	2.31	33.3	185.0	.042
BC	3.91	0.0	65.0	.018
BC	2.71	22.2	70.0	.028
BC	2.82	8.3	177.5	.030
BC	4.03	0.0	100.0	.019
BC	4.13	0.0	17.5	.011
BC	3.86	8.3	62.5	.020
PCC	3.19	13.9	135.0	.030
PCC	3.60	0.0	152.5	--
PCC	3.04	13.9	212.5	.038
PCC	4.47	0.0	20.0	--
PCC	3.69	2.8	135.0	.023
PCC	3.78	2.8	100.0	.021
PCC	4.26	0.0	75.0	.020
PCC	4.17	2.8	80.0	.023
PCC	3.58	5.6	115.0	.019
PCC	3.40	5.6	205.0	.033
PCC	2.53	38.9	230.0	.035
PCC	2.96	13.9	185.0	.025
PCC	4.05	0.0	87.5	.020
PCC	4.19	0.0	65.0	.019
PCC	3.94	0.0	77.5	.018
PCC	2.65	25.0	302.5	.038
PCC	3.79	2.8	165.0	.029
PCC	3.64	2.8	1256.0	.019
PCC	3.72	0.0	97.5	.018
PCC	3.23	13.9	82.5	.026
PCC	2.63	25.0	215.0	.040
PCC	2.78	27.8	225.0	.045
PCC	3.14	16.7	177.5	.040
PCC	4.05	0.0	115.0	.018
PCC	3.96	2.8	90.0	.080
PCC	3.16	11.1	180.0	.041

TABLE C-4 LA DATA (Continued)

Surface	MPR	NR	MRM	PI
COMP	2.53	30.6	135.0	.044
COMP	2.81	27.8	130.0	.043
COMP	2.62	30.6	160.0	.049
COMP	3.38	16.7	105.0	.021
COMP	3.24	13.9	107.5	.031
COMP	2.50	50.0	105.0	.058
COMP	3.90	0.0	62.5	.013
COMP	4.28	0.0	42.5	.014
COMP	2.94	14.3	175.0	.038
COMP	2.04	66.7	160.0	.060
COMP	3.22	0.0	60.0	.024
COMP	4.13	0.0	62.5	.013
COMP	2.65	34.3	150.0	.045
COMP	3.52	5.6	87.5	.025

TABLE C-5 OHIO DATA

Surface	MPR	MRM	1/4 CAR	NR	PI
BC	3.20	161.6	155	8.3	.027
BC	2.26	247.3	202	38.8	.032
BC	1.01	661.3	449	86.1	.100
BC	2.25	221.9	213	41.7	.065
BC	2.09	441.3	351	47.2	.080
BC	3.18	149.0	155	13.9	.028
BC	4.05	49.0	59	0.0	.014
BC	1.94	279.1	240	58.3	.049
BC	3.54	132.9	124	5.6	.021
BC	3.81	77.6	82	2.8	.015
BC	2.54	142.2	129	44.4	.031
BC	1.64	286.0	247	83.3	.060
BC	1.38	432.8	322	81.8	.072
BC	2.31	203.7	183	41.7	.044
BC	1.82	348.1	255	72.2	.046
BC	1.27	280.8	237	91.7	.132
BC	3.23	98.7	111	19.4	.023
BC	3.84	42.0	63	0.0	.014
PCC	2.85	219.0	198	30.6	.041
PCC	3.31	236.3	140	25.0	.025
PCC	3.42	66.1	77	13.9	.021
PCC	1.93	132.7	125	83.3	.040
PCC	3.73	97.0	101	5.6	.018
PCC	2.76	172.3	151	57.6	.041
PCC	2.72	147.9	138	61.6	.037
PCC	2.79	217.6	196	44.4	.036
PCC	2.56	188.9	178	72.2	.040
PCC	2.49	138.1	161	72.2	.037
PCC	3.47	134.5	141	13.9	.019
PCC	3.75	91.4	82	5.6	.015
PCC	3.63	89.2	99	8.3	.018
PCC	3.51	102.2	108	11.1	.025
PCC	3.79	105.2	112	2.8	.017
PCC	3.41	110.9	123	19.4	.021
PCC	2.07	150.5	166	88.9	.048

TABLE C-5 OHIO DATA (Continued)

Surface	MPR	MRM	1/4 CAR	NR	PI
COMP	4.41	34.6	44	0.0	.009
COMP	3.12	108.5	101	22.2	.030
COMP	3.21	55.8	56	19.4	.015
COMP	2.49	83.4	90	44.4	.034
COMP	2.89	64.0	69	30.6	.034
COMP	3.93	55.9	62	0.0	.011
COMP	1.86	221.5	182	72.2	.052
COMP	2.66	178.4	138	27.8	.053
COMP	3.68	59.2	66	2.8	.018
COMP	4.25	42.0	57	0.0	.012
COMP	4.15	83.2	84	2.8	.013
COMP	3.54	101.1	117	13.9	.017
COMP	3.37	61.8	84	11.1	.020
COMP	2.61	138.1	133	50.0	.041
COMP	2.00	106.0	108	75.8	.040
COMP	2.56	96.6	102	55.6	.038
COMP	2.43	39.7	60	63.9	.025

TABLE C-6 VEHICLE SPECIFICATIONS

ITEM	HORIZON	K-CAR	FORD LTD
Wheelbase	99.1	100.3	105.6
Length (in)	163.2	178.6	196.5
Width (in)	66.8	68.0	71.0
Height (in)	53.0	52.9	53.8
Weight (lb)	2160.0	2415.0	3001.0
Engine	Front	Front	Front
Drive	Front	Front	Rear

