*SERVICEABILITY RATINGS
OF HIGHWAY PAVEMENTS*

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*by
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Final Report

SERVICEABILITY RATINGS OF HIGHWAY PAVEMENTS

TO: K. B. Woods, Director
Joint Highway Research Project

February 14, 1962

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

File: 3-3-28
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Attached is a final report entitled "Serviceability Ratings of Highway Pavements" by Miss Velma Nakamura, graduate assistant on our staff. The study was also used by Miss Nakamura as her thesis for part of the requirements for the MSCE degree. The study was performed under the direction of Professor H. L. Michael with the assistance of Professors E. J. Yoder and W. H. Goetz.

The panel rating method for pavement serviceability was found to be practical. The three panels used gave results which were very similar, even though one of the panels was composed of members who were not trained in highway engineering. Roughness measurements made by the Highway Department's roughometer were found to be very highly correlated with the panel ratings for rigid pavements but poorly correlated for overlay and flexible pavements. Additional research is contemplated on finding pavement characteristics which can be measured and which will be better correlated with panel ratings for overlay and flexible pavements.

The Project sincerely appreciates the cooperation of the members of the staff of the School of Civil Engineering who rated the sections and the cooperation of the Indiana State Highway Commission for providing the members of one panel and the equipment and manpower to make the roughness measurements. The efforts, advice and assistance of Mr. Fred Ashbaucher in this study is particularly acknowledged.

The report is presented for the record.

Very truly yours,

Harold L. Michael

Harold L. Michael, Secretary

HLM:kmc

Attachment

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FINAL REPORT

SERVICEABILITY RATINGS OF HIGHWAY PAVEMENTS

by

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Graduate Assistant

Joint Highway Research Project
File No: 3-3-28
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Purdue University
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ABSTRACT

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Two simple methods of evaluating the present serviceability of highway pavements are studied. Present serviceability is defined as the adequacy of a section of pavement in its existing condition to serve its intended use. One method utilizes a rating panel and the second method utilizes roughometer measurements to obtain present serviceability ratings.

The present serviceability of nineteen rigid pavement sections, nineteen flexible pavement sections, and twenty-two overlay pavement sections were rated by three ten-member rating panels and measured by the Indiana roughometer. Two of the panels were composed of men professionally associated with highway engineering. The third panel consisted of "laymen" who were assumed to be typical road users.

Rating data were analyzed by an analysis of variance design. The serviceability ratings of the raters within each of the panels varied widely, but there was no significant difference between the mean serviceability ratings of the three panels.

Information relative to the number of raters to use on a panel is also included. Although the number of members for the rating panel is determined by the "accuracy" required, it is shown that for priority ranking purposes as few as three raters on a single panel may be sufficient.

Linear and exponential least-squares regression equations were calculated for each pavement type with roughometer measurements as the independent variable and the present serviceability ratings as determined by the thirty raters as the dependent variable. When compared to serviceability ratings obtained by a large rating panel, the serviceability ratings obtained by the use of roughness measurements were only fair approximations for overlay and flexible pavement sections but were almost exactly the same for rigid pavements.

INTRODUCTION

".....highways are for the comfort and convenience of the traveling public."

D. C. Greer, State Highway Engineer of Texas

This simple statement implies that the purpose for any road or highway pavement is to serve the highway user and that a good highway pavement is one on which the traveling public has a comfortable ride.

What is a comfortable ride? How can the comfort and convenience provided by a highway pavement be measured? These are the unanswered questions which plague the highway authority when the decision as to which highway to improve must be made.

One measure of the present serviceability* of a highway pavement is the mean evaluation given it by all highway users. However, it is difficult to collect from the many highway users their judgment of the serviceability of all highway pavements; furthermore, the opinions of highway users as to how well a pavement serves may vary widely and even differ. The human mind is very flexible and there are many variables. One person's judgment or opinion today may also differ from his opinion tomorrow due to his temperament, perception, or other factors. It is also time consuming, tedious, and expensive for many individuals to evaluate each and every road.

* In this study, present serviceability is defined as the ability of a specific section of pavement in its existing condition to serve relative to the intended use of the highway (i.e., the section may be part of a primary highway, secondary highway, city street, farm road, etc.).

For many years state highway departments have developed construction and maintenance programs on the basis of the personal knowledge of their staffs relative to the needs of their highway systems. However, highway personnel in general have vague or varying knowledge of the condition of all portions of the highway systems and, thus, their concept of the serviceability for a highway pavement may vary widely. It is also probable that a poor highway pavement to one engineer might mean that the pavement has a few cracks, while to another it might mean that a considerable number of cracks and patches are present. One engineer might classify a highway pavement with ten foot lanes as excellent, while another might classify only highway pavements with twelve foot lanes in the excellent category.

These differences of opinion as to what is good pavement serviceability are also evident in construction and maintenance practices. For example: there may be an evident difference in riding smoothness as one passes from maintenance section A to maintenance section B on highway X. The ride on section A is much smoother than on section B. Why should this be? Both sections were constructed at the same time, are of similar design, have the same traffic volume, and have a similar underlying soil strata. However, the two sections were constructed under separate contracts and by two different construction companies. Moreover, they are in adjacent counties and, thus, are maintained separately and differently.

Many of the variations in pavement serviceability ratings, however, may exist because there is no accepted definition of the various grades of serviceability, and in many cases there is no agreement in terminology that can be used in an evaluation of highway pavements. (12)*

* Numbers in parenthesis refer to the references in the bibliography.

It may be true that one pavement can perform its services better than another. The following questions, however, are raised: "How much better?" and "How can this comparison be determined?" What is needed is a method of measurement and evaluation of pavement serviceability -- one that provides accuracy, that is simple, and that is economical. The results of such a method should be as unprejudiced and consistent as possible.

A simple evaluation procedure, which would accurately rate the serviceability of highway pavements by an objective measurement or measurements and which would be highly correlated with the subjective human judgment of the traveling public, would facilitate the efficient development of a highway improvement program. Such a procedure should also indicate the performance of any pavement throughout its life if evaluated periodically, be applicable to all roads, and could form the basis for highway improvement programs.

Previous Investigations

Many studies have been devoted to the problem of the evaluation of highway pavement serviceability and/or performance. Various evaluation procedures have resulted from these studies and are being used by state highway departments throughout the country. These procedures may be classified into the following general types: 1) evaluation by sufficiency rating systems, 2) evaluation by surface riding quality indicators, and 3) evaluation by surface riding quality indicators and subjective serviceability ratings. The third type of evaluation is the most recently proposed and is the subject of this study.

Evaluation by Sufficiency Ratings

The sufficiency rating system is a system through which a numerical value is assigned to each road section to aid in establishing priorities of highway improvements. As early as 1933 the Bureau of Public Roads (hereafter referred to as the BPR) pointed out the key features of condition, safety and service which have since become the basis for all sufficiency rating systems. Kipp (13) states that:

Sufficiency rating procedures have been devised so as to provide a means of evaluating the relative adequacy of each section of a highway according to certain prescribed standards. Since these standards are prescribed on the basis of traffic volume and the functional characteristics of the system, the resultant ratings give an evaluation of the road section's ability to carry its quota of traffic safely, rapidly and economically. Thus, the ratings have been used to measure, on a comparative basis with other highway sections, the relative importance and need for renewal and replacement.

The formulas have been designed and the rating procedures developed with the intention of eliminating, or at least minimizing, the element of personal judgment in determining the relative sufficiency of highway sections. This has been done chiefly so that the public would accept the method as an impartial, unbiased appraisal, because any method of establishing improvement priorities to be of value must have the full understanding, acceptance, and confidence of all individuals and groups interested in improving the adequacy of the highway network.

An excellent discussion and bibliography of sufficiency rating procedures in use by state and county highway departments for priority establishment is presented by Baerwald (3). The present Indiana State Highway Commission evaluation procedure is presented in a Sufficiency Study Manual published in 1960 (21).

Evaluation by Roughness Indicators

One of the earliest pioneers in the development of a roughness indicator was the BPR. As early as 1923 the BPR collaborated with the Bureau

of Tests of the Illinois Division of Highways in the development of the "Profilometer". In 1925 the BPR developed a second machine called the "Relative Roughness Determinator". In the 1930's the BPR developed a third machine called the "Relative Roughness Indicator" in an attempt to overcome the poor features of the previous machines (4). Holloway (9) states that:

This machine removed the uncertainties of vehicle operation that were present in earlier equipment when an automobile was a component part of the measuring apparatus. Also of importance was the fact that this machine was so designed that it could be duplicated and thereby duplicate results could be expected from any machine which was constructed according to the same plans and specifications as the original.

Many studies of the surface riding qualities of highways have been made utilizing duplicate or modified versions of the BPR "Relative Roughness Indicator" (hereafter referred to as the roughometer). Various standards for the evaluation and determination of the riding quality of highways by the different roughometers have been recommended in these studies (1, 9, 10, 15, 16, 17 and 18).

Moyer and Shupe (18) state that:

.... it should be recognized that the public judges whether a road is good or bad largely on the basis of its riding qualities and an accurate measure of roughness with a machine such as the Bureau of Public Roads Roughness Indicator should give the public and engineer a reliable measure of the riding qualities of all pavement surfaces.

Evaluation by Riding Quality Indicators and Subjective Serviceability Ratings

Holloway (9) states that:

As a part of the "Inventory of Indiana State Highway Conditions", conducted during the winter of 1954 and 1955, the inventory parties recorded the surface riding qualities of the pavements as excellent, good, fair, or poor. This was largely a "seat of the pants" determination and was subject to the variations of

opinions of different observers. These observers are engineers of the Indiana State Highway Department and as such it seems reasonable to assume that their opinions would be better than that of the ordinary layman. The conclusion indicated by (a comparison between road roughness indices and surface riding qualities as expressed by the highway inventory observers) is that personal opinion is widespread concerning the surface riding quality of a road and is therefore an unsatisfactory evaluation method.

However, Hveem and Tremper in a discussion of the Housel and Stokstad study (10) state the following:

An examination of California pavements employing the jury system of rating indicates that there was usually good agreement as to which pavements were smooth, fair, or definitely rough.

Carey and Irick (6) in 1958-59 at the AASHO Road Test conducted an investigation, evolving a pavement serviceability-performance concept, which was very comprehensive and which employed many of the procedures used in the present study. In that study 138 pavement sections in Illinois, Minnesota, and Indiana were evaluated over a two year period in three different ways: by a panel of experts, by a panel of laymen, and by objective measurements of selected characteristics of the pavement. The pavement sections were divided into two categories: rigid pavements and flexible pavements. About one-half were rigid pavements and one-half were flexible. Each pavement section was 1,200 feet long except for those at the AASHO Road Test, which averaged 215 feet. The panel of experts consisted of ten men long associated with highways and representing such interests as highway administration, highway maintenance, highway research, highway materials supply (cement and asphalt), and a federal highway agency. The panel of experts was intended to represent all highway users. The panel of laymen consisted of two truck drivers and twenty Canadian automobile drivers who were not professionally associated with

highways. The pavement sections were rated on a 0 to 5 point rating scale. By comparing the evaluations made by the panel of experts and the panel of laymen, it was found that "... the ratings given pavements by the Road Test Panel were quite similar to those that were given by the other user groups" and that "... if a greater number of sample groups had been studied, more positive statements could be made as to how well the Panel represents the universe of all users".

Objective measurements were made of the longitudinal and transverse roughness, surface cracking, and surface patching of the pavement sections. Roughness measurements of the wheelpaths were made by the Road Test longitudinal profilometer. The AASHO roughometer was not adapted for use at the Road Test until just prior to the rating of the Indiana pavements, therefore, only the Indiana and Road Test pavement sections were measured by the roughometer. However, "... it may be noted that the roughometer values averaged for both wheelpaths, $\overline{AR}$, are correlated with the corresponding mean slope variances". The AASHO roughometer was operated at 10 mph.

By means of statistical analysis a high correlation was found to exist between the Road Test Panel ratings and the slope variance of the profilometer measurements for both rigid and flexible pavements. A fair correlation was found to exist between the ratings and the rut depth gage measurements on the flexible pavements. There was also a fair degree of correlation between the ratings and the amount of cracks and patches on rigid pavements. However, there was little correlation between the ratings and the amount of cracks and patches on the flexible pavements.

Through multiple regression analyses the following predictive equations resulted:

For flexible pavements:

$$PSI = 5.03 - 1.91 \log (1 + \overline{SV}) - 1.38 \overline{RD}^2 - 0.01 \sqrt{C + P}$$

For rigid pavements:

$$PSI = 5.41 - 1.78 \log (1 + \overline{SV}) - 0.09 \sqrt{C + P}$$

Where,

PSI = Present serviceability index; a mathematical combination of values, obtained from certain physical measurements of a large number of pavements, so formulated as to predict the present serviceability rating for those pavements within prescribed limits.

$\overline{SV}$ = Average slope variance on both wheelpaths as obtained by the AASHO profilometer.

$\overline{RD}$ = Average rut depth of both wheelpaths in inches.

C = Major cracking in ft. per 1000 sq. ft. of pavement area.

P = Bituminous patching in sq. ft. per 1000 sq. ft. of pavement area.

The PSI formulas were found to account for 84.4 per cent and 91.6 per cent of the variation in PSR for the flexible and rigid pavements, respectively.

In a further study by the same group, Hudson and Hain (11) report that the AASHO profilometer and roughometer were run coincidentally on twenty rigid pavement sections either 120 or 240 ft. long. The slope variance of the profilometer (SV) was regressed on the roughometer output at 10 mph (AR_{10}) and the following equality resulted:

$$\hat{SV} = 0.40 AR_{10} - 34$$

Substitution in the Carey-Irick rigid pavement equation gave the following equation:

$$PSI = 5.41 - 1.80 \log (0.40 \overline{AR}_{10} - 33) - 0.09 \sqrt{C + P}$$

It is noted that this analysis assumes that the relationship between SV and AR_{10} is a linear one, but that "there are at least two reasons why slope variance and AR_{10} will never be perfectly correlated.

1. The profilometer and roughometer probably do not measure the same elements of pavement roughness. The roughometer runs faster than the profilometer and has an entirely different tire and suspension system.
2. The instruments have different frequency response characteristics."

It was also found that "... the roughness recorded at 10 mph is highly correlated with the roughness recorded at 20 mph", and "The roughometer is one answer to the problem of measuring roughness or performance." Therefore, they "... hoped that the roughometer will help expand the use of the 'Pavement Serviceability-Performance' concept."

A more recent investigation of pavement performance was conducted on July 6, 1961 by the personnel of the AASHO Road Test (20). The object of this study was to correlate roughometer output with profilometer slope-variance and, thus, to utilize roughometer output, by substitution, as a predictor in the serviceability equations. The study consisted of measuring both wheelpaths of 12 rigid and 14 flexible pavement sections varying in length from 500 to 1200 feet. The pavement sections were measured by the AASHO Road Test profilometer, the Virginia Highway Department roughometer, and the Indiana State Highway Department roughometer.

The equations transforming the output of the Indiana roughometer at 20 mph (InR_{20}) to the profilometer slope variance from least-squares regression analyses are as follows:

For rigid pavements:

$$\log (1 + SV) = 3.24 \log InR_{20} - 5.62$$

For flexible pavements:

$$\log (1 + SV) = 2.43 \log \ln R_{20} - 4.02$$

The squared correlation coefficients (r^2), which measure the association between the transformed roughometer output and profilometer slope-variance, were found to be 0.79 and 0.85 for flexible and rigid pavements, respectively. The root mean square residuals, which estimate the amount of error that is present in the prediction of an observation, were found to be 0.18 and 0.19 for flexible and rigid pavements, respectively. The values of these statistics are satisfactory for prediction purposes. However, it is to be noted that the r^2 for flexible pavements is somewhat lower than for rigid pavements. This characteristic "presumably reflects an inability to measure some characteristics of flexible pavement roughness."

Substitution of the above equalities into the Carey-Irick equations gives the following:

For rigid pavements:

$$PSI = 15.53 - 5.83 \log \overline{\ln R}_{20} - 0.09 \sqrt{C + P}$$

Limitations: When $\overline{\ln R}_{20} < 64$ and $C + P = 0$, take

$(5.83 \log \overline{\ln R}_{20}) = 10.53$, since no section may rate more than 5.0 by definition.

For flexible pavements:

$$PSI = 13.16 - 4.86 \log \overline{\ln R}_{20} - 0.01 \sqrt{C + P}$$

Limitations: When $\overline{\ln R}_{20} < 49$ and $C + P = 0$, take

$(4.86 \log \overline{\ln R}) = 8.16$, since no section may rate more than 5.0 by definition.

It is noted that the PSI obtained with roughometer output as a predictor is expected to have a somewhat larger error than that obtained by the original Carey-Irick equations. This results from the additive errors in predicting PSI from SV and in predicting SV from roughometer output. The PSI-roughometer relationship is an indirect one. No direct regression analysis of roughometer output with subjective human evaluations (PSR) was made.

PURPOSE

This study is concerned with the traveling public's opinion of pavement serviceability and its desirable level and with the ability of highway personnel to understand the wants of the traveling public. It is also concerned with road roughness, as measured by the roughometer, as a method for the objective determination of highway pavement serviceability.

Therefore, the purpose of this study was 1) to determine the correlation of pavement serviceability ratings made by experts in the field of highway engineering with ratings made by typical road users, 2) to determine the correlation of roughometer measurements with pavement serviceability ratings, and 3) to determine a simple, economical evaluation procedure which would accurately rate the serviceability of highway pavements.

SCOPE

Sixty pavement sections located within a forty mile radius of Lafayette, Indiana were studied (see Figure 1, Location of the Study Area). The pavement sections varied in length from 0.5 to 12.75 miles, averaged 5 miles, and totaled approximately 300 miles. Nineteen of the sections were rigid pavements; twenty-two were rigid with bituminous overlay; and nineteen were flexible pavements. All types of pavement condition were represented.

All of the pavement sections were rated by thirty persons, who represented the highway field and the general public, and were measured by the Indiana State Highway roughometer. All ratings and measurements were made in the fall of 1961.

FIGURE 1. LOCATION OF THE STUDY AREA

PROCEDURE

Selection of Pavement Sections

It was assumed that the highways within a forty mile radius of Lafayette, Indiana are representative of the total population of highways (i.e., all types of pavement conditions varying from very good to very poor in Indiana). All State, United States, and Interstate highways within this area were categorized according to the following pavement types: rigid, rigid with bituminous overlay, and flexible.

Test sections of previous serviceability studies (6, 11, and 20) have all been of relatively short (120 and 1200 ft.) and similar lengths. While short test sections are ideally simple to measure and rate, the real test of an evaluation procedure is in its ability to evaluate the actual situation. State highway maintenance and construction programs are based on longer and variable length maintenance sections. Logical and ideal test sections, therefore, would be actual maintenance sections. Maintenance and sub-maintenance sections were employed as test sections in this study.

Maintenance sections which were "non-homogeneous" (i.e., there was evident variability within the maintenance section of such characteristics as surface texture, surface riding quality, etc.) were divided into sub-sections. Reasonably homogeneous test sections were desired and selected.*

* It should be noted that the non-homogeneity or homogeneity of a test section was determined subjectively by human observers. Some of the test sections (see Tables 25, 26 and 27, Appendix A) were judged to be non-homogeneous by some of the raters. This caused some distress since it was thought that the non-homogeneity might influence the variability of the serviceability ratings. A scatter-plot of the range of the roughometer values for one-fourth mile lengths versus the range of the ratings showed a "shot-gun" pattern. Apparently the relative non-homogeneity of the test sections had no direct bearing on the variability of the serviceability ratings.

The sections were then preliminarily rated. A rating scale similar to that finally utilized by the raters was employed. The sections of each pavement type were then stratified according to their preliminary rating into the following general classes: very good, good, fair, poor, and very poor. Economical limitations determined that sixty test sections -- twenty of each pavement type -- would be studied. A stratified random sample was then taken for each pavement type, so that there would be twenty pavement sections of each type with conditions varying from very good to very poor for each type (see Figure 2).

The preliminary rating and selection of the test sections took place during the summer of 1961. The measurement and ratings of the sections were made during the fall of 1961. In the interim, two of the selected rigid pavement sections were resurfaced. The Union St. section (section 59) was substituted for one of these resurfaced sections; hence, only nineteen rigid pavement sections were rated. Also, a pavement section which was preliminarily classified as a flexible pavement section was discovered to be an overlay; hence, only nineteen flexible pavement sections were rated. It should also be noted that one of the flexible pavement sections (section 33) has a brick base.

Marking of the Pavement Sections

To aid and confirm the identification of the pavement sections by the raters and roughometer crew, the beginning and end of each pavement section was marked with yellow paint near the edge of the pavement. A two foot strip of paint perpendicular to the edge of the pavement indicated the beginning and end of the pavement section; an arrow pointed in the direction of the pavement section to be rated; and a number identified the pavement section.

FIGURE 2. LOCATION OF THE PAVEMENT SECTIONS

Selection of the Panels of Raters

The sixty pavement sections were rated by three panels of raters. There were ten raters in each panel. Two of the panels were composed of experts in the field of highway engineering. One panel represented the Indiana State Highway Commission (ISHC); the other was composed of faculty members of the Purdue University School of Civil Engineering. The third panel was composed of laymen; that is, typical road users not professionally associated with highway engineering.

The members of the ISHC panel were selected by officials of the Indiana State Highway Commission from their engineering personnel. The personnel were selected on the basis of their availability at the time of the rating and on their familiarity with the state highway system. All personnel were from the central office in Indianapolis or from the Crawfordsville district (the district serving the Lafayette area). They represented such interests as planning, road design, road construction, bituminous construction, maintenance, and traffic. The ages of these men ranged from 31 to 62 years with 53 being the mean age. Driving experience ranged from 15 to 45 years with a mean of 34 years; and annual driving mileage ranged from 15,000 to 60,000 miles with a mean of 30,700 miles.

The members of the Purdue panel were selected from the staff of the School of Civil Engineering at Purdue University. Those selected were from the Transportation staff or from an area directly interested in transportation. They represented such areas as pavement design, structures, soils, bituminous materials, air photos, planning, and research. The ages of the men ranged from 34 to 56 years with 41 being the mean age. Driving experience ranged from 15 to 46 years with a mean of 25 years; and annual

driving mileage ranged from 9,000 to 20,000 miles with a mean of 12,900 miles.

The sampling method used in obtaining the ten "laymen" raters was as follows: The sampling population was confined to the West Lafayette-Lafayette telephone directory and the Purdue University student directory. Sixty names from the telephone directory and fifteen names from the student directory were randomly selected. All of the people were then telephoned, briefly informed of the project, and asked if they would be interested in participating as raters. Those who gave positive responses were then visited and given more information. Those who were interested filled out application forms (see Appendix A). The selection of the ten raters from the applicants was based on the following factors: age, sex, occupation, type of vehicle owned, years of driving experience, annual driving mileage, and amount of liability and property damage insurance. The last factor was used only for administrative reasons.

The laymen panel consisted of seven men and three women who were assumed to be typical road users and representative of the traveling public. The occupations of the raters were as follows: student, graduate-staff member, plant supervisor, professor of electrical engineering, welder, tavern manager, truck driver, housewife, housewife-former teacher, and school nurse. The ages of the raters ranged from 23 to 53 with 38 being the mean age. Driving experience ranged from 4 to 35 years with a mean of 19 years; and annual driving mileage ranged from 2,000 to 20,000 miles with a mean of 7,800 miles.

Rating Instructions

Unlike the AASHO rating instruction procedure, where the rating instructions were orally presented at a business meeting of the rating group; the raters in the present study were individually instructed. This was done to keep them from being influenced by the other raters. Also, it was thought that rater response would be better under individual instruction. That is, the rater, if in doubt about any aspect of the instructions, would be more apt to ask questions. Thus, a better understanding of the rating procedure could be gained under individual instruction than in group instruction. It was very important that the raters clearly understand the "rules of the game". All raters were given identical instructions.

The instruction given to raters in this study was as follows:

1) The rater was briefly informed of the general purpose and scope of the study as follows:

The Joint Highway Research Project at Purdue University is undertaking a Pavement Serviceability Study in which you are to participate. Since highways are for the comfort and convenience of the general public, we are interested in finding out how the motorist rates the serviceability of highway pavements. Therefore, we want you to tell us what you think of the riding qualities of a selected sample of highway pavement sections.

There will be twenty-nine persons, representing the highway field and the general public, besides you rating the same sixty pavement sections. We want to know if people more or less agree on the serviceability of highway pavements. Therefore, it is very important that we get your frank opinion. Do not ask anyone else for his or her opinion.

You are to drive a car similar to one you normally drive over the sixty pavement sections alone in the given order in three days, not necessarily three consecutive days.

2) The rater was given the following items:

a. A written set of the Rating Instructions (see Appendix A)

- b. A written set of the Rating Order (see Appendix A)
- c. An appropriate number of rating cards (see Figure 3)
- d. A pen for marking the rating cards
- e. A clipboard

3) The instructor read aloud the Rating Instructions. To avoid misinterpretation of the instructions, the rater was encouraged to ask questions if he was in doubt about any aspect of the instructions.

The rater was instructed to always keep the following question in mind when rating the pavement sections: If I were to ride over a pavement that is just like that represented by this section of pavement every day for the usual purposes, how well would the pavement serve me? For secondary highway pavements this service would be primarily for short trips, such as to work or to town, while for primary highway pavements the service would be, in general, for some longer trips. The location map denoted the classification (i.e., primary or secondary) of the pavement sections and also defined the two classifications. A primary highway was defined as a highway which connects major population centers and provides routes for all significant movements of traffic in the state. A secondary highway was defined as a highway which connects communities and provides access to higher type roads (i.e., primary).

It was stressed that the serviceability of the pavement only was to be rated. All features not part of the pavement itself, such as right of way and median width, grade, alignment, and shoulder and ditch conditions, were not to be considered in the rating of the pavement section. Also, the existing condition of the pavement section was to be rated.

The rater was requested to drive over the pavement sections in a vehicle similar to one that he normally drove. The members of the Laymen

HIGHWAY _____	5	
SECTION _____	4	Very Good
DATE _____	3	Good
TIME _____	2	Fair
WEATHER _____	1	Poor
RATER _____	0	Very Poor

Is this a primary or secondary road? _____

Is this pavement acceptable for this classification? _____

FIGURE 3. RATING CARD

and Purdue panels drove their own personal vehicles. Most of the members of the ISHC panel drove state highway vehicles. The rater could ride over the pavement sections at any speed he desired. Rating was not to be done during rain or other inclement weather conditions.

It was also stressed that the rater was to travel alone and work independently. It was very important that the rater not be influenced by the opinions of others.

The rater was instructed to rate the serviceability of each pavement section on the 0 to 5 point rating scale. The rating scale utilized in the present study was similar to that employed in the AASHO serviceability-performance studies.

The rater was also instructed to rate the acceptability (Yes or No) of each pavement section, after noting its highway classification. The AASHO raters also rated the acceptability of the pavement sections. However, all of the AASHO pavement sections were of the same classification (i.e., primary), and there were three acceptability responses: Yes, No and Undecided.

4) The Rating Order was explained. The rater was required to rate the sixty pavement sections according to a specified rating order.

Since approximately 300 miles of highways and 4,000 square miles of land area were involved in the rating of the pavement sections, it was decided that the rating of the sixty sections would be done in three days, not necessarily three consecutive days. The land area was then divided into three parts: A, B, and C (see Figure 2). Each part represented a full day of rating. Part A consisted of 25 pavement sections; part B consisted of 20; and part C consisted of 15. For statistical randomizing

purposes, three different rating routes within each of the three parts and four different sequences in rating the parts were determined. The four sequences are as follows: ABC, BCA, CAB, and CBA. From the four different sequences and the three different rating routes, ten different rating orders were determined. In this way, three raters, one from each of the three panels, had the same rating order. A sample Rating Order can be found in Appendix A.

As an example: If given the sequence BCA and the rating route 1, the rater would rate part B on the first day of rating, part C on the second day of rating, and part A on the third day. On the first day of rating he would rate section 59 first, section 60 second, section 41 third,, and section 39 last. On the second day he would rate section 36 first, section 31 second, section 32 third,, and section 24 last. On the third day he would rate section 28 first, section 54 second, section 18 third,, and section 23 last.

Road Roughness Measurement

The Indiana State Highway roughometer is a modified version of the BPR "Relative Roughness Indicator". A general description of the roughometer is given by Yoder (22). He states the following:

The roughometer is a device which, when towed over a paved surface, is assumed to stay in a relatively fixed plane due to its own inertia. Changes in elevation are measured by means of a floating wheel which follows the paved surface and deviates from the machine proper.

The device consists of a rectangular frame, inside of which is a single wheel equipped with a pneumatic tire that has its axle attached to the center of two single-leaf springs, one on each side of the wheel. The integrator unit is mounted on the cross frame over the wheel, and the pistons of two dash-pot-spring damping devices are also attached to the cross piece.

A detailed description of the Indiana State Highway roughometer is given by Holloway (9). A close-up view of the Indiana roughometer and tow truck can be seen in Figures 4 and 5.

The entire lengths of all sixty pavement sections were measured by the Indiana State Highway roughometer. Roughometer roughness was measured in the right wheelpath of the traffic lane. The roughometer was operated at 20 mph. Two runs were made on each traffic lane, thus, four runs were made on two-lane highway sections. On four-lane highway sections, two runs were made on the outside lanes; passing lanes were not measured. Roughness readings were recorded at quarter-mile intervals.

The roughness index for any pavement section is the total inches of accumulated roughness divided by the length of the section in miles. The roughness values given for two-lane highway sections represent the average of four test runs, while those for sections on four-lane highways represent the average of two test runs.

Tire inflation pressure, air temperature, and fluid temperature were checked both before and after each run. Roughometer calibration and servicing were made in accordance with the BPR "Manual of Information Regarding the Operation and Maintenance of the Public Roads Relative Road Roughness Indicator" (14).

FIGURE 4. CLOSE-UP VIEW OF INDIANA
STATE HIGHWAY ROUGHOMETER

FIGURE 5. INDIANA STATE HIGHWAY
ROUGHOMETER AND TOW TRUCK.

RESULTS - SERVICEABILITY RATINGS

Analysis of Variance

A mixed model, cross-classified nested analysis of variance (ANOV) design was utilized to analyze the rating data. Basically, the ANOV consists of classifying and cross-classifying data and testing whether the means of a specified classification differ significantly. In this way the highway serviceability ratings made by experts in the field of highway engineering could be tested for a significant difference from the highway serviceability ratings made by typical road users. Also, the means of the individual raters within each of the rating panels could be tested to determine the validity of the statement made in the introduction that "the opinions of highway users as to how they are being served may vary widely and even differ."

The assumptions which underlie this method include: homogeneity of variances, normal distribution of errors, fixed pavement type and panel type, random pavement section samples within each pavement type, and random rater samples within each panel type. Because a good estimate of the number of raters required to estimate the "true" rating required an equal number of pavement sections for each pavement type, three overlay pavement sections (sections 2, 8, and 15) were randomly eliminated. This left an ANOV with an equal number of pavement sections for each of the three pavement types from which exact estimates of the components of variance could be obtained.

One of the raters did not rate pavement section 55. The missing rating was estimated using the randomized block method (7). Calculations for the value herein discussed are presented in Appendix B. The estimated rating was 2.6. The average rating of this section as determined by the other twenty-nine raters was 2.3. The rater's mean absolute deviation from the "true" ratings* for the other fifty-nine sections was 0.4, and he had a tendency to rate higher than the "true"; therefore, it was assumed that 2.6 was a good estimate.

Table 1 shows the results of the ANOV. The model used was:

$$Y_{(i)j(k)l} = \mu + P_i + S_{(i)j} + G_k + R_{(k)l} + (PG)_{i,k} + (PR)_{i(k)l} \\ + (SG)_{(i)j,k} + (SR)_{(i)j(k)l} + e_{(i,j,k,l)}$$

where,

$Y_{(i)j(k)l}$ = the rating of the $(k)l^{\text{th}}$ rater on the $(i)j^{\text{th}}$ strip.

μ = the mean

P = pavement type

S = pavement section within pavement type

G = rating panel type

R = rater within rating panel type

PG = pavement type-rating panel type interaction

PR = pavement type-rater within rating panel type interaction

SG = section within pavement type-rating panel type
interaction

* In the present study, the mean rating of the thirty raters is assumed to be the "true" rating of the pavement section. The present serviceability rating (PSR) is defined as the mean of the individual serviceability ratings made by the thirty raters. Therefore, in the present study the "true" rating and the PSR of a specific section are identical and are used interchangeably.