Note: All vehicles equipped with PS, PB, AC, Auto Trans, Radio

APPENDIX D—SUPPORT MATERIAL FOR DATA ANALYSES

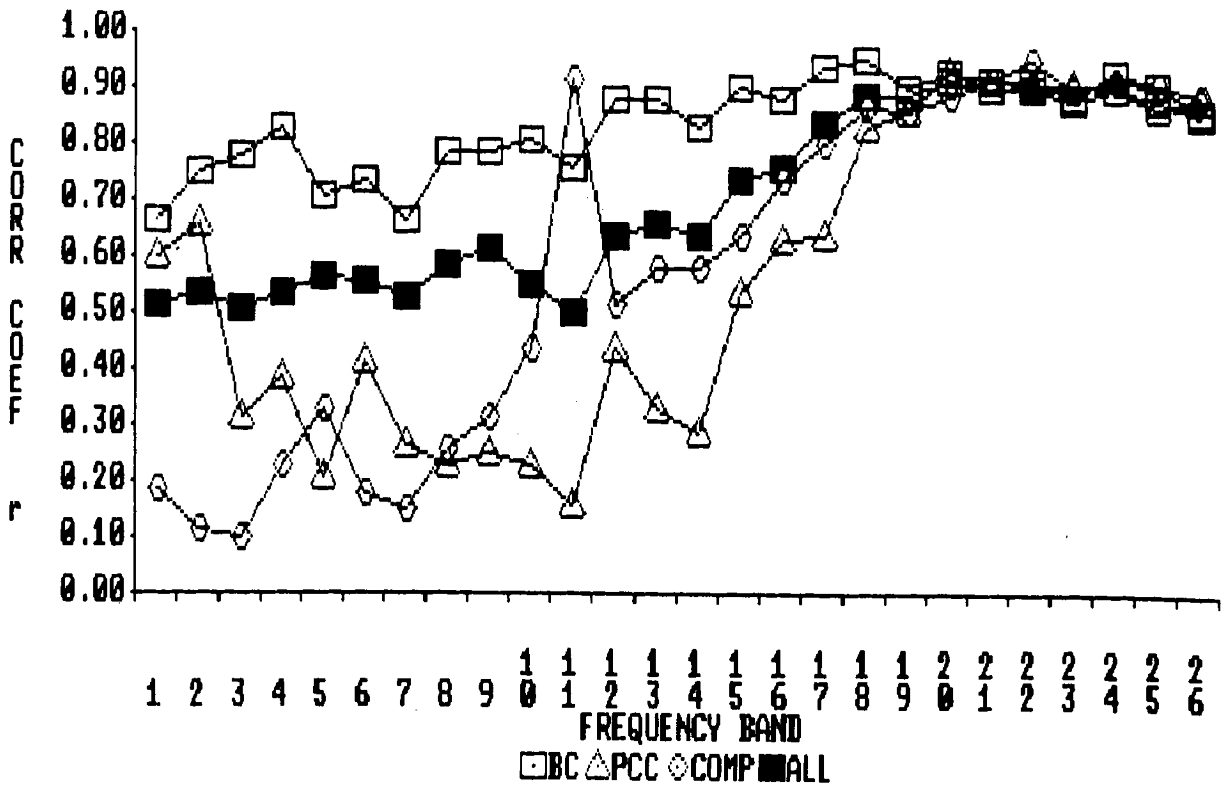


FIGURE D-1 - PI vs MPR; 1/3 OCTAVE BANDS/OH

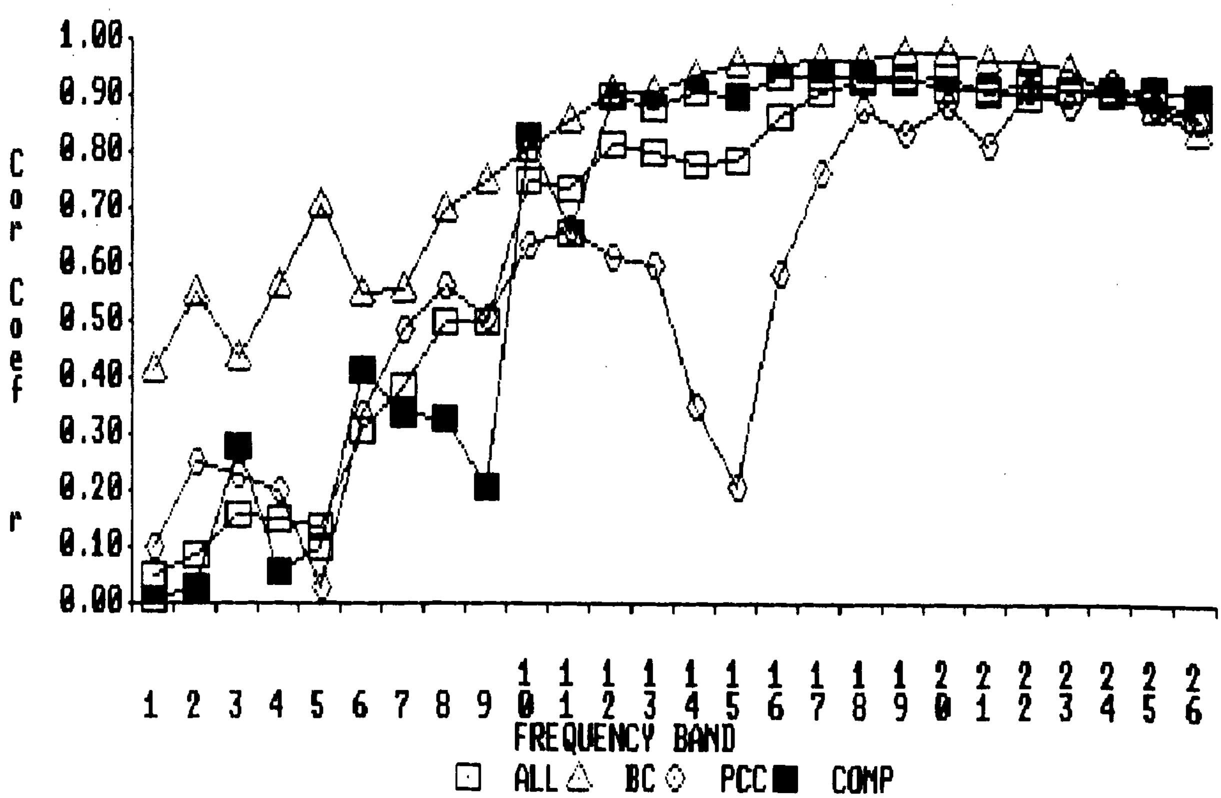


FIGURE D-2 - PI vs MPR; 1/3 OCTAVE BANDS/MI

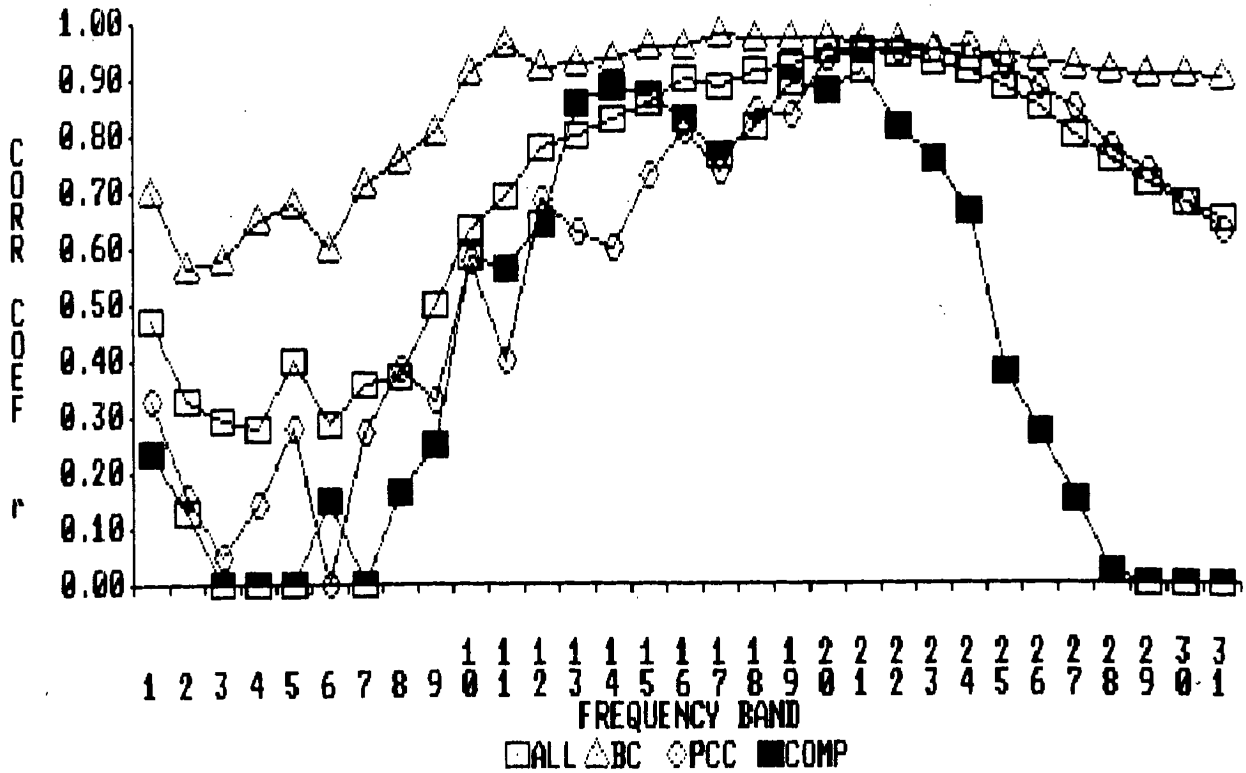