SR = section within pavement type-rater within rating
 panel type interaction
 e = the residual error

TABLE 1
 SUMMARY OF ANALYSIS OF VARIANCE SERVICEABILITY RATINGS

Source	Degrees of Freedom	Sum of Squares	Mean Squares	Variance Ratio	F_{α}	Level of α	Conclusion
P	2	93.265	46.632	2.328*	2.39	0.10	NS ¹
S	54	996.840	18.460	60.924	1.53	0.005	S ²
G	2	1.613	0.806	0.094	1.41	0.25	NS
R	27	230.475	8.536	28.172	1.79	0.005	S
PxG	4	8.236	2.059	1.211	1.35	0.25	NS
PxR	54	91.780	1.700	5.611	1.53	0.005	S
SxG	108	31.604	0.293	0.967	1.08	0.25	NS
SxR	1457	480.619	0.303				
Total	1708	1934.432					

¹ NS means non-significant

² S means significant

Differences between the pavement sections within pavement types, between the raters within panel types, and the pavement type-rater within panel type interaction were significant at the 0.005 level of probability. Differences between the rating panels, the pavement type-rating panel interaction, and the pavement section within pavement type-rating panel interaction were not significant at the 0.25 level of probability; differences between the pavement types were not significant at the 0.10 level of probability.

* See Appendix B for the determination of the variance ratios.

The finding that raters within a panel type differed significantly supports the above mentioned statement that "the opinions of highway users as to how they are being served may vary widely and even differ." The significant pavement type-rater within panel type interaction means that the differences between the raters within a panel type differed over the three pavement types. As an example: one rater might tend to rate the rigid pavement sections "higher" than the other raters while he might tend to rate the overlay and flexible sections "lower" than the others. Whereas, another rater might tend to rate the rigid sections "lower" than the other raters while rating the flexible and overlay sections "higher" than the other raters.

It was expected that the pavement sections within a pavement type would differ significantly since they were selected to represent all types of pavement conditions varying from very good to very poor. The PSRs of the rigid pavement sections ranged from 1.1 to 4.5; the PSRs of the overlay pavement sections ranged from 2.2 to 4.1; and the PSRs of the flexible pavement sections ranged from 1.5 to 4.1. There was a non-significant difference between the pavement types; that is, the overall means of the three pavement types did not differ significantly. Tables 2, 3, and 4 show the overall means to be 3.1, 3.1, and 2.7, for the rigid, overlay, and flexible pavement types, respectively.

There was a non-significant difference between the rating panels. This is compatible with a conclusion that the mean highway serviceability ratings of highway authorities are similar to the mean serviceability ratings of the traveling public. The non-significant pavement type-rating panel interaction and section within pavement type-rating panel interaction indicate that the difference between the means of the three panels did

not differ significantly over the three pavement types and over the pavement sections within the pavement types at the 0.25 level of probability. The panel serviceability ratings* for the rigid, overlay, and flexible pavement sections are presented in Tables 2, 3, and 4, respectively. It can be seen in these tables that there are no marked differences between the serviceability ratings of the three panels for each pavement section. The PSR for each pavement section is also given in the tables.

Individual Serviceability Rating Variability

As stated earlier, the ANOV results supported the statement that "the opinions of highway users as to how they are being served vary widely and even differ". The widely varying opinions are further evidenced in Tables 5, 6, and 7. The overall and panel ranges** are given in these tables for the rigid, overlay, and flexible sections, respectively. The 100 per cent (i.e., all of the individual serviceability ratings of the specific group are taken into account) mean ranges of the overall, ISHC, Purdue, and Laymen panels were 2.9, 2.4, 1.9, and 2.4, respectively, for the sixty pavement sections. Assuming the possibility of individual rating blunders, the 90 per cent ranges were also determined (i.e., one rating from each panel range and three ratings from each overall range which contributed most to the range were eliminated). The 90 per cent mean ranges of the overall, ISHC, Purdue, and Laymen panels were 2.0, 1.8, 1.4, and 1.7, respectively for the sixty sections. A substantial decrease occurred in the ranges at the 90 per cent level. The Purdue panel had the

* In the present study, panel serviceability rating is defined as the mean of the individual serviceability ratings made by members of a specific rating panel.

** The range of a pavement section is the difference between the highest individual serviceability rating and the lowest individual serviceability rating given to the pavement section by a stated group of raters.

Pavement Section	Highway Number	Ratios	
		Laymen	All
1	25	0.8	0.8
4	35	0.7	0.7
7	421	0.7	0.7
17	53	0.9	0.87
18	53	1.0	0.97
19	41	0.5	0.23
21	52	0.9	0.87
22	52	1.0	1.0
23	52	0.9	0.93
28	25	1.0	1.0
45	65	1.0	1.0
46	65	1.0	1.0
47	39	1.0	1.0
49	39	1.0	1.0
50	39	1.0	1.0
54	52	0.9	0.9
57	421	1.0	0.9
59	Unior	0.0	0.07
60	25	0.8	0.73

Sub-Total

Type Mean

TABLE 2
SUMMARY OF DATA - RIGID PAVEMENT SECTIONS

Pavement Section	Highway Number	Classification	Length	Mean Serviceability Ratings				Roughness Index (in./mi.)	Acceptability Ratios			
				ISHC	Purdue	Laymen	PSR		ISHC	Purdue	Laymen	All
1	25	P	1.25	2.7	2.8	2.5	2.7	128	0.9	0.7	0.8	0.8
4	35	P	6.50	2.6	2.6	2.3	2.5	129	0.7	0.7	0.7	0.7
7	421	P	1.75	2.6	2.4	2.2	2.4	116	0.6	0.8	0.7	0.7
17	53	S	4.75	2.4	2.2	2.2	2.3	128	0.8	0.9	0.9	0.87
18	53	S	8.75	2.6	2.6	2.4	2.6	124	0.9	1.0	1.0	0.97
19	41	P	1.25	1.3	1.3	1.5	1.4	175	0.1	0.1	0.5	0.23
21	52	P	4.50	3.1	3.1	3.0	3.1	115	0.9	0.8	0.9	0.87
22	52	P	1.75	3.8	4.1	4.0	4.0	89	1.0	1.0	1.0	1.0
23	52	P	11.00	3.3	3.6	3.3	3.4	99	0.9	1.0	0.9	0.93
28	25	S	1.00	4.1	4.0	3.7	3.9	87	1.0	1.0	1.0	1.0
45	65	P	3.25	4.4	4.7	4.2	4.4	85	1.0	1.0	1.0	1.0
46	65	P	3.25	4.6	4.6	4.4	4.5	91	1.0	1.0	1.0	1.0
47	39	P	3.75	4.4	4.3	3.9	4.2	90	1.0	1.0	1.0	1.0
49	39	P	2.25	4.2	4.1	4.0	4.1	91	1.0	1.0	1.0	1.0
50	39	P	2.25	4.3	4.3	3.9	4.2	75	1.0	1.0	1.0	1.0
54	52	P	5.50	3.4	3.2	3.1	3.2	107	1.0	0.8	0.9	0.9
57	421	P	2.00	3.0	2.9	2.7	2.9	112	0.7	1.0	1.0	0.9
59	Union	P _c	0.50	1.4	0.9	1.0	1.1	237	0.2	0.0	0.0	0.07
60	25	P	0.75	2.4	2.3	2.5	2.4	132	0.8	0.6	0.8	0.73
Sub-Total			66.00	60.8	60.0	56.8	59.3	2210				
Type Mean			3.50	3.2	3.2	3.0	3.1	116				

Pavement Section	Highway Number	Quality Ratios	
		Laymen	All
2	17	0.9	0.87
5	26	0.9	0.67
6	26	0.7	0.63
8	427	1.0	0.9
10	47	1.0	0.93
11	427	1.0	1.0
12	57	1.0	1.0
13	57	1.0	0.97
14	20	0.9	0.93
15	27	0.9	0.8
16	57	0.9	0.93
25	29	1.0	0.93
26	20	1.0	0.97
29	130	1.0	1.0
31	47	1.0	1.0
34	130	0.9	0.9
36	47	1.0	1.0
38	20	1.0	1.0
42	29	0.7	0.8
43	26	0.9	0.73
52	427	1.0	1.0
58	27	1.0	1.0

Sub-Total

Type Mean

TABLE 3
SUMMARY OF DATA - OVERLAY PAVEMENT SECTIONS

Pavement Section	Highway Number	Classification	Length	Mean Serviceability Ratings				Roughness Index (in./mi.)	Acceptability Ratios			
				ISHC	Purdue	Laymen	PSR		ISHC	Purdue	Laymen	All
2	17	S	6.00	2.0	2.6	2.4	2.3	167	0.7	1.0	0.9	0.87
5	24	P	7.75	2.7	2.2	2.3	2.4	93	0.6	0.5	0.9	0.67
6	24	P	4.25	2.6	2.2	1.9	2.2	98	0.7	0.5	0.7	0.63
8	421	P	7.50	3.0	3.1	3.3	3.1	89	0.8	0.9	1.0	0.9
10	43	P	9.25	3.1	2.7	3.1	3.0	105	0.9	0.9	1.0	0.93
11	421	P	3.00	4.1	4.0	4.2	4.1	75	1.0	1.0	1.0	1.0
12	53	P	3.75	3.6	3.6	3.9	3.7	80	1.0	1.0	1.0	1.0
13	53	P	6.50	3.6	3.6	3.6	3.6	87	1.0	0.9	1.0	0.97
14	24	P	6.50	2.9	2.9	2.8	2.8	85	0.9	1.0	0.9	0.93
15	24	P	8.25	2.7	2.5	2.8	2.7	98	0.8	0.7	0.9	0.8
16	53	S	4.50	2.4	2.4	2.4	2.4	154	0.9	1.0	0.9	0.93
25	25	P	12.75	3.8	3.5	3.3	3.5	91	0.9	0.9	1.0	0.93
26	28	P	3.50	3.9	3.8	3.9	3.9	76	0.9	1.0	1.0	0.97
29	136	P	5.75	3.9	3.9	3.5	3.8	79	1.0	1.0	1.0	1.0
31	43	P	2.50	4.0	4.0	3.4	3.8	73	1.0	1.0	1.0	1.0
34	136	P	9.00	3.1	3.0	3.0	3.0	91	0.9	0.9	0.9	0.9
36	43	P	10.75	3.9	3.9	3.6	3.8	88	1.0	1.0	1.0	1.0
38	28	S	0.50	2.7	3.0	3.2	3.0	114	1.0	1.0	1.0	1.0
42	29	P	1.50	2.6	2.6	2.6	2.6	92	0.8	0.9	0.7	0.8
43	28	P	2.50	2.5	2.5	2.6	2.6	106	0.7	0.6	0.9	0.73
52	421	P	5.25	3.7	4.0	3.8	3.8	85	1.0	1.0	1.0	1.0
58	25	P	4.25	4.0	4.2	4.1	4.1	82	1.0	1.0	1.0	1.0
Sub-Total			125.50	70.8	70.2	69.7	70.2	2108				
Type Mean			5.70	3.2	3.2	3.2	3.2	96				

Pavement Section	Highway Number	Quality Ratios	
		Laymen	All
3	16	0.9	0.83
9	18	1.0	0.93
20	18	0.9	0.9
24	26	1.0	0.97
27	55	0.7	0.53
30	32	0.9	0.87
32	234	1.0	1.0
33	136	1.0	0.97
35	47	1.0	0.97
37	28	1.0	0.87
39	26	1.0	1.0
40	26	1.0	0.93
41	38	0.9	0.73
44	32	1.0	1.0
48	47	0.7	0.8
51	38	1.0	0.9
53	26	1.0	0.73
55	75	1.0	0.83
56	18	1.0	0.93

Sub-Total

Type Mean

TABLE 4
SUMMARY OF DATA - FLEXIBLE PAVEMENT SECTIONS

Pavement Section	Highway Number	Classification	Length	Mean Serviceability Ratings				Roughness Index (in./mi.)	Acceptability Ratios			
				ISHC	Purdue	Laymen	PSR		ISHC	Purdue	Laymen	All
3	16	S	5.75	2.1	2.3	2.1	2.2	116	0.8	0.8	0.9	0.83
9	18	S	1.75	2.5	2.3	2.6	2.5	134	0.9	0.9	1.0	0.93
20	18	S	3.75	2.7	2.9	3.1	2.9	139	0.8	1.0	0.9	0.9
24	26	S	3.75	2.8	3.1	3.0	2.9	110	0.9	1.0	1.0	0.97
27	55	S	10.50	1.3	1.8	1.5	1.5	144	0.3	0.6	0.7	0.53
30	32	S	5.00	2.7	2.5	2.8	2.7	155	0.8	0.9	0.9	0.87
32	234	S	5.50	3.5	3.6	4.0	3.7	87	1.0	1.0	1.0	1.0
33	136	P	3.25	4.1	4.2	3.9	4.1	62	1.0	1.0	1.0	0.97
35	47	S	7.00	2.7	3.1	3.0	2.9	103	0.9	1.0	1.0	0.97
37	28	S	8.50	2.1	2.3	2.4	2.2	152	0.7	0.9	1.0	0.87
39	26	S	9.50	3.2	3.3	3.1	3.2	92	1.0	1.0	1.0	1.0
40	26	S	3.00	2.3	2.7	2.9	2.6	110	0.8	1.0	1.0	0.93
41	38	S	3.25	1.6	2.1	2.3	2.0	144	0.6	0.7	0.9	0.73
44	32	S	6.75	3.7	3.7	3.7	3.7	64	1.0	1.0	1.0	1.0
48	47	S	7.75	2.1	2.6	1.7	2.1	94	0.8	0.9	0.7	0.8
51	38	S	6.25	2.9	2.9	3.2	3.0	108	0.8	0.9	1.0	0.9
53	26	S	3.50	1.8	2.0	2.2	2.0	137	0.5	0.7	1.0	0.73
55	75	S	8.25	2.2	2.4	2.4	2.3	133	0.7	0.8	1.0	0.83
56	18	S	5.25	2.8	2.9	3.1	2.9	131	0.8	1.0	1.0	0.93
Sub-Total			108.25	49.1	52.7	53.0	51.4	2215				
Type Mean			5.70	2.6	2.8	2.8	2.7	117				

TABLE 5

ONE-HUNDRED PERCENT AND NINETY PERCENT OVERALL
AND PANEL RANGES - RIGID PAVEMENT SECTIONS

Pavement Section	Overall Range		ISHC Panel		Purdue Panel		Laymen Panel	
	100%	90%	100%	90%	100%	90%	100%	90%
1	2.8	2.1	2.5	2.1	2.3	1.1	2.4	1.6
4	3.5	1.4	1.1	0.9	2.6	1.1	2.0	1.5
7	3.0	2.6	3.0	2.6	2.4	1.5	2.2	1.7
17	4.5	1.5	3.6	1.7	1.3	0.7	2.9	1.5
18	3.5	2.1	3.0	1.9	1.4	0.8	2.4	2.0
19	2.7	2.1	2.5	2.3	1.8	1.5	2.5	2.0
21	3.8	2.6	3.3	2.2	2.5	2.2	3.5	2.2
22	2.4	1.9	2.2	2.1	1.5	1.3	1.9	1.7
23	3.7	2.5	3.0	2.6	2.4	1.7	3.7	2.4
28	3.0	2.0	2.0	1.5	2.0	1.8	3.0	2.1
45	2.8	1.1	1.6	1.1	1.2	0.9	2.8	1.0
46	1.8	1.0	1.0	0.9	1.4	1.0	1.8	1.0
47	1.8	1.3	1.3	1.1	1.5	1.3	1.1	0.6
49	2.3	2.0	2.0	1.1	2.2	2.0	2.3	1.8
50	2.2	1.7	2.2	1.6	1.5	1.2	2.2	1.8
54	3.9	2.4	2.7	2.1	1.6	1.5	3.7	2.4
57	2.8	1.4	2.8	1.6	1.4	0.9	1.0	0.8
59	2.2	1.9	1.9	1.7	1.5	1.2	2.0	1.6
60	3.2	2.5	2.0	1.9	2.7	1.9	3.2	1.9
Sub-mean	2.9	1.9	2.3	1.7	1.9	1.3	2.5	1.7
Overall Mean	2.9	2.0	2.4	1.8	1.9	1.4	2.4	1.7

TABLE 6

ONE-HUNDRED PERCENT AND NINETY PERCENT OVERALL
AND PANEL RANGES - OVERLAY PAVEMENT SECTIONS

Pavement Section	Overall Range		ISHC Panel		Purdue Panel		Laymen Panel	
	100%	90%	100%	90%	100%	90%	100%	90%
2	2.6	2.1	1.8	1.6	2.0	1.6	1.8	1.4
5	3.3	2.9	3.2	2.6	2.3	1.1	2.3	1.3
6	3.5	3.1	3.5	2.6	2.8	1.6	2.2	2.0
8	2.5	1.9	2.3	1.4	2.2	1.4	1.6	1.1
10	3.5	2.1	2.6	1.9	2.7	1.7	1.8	1.5
11	2.0	1.5	1.8	1.5	1.8	1.3	1.7	1.4
12	3.0	1.6	1.9	1.7	2.6	1.5	2.3	2.0
13	2.1	1.9	2.1	1.8	1.8	1.3	1.7	1.2
14	3.1	2.3	3.1	2.6	1.7	0.9	2.5	1.9
15	3.2	2.2	3.2	2.6	1.3	1.2	2.3	1.2
16	2.9	1.6	2.9	1.6	1.2	1.0	2.1	1.8
25	2.6	2.0	1.9	1.7	2.1	1.9	2.5	1.3
26	2.2	1.9	1.7	1.6	2.2	1.6	2.2	1.9
29	2.2	1.7	2.0	1.6	2.0	1.2	1.7	1.2
31	3.5	2.2	3.5	1.6	2.0	1.6	2.9	1.9
34	2.4	2.0	2.3	2.0	2.3	1.9	1.8	1.5
36	2.7	2.1	2.0	1.8	1.9	1.7	2.6	2.1
38	3.1	2.2	1.8	1.7	1.9	1.7	2.9	2.4
42	1.9	1.2	1.6	1.0	1.2	1.0	1.7	1.4
43	4.2	2.6	2.8	1.8	2.2	1.8	4.2	2.4
52	3.7	2.0	3.7	2.0	1.5	1.0	2.8	1.9
58	2.0	1.7	2.0	1.7	0.9	0.7	2.0	1.8
Sub-mean	2.8	2.0	2.4	1.8	1.9	1.4	2.3	1.7
Overall Mean	2.9	2.0	2.4	1.8	1.9	1.4	2.4	1.7

TABLE 7

ONE-HUNDRED PERCENT AND NINETY PER CENT OVERALL
AND PANEL RANGES - FLEXIBLE PAVEMENT SECTIONS

Pavement Section	Overall Range		ISHC Panel		Purdue Panel		Laymen Panel	
	100%	90%	100%	90%	100%	90%	100%	90%
3	2.4	1.9	2.2	2.0	1.9	1.2	2.2	1.5
9	3.1	1.4	2.6	1.4	1.6	1.0	2.9	1.8
20	3.2	2.0	2.0	1.5	2.1	1.6	3.0	2.0
24	2.7	1.8	2.2	2.0	2.5	1.9	1.6	1.3
27	2.1	1.7	2.0	1.6	1.3	1.0	2.0	1.6
30	3.3	2.5	3.1	2.2	2.1	1.8	3.2	2.2
32	3.2	2.1	3.0	2.2	3.2	2.3	1.8	1.5
33	2.2	1.5	2.2	1.4	1.4	1.2	1.5	1.1
35	4.3	2.5	2.0	1.7	2.4	2.1	4.3	1.8
37	2.0	1.2	1.5	1.3	1.4	1.1	1.4	1.2
39	3.3	2.3	3.3	2.7	2.3	2.0	2.1	1.8
40	3.0	2.4	2.8	2.3	2.1	1.4	2.9	1.8
41	2.4	1.6	1.6	1.2	1.3	0.8	1.5	1.3
44	2.0	1.4	2.0	1.3	1.7	1.4	1.4	1.3
48	3.4	2.4	2.7	1.8	1.6	1.3	2.9	2.3
51	3.8	2.4	3.8	3.0	2.0	1.5	2.8	2.1
53	2.4	1.9	2.4	1.8	1.6	0.9	2.3	1.9
55	3.0	2.3	3.0	1.6	2.0	1.3	2.0	1.3
56	3.7	2.1	2.4	1.2	1.3	1.2	3.7	2.7
Sub-mean	2.9	2.0	2.5	1.8	1.9	1.4	2.4	1.7
Overall Mean	2.9	2.0	2.4	1.8	1.9	1.4	2.4	1.7

smallest 100 and 90 per cent mean ranges, while the ranges of the ISHC and Laymen panels were similar.

The widely varying concepts of serviceability by highway authorities is evidenced when one compares the individual serviceability ratings and priority rankings. Raters #1, 2, and 9 of the ISHC panel were selected at random. They were not the most variable persons in the ISHC panel, neither were they the least variable. Raters #1 and 9 are maintenance engineers; rater #2 is a planning engineer. The individual serviceability ratings and priority rankings of these three "highway authorities" are presented in Tables 8, 9, and 10 for the rigid, overlay, and flexible pavement sections, respectively. The priority ranks are based on the individual serviceability ratings; i.e., the lower the serviceability rating, the higher the maintenance or reconstruction priority.

Therefore, if rater #1, a maintenance engineer, were to determine the maintenance program for the nineteen flexible pavement sections (see Table 10), pavement sections 48, 41, 27, and 37 would be the first four sections to be improved. However, if rater #9, also a maintenance engineer, were to determine the maintenance program, pavement sections 27, 41, 55, and 48 or 3 would be the first four sections to be improved. Section 37, which was ranked number four by rater #1, would be number ten on the priority list of rater #9. Rater #2 agrees with rater #1 that section 48 should receive top priority and ranks sections 55, 40, and 53 as the next three to be improved. However, he ranks sections 41, 27, and 37: seventh, fifth, and tenth, respectively.

The individual serviceability ratings also vary widely. Section 48, which is ranked number one by both rater #1 and 2, is given a 2.1 serviceability rating by rater #1 and a 0.9 serviceability rating by rater #2.

TABLE 8

COMPARISON OF INDIVIDUAL PRIORITY RANKINGS AND SERVICEABILITY
RATINGS OF THREE RATERS - RIGID PAVEMENT SECTIONS

Pavement Section	Rater #1		Rater #2		Rater #9	
	Rank	Rating	Rank	Rating	Rank	Rating
59	1	2.2	2	0.7	2	0.8
19	2	2.5	1	0.4	1	0.2
18	2	2.5	7	1.7	4	1.5
17	2	2.5	4	1.0	4	1.5
4	5	2.8	9	2.2	9	2.7
60	6	3.3	6	1.3	6	2.0
21	6	3.3	11	2.7	11	3.1
1	8	3.8	7	1.7	8	2.3
7	8	3.8	3	0.9	2	0.8
57	10	4.0	5	1.2	10	3.0
54	10	4.0	12	2.8	7	2.2
23	12	4.2	9	2.2	12	3.2
22	13	4.6	14	3.8	13	3.8
49	14	4.7	15	4.2	16	4.5
47	14	4.7	16	4.3	16	4.5
50	16	4.8	17	4.4	19	4.8
28	16	4.8	13	3.6	14	4.1
45	18	4.9	18	4.7	16	4.5
46	18	4.9	19	4.8	15	4.2

TABLE 9

COMPARISON OF INDIVIDUAL PRIORITY RANKINGS AND SERVICEABILITY
RATINGS OF THREE RATERS - OVERLAY PAVEMENT SECTIONS

Pavement Section	Rater #1		Rater #2		Rater #9	
	Rank	Rating	Rank	Rating	Rank	Rating
2	1	2.2	4	1.5	9	2.8
42	2	2.4	7	2.1	9	2.8
16	3	3.0	2	1.4	5	1.8
43	4	3.2	7	2.1	3	1.0
38	5	3.3	15	3.5	5	1.8
10	6	3.8	11	3.1	9	2.8
15	7	3.9	5	1.6	4	1.3
5	8	4.0	2	1.4	1	0.8
14	9	4.1	1	1.3	8	2.4
6	9	4.1	6	1.7	1	0.8
34	11	4.3	12	3.2	12	3.0
8	11	4.3	12	3.2	7	2.1
52	13	4.5	17	4.1	18	4.0
25	13	4.5	14	3.4	18	4.0
13	13	4.5	9	2.7	15	3.5
29	16	4.6	20	4.5	13	3.2
36	16	4.6	21	4.8	17	3.8
58	16	4.6	19	4.3	22	4.7
12	16	4.6	10	3.0	14	3.4
26	20	4.7	16	3.8	16	3.7
11	21	4.8	17	4.1	18	4.0
31	22	4.9	21	4.8	18	4.0

TABLE 10

COMPARISON OF INDIVIDUAL PRIORITY RANKINGS AND SERVICEABILITY
RATINGS OF THREE RATERS - FLEXIBLE PAVEMENT SECTIONS

Pavement Section	Rater #1		Rater #2		Rater #3	
	Rank	Rating	Rank	Rating	Rank	Rating
48	1	2.1	1	0.9	4	1.5
41	1	2.1	7	2.1	2	1.0
27	3	2.2	5	1.8	1	0.5
37	4	2.5	10	2.7	10	2.0
3	5	3.2	8	2.5	4	1.5
53	6	3.3	4	1.5	9	1.9
40	7	3.5	3	1.3	7	1.8
35	7	3.5	14	3.5	7	1.8
24	7	3.5	15	3.8	17	4.0
20	10	3.8	11	2.9	14	3.1
55	11	4.0	2	1.2	2	1.0
30	12	4.1	13	3.2	12	3.0
9	13	4.2	5	1.8	6	1.7
56	14	4.3	12	3.1	14	3.1
51	14	4.3	8	2.5	12	3.0
39	16	4.4	15	3.8	11	2.2
44	17	4.8	17	4.1	17	4.0
32	18	4.9	18	5.0	14	3.1
33	18	4.9	18	5.0	19	4.1

Rater #9, who ranked section 48 fourth, gives it a 1.5 serviceability rating.

It is apparent that altogether different priority and maintenance programs would result if they were determined by different individuals.

Number of Raters Required to Estimate the "True" Rating

The panel evaluation method minimizes the variability in serviceability ratings and priority rankings of pavement sections by individuals. In this method, members of a rating panel individually rate a pavement section, and the mean of the individual ratings is the PSR of the section.

The following equation was used to estimate the number of raters that would be required to estimate the "true" rating of any pavement section:

$$N = \frac{t^2 s^2}{d^2}$$

where,

$$t^2 = t_{\alpha/27 \text{ d.f.}}^2$$

$$d^2 = \text{interval squared}$$

$$s^2 = \text{variance of } \bar{Y}_{(i)jk}$$

An unbiased estimate of the variance ($s^2 = 0.658$) was obtained from the estimated variance components of the previously discussed ANOV. The model used in the estimation of the variance is presented in Appendix B. The number of raters required at the 0.05 and 0.10 levels of probability to rate a section within deviations ranging from 0.3 to 1.0 of the "true" rating are shown in Table 11.

TABLE 11
NUMBER OF RATERS REQUIRED TO ESTIMATE THE "TRUE" RATING
RATING PANEL EVALUATION METHOD

Permissible Error	Probability Level	
	0.05	0.10
0.3	31	21
0.4	17	12
0.5	11	8
0.6	8	5
0.7	6	4
0.8	4	3
0.9	3	2
1.0	3	2

A typical panel study, unlike this study which utilized a total of thirty raters and three panels, would use only one rating panel. The number of raters within the rating panel would depend on the accuracy and level of probability desired. That is, if it were desired that the PSRs of the pavement sections be within 0.5 of the "true" ratings of the section 95 per cent of the time, eleven raters would be required. The 0.05 level of probability states that the chances are nineteen out of twenty that the PSRs will deviate less than or will be equal to 0.5 from the "true" rating.

Evaluation of the Rating Panel Method

As noted previously, there was a difference between the ratings and rankings of raters #1, 2, and 9 of the ISHC. By combining the ratings of these three men and referring to Table 11 one can note that the chances

are nineteen out of twenty that the mean serviceability ratings of the three men will deviate less than or will be equal to 0.9 from the "true" ratings, and nine out of ten that the mean serviceability ratings will deviate less than or will be equal to 0.8 from the "true" ratings. Moreover, if we utilize the mean serviceability ratings of all ten ISHC raters we are informed that the chances are better than eighteen out of twenty that the mean serviceability ratings will deviate less than or will be equal to 0.5 from the "true" ratings.

The individual ratings of raters #1, 2, and 9, the mean ratings of the three raters, the ISHC panel ratings, and the "true" ratings are presented in Tables 12, 13, and 14 for the rigid, overlay, and flexible pavement sections, respectively. The deviations from the "true" ratings and priority rankings are also presented. As previously noted, in the present study the mean of the thirty individual serviceability ratings is assumed to be the "true" rating of a section. The individual ratings of the three selected raters and the ISHC panel ratings are also represented in the "true" ratings.

Of the sixty ISHC panel serviceability ratings not one deviated 0.5 from the "true" and only two deviated 0.4 from the "true". Of the sixty ratings made by the selected three-member-panel only one deviated 0.8 from the "true" and one deviated 0.9 from the "true". Of rater #1's sixty ratings twenty-three deviated 1.0 or greater from the "true", while seventeen of rater #2's ratings and sixteen of rater #9's ratings deviated 1.0 or greater from the "true".

There is a marked difference between the mean absolute deviations of the panels and of the selected individuals. The mean absolute deviation of the ISHC panel for the rigid pavement sections was 0.111, and the

TABLE 12

COMPARISON OF SERVICEABILITY RATINGS AND PRIORITY RANKINGS
OF THIRTY, TEN, AND THREE MEMBER RATING PANELS AND INDIVIDUALS
RIGID PAVEMENT SECTIONS

Pavement Section	Serviceability Ratings										Priority Rankings							
	30 Raters	10 Raters	Deviation	3 Raters	Deviation	Rater #1	Deviation	Rater #2	Deviation	Rater #9	Deviation	30 Raters	10 Raters	3 Raters	#1	#2	#9	
59	1.1	1.4	✓ 0.3	1.2	✓ 0.1	2.2	✓ 1.1	0.7	- 0.4	0.8	- 0.3	1	2	2	1	2	2	
19	1.4	1.3	- 0.1	1.0	- 0.4	2.5	✓ 1.1	0.4	- 1.0	0.2	- 1.2	2	1	1	2	1	1	
17	2.3	2.4	✓ 0.1	1.7	- 0.6	2.5	✓ 0.2	1.0	- 1.3	1.5	- 0.8	3	3	3	2	4	4	
60	2.4	2.4	0.0	2.2	- 0.2	3.3	✓ 0.9	1.3	- 1.1	2.0	- 0.4	4	3	6	6	6	6	
7	2.4	2.6	✓ 0.2	1.8	- 0.6	3.8	✓ 1.4	0.9	- 1.5	0.8	- 1.6	4	5	4	8	3	2	
4	2.5	2.6	✓ 0.1	2.6	✓ 0.1	2.8	✓ 0.3	2.2	- 0.3	2.7	✓ 0.2	6	5	7	5	9	9	
18	2.6	2.6	0.0	1.9	- 0.7	2.5	- 0.1	1.7	- 0.9	1.5	- 1.1	7	5	5	2	7	4	
1	2.7	2.7	0.0	2.6	- 0.1	3.8	✓ 1.1	1.7	- 1.0	2.3	- 0.4	8	8	7	8	7	8	
57	2.9	3.0	✓ 0.1	2.7	- 0.2	4.0	✓ 1.1	1.2	- 1.7	3.0	✓ 0.1	9	9	9	10	5	10	
21	3.1	3.1	0.0	3.0	- 0.1	3.3	✓ 0.2	2.7	- 0.4	3.1	0.0	10	10	10	6	11	11	
54	3.2	3.4	✓ 0.2	3.0	- 0.2	4.0	✓ 0.8	2.8	- 0.4	2.2	- 1.0	11	12	10	10	12	7	
23	3.4	3.3	- 0.1	3.2	- 0.2	4.2	✓ 0.8	2.2	- 1.2	3.2	- 0.2	12	11	12	12	9	12	
28	3.9	4.1	✓ 0.2	4.2	✓ 0.3	4.8	✓ 0.9	3.6	- 0.3	4.1	✓ 0.2	13	14	14	16	13	14	
22	4.0	3.8	- 0.2	4.1	✓ 0.1	4.6	✓ 0.6	3.8	- 0.2	3.8	- 0.2	14	13	13	13	14	13	
49	4.1	4.2	✓ 0.1	4.5	✓ 0.4	4.7	✓ 0.6	4.2	✓ 0.1	4.5	✓ 0.4	15	15	15	14	15	16	
47	4.2	4.4	✓ 0.2	4.5	✓ 0.3	4.7	✓ 0.5	4.3	✓ 0.1	4.5	✓ 0.3	16	17	15	14	16	16	
50	4.2	4.3	✓ 0.1	4.7	✓ 0.5	4.8	✓ 0.6	4.4	✓ 0.2	4.8	✓ 0.6	16	16	18	16	17	19	
45	4.4	4.4	0.0	4.7	✓ 0.3	4.9	✓ 0.5	4.7	✓ 0.3	4.5	✓ 0.1	18	17	18	18	18	16	
46	4.5	4.6	✓ 0.1	4.6	✓ 0.1	4.9	✓ 0.4	4.8	✓ 0.3	4.2	- 0.3	19	19	17	18	19	15	
Total Abs. Dev.			2.1				5.5				13.2				12.7			9.4
Mean Abs. Dev.			0.111				0.289				0.695				0.668			0.495