FIGURE D-3 - PI vs MPR; 1/3 OCTAVE BANDS/NJ

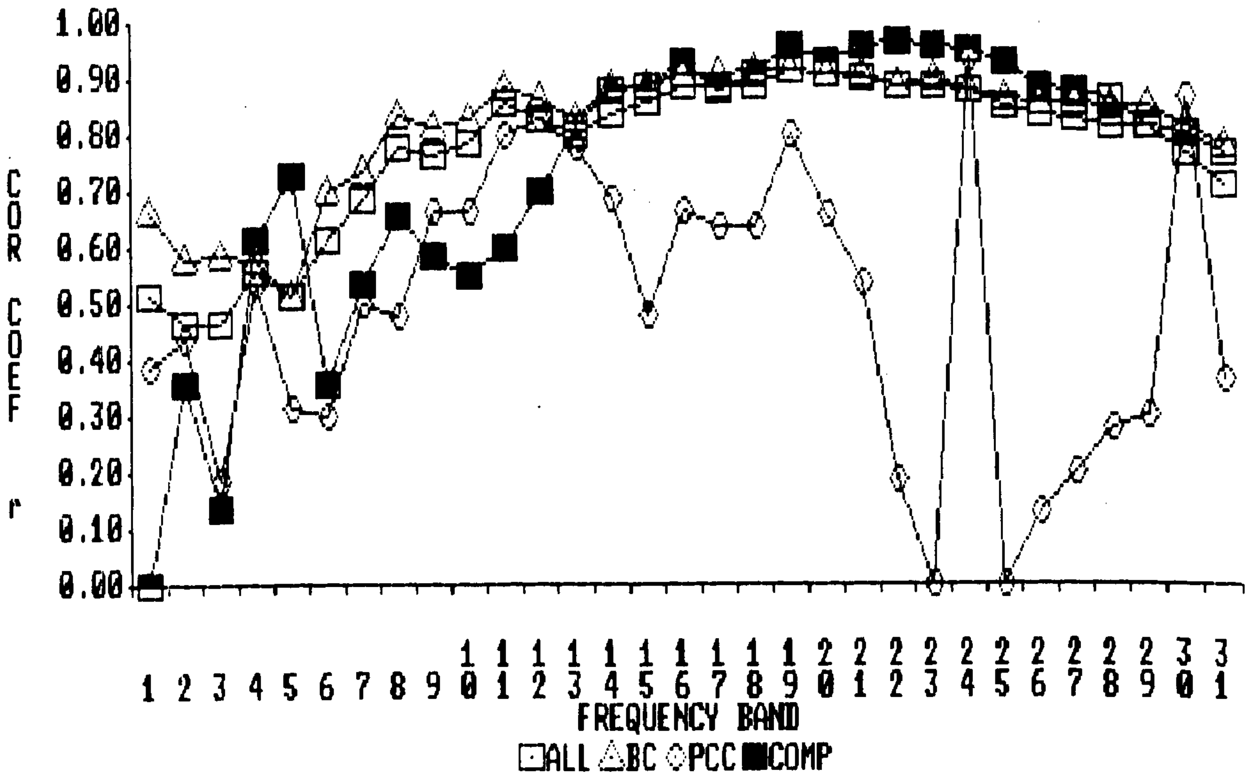


FIGURE D-4 - PI vs MPR; 1/3 OCTAVE BANDS/NM

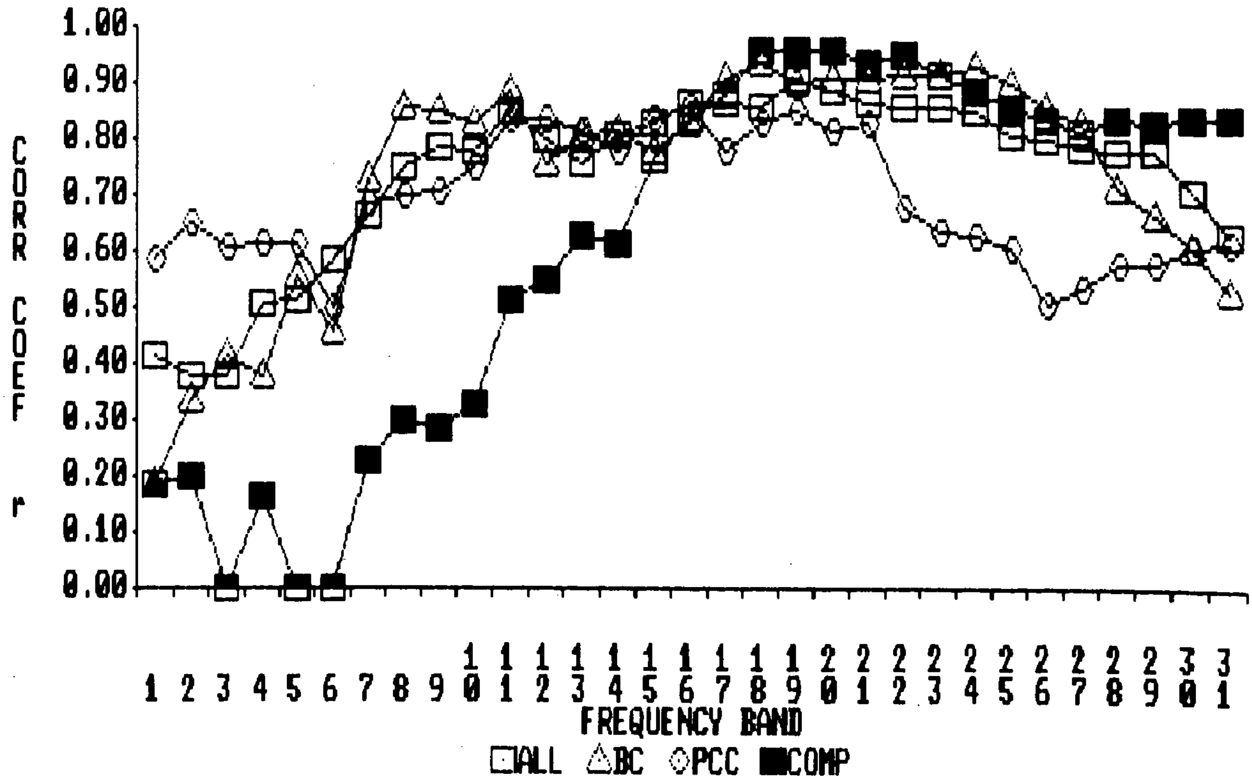


FIGURE D-5 - PI vs MPR; 1/3 OCTAVE BANDS/LA

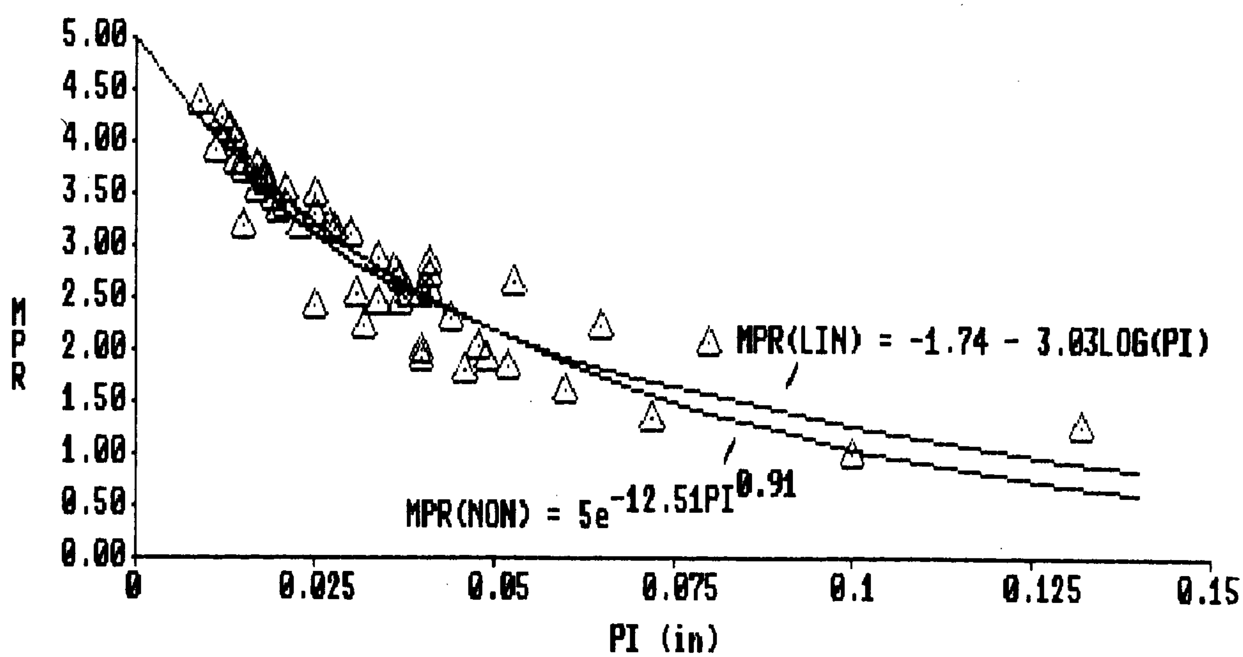


FIGURE D-6 - PI vs MPR/OH

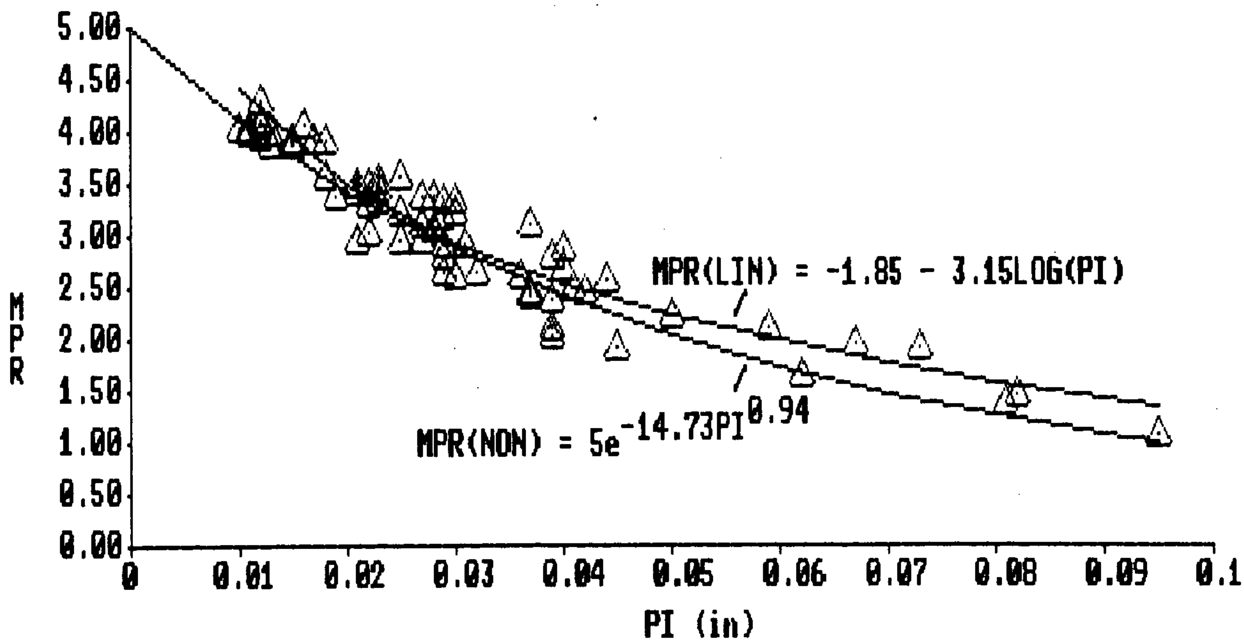


FIGURE D-7 - PI vs MPR/MI

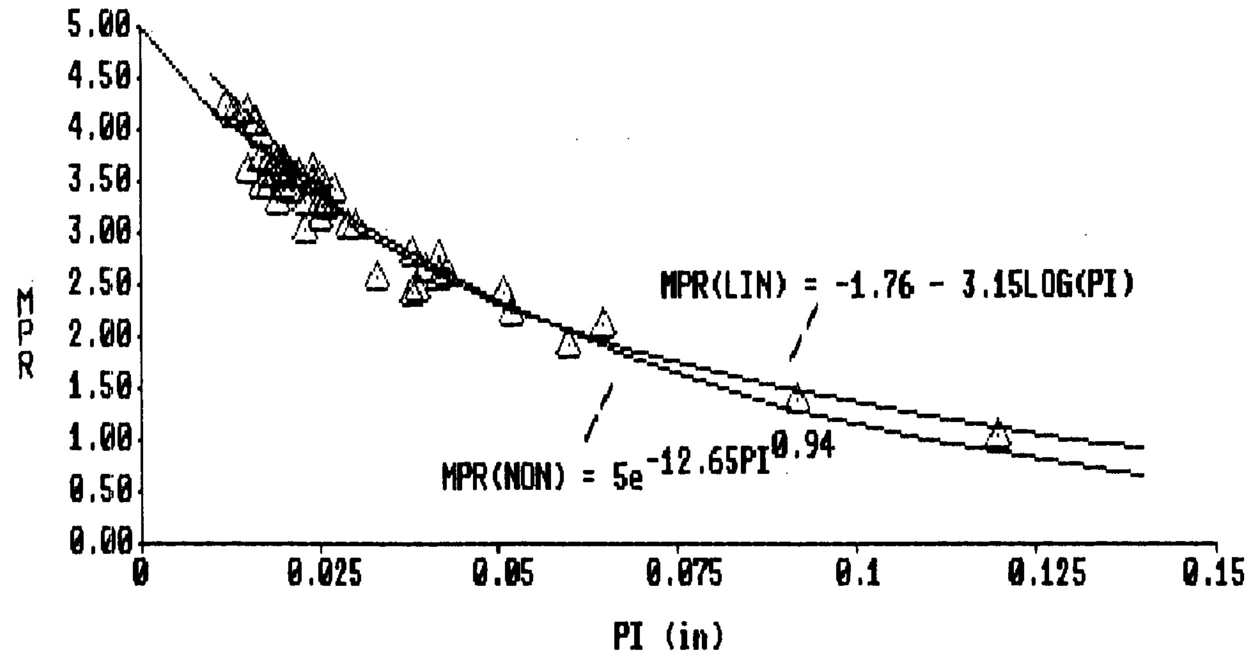


FIGURE D-8 - PI vs MPR/NJ

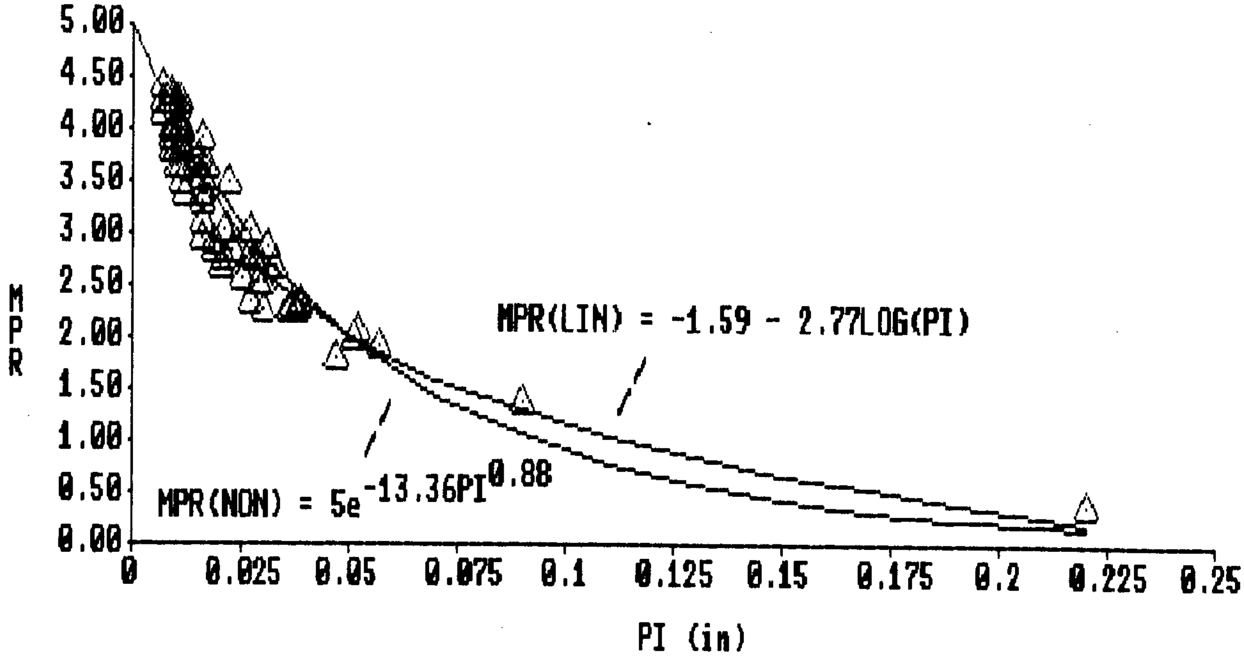


FIGURE D-9 - PI vs MPR/NM

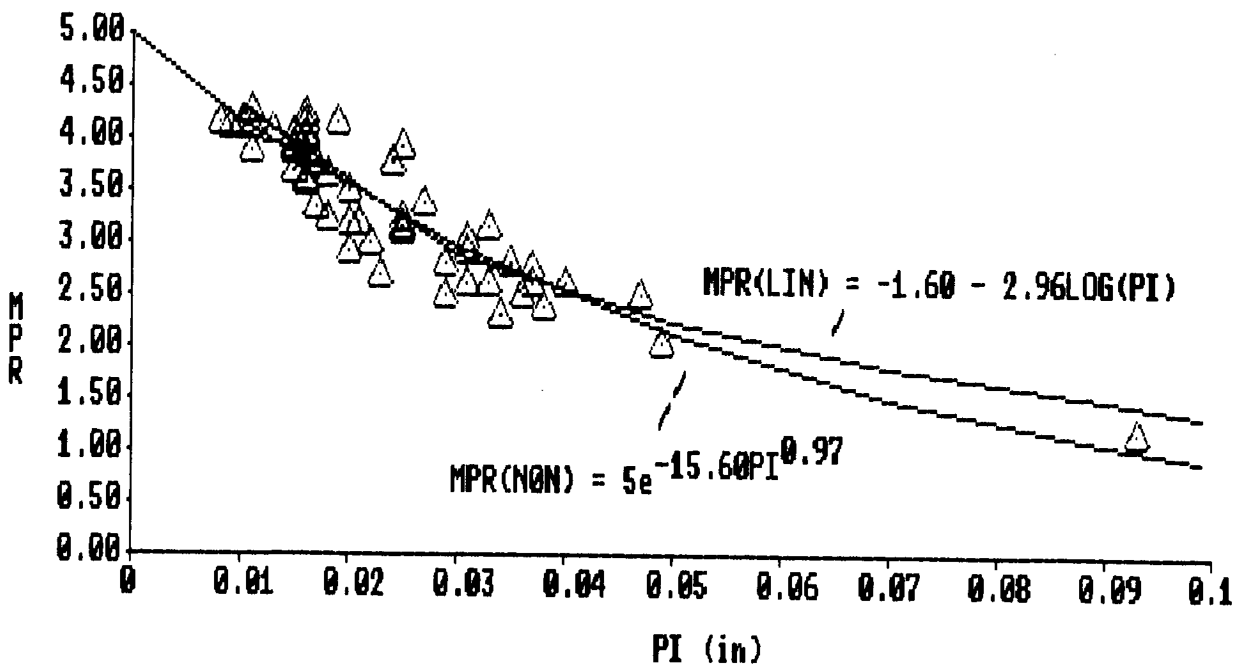


FIGURE D-10 - PI vs MPR/LA

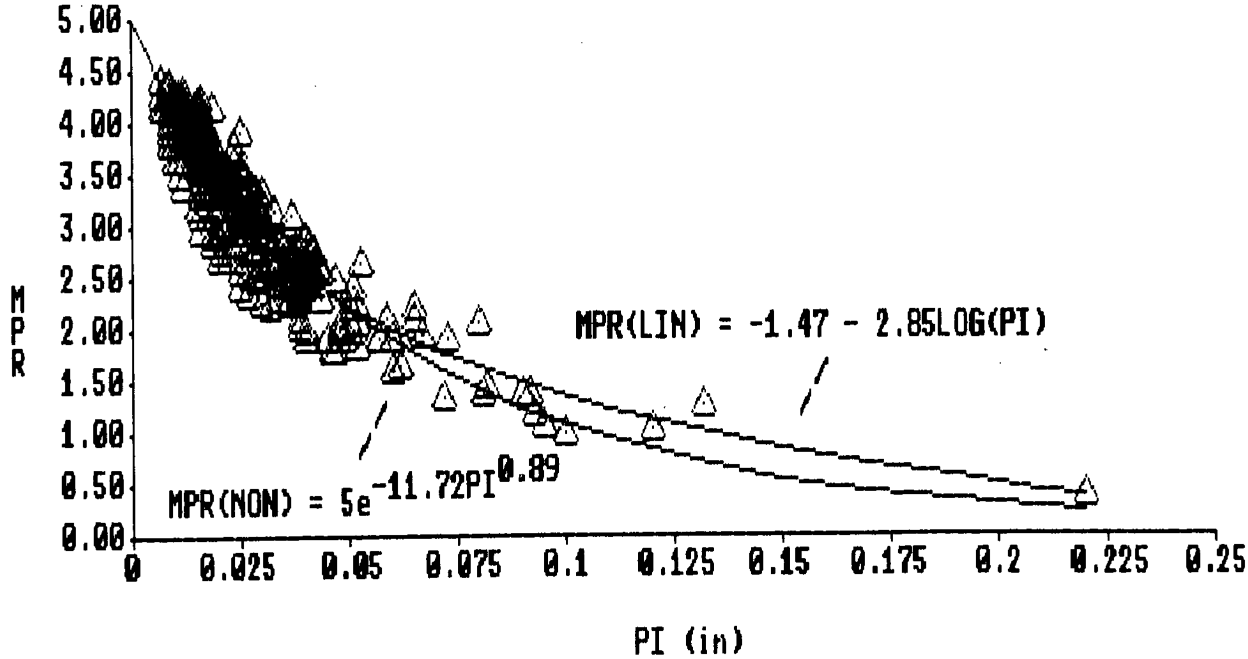


FIGURE D-11 - PI vs MPR/5-STATES