Pavement Section			Priority Rankings				
	30 Raters	10 Raters	10 Raters	3 Raters	#1	#2	#9
6	2.2		4	4	9	6	1
2	2.3		1	4	1	4	9
16	2.4		2	1	3	2	5
5	2.4		6	1	8	2	1
43	2.6		3	1	4	7	3
42	2.6		4	7	2	7	9
15	2.7		6	6	7	5	4
14	2.8		9	8	9	1	8
38	3.0		6	9	5	15	5
10	3.0		11	10	6	11	9
34	3.0		11	12	11	12	12
8	3.1		10	10	11	12	7
25	3.5		16	15	13	14	18
13	3.6		13	13	13	9	15
12	3.7		13	14	16	10	14
36	3.8		17	20	16	21	17
52	3.8		15	18	13	17	18
29	3.8		17	16	16	20	13
31	3.8		20	22	22	21	18
26	3.9		17	16	20	16	16
58	4.1		20	21	16	19	22
11	4.1		22	19	21	17	18

Total At

Mean At

TABLE 13

COMPARISON OF SERVICEABILITY RATINGS AND PRIORITY RANKINGS
OF THIRTY, TEN, AND THREE MEMBER RATING PANELS AND INDIVIDUALS
OVERLAY PAVEMENT SECTIONS

Pavement Section	Serviceability Ratings											Priority Rankings						
	30 Raters	10 Raters	Deviation	3 Raters	Deviation	Rater #1	Deviation	Rater #2	Deviation	Rater #9	Deviation	30 Raters	10 Raters	3 Raters	#1	#2	#9	
6	2.2	2.6	✓ 0.4	2.2	0.0	4.1	✓ 1.9	1.7	- 0.5	0.8	- 1.4	1	4	4	9	6	1	
2	2.3	2.0	- 0.3	2.2	- 0.1	2.2	- 0.1	1.5	- 0.8	2.8	✓ 0.5	2	1	4	1	4	9	
16	2.4	2.4	0.0	2.1	- 0.3	3.0	✓ 0.6	1.4	- 1.0	1.8	- 0.6	3	2	1	3	2	5	
5	2.4	2.7	✓ 0.3	2.1	- 0.3	4.0	✓ 1.6	1.4	- 1.0	0.8	- 1.6	3	6	1	8	2	1	
43	2.6	2.5	- 0.1	2.1	- 0.5	3.2	✓ 0.6	2.1	- 0.5	1.0	- 1.6	5	3	1	4	7	3	
42	2.6	2.6	0.0	2.4	- 0.2	2.4	- 0.2	2.1	- 0.5	2.8	✓ 0.2	5	4	7	2	7	9	
15	2.7	2.7	0.0	2.3	- 0.4	3.9	✓ 1.2	1.6	- 1.1	1.3	- 1.4	7	6	6	7	5	4	
14	2.8	2.9	✓ 0.1	2.6	- 0.2	4.1	✓ 1.3	1.3	- 1.5	2.4	- 0.4	8	9	8	9	1	8	
38	3.0	2.7	- 0.3	2.9	- 0.1	3.3	✓ 0.3	3.5	✓ 0.5	1.8	- 1.2	9	6	9	5	15	5	
10	3.0	3.1	✓ 0.1	3.2	✓ 0.2	3.8	✓ 0.8	3.1	✓ 0.1	2.8	- 0.2	9	11	10	6	11	9	
34	3.0	3.1	✓ 0.1	3.5	✓ 0.5	4.3	✓ 1.3	3.2	✓ 0.2	3.0	0.0	9	11	12	11	12	12	
8	3.1	3.0	- 0.1	3.2	✓ 0.1	4.3	✓ 1.2	3.2	✓ 0.1	2.1	- 1.0	12	10	10	11	12	7	
25	3.5	3.8	✓ 0.3	4.0	✓ 0.5	4.5	✓ 1.0	3.4	- 0.1	4.0	✓ 0.5	13	16	15	13	14	18	
13	3.6	3.6	0.0	3.6	0.0	4.5	✓ 0.9	2.7	- 0.9	3.5	- 0.1	14	13	13	13	9	15	
12	3.7	3.6	- 0.1	3.7	0.0	4.6	✓ 0.9	3.0	- 0.7	3.4	- 0.3	15	13	14	16	10	14	
36	3.8	3.9	✓ 0.1	4.4	✓ 0.6	4.6	✓ 0.8	4.8	✓ 1.0	3.8	0.0	16	17	20	16	21	17	
52	3.8	3.7	- 0.1	4.2	✓ 0.4	4.5	✓ 0.7	4.1	✓ 0.3	4.0	✓ 0.2	16	15	18	13	17	18	
29	3.8	3.9	✓ 0.1	4.1	✓ 0.3	4.6	✓ 0.8	4.5	✓ 0.7	3.2	- 0.6	16	17	16	16	20	13	
31	3.8	4.0	✓ 0.2	4.6	✓ 0.8	4.9	✓ 1.1	4.8	✓ 1.0	4.0	✓ 0.2	16	20	22	22	21	18	
26	3.9	3.9	0.0	4.1	✓ 0.2	4.7	✓ 0.8	3.8	- 0.1	3.7	- 0.2	20	17	16	20	16	16	
58	4.1	4.0	- 0.1	4.5	✓ 0.4	4.6	✓ 0.5	4.3	✓ 0.2	4.7	✓ 0.6	21	20	21	16	19	22	
11	4.1	4.1	0.0	4.3	✓ 0.2	4.8	✓ 0.7	4.1	0.0	4.0	- 0.1	21	22	19	21	17	18	
Total Abs. Dev.			2.8				6.3				19.3				12.8			
Mean Abs. Dev.			0.127				0.286				0.877				0.582			

Pavement Section	Priority Rankings						
	30 Raters	10 Raters	10 Raters	3 Raters	#1	#2	#9
27	1.5		1	1	3	5	1
41	2.0		2	3	1	7	2
53	2.0		3	5	6	4	9
48	2.1		4	1	1	1	4
37	2.2		4	7	4	10	10
3	2.2		4	7	5	8	4
55	2.3		7	4	11	2	2
9	2.5		9	9	13	5	6
40	2.6		8	5	7	3	7
30	2.7		10	13	12	13	12
20	2.9		10	11	10	11	14
56	2.9		13	14	14	12	14
24	2.9		13	16	7	15	17
35	2.9		10	10	7	14	7
51	3.0		15	11	14	8	12
39	3.2		16	14	16	15	11
32	3.7		17	17	18	18	14
44	3.7		18	17	17	17	17
33	4.1		19	19	18	18	19

Total Abs

Mean Abs

TABLE 14

COMPARISON OF SERVICEABILITY RATINGS AND PRIORITY RANKINGS
OF THIRTY, TEN, AND THREE MEMBER RATING PANELS AND INDIVIDUALS
FLEXIBLE PAVEMENT SECTIONS

Pavement Section	Serviceability Ratings											Priority Rankings					
	30 Raters	10 Raters	Deviation	3 Raters	Deviation	Rater #1	Deviation	Rater #2	Deviation	Rater #9	Deviation	30 Raters	10 Raters	3 Raters	#1	#2	#9
27	1.5	1.3	- 0.2	1.5	0.0	2.2	✓ 0.7	1.8	✓ 0.3	0.5	- 1.0	1	1	1	3	5	1
41	2.0	1.6	- 0.4	1.7	- 0.3	2.1	✓ 0.1	2.1	✓ 0.1	1.0	- 1.0	2	2	3	1	7	2
53	2.0	1.8	- 0.2	2.2	✓ 0.2	3.3	✓ 1.3	1.5	- 0.5	1.9	- 0.1	2	3	5	6	4	9
48	2.1	2.1	0.0	1.5	- 0.6	2.1	0.0	0.9	- 1.2	1.5	- 0.6	4	4	1	1	1	4
37	2.2	2.1	- 0.1	2.4	✓ 0.2	2.5	✓ 0.3	2.7	✓ 0.5	2.0	- 0.2	5	4	7	4	10	10
3	2.2	2.1	- 0.1	2.4	✓ 0.2	3.2	✓ 1.0	2.5	✓ 0.3	1.5	- 0.7	5	4	7	5	8	4
55	2.3	2.2	- 0.1	2.1	- 0.2	4.0	✓ 1.7	1.2	- 1.1	1.0	- 1.3	7	7	4	11	2	2
9	2.5	2.5	0.0	2.6	✓ 0.1	4.2	✓ 1.7	1.8	- 0.7	1.7	- 0.8	8	9	9	13	5	6
40	2.6	2.3	- 0.3	2.2	- 0.4	3.5	✓ 0.9	1.3	- 1.3	1.8	- 0.8	9	8	5	7	3	7
30	2.7	2.7	0.0	3.4	✓ 0.7	4.1	✓ 1.4	3.2	✓ 0.5	3.0	✓ 0.3	10	10	13	12	13	12
20	2.9	2.7	- 0.2	3.3	✓ 0.4	3.8	✓ 0.9	2.9	0.0	3.1	✓ 0.2	11	10	11	10	11	14
56	2.9	2.8	- 0.1	3.5	✓ 0.6	4.3	✓ 1.4	3.1	✓ 0.2	3.1	✓ 0.2	11	13	14	14	12	14
24	2.9	2.8	- 0.1	3.8	✓ 0.9	3.5	✓ 0.6	3.8	✓ 0.9	4.0	✓ 1.1	11	13	16	7	15	17
35	2.9	2.7	- 0.2	2.9	0.0	3.5	✓ 0.6	3.5	✓ 0.6	1.8	- 1.1	11	10	10	7	14	7
51	3.0	2.9	- 0.1	3.3	✓ 0.3	4.3	✓ 1.3	2.5	- 0.5	3.0	0.0	15	15	11	14	8	12
39	3.2	3.2	0.0	3.5	✓ 0.3	4.4	✓ 1.2	3.8	✓ 0.6	2.2	- 1.0	16	16	14	16	15	11
32	3.7	3.5	- 0.2	4.3	✓ 0.6	4.9	✓ 1.2	5.0	✓ 1.3	3.1	- 0.6	17	17	17	18	18	14
44	3.7	3.7	0.0	4.3	✓ 0.6	4.8	✓ 1.1	4.1	✓ 0.4	4.0	✓ 0.3	17	18	17	17	17	17
33	4.1	4.1	0.0	4.7	✓ 0.6	4.9	✓ 0.8	5.0	✓ 0.9	4.1	0.0	19	19	19	18	18	19
Total Abs. Dev.				2.3		7.2		18.2		11.9		11.3					
Mean Abs. Dev.				0.121		0.379		0.958		0.626		0.595					

mean absolute deviation of the three-rater panel was 0.289. Whereas, the mean absolute deviations were 0.695, 0.668, and 0.495 for raters #1, 2, and 9, respectively.

The ISHC panel priority ranking of the three types of pavement sections is quite similar to the priority ranking as determined by all thirty raters. Even the three-rater panel priority ranking is in fair agreement, but the individual priority rankings are in poor agreement (see Tables 12, 13, and 14).

It is evident that the panel method of rating is superior to a method which utilizes individual ratings as the "accuracy" of priority ranking is appreciably improved.

Acceptability Ratios

The Acceptability Ratio (AR) of a pavement section is defined as the number of raters stating "Yes" divided by the total number of raters. Therefore, the panel acceptability ratios for this study are the number of members of the specific panel stating "Yes" divided by ten; and the overall acceptability ratios are the number of all of the raters stating "Yes" divided by thirty.

The panel and overall ARs are presented in Tables 2, 3, and 4 for the rigid, overlay, and flexible sections, respectively. Scatter-diagrams were plotted with the ARs as ordinates and PSRs as abscissas. Scatter-diagrams for the primary highway sections are shown in Figures 6, 7, 8, and 9 for the overall, ISHC panel, Purdue panel, and Laymen panel, respectively. Scatter-diagrams for the secondary highway sections are shown in Figures 10, 11, 12, and 13.

FIGURE 6. ACCEPTABILITY RATIOS VS. SERVICEABILITY RATINGS OF PRIMARY SECTIONS; OVERALL

FIGURE 7. ACCEPTABILITY RATIOS VS. SERVICEABILITY RATINGS OF PRIMARY SECTIONS; ISHC PANEL

FIGURE 8. ACCEPTABILITY RATIOS VS. SERVICEABILITY RATINGS OF PRIMARY SECTIONS; PURDUE PANEL

FIGURE 9. ACCEPTABILITY RATIOS VS. SERVICEABILITY RATINGS OF PRIMARY SECTIONS; LAYMEN PANEL

FIGURE 10. ACCEPTABILITY RATIOS VS. SERVICEABILITY RATINGS OF SECONDARY SECTIONS; OVERALL

FIGURE 11. ACCEPTABILITY RATIOS VS. SERVICEABILITY RATINGS OF SECONDARY SECTIONS; ISHC PANEL

FIGURE 13. ACCEPTABILITY RATIOS VS. SERVICEABILITY RATINGS OF SECONDARY SECTIONS; LAYMEN PANEL

FIGURE 12. ACCEPTABILITY RATIOS VS. SERVICEABILITY RATINGS OF SECONDARY SECTIONS; PURDUE PANEL

Although there is agreement by the highway authorities and laymen on the serviceability of pavements, there is some variation of opinion as to the acceptability of pavement condition. From observation of the figures, the ISHC panel appears to have the highest standards for acceptability of pavement sections and the laymen panel appears to have the lowest.

It was arbitrarily assumed for this study that if 70 per cent of all the raters accepted a section, the section would be considered "acceptable". (i.e., the section is all right as it is, and no reconstruction is required); and if 50 per cent of all the raters did not accept a section, the section would be "unacceptable" (i.e., reconstruction is required). Therefore, all pavement sections with ARs equal to or greater than 0.7 were classified as acceptable; and all pavement sections with ARs equal to or less than 0.5 were classified as unacceptable. Pavement sections within the 0.5 and 0.7 limits were classified as "doubtful" relative to reconstruction. The condition of these pavement sections is not as poor or serious as those classified as "unacceptable". Pavement sections which were classified as unacceptable definitely require reconstruction and should receive top priority.

From observation of the scatter-diagrams, primary sections with ARs equal to or greater than 0.7 were given PSRs of 2.5 or higher, while secondary sections with ARs equal to or greater than 0.7 were given PSRs of 2.0 or higher. Primary sections with ARs equal to or less than 0.5 were given PSRs of 2.0 or less, while a PSR of 1.5 or less would have been unacceptable for secondary highways. The zones of doubt of PSRs in this study as to acceptability, therefore, were 2.0 to 2.5 for primary highways and 1.5 to 2.0 for secondary highways.

Rater Characteristics

Various rater characteristics -- range of ratings, sum of ratings, sum difference, mean absolute deviation, standard deviation of mean absolute deviation, and the respective ranking orders -- and panel and overall totals and means are summarized in Tables 15, 16, and 17. These characteristics are explained below.

The range indicates the amount of the rating scale utilized by the rater, the lowest rating, and the highest rating. This characteristic, like the sum of ratings and sum difference, indicates the "high" and "low" raters. It is interesting to note that only one rater utilized the entire rating scale and that this rater ranked 27th and 30th according to the mean deviation and standard deviation rankings, respectively.

The sum of ratings is the sum of the rater's sixty ratings. The sum difference is the difference of the sum of ratings from the sum of the sixty "true" ratings which was 180.7. A positive sum difference indicates a higher than "true" sum of ratings and indicates a tendency of the rater to rate sections "higher" than the "true" value. A negative sum difference indicates a tendency of the rater to rate the sections "lower" than the "true" value. All thirty raters are ranked from high to low according to the sum differences, thus, the rater ranked number one by this measure is the "highest" rater and the rater ranked number thirty is the "lowest" rater.

The mean deviation is the sum of the absolute differences of the individual ratings from the "true" ratings for each of the sections divided by the number of sections. The mean deviation indicates the average "closeness" of the individual's ratings to the "true" ratings with the

Rater	Low	Standard Deviation	St. Dev. Rank
1	2.1	0.438	21
2	0.4	0.437	20
3	1.5	0.445	23
4	1.2	0.358	11
5	1.0	0.365	12
6	0.7	0.336	9
7	1.2	0.479	26
8	0.2	0.520	28
9	0.2	0.464	24
10	0.3	0.412	17
Sub-Total	8.8	4.254	
Panel Mean	0.88	0.4254	
Grand Total	22.4	11.835	
Grand Mean	0.75	0.3945	

TABLE 15
SUMMARY OF RATER CHARACTERISTICS
INDIANA STATE HIGHWAY COMMISSION PANEL

Rater	Range			Mean of Ratings	Sum of Ratings	Sum Difference	Sum Dif. Rank	Mean Deviation	Mean Dev. Rank	Standard Deviation	St. Dev. Rank
	Low	High	Difference								
1	2.1	4.9	2.8	3.85	230.8	✓ 50.1	1	0.828	28	0.438	21
2	0.4	5.0	4.6	2.78	166.9	- 13.8	20	0.623	22	0.437	20
3	1.5	5.0	3.5	3.44	206.4	✓ 25.7	6	0.498	16	0.445	23
4	1.2	4.1	2.9	2.60	156.1	- 24.6	29	0.460	11	0.358	11
5	1.0	4.5	3.5	2.83	170.2	- 10.5	18	0.422	9	0.365	12
6	0.7	4.6	3.9	3.04	182.5	✓ 1.8	12	0.370	4	0.336	9
7	1.2	4.5	3.3	2.85	170.9	- 9.8	17	0.563	19	0.479	26
8	0.2	5.0	4.8	3.63	217.8	✓ 3.71	2	1.068	30	0.520	28
9	0.2	4.8	4.6	2.66	159.7	- 21.0	26	0.562	18	0.464	24
10	0.3	4.0	3.7	2.28	136.5	- 44.2	30	0.743	26	0.412	17
Sub-Total	8.8	46.4	37.6	29.96	1797.8			6.137		4.254	
Panel Mean	0.88	4.64	3.76	2.996	179.78			0.6137		0.4254	
Grand Total	22.4	140.3	117.9	90.33	5419.7			16.553		11.835	
Grand Mean	0.75	4.68	3.93	3.01	180.7			0.5518		0.3945	

Rater	Low	Standard Deviation	St. Dev. Rank
1	1.1	0.319	8
2	0.3	0.440	22
3	0.6	0.348	10
4	1.0	0.297	5
5	0.5	0.245	1
6	0.9	0.272	4
7	0.7	0.265	3
8	0.7	0.302	7
9	0.8	0.475	25
10	1.4	0.395	16
Sub-Total	8.0	3.358	
Panel Mean	0.80	0.3358	
Grand Total	22.4	11.835	
Grand Mean	0.75	0.3945	

TABLE 16
SUMMARY OF RATER CHARACTERISTICS
PURDUE PANEL

Rater	Low	High	Range Difference	Mean of Ratings	Sum of Ratings	Sum Difference	Sum Dif. Rank	Mean Deviation	Mean Dev. Rank	Standard Deviation	St. Dev. Rank
1	1.1	4.9	3.8	3.16	189.7	9.0	11	0.437	10	0.319	8
2	0.3	5.0	4.7	2.75	165.4	-15.3	22	0.672	24	0.440	22
3	0.6	4.2	3.6	2.66	159.3	-21.4	27	0.477	12	0.348	10
4	1.0	4.6	3.6	2.73	163.6	-17.1	25	0.378	5	0.297	5
5	0.5	4.1	3.6	2.90	173.9	-6.8	15	0.307	1	0.245	1
6	0.9	4.9	4.0	3.24	194.6	13.9	9	0.402	7	0.272	4
7	0.7	4.7	4.0	3.28	197.0	16.3	8	0.408	8	0.265	3
8	0.7	4.8	4.1	2.82	169.0	-11.7	19	0.392	6	0.302	7
9	0.8	4.9	4.1	3.41	204.9	24.2	7	0.620	21	0.475	25
10	1.4	5.0	3.6	3.56	213.3	32.6	3	0.658	23	0.395	16
Sub-Total	8.0	47.1	39.1	30.51	1830.7			4.751		3.358	
Panel Mean	0.80	4.71	3.91	3.051	183.07			0.4751		0.3358	
Grand Total	22.4	140.3	117.9	90.33	5419.7			16.553		11.835	
Grand Mean	0.75	4.68	3.93	3.01	180.7			0.5518		0.3945	

Rater	Low	Standard Deviation	St. Dev. Rank
1	0.6	0.376	13
2	0.2	0.298	6
3	1.0	0.504	27
4	0.5	0.389	15
5	1.3	0.428	19
6	0.2	0.558	29
7	0.0	0.609	30
8	0.8	0.379	14
9	0.2	0.427	18
10	0.8	0.255	2
Sub-Total	5.6	4.223	
Panel Mean	0.56	0.4223	
Grand Total	22.4	11.835	
Grand Mean	0.75	0.3945	

TABLE 17
SUMMARY OF RATER CHARACTERISTICS

LAYMEN PANEL

Rater	Range			Mean of Ratings	Sum of Ratings	Sum Difference	Sum Dif. Rank	Mean Deviation	Mean Dev. Rank	Standard Deviation	St. Dev. Rank
	Low	High	Difference								
1	0.6	4.4	3.8	2.62	157.4	- 23.3	28	0.495	14	0.376	13
2	0.2	4.8	4.6	3.23	193.8	✓ 13.1	10	0.352	3	0.298	6
3	1.0	5.0	4.0	3.55	213.0	✓ 32.3	4	0.732	25	0.504	27
4	0.5	4.5	4.0	2.76	165.4	- 15.3	22	0.498	15	0.389	15
5	1.3	4.5	3.2	2.92	175.0	- 5.7	14	0.598	20	0.428	19
6	0.2	5.0	4.8	3.47	208.4	✓ 27.7	5	0.885	29	0.558	29
7	0.0	5.0	5.0	2.73	163.7	- 17.0	24	0.757	27	0.609	30
8	0.8	4.3	3.5	2.85	171.0	- 9.7	16	0.485	13	0.379	14
9	0.2	4.7	4.5	2.77	166.0	- 14.7	21	0.518	17	0.427	18
10	0.8	4.6	3.8	2.96	177.5	- 3.2	13	0.340	2	0.255	2
Sub-Total	5.6	46.8	41.2	29.86	1791.2			5.660		4.223	
Panel Mean	0.56	4.68	4.12	2.986	179.12			0.5660		0.4223	
Grand Total	22.4	140.3	117.9	90.33	5419.7			16.553		11.835	
Grand Mean	0.75	4.68	3.93	3.01	180.7			0.5518		0.3945	

smallest numerical value being the "closest". The standard deviation of the mean deviation is a measure of the variability of the individual's ratings. It is an indication of the rater's consistency. Thus, the rater with the lowest standard deviation is the most consistent rater. Each of the thirty raters are ranked as to their closeness (column 10, Tables 15, 16, and 17) and consistency (column 12, Tables 15, 16, and 17) to the "true" ratings. The individual who was closest or most consistent received the ranking of 1 in the appropriate column.

It is interesting to note that the Purdue panel had the smallest panel mean deviation and standard deviation, and that seven of its members ranked in the top twelve according to mean deviation. The same seven raters ranked in the top ten according to standard deviations. The close agreement of these seven raters was offset by the three remaining raters who ranked 24th, 21st, 23rd, and 22nd, 25th, 16th for their mean deviations and standard deviations, respectively.

Two of the laymen were in the top ten for both mean deviations and standard deviations. The three women raters ranked 20th, 29th, 27th and 19th, 29th, 30th for their mean deviations and standard deviations, respectively.

The ISHC panel had the largest mean deviation and standard deviation and had two of its members in the top ten for mean deviations but only one for standard deviations. Also, four of its members were in the bottom third for mean deviations and five for standard deviations. It is also interesting to note that the rater who ranked number one according to sum difference (that is, the "highest" rater) was the maintenance engineer of most of the highways in the study.

RESULTS - CORRELATION OF SERVICEABILITY RATINGS AND ROUGHNESS INDICES

The inter-relationship between the roughometer roughness values and the serviceability ratings for the three pavement types necessitated correlation and regression analyses. Since there was found to be no significant differences between the three rating panels, the mean of the thirty ratings was assumed to be the present serviceability rating (PSR) of the section.

Scatter-diagrams were plotted with the PSRs as the ordinates and the roughometer roughness values as the abscissas for each pavement type. The scatter-diagrams are shown in Figures 14, 15, and 16 for the rigid, overlay, and flexible sections, respectively.

Linear Analysis

Correlation coefficients (r) and squared correlation coefficients (r^2) were calculated for the three pavement types. The correlation coefficients and squared correlation coefficients are summarized in Table 18. Sample calculations for the results herein discussed are presented in Appendix B.

FIGURE 14. PRESENT SERVICEABILITY RATING VS. ROUGHNESS INDEX; RIGID PAVEMENT SECTIONS

FIGURE 15. PRESENT SERVICEABILITY RATING VS. ROUGHNESS INDEX; OVERLAY PAVEMENT SECTIONS 61

FIGURE 16. PRESENT SERVICEABILITY RATING VS. ROUGHNESS INDEX; FLEXIBLE PAVEMENT SECTIONS

TABLE 18

CORRELATION COEFFICIENTS AND SQUARED CORRELATION COEFFICIENTS OF
PRESENT SERVICEABILITY RATINGS WITH ROUGHNESS INDICES -
LINEAR AND EXPONENTIAL CASES -
RIGID, OVERLAY, AND FLEXIBLE PAVEMENT SECTIONS

Pavement Type	r		r ²	
	Linear	Exponential	Linear	Exponential
Rigid	- 0.90	- 0.98	0.82	0.96
Overlay	- 0.65	- 0.72	0.42	0.52
Flexible	- 0.81	- 0.71	0.66	0.51

The correlation coefficient indicates the amount of relationship between PSRs and roughometer roughness values. The squared correlation coefficient is the amount of the variation of the PSR that can be considered to be explained by the roughometer roughness values. The negative correlation coefficients indicate a negative association of the variables; that is, as the roughometer roughness values increase, the PSR values tend to decrease.

The results indicate the presence of a high negative correlation ($r = - 0.90$) between the PSRs and the roughometer values for the rigid sections. Approximately eighty-two per cent of the variation in the PSR can be explained by a dependence on the roughometer value. There is a fair degree of negative correlation between the PSRs and the roughometer values for the overlay ($r = - 0.65$) and the flexible sections ($r = - 0.81$). Roughometer roughness values account for forty-two per cent and sixty-six per cent of the variation in the PSRs of the overlay and flexible sections, respectively. Therefore, fifty-eight per cent of the variations in the PSRs of the overlay sections and thirty-four per cent of the variation in the PSRs of the flexible sections must be due to other factors.

These factors may be non-linear forms of the roughometer measurements and/or other physical factors.

Linear Regression Equations

Linear regression equations were calculated for each pavement type using the roughness measurements as the independent variable (X) and the PSRs as the dependent variable (Y). The method of least-squares was used. Sample calculations of results herein discussed are presented in Appendix B.

The following least-squares equations resulted:

For rigid pavement sections:

$$Y = 5.90 - 0.0241 X$$

For overlay pavement sections:

$$Y = 4.88 - 0.0176 X$$

For flexible pavement sections:

$$Y = 4.90 - 0.0188 X$$

The least-square regression lines are shown in Figures 14, 15, and 16 for the rigid, overlay, and flexible sections, respectively.

Curvilinear Analysis

The scatter-diagrams (see Figures 14 and 15) of the rigid and overlay sections indicated an exponential curve of the type: $Y = aX^b$, or $\log Y = a' + b \log X$. Scatter-plots of the roughometer and PSR values on log-log scales (see Figures 17, 18, and 19) showed apparently "straighter" lines for the rigid and overlay sections. Therefore, correlation coefficients and least-square regression equations were calculated for the exponential relationship. Sample calculations of the results herein discussed are presented in Appendix B.

FIGURE 17. PRESENT SERVICEABILITY RATING VS. ROUGHNESS INDEX; LOG-LOG SCALE; RIGID PAVEMENT SECTIONS

FIGURE 18. PRESENT SERVICEABILITY RATING VS. ROUGHNESS INDEX; LOG-LOG SCALE; OVERLAY PAVEMENT SECTIONS

FIGURE 19. PRESENT SERVICEABILITY RATING VS. ROUGHNESS INDEX; LOG-LOG SCALE; FLEXIBLE PAVEMENT SECTIONS

The correlation coefficients for the exponential relationship are presented in Table 18. The correlation coefficients for the exponential relationship of the rigid and overlay sections are higher than for the linear relationship. "F" tests were used to see if the variability explained by the exponential function was significantly different from the variability explained by the linear function for each pavement type.

The following equation was used:

$$F = \frac{s_{y,x}^2}{s_{y,x}^{'2}}$$

where,

$s_{y,x}^2$ = unexplained variability for the linear function

$s_{y,x}^{'2}$ = unexplained variability for the exponential function

The results are summarized in Table 19. There were found to be no significant differences for the overlay and flexible sections. There was a significant difference at the 0.10 level of probability between the variability explained by the exponential function and the variability explained by the linear function for the rigid sections. The exponential curve presents a better "fit" for the given data than the straight line, and explains 0.14 more of the PSR variance.

TABLE 19

"F" TEST COMPARISON OF THE UNEXPLAINED PSR VARIABILITY
FOR THE LINEAR AND EXPONENTIAL FUNCTIONS -
RIGID, OVERLAY, AND FLEXIBLE PAVEMENT SECTIONS

Pavement Type	D.F. (N-2)	$s_{y.x}^2$	$s_{y.x}^2$	F	$F_{0.10}$	Conclusion
Rigid	17	2.059	0.947	2.17	1.91	S
Overlay	20	2.400	1.910	1.26	1.79	NS
Flexible	17	2.012	1.888	1.07	1.91	NS

Regression Equations

The least-squares method of regression was used and the following equations resulted:

For rigid pavement sections:

$$\log Y = 3.2457 - 1.3559 \log X$$

For overlay pavement sections:

$$\log Y = 1.8874 - 0.7060 \log X$$

For flexible pavement sections:

$$\log Y = 1.7827 - 0.6640 \log X$$

The least-squares exponential regression lines are shown in Figures 17, 18, and 19 for the rigid, overlay, and flexible sections, respectively. Tables 20, 21, and 22 show a comparison of the PSRs with the predicted values of both the linear and exponential equations for the rigid, overlay, and flexible sections, respectively.