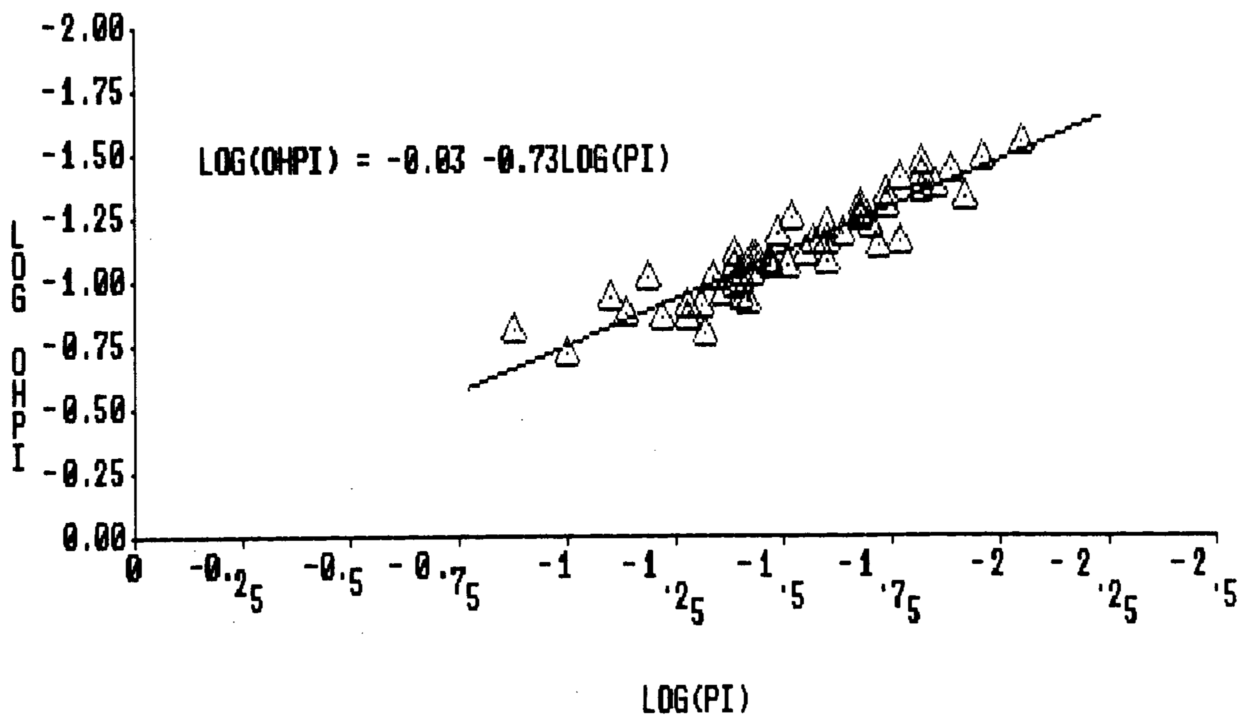


FIGURE D-12 - PI vs OHPI/OH

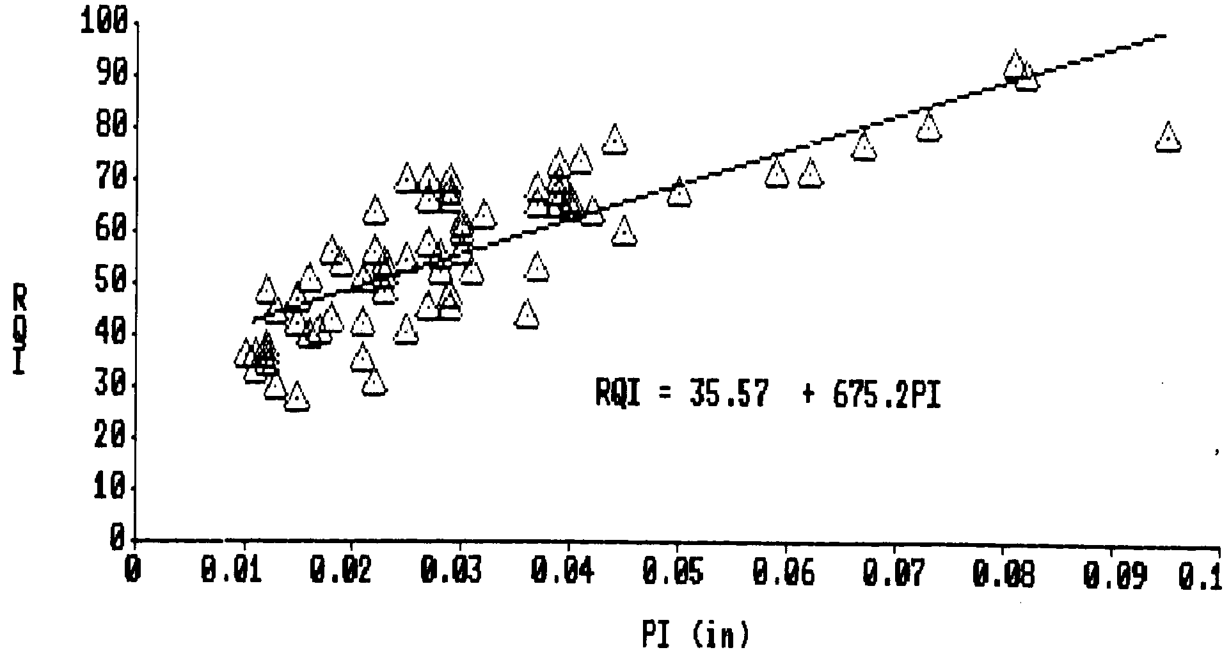


FIGURE D-13 - PI vs RQI/MI

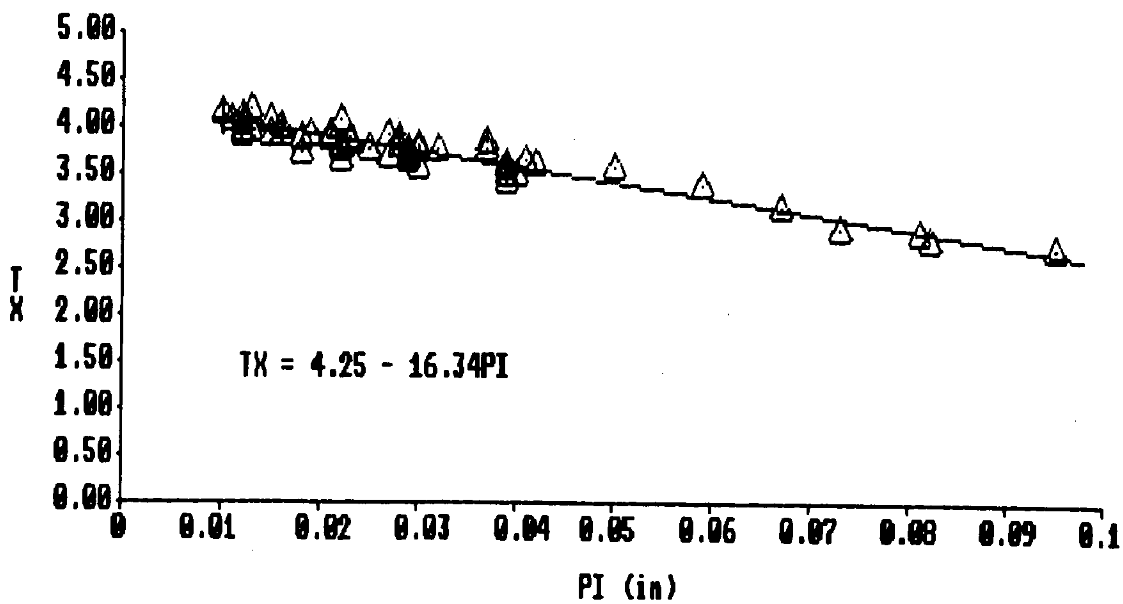


FIGURE D-14 - PI vs TX/MI

TABLE D-1: EFFECT OF SURFACE TYPE ON PI vs MPR REGRESSION ANALYSES

LINEAR: MPR = a + bLog(PI)

STATE	BC			PCC			COMP		
	a	b	r	a	b	r	a	b	r
OH	-1.79	-3.04	-.94	-2.01	-3.25	-.93	-1.58	-2.89	-.91
NJ	-1.75	-3.14	-.98	-1.63	-3.07	-.95	-2.65	-3.69	-.93
MI	-1.77	-3.14	-.98	-2.46	-3.54	-.89	-1.70	-3.04	-.95
NM	-1.53	-2.77	-.97	0.54	-1.38	-.52	-1.84	-2.93	-.96
LA	-2.01	-3.10	-.96	-1.87	-3.20	-.79	-1.25	-2.72	.97
ALL	-1.55	-2.87	-.96	-1.62	-2.99	-.83	-1.32	-2.76	-.93

NON-LINEAR: $MPR = 5e^{aPI^b}$

STATE	BC		PCC		COMP	
	a	b	a	b	a	b
OH	-10.28	0.85	-15.03	0.96	-17.11	0.98
NJ	-12.19	0.94	-10.97	0.89	-22.40	1.08
MI	-10.59	0.87	-18.73	1.02	-15.49	0.99
NM	-12.76	0.88	- 2.29	0.37	-18.49	0.95
LA	-17.36	0.97	-25.10	1.12	-12.72	0.91
ALL	-11.37	0.88	-12.63	0.91	-12.65	0.91

TABLE D-2: EFFECT OF SURFACE TYPE ON MRM vs MPR REGRESSION ANALYSES

LINEAR MPR = a + bLog(MRM)

STATE	ALL			PCC			COMP		
	a	b	r	a	b	r	a	b	r
OH	7.21	-2.06	-.73	4.98	-0.90	-.24	7.37	-2.26	-.66
NJ	7.29	-2.07	-.96	7.61	-2.23	-.87	5.84	-1.34	-.63
LA	7.25	-1.92	-.74	7.46	-1.88	-.83	9.02	-2.94	-.85
ALL 3	7.37	-2.07	-.79	7.12	-1.86	-.69	7.08	-2.03	-.68

NON-LINEAR: $MPR = 5e^{aMRM^b}$

STATE	ALL		PCC		COMP	
	a	b	a	b	a	b
OH	-0.02	0.66	-0.02	0.62	-0.02	0.74
NJ	-0.02	0.62	-0.02	0.70	-0.06	0.47
LA	-0.02	0.68	-0.01	0.74	-0.04	1.01
ALL 3	-0.02	0.65	-0.02	0.64	-0.02	0.67

TABLE D-3: EFFECT OF SURFACE TYPE ON
QTR CAR vs. MPR REGRESSION ANALYSES

LINEAR MPR = a + bLog(QTR)

STATE	ALL			BC			PCC			COMP		
	a	b	r	a	b	r	a	b	r	a	b	r
OH	8.65	-2.75	-.75	10.46	-3.55	-.92	6.98	-1.85	-.39	9.67	-3.42	-.71
MI	9.73	-3.31	-.88	8.86	-2.94	-.94	12.99	-4.80	-.78	10.42	-3.68	-.94
BOTH	9.29	-3.07	-.84	9.04	-2.97	-.94	11.25	-3.94	-.71	10.00	-3.51	-.84

NON-LINEAR: $MPR = 5e^{a(QTR)^b}$

STATE	ALL		BC		PCC		COMP	
	a	b	a	b	a	b	a	b
OH	-0.010	-0.85	-0.004	1.00	-0.005	0.95	-0.004	1.06
MI	-0.004	1.00	-0.007	0.87	-0.001	1.32	-0.002	1.16
BOTH	-0.010	0.86	-0.009	0.86	-0.001	1.22	-0.003	1.13

TABLE D-4: SUMMARY OF MPR vs PI ANALYSES;
SURFACE & ROAD CLASS

MPR = a + bLog(PI)

SURFACE	ROAD CLASS	a	b
BC	ALL	-1.55	-2.87
PCC	ALL	-1.62	-2.99
COMP	ALL	-1.32	-2.76
ALL	ALL	-1.47	-2.85
BC	INT.	-1.38	-2.74
BC	NON INT.	-1.71	-2.98
PCC	INT.	-2.51	-3.63
PCC	NON INT.	-1.89	-3.17

TABLE D-5: SUMMARY OF NR vs MPR ANALYSES;
SURFACE & ROAD CLASS (4 STATES)

NR = a + bMPR

SURFACE	ROAD CLASS	a	b
BC	ALL	125.2	-32.2
PCC	ALL	158.9	-42.3
COMP	ALL	124.2	-31.7
ALL	ALL	131.7	-33.9
BC	INT.	150.6	-37.0
BC	NON INT.	128.9	-34.2
PCC	INT.	153.7	-40.1
PCC	NON INT.	155.1	-42.8

APPENDIX E

GUIDELINES FOR CONDUCTING PANEL RATING EXPERIMENTS OF PAVEMENT RIDEABILITY

INTRODUCTION

This appendix provides a set of guidelines for highway agency personnel to use to conduct panel rating studies of rideability or ride quality. The guide describes the six key issues that must be addressed: (1) selection of test sections and route formation, (2) panel selection, (3) rating procedures, (4) panel study, (5) data reduction, and (6) physical measurements.

SELECTION OF TEST SECTIONS AND ROUTE FORMATION

This section of the user's guide describes the steps required to: (1) identify potential test sections; (2) select test sections; (3) develop the route; (4) create an inventory of the test sections and their characteristics; (5) mark the test sections; and (6) inform maintenance departments about the necessary deferment of repair work on the test sections.

Identification of Potential Test Sections

Identifying potential test sites is begun by reviewing historical roughness data, inspecting routes of probable interest, and gathering roughness data on the potential sites.

Historical roughness data can be obtained from various sources of information, including: road logs or inventories, pavement roughness or serviceability index data, and local knowledge.

Some states have road logs or pavement inventories (by particular district, division, or county) which describe the physical and geographical characteristics of pavement sections. For example, the road log books of the Pennsylvania Department of Transportation (PADOT) include the following informative data: legislative route, station number, maintenance functional code (MFC), functional class code, federal-aid status, traffic route, urban or rural location, length of test section, average daily traffic, surface width, year built, year resurfaced, and description of pavement.

Some of these data can be useful background information for identifying pavement and other characteristics of routes. The road log can provide the historical record of when routes were constructed and repaired and can also provide a logical starting place for the field survey team. For example, determining where to look for extremely "rough" road surface sections could be logically deduced from routes that were constructed long ago or have a history of frequent repair (such as a route that is in a poor drainage area where the road surface often cracks). Determining where to look for an extremely "smooth" road surface could be logically deduced from identifying the newly constructed highways or the roads that have been freshly overlayed with new asphalt. In addition, traffic patterns identified in the road logs can give the survey team an idea of what level of pavement roughness can be expected on certain routes.

A second source of information is the available pavement roughness or serviceability data of the highway system. Some states inventory Mays meter (or other RTRRMS) data and many transform the data to a present serviceability index (PSI) based on statistical transforms. With this information, the field survey team can go to sections of highway with a general idea of what roughness levels they will encounter.

A third source of information that provides leads for determining where potential test sites might be located is to interview local maintenance engineers or other highway agency personnel who are familiar with the highways of the area. It is very likely that such persons can inform the field crew of "rough" or "very smooth" pavement sections with which they are familiar.

From the leads provided by historical roughness data, the next step would be to visit the sites, determine the feasibility of using the site, and make notes on additional test sections that may be useful to include in the study.

Once potential sites have been identified, roughness measurements should be made to give the research team an accurate assessment of the roughness of these sections.

Historic information only provides the leads in finding potential sites that might meet the roughness ranges required for the study; a field survey team still has to go out and find the sites and assure that they meet the requirements described in the next section.

Selection of Test Sections

There are four general criteria that must be met to include a potential test section into the panel rating study. Each section should: (1) be one and only one of three pavement surface types (bituminous concrete, portland cement concrete, and composite); (2) have appropriate roughness (i.e., all levels required); (3) have uniformity of roughness throughout test section; and (4) have appropriate length.

Twenty test sections for each of the three pavement surface types are preferred for the study. It is advisable to have a few extra sections of each pavement surface type in case some of the original sections have to be dropped at the time of the panel study. There are various reasons why this may be necessary, including: change in ADT pattern, knowledge about slow-moving farm vehicles that could impede the rating vehicle, maintenance work scheduled for site, and seasonal conditions (such as flooding or mud and dirt on the road in the springtime). The 20 sections should, taken together, span the widest possible range of roughness.

During field site visits the crew should make an estimated guess of the roughness level of the section, using the subjective scale of 0 to 5 developed in NCHRP Project 1-23 and illustrated in Appendix B. The estimates will provide an idea of the number of sections that fall into each level of roughness. Table E-1 provides an alternate guide to estimating subjective roughness levels based on Mays meter measurements.

Table E-1. Approximation of mean panel ratings from Mays meter measurements.

MAYS METER MEASUREMENT (INCHES PER MILE)	APPROXIMATE MEAN PANEL RATING (MPR)
25	4.5
50	4.0
75	3.5
125	3.0
200	2.5
300	2.0
500	1.5
800	1.0

Uniformity of roughness throughout the test section is extremely important for the study. One anomaly (such as a pothole) in a relatively smooth section of pavement surface can affect a panel rating. One of the most common anomalies that prevents using a potential test section is the case where the end is at a bridge expansion joint. The "clunk" heard, as one drives over the expansion joint is an anomaly that must be avoided in test section selection. However, a site that has numerous "clunk" sounds, such as the road with many potholes, is a good prospective site for a very rough test section (i.e., 0 to 1 subjective rating). Other anomalies include: bridges, railroad tracks, asphalt patches, or isolated potholes.