TABLE 20

COMPARISON OF THIRTY-MEMBER RATING PANEL PSRs WITH LINEAR AND
EXPONENTIAL REGRESSION EQUATION PSRs - RIGID PAVEMENT SECTIONS

Pavement Section	Roughness Index	Thirty Raters PSR	Linear PSR	Linear Dev.	Exponential PSR	Exponential Dev.
1	128	2.7	2.8	+ 0.1	2.4	- 0.3
4	129	2.5	2.8	+ 0.3	2.4	- 0.1
7	116	2.4	3.1	+ 0.7	2.8	+ 0.4
17	128	2.3	2.8	+ 0.5	2.4	+ 0.1
18	124	2.6	2.9	+ 0.3	2.6	0.0
19	175	1.4	1.7	+ 0.3	1.6	+ 0.2
21	115	3.1	3.1	0.0	2.8	- 0.3
22	89	4.0	3.8	- 0.2	4.0	0.0
23	99	3.4	3.5	+ 0.1	3.5	+ 0.1
28	87	3.9	3.8	- 0.1	4.1	+ 0.2
45	85	4.4	3.8	- 0.6	4.3	- 0.1
46	91	4.5	3.7	- 0.8	3.9	- 0.6
47	90	4.2	3.7	- 0.5	3.9	- 0.3
49	91	4.1	3.7	- 0.4	3.9	- 0.2
50	75	4.2	4.1	- 0.1	5.0	+ 0.8
54	107	3.2	3.3	+ 0.1	3.1	- 0.1
57	112	2.9	3.2	+ 0.3	2.9	0.0
59	237	1.1	0.2	- 0.9	1.1	0.0
60	132	2.4	2.7	<u>+ 0.3</u>	2.3	<u>- 0.1</u>
Abs. Total				6.6		3.9
Abs. Mean Dev.				0.347		0.205

TABLE 21

COMPARISON OF THIRTY-MEMBER RATING PANEL PSRs WITH LINEAR AND
EXPONENTIAL REGRESSION EQUATION PSRs - OVERLAY PAVEMENT SECTIONS

Pavement Section	Roughness Index	Thirty Raters PSR	Linear PSR	Linear Dev.	Exponential PSR	Exponential Dev.
2	167	2.3	1.9	- 0.4	2.1	- 0.2
5	93	2.4	3.2	+ 0.8	3.1	+ 0.7
6	98	2.2	3.2	+ 1.0	3.0	+ 0.8
8	89	3.1	3.3	+ 0.2	3.2	+ 0.1
10	105	3.0	3.0	0.0	2.9	- 0.1
11	75	4.1	3.6	- 0.5	3.7	- 0.4
12	80	3.7	3.5	- 0.2	3.5	- 0.2
13	87	3.6	3.4	- 0.2	3.3	- 0.3
14	85	2.8	3.4	+ 0.6	3.4	+ 0.6
15	98	2.7	3.2	+ 0.5	3.0	+ 0.3
16	154	2.4	2.2	- 0.2	2.2	- 0.2
25	91	3.5	3.3	- 0.2	3.2	- 0.3
26	76	3.9	3.5	- 0.4	3.6	- 0.3
29	79	3.8	3.5	- 0.3	3.5	- 0.3
31	73	3.8	3.6	- 0.2	3.7	- 0.1
34	91	3.0	3.3	+ 0.3	3.2	+ 0.2
36	88	3.8	3.3	- 0.5	3.3	- 0.5
38	114	3.0	2.9	- 0.1	2.7	- 0.3
42	92	2.6	3.3	+ 0.7	3.2	+ 0.6
43	106	2.6	3.0	+ 0.4	2.9	+ 0.3
52	85	3.8	3.4	- 0.4	3.3	- 0.5
58	82	4.1	3.4	<u>- 0.7</u>	3.4	<u>- 0.7</u>
Abs. Total				8.8		7.9
Abs. Mean Dev.				0.400		0.359

TABLE 22

COMPARISON OF THIRTY-MEMBER RATING PANEL PSRs WITH LINEAR AND
EXPONENTIAL REGRESSION EQUATION PSRs - FLEXIBLE PAVEMENT SECTIONS

Pavement Section	Roughness Index	Thirty Raters PSR	Linear PSR	Linear Dev.	Exponential PSR	Exponential Dev.
3	116	2.2	2.7	+ 0.5	2.6	+ 0.4
9	134	2.5	2.4	- 0.1	2.3	- 0.2
20	139	2.9	2.3	- 0.6	2.3	- 0.6
24	110	2.9	2.8	- 0.1	2.7	- 0.2
27	144	1.5	2.2	+ 0.7	2.2	+ 0.7
30	155	2.7	2.0	- 0.7	2.1	- 0.6
32	87	3.7	3.3	- 0.4	3.1	- 0.6
33	62	4.1	3.7	- 0.4	3.9	- 0.2
35	103	2.9	3.0	+ 0.1	2.8	- 0.1
37	152	2.2	2.0	- 0.2	2.2	0.0
39	92	3.2	3.2	0.0	3.0	- 0.2
40	110	2.6	2.8	+ 0.2	2.7	+ 0.1
41	144	2.0	2.2	+ 0.2	2.2	+ 0.2
44	64	3.7	3.7	0.0	3.8	+ 0.1
48	94	2.1	3.1	+ 1.0	3.0	+ 0.9
51	108	3.0	2.9	- 0.1	2.7	- 0.3
53	137	2.0	2.3	+ 0.3	2.3	+ 0.3
55	133	2.3	2.4	+ 0.1	2.4	+ 0.1
56	131	2.9	2.4	<u>- 0.5</u>	2.4	<u>- 0.5</u>
Abs. Total				6.2		6.3
Abs. Mean Dev.				0.326		0.332

DISCUSSION OF RESULTS

If one assumes that the present serviceability rating (PSR) is a good measure of the adequacy of a pavement and further assumes that the best judge of the adequacy of a pavement is the judgment of the traveling public, serviceability ratings obtained by a large panel of motorists would be an excellent measure of the present adequacy of a highway pavement.

Two methods of determining present serviceability ratings have been presented. One method makes use of a rating panel -- the number of raters required in the rating panel being dependent on the "accuracy" of the required serviceability ratings. Since there was found to be non-significant panel differences, it is inferred that the amount of rater experience and knowledge in the highway field is not of importance in the selection of raters.

The second method utilizes measurements obtained by a roughometer as the independent variable in least-squares regression equations to obtain present serviceability ratings. When compared to serviceability ratings obtained by a large rating panel, the ratings obtained by the use of roughness measurements are only fair approximations for overlay and flexible pavement sections but are almost exactly the same for rigid pavements.

Factors apparently not measurable by the roughometer account for approximately fifty per cent of the serviceability rating variation of overlay and flexible pavement sections. cursory examination of the pavement sections (see Tables 25, 26 and 27, Appendix A) indicates that factors

not completely measured by the roughometer, such as porpoising, sideways, cracks, patches, and bleeding may account for some of the rating variation of flexible pavements; and factors such as reflection cracks, faulted cracks and joints, blow ups, and widening may account for some of the rating variation of overlay pavements. The least-squares equations derived using roughometer output as the only predictor are not satisfactory for determining the present serviceability ratings for overlay and flexible sections.

The results of this study, however, show that roughness measurements are excellent indicators of the serviceability ratings of rigid pavement sections. Either of the following equations may be employed in predicting PSRs from the roughometer output, but the exponential relationship will provide the more accurate results:

$$Y = 5.90 - 0.0241 X$$

or,

$$\log Y = 3.2457 - 1.3559 \log X$$

where,

X = roughometer output (in./mi.)

Y = present serviceability rating (PSR)

Since both the roughometer and the panel rating methods provide excellent serviceability ratings for rigid pavement sections, a cost comparison of the two methods was made using the nineteen rigid pavement sections in this study as the pavements to be rated.

The following costs were assumed: 1) all preliminary costs (i.e., costs involved in the determination of homogeneous pavement sections, location of sections, routing of the roughometer and raters, etc.) would be the same for both methods, 2) labor costs would be \$20/day/person for both roughometer crew and rating panel, 3) rating vehicles operational and overhead

cost would be 7 cents/mile, 4) roughometer and tow truck operational and overhead cost would be 10 cents/mile, and 5) all summarization and analysis costs of the data would be the same (a study of the required work indicates that the costs would be similar).

The measurement of the nineteen rigid pavement sections by the roughometer would require five days. This time was determined from experience with the roughometer on the nineteen sections of the study. For these nineteen sections the roughometer would log approximately 200 miles of pavement. Additional mileage for traveling to and from a central home base and for traveling from one test section to another would require approximately 350 miles. Therefore, a total of 550 miles would be traveled by the roughometer tow vehicle resulting in an operational expense of:

$$550 (\$0.10) = \$55.00$$

The roughometer crew consisted of two men: one man to drive and the other to record. Cost of labor was approximately:

$$2 (5)(\$20) = \$200$$

Therefore, the total cost of evaluating the nineteen rigid pavement sections by the roughometer would be approximately:

$$\$55 + \$200 = \$255$$

The evaluation of the nineteen rigid pavement sections by a rating panel would require one day. Each member of the rating panel operating from the same central home base would be required to drive approximately 264 miles in order to rate the nineteen sections. Vehicle operating expense would be approximately:

$$264 (\$0.07) = \$18.50$$

The total cost for one rater and vehicle for rating the nineteen rigid

pavement sections would then be:

$$\$18.50 + \$20.00 = \$38.50$$

The number of raters in the rating panel would depend on the accuracy required. The approximate costs for evaluating the nineteen rigid pavement sections by a rating panel with from three to eight members is presented in Table 23.

TABLE 23
APPROXIMATE COST FOR EVALUATING NINETEEN RIGID
PAVEMENT SECTIONS - RATING PANEL EVALUATION METHOD

No. of Raters	Cost
3	\$115
4	155
5	190
6	230
7	270
8	310

A seven member rating panel would cost only slightly more than the roughometer. A seven member rating panel would predict mean serviceability ratings that would deviate less than 0.7 from the "true" ratings by chance nineteen out of twenty times, and would predict mean serviceability ratings that would deviate less than 0.6 from the "true" ratings by chance nine out of ten times.

If it is required that the deviations of the predicted serviceability ratings be equal to or greater than 0.6 at the 0.10 level, or equal to or greater than 0.7 at the 0.05 level, the more economical method would be

the rating panel method, since at most six members will be required, resulting in a maximum cost of approximately \$230. However, if it is required that the deviations be equal to or less than 0.5 at the 0.10 level, or equal to or less than 0.6 at the 0.05 level, the roughometer would be more economical since an eight member panel would cost approximately \$310.

The decision of which method to use will depend on the use to be made of the results. If the results are to be used primarily for priority determination in program planning, it should be remembered that even a three member panel (see Section of this report entitled "Evaluation of the Rating Panel Method") produced good results. The method used to determine serviceability ratings for overlay and flexible pavements will also affect the decision as to which method to use for rigid pavements. If the panel method is used for these pavements (and no other good method is known), then it would be efficient to also use it for the rigid pavements.

CONCLUSIONS

The conclusions made from the data herein analyzed are as follows:

- 1) The rating panel method of evaluating pavement serviceability is practical; is applicable to rigid, overlay, and flexible pavements; and minimizes the variations and personal bias involved when pavement maintenance and reconstruction priority programs are determined on the basis of the personal knowledge and judgments of individuals.
- 2) Although pavement serviceability ratings of individuals vary widely, the mean serviceability ratings of panels of individuals do not and are good estimates of the "true" present serviceability ratings of highway pavement sections.
- 3) The amount of knowledge and experience in the highway engineering field is not of importance in the selection of members for a rating panel.
- 4) The roughometer method of evaluating pavement serviceability is objective and simple, but is accurate (i.e., highly correlated with the judgments of the traveling public) only for rigid pavements.
- 5) The present serviceability rating (PSR) of a rigid pavement section can be accurately determined from roughometer measurements by the following exponential relationship:

$$\log Y = 3.2457 - 1.3559 \log X$$

where,

X = roughometer output (in./mi.)

Y = present serviceability rating (PSR)

A slightly less accurate rating can be determined from the following linear relationship:

$$Y = 5.90 - 0.0241 X$$

- 6) Roughometer measurements are not good predictors of the present serviceability ratings of overlay and flexible pavements.
- 7) The panel method of obtaining present serviceability ratings for rigid pavements will be more economical than the method utilizing roughometer measurements if the accuracy required of the panel permits the use of a small panel. Cost calculations should be employed to determine the method which is less costly.
- 8) Primary highway pavements with PSRs of 2.5 or higher and secondary highway pavements with PSRs of 2.0 or higher are "acceptable" to the traveling public.
- 9) Primary highway pavements with PSRs of 2.0 or lower and secondary highway pavements with PSRs of 1.5 or lower are "unacceptable" to the traveling public and should be reconstructed.

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BIBLIOGRAPHY

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APPENDIX A

RATER APPLICATION

Name _____

Local Address _____ Phone _____

Permanent Address _____

Age _____ Sex _____ Married _____ Social Security No. _____

Occupation _____

Are you planning to use your own vehicle? _____ Yes _____ No

If you are not, who is the owner? _____

Is the vehicle of a type you usually drive? _____ Yes _____ No

Is the vehicle covered by public liability and property damage insurance?

_____ Yes _____ No

If so, in what amount? _____

What type of vehicle is it? Make _____ Year _____

How many years of driving experience do you have? _____

How many miles of driving do you average a year? _____

I understand, if I am selected as one of the raters for the Pavement Serviceability Study, that Purdue University will pay me the sum of one hundred dollars for sixty completed rating forms, which I agree to complete according to instructions. I further understand that all travel expense and responsibilities necessary to complete the sixty forms will be furnished by me at my own expense.

(Signed)

Applicant Selected and Accepted _____

Forms and Instructions Delivered _____ Completed Forms Returned _____

RATING INSTRUCTIONS

1. In rating the sections of pavement always keep this question in mind:
If I were to ride over a pavement that is just like that represented by this section of pavement every day for the usual purposes, how well would the pavement serve me? For secondary highways this service would be primarily for short trips, such as to work or to town, while for primary highways the service would be, in general, for some longer trips.
2. Rate the serviceability of the pavement only. Exclude all features not part of the pavement itself, such as right of way and median width, grade, alignment, shoulder and ditch conditions, etc.
3. You must not let your opinion as to how the pavement may perform in the future influence your rating of the existing serviceability.
4. You may ride over the pavement as you wish. That is, you may ride over the length of pavement you are rating in a car or truck similar to the one in which you normally ride at a high speed and/or at a low speed.
5. Remember you are rating the pavement only. Your car serves as an instrument by which you can compare one pavement with all other pavements on which you have ridden. For example: a truck driver accustomed to driving trucks can readily compare one pavement with another if he is in his truck, whereas a man who normally drives a Cadillac would find a ride in a truck so relatively rough that he would not be able to compare successfully one pavement with another.

RATING INSTRUCTIONS (continued)

6. You are to travel alone and work independently. You must not discuss your work with, or be influenced by, others.
7. On the rating card there is a scale reading from 0 to 5 with appropriate descriptive adjectives along the side. Mark with a horizontal line the appropriate numerical rating on the scale. Your rating will be read to two significant figures (e.g., 3.4, 1.8).
8. Fill out every item on the rating card.
9. If you have any questions call Lafayette, 92-2111, or come to Room 215, Civil Engineering Building, Purdue University.

RATING PROCEDURE

1. You are to rate the pavement sections in three days. The three days need not be in consecutive order, however, the rating should be completed by _____. Rating cannot be done during rain or other inclement weather conditions.
2. The map is divided into three parts (i.e., parts A, B, and C). You are to rate part ____ on the first day of rating, part ____ on the second day, and part ____ on the third day.
3. The pavement sections are numerically identified. You are to rate the pavement sections within each part in the order given on the following page. For example: on the first day you are to rate pavement section _____ first, pavement section _____ second, pavement section _____ third, etc.
4. It is very important that you rate the pavement sections in the above mentioned order.
5. The sections are identified by yellow paint markings on the pavement (see sketch below). The yellow paint strip indicates the beginning and end of the section; the arrow points in the direction of the pavement section to be rated; and the number identifies the section.