The test section area should include a preliminary warning section, the actual test section, and a follow-up section. The entire section must have uniform roughness characteristics. The length of the actual test section should be proportional to a 25-sec exposure time. A section whose operating speed is 50 to 55 mph should be approximately 2,000 ft long; 40 to 45 mph, approximately 1,650 feet long; and 30 to 35 mph, approximately 1,200 ft long. In addition, the preliminary warning and follow-up sections should be approximately 200 to 300 ft long.

While visiting potential sections and looking for additional test sections, one should keep a field notebook to inventory the sections. Information in the notebook should include: a section identification number, location by traffic route, mileage test station, and other geographical information (i.e., county), speed limit, direction of travel, pavement surface type, and field survey team "guesstimate" of pavement roughness level (and historic RTRRMS measurements).

In addition, test sections should not be selected if they are on sharp curves or steep inclines. For sharp curves it is difficult for the driver to maintain constant speed throughout the test section; on steep inclines, the potential conflict with a truck or other slow-moving vehicle ascending the incline in front of the test vehicle may affect the driver's ability to maintain the test speed during the panel rating sessions.

Route Information

Once a large sample of test sections is selected that encompasses a wide range of roughness levels for each of the three surface types, the test sections should be located and marked on a map of the area and identified on the map by surface type and roughness.

The test sections should then be linked together into a route which (a) minimizes travel time across the route, (b) equalizes travel time between test sections, and (c) allows time between test sections for the panel members to rate the site and prepare for the next test section.

Large gaps of mileage between sites should be filled with dummy sites. These dummy sites are treated in the experiment as real test sections, but are not used in the analyses of the data. A 2-min to 10-min gap is considered a reasonable amount of time between test sections. If the gap is more than 10-min, it is recommended that a dummy site be included between the sites.

The route can either be a one-day trip of one loop or a two-day route of two distinct loops. The latter is more common and easier to conduct. The beginning and ending points of the routes should be near the facility that is used for the central meeting location.

In addition, restaurants, rest stops, and comfort stations should be located approximately every hour into the route.

Test Section Listing and Maps

Once the route is formed and test sections are selected, a final listing of all the test sections should be developed. Information in the listing should include, at the least, the following: test section number, pavement surface type, RTRRMS number, traffic route name, test section location, geographical location, lane of travel, and test speed. An example of a listing is provided in Table E-2.

A map of the route and written driving instructions should be developed. The map (Fig. E-1) should include major highways, towns, and location of test sections. The written driving instructions (Fig. E-2) should include the location of each test section on the route, the driving order of the test sections, all turns on the route, rest stop and restaurant locations, and landmarks.

Marking Test Sections

During the initial site visits and field work stages potential test sections (including the warning and follow-up sections) should be temporarily marked with either "flag" tape, which usually comes in bright red or yellow-green colors, or small paint markings. The tape should be put on vertical objects (such as guardrail/guiderail, telephone poles, sign poles, or utility poles) and can be nailed or tied to the surfaces. Paint or surface marks can be placed either on the road surface, on the shoulder, or on a vertical object.

Once the test sections are finalized, a more permanent marking (such as spray paint) can be applied to the test sections. Paint markings (rectangular patch) should be applied on the road surface at the upstream warning point, at the beginning of the actual test section, and at the end of the actual test section. Each can be a different color for positive identification. In addition, a marking should be applied on a vertical object (such as a telephone pole) near the upstream warning point. This vertical marking makes it very easy for the driver to spot the section while driving the route.

Deferred Maintenance

Once final markings are in place it is wise to notify maintenance crews of the road markings and make an attempt to

Table E-2. Test site locations.

Section No.	MFC	Type	I/M	LR	Traffic Route	Test Station	County	Lane	Speed (mph)
71D	-	BC	(+800)	-	Gateway Shopping Center	Example of poor Rideability site	Chester	-	25
1	B	BC	350	202	West Chester State Road	399 + 22 - 414 + 32	Chester	East	45
2	C	BC	130	202	West Chester State Road	469 + 72 - 484 + 72	Chester	East	45
3	D	BC	639	15009	Hollow Rd.	232 + 14 - 222 + 14	Chester	West	30
4	D	BC	482	15009	Yellow Springs Rd.	165 + 00 - 155 + 00	Chester	West	35
5	E	BC	315	15189	Foster Rd.	174 + 72 - 160 + 56	Chester	South	30
6	E	BC	212	15189	Seven Oaks Rd.	138 + 75 - 129 + 73	Chester	South	35
7	D	BC	207	15139	Route 401	734 + 44 - 719 + 44	Chester	West	40
8	D	BC	85	270	Route 113	350 + 56 - 370 + 56	Chester	North	55
9	E	BC	260	15216	Chester Springs Rd.	84 + 92 - 64 + 92	Chester	West	35
10	D	BC	94	15139	Route 401	610 + 20 - 630 + 05	Chester	East	45

prevent them from repairing any of the test sections. The "rougher" test sections are usually in more jeopardy of being repaired first, so it is extremely important to bring these sites to the attention of the maintenance department as soon as possible.

PANEL SELECTION

This section of the user's guide discusses the sample size, characteristics, and recruitment procedures for panels.

Size and Characteristics of Test Panel

The size of the panel should be at least 36 persons and should include drivers of all ages and years of driving experience and not be overrepresented by young drivers. Panelists should be residents of the state for at least 5 years. More than 36 persons should be identified to allow for sickness and unavoidable absences of subjects during the panel study.

Results of previous studies have shown that the sex of a panel member is not a critical factor in the subjective rating of highway roughness, but it is advisable to include members of both sexes in the panel. Similarly, for the type of subject (i.e., laymen rate the roads the same as engineers involved with road construction, maintenance, or evaluation) it is advisable to include panelists from all walks of life.

Recruiting Members

The most effective method for recruiting panel members is to select a sample of people from the state agencies that are affiliated with the group conducting the panel study.

Other recruiting methods include borrowing other state personnel and placing advertisements in local newspapers and magazines. Elderly panel members, who are sometimes difficult to find for some research experiments, can be recruited from automobile and senior citizens clubs.

Each prospective panel member should complete a Panel Selection Form (see Fig. E-3), which describes the person's age, driving experience and availability for the panel study. Each panel member will be scheduled for testing on two consecutive working days (for a two-day route). The days must be consecutive (e.g., Monday/Tuesday or Wednesday/Thursday—Friday is set aside for a tentative make-up day if rain or another emergency postpones an earlier day in the week).

For each two-day period, groups of three panelists should be formed. The number of groups during any two-day period is determined from the availability of drivers and vehicles. Four drivers/vehicles are preferred, requiring 6 days for 36 panel members to be tested.

Once panel members have been scheduled they are given an identification number and notified of the testing dates and meeting location. A follow-up call the day before the test date is advised to remind panel members of their participation dates.

Panel members from state agencies are frequently given a meal allowance for lunch each day of the study. Panel members recruited from outside the state agencies are usually given $20 to $30 per day for their participation in the study.

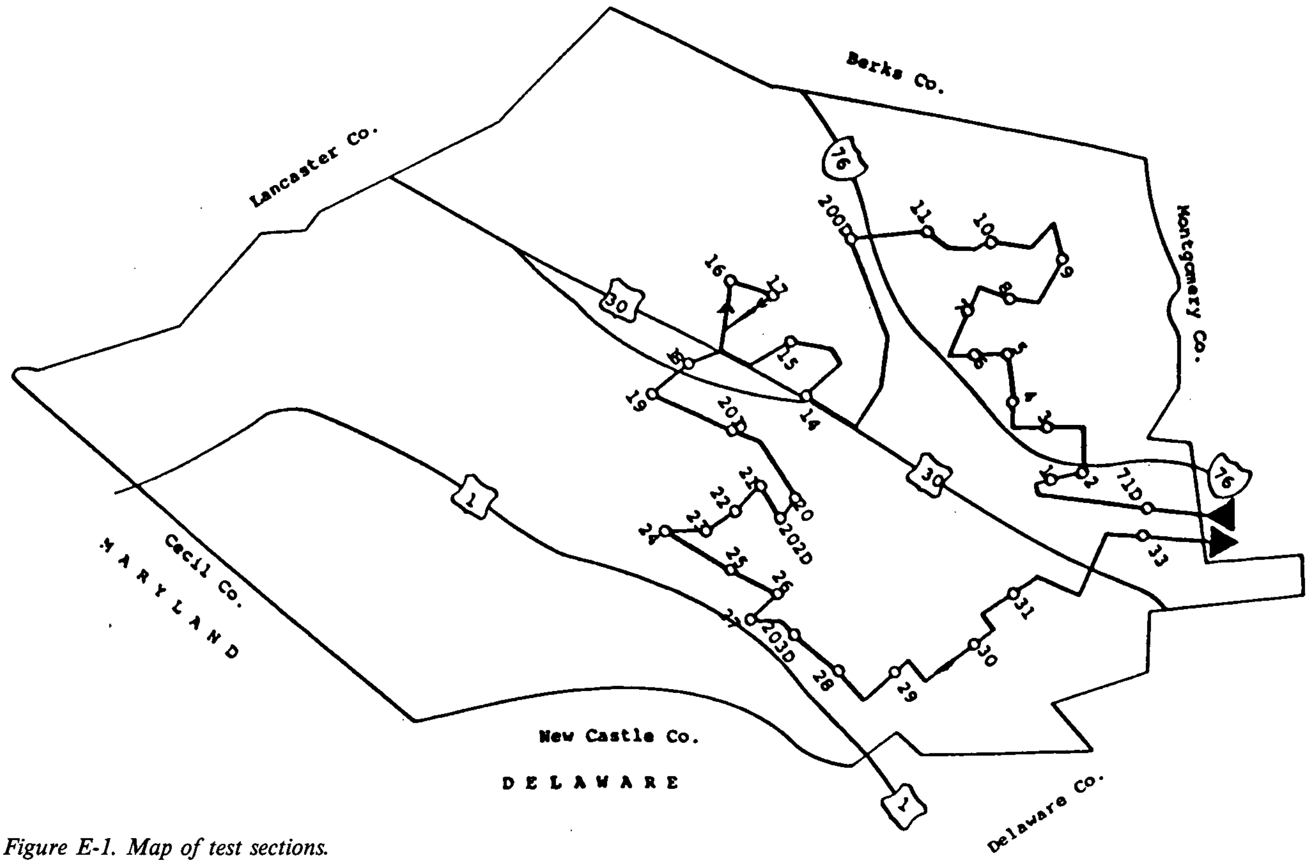


Figure E-1. Map of test sections.

PROCEDURES FOR CONDUCTING THE PANEL RATING STUDY

This section details the steps and procedures for conducting the panel study.

Preliminary Steps

Before conducting the actual panel study the following steps should be taken:

1. Drivers should be selected and become familiar with the route and the location of the specific test sections. Familiarity with the route can be achieved by driving the route a few times. (It is desirable to use the same people who marked test sections as drivers since they would already be familiar with the route.)
2. Drivers should be trained on how to deal with inclement weather. The panel rating study can be conducted in light rain. However, during a sudden downpour or an intense period of rain, it is advised to discontinue the route and either stop at a rest facility until the rain subsides or continue the route on the next day. Puddling that causes noise as the car traverses a test section must be avoided.
3. The drivers should also be made aware of how to deal with slow-moving vehicles, such as a truck upstream that may conflict with the driver's ability to maintain speed in the test section. In this scenario, it is advisable for the driver to pull over to the side of the road until the slow-moving vehicle is an ample distance away from the test section so that the driver can maintain speed through the section. Unavoidable slow-moving vehicles (e.g., a truck entering the test section ahead of the test vehicle) that force the driver to slow down should be reported to the experimenter.
4. Rating forms (see App. B) should be prepared in advance of the day of the study. The total number of forms required is equal to the number of panelists times the number of test sections. When copying forms make sure the final form is exactly 5 in. long, with ½ and 1-in. increments marked off.
5. The rating forms should be precoded by placing the site number and panel rater number on each form and collating the forms in the order of the sections on the route.
6. One individual should be assigned the responsibility of giving the standard instructions (see App. B) to each set of panelists. The instructions should be read aloud and displayed on poster board or on overhead transparencies so that the panelists can read the instructions as well as hear them. A videotape is an alternative. A copy of the instructions should be given to each panel member.
7. Determine the number of vehicles to be used. The vehicles should be the same size, type, and age, and have similar mileage. Previous studies have used Chrysler K-cars and this size is recommended. The vehicles should be inspected and maintained on a regular basis. Special attention should be paid to the suspension and proper air pressure in the tires of the vehicles. In addition, the interior and exterior appearance of the vehicles should be clean and the gas tank full at the start of each day of the panel study.
8. Arrange for a central meeting facility where panelists will meet and instructions can be given.

```
           Gateway Shopping Center

                SECTION #71-D

           202 South to Exit 401 West

R -        401 West

Green Arrows Start

R -        West Chester State Road

                SECTION #1    45 MPH

                SECTION #2    45 MPH

L -        Charlestown Road

L -        Pikeland Road

L -        Hollow Road

                SECTION #3    30 MPH

R -        Yellow Springs Road

                SECTION #4    35 MPH

L -        Foster Road

                SECTION #5    30 MPH

R -        Bodine Road

L -        Seven Oaks Road

                SECTION #6    35 MPH

R -        Route 401

                SECTION #7    40 MPH

R -        Route 113

                SECTION #8    55 MPH

L-         Chester Spring Road

                SECTION #9    35 MPH

L -        Route 401 (Conestoga Pike)

                SECTION #10   45 MPH
```

Figure E-2. Excerpt of driving instructions.

```
                    PANEL SELECTION FORM

NAME ____________________________________________________
ADDRESS__________________________________________________
       __________________________________________________
CITY/STATE/ZIP___________________________________________
NUMBER OF YEARS LIVING IN THIS STATE ____________________
TELEPHONE NO. (H/O)______________________________________
AGE______________ NUMBER OF YEARS DRIVING _______________
STATE ISSUING LICENSE ___________________________________
UNAVAILABLE WEEKDAYS DURING NEXT THREE MONTHS ___________
_________________________________________________________
COMMENTS ________________________________________________

                    DO NOT WRITE BELOW

SELECTED Y/N
SCHEDULED_____________________
IDENTIFICATION NUMBER ________
```

Figure E-3. Panel selection form.

Procedures

At the scheduled meeting time for the first groups, hand out instructions, rater forms, red pens, and clipboards to each panelist of a given group. Instructions should be given in one room to all panelists of a given group at the same time. Once instructions are given, assign seat positions to the panelists (let them choose). Remind the panelists that they have to retain these seat positions for the entire route. Three panelists are assigned to each test vehicle.

Other topics that should be covered include: meal stops and other breaks, number of hours per day for testing, confidentiality of the data, geographical interests along the route, and any type of per diem food allowance. Answer all questions uniformly to all groups. All later groups should receive the same instructions and protocol.

The panel rating study proceeds with the following steps:

1. Board vehicles (a driver and three panelists).
2. Drive to beginning of the route.
3. Driver warns panelists a test section is approaching, announces the site number, and asks them to check to see if they have the correct form (i.e., form should have the site number on it that matches the test section, as well as their rater number).
4. Driver sets and maintains test speed and informs the panelists when they are in the test section by declaring, "now." When the driver has driven through the test section and reaches the end of the test section, "stop" is declared.
5. The panelists rate the site and mark the forms.
6. The forms are collected by the right front panelist and placed in a box or large envelope. It is stressed to the panelists not to look at the other person's ratings and not to discuss the ratings. (The forms are passed up to the front panelist, upside down.)
7. The panelists are then taken to the next site. The driver can inform the panelists on how much time it will take to get to the next site and the geographical points of interest they will be passing.
8. Repeat steps 3 to 7.
9. Take breaks as necessary, at most every 2 hours. The driver should ask the panelists every hour if anyone is interested in stopping for any reason. Schedule lunch about halfway through the route each day.
10. At completion of day (route) return to central site.

DATA REDUCTION

At the end of each day, the box (or envelope) with the forms is collected by the driver. The driver checks the forms to make sure the panelists' rater numbers and ratings are on the forms.

Table E-3. Data reduction form.

	TEST SECTION				
PANELIST	1	2	3	4 . . .	n
1	(1)				
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18				. . .	
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
TOTAL (2)					
MEAN PANEL RATING (3)					

(1) = ENTRIES FROM RATING FORMS
(2) = SUM OF THE INDIVIDUAL PANEL RATINGS FOR A GIVEN TEST SECTION
(3) = TOTAL/NUMBER OF PANEL MEMBERS (36)

A copy of the completed rating forms should be made and filed in a secure place.

Data reduction consists of measuring (with an engineer's scale) to the nearest 0.1 in., the distance from the bottom of the scale (0) to the rating mark for each form. The ratings should be measured first, before compiling the data. A suggested tabulation procedure is a matrix of $n \times 36$ cells where n = number of test sections and 36 = number of panelists, as shown in Table E-3.

PHYSICAL MEASUREMENTS

It is advisable to collect profiles and/or RTRRMS measurements concurrently with the panel rating study. Such measurements should begin during the day immediately after the panelists begin their ratings to ensure that no conflict will occur on the test route.

APPENDIX F

ACRONYMS

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ANOVA	Analysis of variance
BC	Bituminous concrete
Comp or CO	Composite (bituminous over portland cement)
Corr Coef	Correlation coefficient
e	limit of $(1+t)^{1/t}$ as t approaches 0 (= 2.71828. . .)
FHWA	Federal Highway Administration
I or INT	Interstate highways
Large	Large car (Ford LTD)
LIN	Linear regression
Log	Logarithm to the base 10
MPR	Mean panel rating
MRM	Mays ride meter
NCHRP	National Cooperative Highway Research Program
NON	Nonlinear regression
NONI	Non-interstate highways
NR	Need for repair
ODOT	Ohio Department of Transportation
OHPI	Ohio model of profile roughness
PCC	Portland cement concrete
PI	Profile index
PSI	Present Serviceability Index
PSR	Present Serviceability Rating
PSU	Pennsylvania State University
QTR or 1/4	Quarter car index
RN	Rideability or ride number
RQI	Ride Quality Index—Michigan's roughness model
RTRRMS	Response-type road roughness measuring system
SML	Small car (Horizon)
TX	Texas roughness model

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