Rating Order I
(Sample of Ten Rating Orders Used)

	First Day	Second Day	Third Day
Part: Order of Rating	B Section	C Section	A Section
1	59	36	28
2	60	31	54
3	41	32	18
4	50	33	9
5	43	34	58
6	21	30	1
7	45	29	2
8	46	27	3
9	47	35	4
10	48	44	5
11	49	38	6
12	51	37	7
13	52	26	8
14	42	25	10
15	53	24	15
16	55		11
17	56		12
18	57		13
19	40		14
20	39		16
21			17

Rating Order I (continued)

Part: Order of Rating	First Day	Second Day	Third Day
	B Section	C Section	A Section
22			19
23			20
24			22
25			23

TABLE 24

RATER INFORMATION

Panel	Rater	Age	Sex	Occupation	Type of Vehicle Used Make	Year	Driving Years	Experience Miles/year
I	1	56	M	Maintenance Engineer	Chevrolet	1960	36	40,000
	2	31	M	Planning Engineer	Studebaker Lark	1960	15	20,000
	3	59	M	Traffic Engineer	Ford	1960	40	40,000
	4	57	M	Road Construction Engineer	Chevrolet	1959	40	30,000
	5	62	M	Traffic Engineer	Ford	1960	43	25,000
	6	62	M	Planning Engineer	DeSoto	1952	43	25,000
	7	34	M	Road Construction Engineer	Chevrolet	1960	18	60,000
	8	56	M	Road Design Engineer	Chevrolet	1960	38	15,000
	9	52	M	Maintenance Engineer	Chevrolet	1960	30	37,000
	10	61	M	Bituminous Const. Engineer	Chevrolet	1960	45	15,000
II	1	36	M	Civil Engineering Professor	Rambler	1959	20	12,000
	2	56	M	"	Rambler	1961	46	20,000
	3	44	M	"	Chevrolet	1957	24	20,000
	4	39	M	"	Oldsmobile	1956	23	10,000
	5	38	M	"	Chevrolet	1955	15	10,000
	6	41	M	"	Buick	1961	25	9,000
	7	47	M	"	Plymouth	1958	33	15,000
	8	42	M	"	Chevrolet	1961	26	12,000
	9	36	M	"	Plymouth	1958	20	9,000
	10	34	M	"	Plymouth	1959	15	12,000

TABLE 24 (continued)

Panel	Rater	Age	Sex	Occupation	Type of Vehicle Used		Driving Experience	
					Make	Year	Years	Miles/year
III	1	23	M	Student	Ford	1961	9	22,500
	2	45	M	Plant Supervisor	Chevrolet	1959	25	13,000
	3	27	M	Graduate-Staff Member	Hudson	1953	4	8,000
	4	28	M	Assist. Prof. Elec. Eng.	Chevrolet	1953	11	12,000
	5	47	F	Housewife	Mercury	1960	25	2,000
	6	36	F	School Nurse	Ford Station Wagon	1955	20	10,000
	7	33	F	Homemaker-Former Teacher	Nash	1952	10	5,000
	8	53	M	Tavern Manager	Ford	1958	35	5,000
	9	43	M	Truck Driver	Rambler	1959	29	12,000
	10	46	M	Welder	Studebaker	1956	26	8,000

TABLE 25
DESCRIPTION OF RIGID PAVEMENT SECTIONS

Section	PSR	Rank	Roughness Index	Rank	Description
59	1.1	1	237	1	Transverse and faulted cracks, faulted joints, blow ups
19	1.4	2	175	2	Transverse and faulted cracks, patched cracks, widened
17	2.3	3	128	5	Transverse and faulted cracks, faulted joints, scaled, widened
60	2.4	4	132	3	Faulted short slabs
7	2.4	4	116	8	Transverse and faulted cracks, faulted joints, patches
4	2.5	6	129	4	Transverse cracks
18	2.6	7	124	7	Transverse and faulted cracks, faulted joints, widened
1	2.7	8	128	5	Transverse and faulted cracks, faulted joints
57	2.9	9	112	10	Transverse cracks, faulted joints, blow ups, patched joints
21	3.1	10	115	9	Transverse and faulted cracks, faulted joints, patches, corner breaks
54	3.2	11	107	11	Transverse and faulted cracks, faulted joints
23	3.4	12	99	12	Cracks, non-homogeneous
28	3.9	13	87	17	Faulted cracks, porpoising
22	4.0	14	89	16	Transverse cracks
49	4.1	15	91	13	
47	4.2	16	90	15	
50	4.2	16	75	19	
45	4.4	18	85	18	
46	4.5	19	91	13	

TABLE 26
DESCRIPTION OF OVERLAY PAVEMENT SECTIONS

Section	PSR	Rank	Roughness Index	Rank	Description
6	2.2	1	98	6	Transverse and widening reflection cracks, faulted cracks and joints, blow ups
2	2.3	2	167	1	Transverse reflection cracks, faulted cracks, faulted joints, blow ups, porpoising, non-homogeneous
16	2.4	3	154	2	Transverse and widening reflection cracks, faulted cracks and joints, rutting, blow ups
5	2.4	3	93	8	Transverse and widening reflection cracks
43	2.6	5	106	4	Transverse and widening reflection cracks, faulted cracks and joints, blow ups, spalled cracks
42	2.6	5	92	9	Transverse and widening reflection cracks, patches
15	2.7	7	98	6	Transverse and widening reflection cracks, blow ups, bleeding, non-homogeneous
14	2.8	8	85	15	Transverse and widening reflection cracks, faulted cracks and joints, blow ups, porpoising, rutting
38	3.0	9	114	3	Transverse and widening reflection cracks, bleeding
10	3.0	9	105	5	Widening reflection cracks, blow ups
34	3.0	9	91	10	Transverse and widening reflection cracks, rutting, blow ups
8	3.1	12	89	12	Porpoising
25	3.5	13	91	10	Transverse and widening reflection cracks, blow ups, bleeding, non-homogeneous

TABLE 26 (continued)

Section	PSR	Rank	Roughness Index	Rank	Description
13	3.6	14	87	14	Transverse and widening reflection cracks, porpoising
12	3.7	15	80	18	Transverse and widening reflection cracks, blow ups
36	3.8	16	88	13	Slight reflection cracks
52	3.8	16	85	15	Slight reflection cracks
29	3.8	16	79	19	Slight reflection cracks, non-homogeneous
31	3.8	16	73	22	
26	3.9	20	76	20	Non-homogeneous
58	4.1	21	82	16	
11	4.1	21	75	21	

TABLE 27
DESCRIPTION OF FLEXIBLE PAVEMENT SECTIONS

Section	PSR	Rank	Roughness Index	Rank	Description
27	1.5	1	144	3	Sidesway, porpoising, rutting, patches, longitudinal and transverse cracking, edge failure in cuts
41	2.0	2	144	3	Sidesway, porpoising, rutting, patches, longitudinal and transverse cracks, edge ravelling, non-homogeneous
53	2.0	2	137	6	Sidesway, porpoising, rutting, patches, non-homogeneous
48	2.1	4	94	15	Patches
37	2.2	5	152	2	Sidesway, porpoising, rutting, patches, bleeding, non-homogeneous
3	2.2	5	116	10	Porpoising
55	2.3	7	133	8	Sidesway, porpoising, rutting, patches, non-homogeneous
9	2.5	8	134	7	Sidesway, porpoising, bleeding
40	2.6	9	110	11	Porpoising, longitudinal cracking
30	2.7	10	155	1	Sidesway, porpoising, non-homogeneous
20	2.9	11	139	5	Bleeding, porpoising, sidesway
56	2.9	11	131	9	Bleeding, porpoising
24	2.9	11	110	11	Porpoising, sidesway
35	2.9	11	103	14	Sidesway, porpoising
51	3.0	15	108	13	Porpoising, bleeding
39	3.2	16	92	16	Porpoising, rutting, patches, non-homogeneous
32	3.7	17	87	17	Sidesway, porpoising
44	3.7	17	64	18	Sidesway, porpoising
33	4.1	19	62	19	

TABLE 28
LOCATION OF RIGID PAVEMENT SECTIONS

Pavement Section	Highway	From	To
1	25	Logansport north city limit	1.5 mi. north
4	35	2 mi. south of Royal Center	Jct. with hwy. 24
7	421	Monticello south city limit	2 mi. south
17	53	Jct. with hwy. 18	6 mi. north
18	53	Jct. with hwy. 18	Jct. with hwy. 52
19	41	Jct. with hwy. 18	1.25 mi. north
21	52	Jct. with hwy. 28	5 mi. north
22	52	Jct. with hwy. 352	2 mi. south
23	52	4 mi. south of section 22	Jct. with 52 By-pass
28	25	1 mi. north of Jct. with 52 By-pass	1.4 mi. north
45	65	Lebanon By-pass	Brownsburg turn-off
46	65	Brownsburg turn-off	Lebanon By-pass
49	39	Jct. with hwy. 47	Bridge
50	39	Frankfort south city limit	Jct. with hwy. 38
54	52	Jct. with 52 By-pass	Jct. with hwy. 53
57	421	Jct. with hwy. 18	Delphi south city limit
59	Union	26th St. in Lafayette	52 By-pass
60	25	18th St. in Lafayette	52 By-pass

TABLE 29
LOCATION OF OVERLAY PAVEMENT SECTIONS

Pavement Section	Highway	From	To
2	17	Logansport north city limit	Jct. with hwy. 16
5	24	3 mi. west of Logansport	Burnettsville east city limit
6	24	Monticello east city limit	Idaville west city limit
8	421	2 mi. south of Monticello	Jct. with hwy. 18
10	43	Jct. with hwy. 18	Jct. with hwy. 24
11	421	Jct. with hwy. 16	Pulaski-White County line
12	53	Rensselaer south city limit	Jct. with hwy. 16
13	53	Jct. with hwy. 16	Jct. with hwy. 24
14	24	Jct. with hwy. 53	Goodland east city limit
15	24	Jct. with hwy. 53	Jct. with hwy. 43
16	53	Jct. with hwy. 24	6 mi. south
25	25	Jct. with hwy. 43	Jct. with hwy. 28
26	28	Jct. with hwy. 25	Jct. with hwy. 341
29	136	Veedersburg west city limit	Covington east city limit
31	43	Crawfordsville south city limit	Jct. with hwy. 234
34	136	Crawfordsville east city limit	New Ross west city limit
36	43	Crawfordsville north city limit	Tippecanoe-Montgomery County line
38	28	Jct. with hwy. 52	1 mi. west
42	29	Michigantown south city limit	Clinton Central High School
43	28	Jct. with hwy. 52	Jefferson west city limit
52	29	Kirklin north city limit	Jct. with hwy. 28
58	25	Jct. with hwy. 218	Rockfield south city limit

APPENDIX B

TABLE 30
LOCATION OF FLEXIBLE PAVEMENT SECTIONS

Pavement Section	Highway	From	To
3	16	Jct. with hwy. 17	Royal Center east city limit
9	18	Jct. with hwy. 421	2 mi. west
20	18	Jct. with hwy. 41	4 mi. west
24	26	RR X-ing	4 mi. west
27	55	Jct. with hwy. 25	Jct. with hwy. 136
30	32	Jct. with hwy. 341	Jct. with hwy. 25
32	234	Jct. with hwy. 43	Ladoga west city limit
33	136	Jamestown west city limit	Bridge
35	47	Crawfordsville north city limit	Darlington turn-off
37	28	Jct. with hwy. 43	RR X-ing
39	26	RR X-ing	Edna Mills west city limit
40	26	Edna Mills east city limit	Rossville west city limit
41	38	Tippecanoe-Clinton County line	Bridge
44	32	Jct. with hwy. 75	Jct. with Lebanon By-pass
48	47	Jct. with hwy. 39	Jct. with hwy. 421
51	38	Jct. with hwy. 39	Bridge
53	26	Geetingsville east city limit	Jct. with hwy. 29
55	75	Jct. with hwy. 26	Jct. with hwy. 18
56	18	Jct. with hwy. 75	Jct. with hwy. 421

ESTIMATION OF MISSING RATING

The method for randomized block design (7) was utilized to estimate the missing rating. The pavement sections were considered blocks and the raters were treatments. The equation used is as follows:

$$Y = \text{estimated rating} = \frac{rB + tT - G}{(r - 1)(t - 1)}$$

where,

r = number of pavement sections = 60

B = total of that section with missing value = 66.4

t = total number of raters = 30

T = total of rater's fifty-nine ratings = 194.4

G = grand total of all ratings for all sections = 5417.1

Hence,

$$Y = \frac{60(66.4) + 30(194.4) - 5417.1}{59(29)}$$

$$= 2.6$$

Sample Calculation:

Least-Squares Regression Equation and Correlation
Coefficient for Flexible Pavements

The following equations were employed in the determination of the least-squares regression equations:

$$b = \frac{\sum XY - N\bar{X}\bar{Y}}{\sum X^2 - N(\bar{X})^2}$$

$$a = \bar{Y} - b\bar{X}$$

$$Y = a + bX$$

Where,

N = number of pavement sections within pavement type

Y = dependent variable; present serviceability rating

X = independent variable; roughness index (in/mi)

The calculation of the least-squares regression equation for the linear relationship of PSR and roughness for flexible pavements is as follows:

$$N = 19$$

$$\bar{Y} = 2.71$$

$$\bar{X} = 116.6$$

$$\sum XY = 5742.4$$

$$\sum X^2 = 272,235$$

Substitution into the above mentioned equations gives:

$$\begin{aligned} b &= \frac{5742.4 - 19(116.6)(2.71)}{272,235 - 19(116.6)^2} \\ &= -\frac{261.334}{13,919.36} = -0.0188 \end{aligned}$$

and,

$$a = 2.71 + 0.0188(116.6) = 4.90$$

Hence, the least-squares regression equation for the linear PSR-roughness relationship of flexible pavements is:

$$Y = 4.90 - 0.0188 X$$

The following equation was employed in the determination of the squared correlation coefficients:

$$r^2 = 1 - \frac{(\sum Y^2 - N\bar{Y}^2) - b(\sum XY - N\bar{Y}\bar{X})}{\sum Y^2 - N\bar{Y}^2}$$

for flexible pavements:

N , $\bar{Y}$, $\sum XY$, $\bar{X}$, and b are given above.

$$\sum Y^2 = 147.00$$

Hence, the squared correlation coefficient for the flexible pavements is:

$$\begin{aligned} r^2 &= 1 - \frac{147.00 - 19(2.71^2) + 0.0188 [5742.4 - 19(2.71)(116.6)]}{147.00 - 19(2.71^2)} \\ &= 0.658 \end{aligned}$$

and the correlation coefficient is:

$$r = \sqrt{0.658} = 0.81$$

Determination of the Variance Ratios

The variance ratios of the S, R, PxR, and SxG sources were determined by dividing their respective mean squares by the SxR mean square. The variance ratio of the PxG source was determined by dividing the PxG mean square by the PxR mean square, since the SxG interaction was found to be non-significant. The variance ratio of the G source was determined by dividing the G mean square by the R mean square, since the SxG interaction was found to be non-significant.

Since both the S and PxR sources were found to be significant, Satterthwaite approximations were used to determine the variance ratio of the P source. The following equations were used:

$$F = \frac{Q_1 + Q_4}{Q_2 + Q_3}$$

$$\text{Numerator degrees of freedom} = \frac{(Q_1 + Q_4)^2}{(Q_1^2/\text{d.f.} + Q_4^2/\text{d.f.})}$$

$$\text{Denominator degrees of freedom} = \frac{(Q_2 + Q_3)^2}{(Q_2^2/\text{d.f.} + Q_3^2/\text{d.f.})}$$

where,

$$Q_1 = \text{M.S. (P)}$$

$$Q_2 = \text{M.S. (S)}$$

$$Q_3 = \text{M.S. (PxR)}$$

$$Q_4 = \text{M.S. (SxR)}$$

Determination of the Variance of $\bar{Y}_{(i)jk}$

The equation used to determine the variance of $\bar{Y}_{(i)jk}$ was as follows:

$$\text{Var. } \bar{Y}_{(i)jk} = \hat{\sigma}_S^2 + \frac{\hat{\sigma}_R^2}{10} + \frac{\hat{\sigma}_{PR}^2}{10} + \hat{\sigma}_{SG}^2 + \frac{\hat{\sigma}_{SR}^2 + \hat{\sigma}_e^2}{10}$$

where,

$$\frac{\hat{\sigma}_{SR}^2 + \hat{\sigma}_e^2}{10} = \frac{M.S. SR}{10}$$

$$\hat{\sigma}_{SG}^2 = \frac{M.S. SG - M.S. SR}{15}$$

$$\hat{\sigma}_{PR}^2 = \frac{M.S. PR - M.S. SR}{(57/2)}$$

$$\hat{\sigma}_R^2 = \frac{M.S. R - M.S. SR}{57}$$

$$\hat{\sigma}_S^2 = \frac{M.S. S - M.S. SR}{30}$$