Serviceability Ratings of Highway Pavements

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INTRODUCTION

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

This simple statement made several years ago by D. C. Greer, state highway engineer of Texas, 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. But what is a comfortable ride? And how can the comfort and convenience provided by a highway pavement be measured? These are some of the unanswered questions which plague the highway authority when the final decision as to which highways to improve must be made.

For many years state highway departments have developed reconstruction and maintenance programs on the basis of the personal knowledge of members of their staffs relative to the needs of their highway systems. However, highway personnel usually have different amounts of information on the condition of each highway within the highway system and, thus, their evalution of the serviceability of a specific highway pavement may be heavily biased. It is also typical 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 large number of cracks and patches are present. One engineer might classify a highway pavement with 10-foot lanes as excellent, while another might classify only highway pavements with 12-foot lanes in the excellent category. As a result, it is difficult to compare evalutions made by different personnel and almost impossible to develop optimum reconstruction and maintenance programs on the basis of such evalutions of highway pavement serviceability.

It is often true, however, that one pavement at any one time is performing its services better than another. Questions then are raised—

How much better?, How can an adequate comparison be made? What is needed is a simple, accurate, and economical method of evaluating pavement serviceability.

Such an evalution procedure might be one which would utilize an objective measurement or measurements and which would be highly correlated with the subjective human judgment of the total traveling public. Such a procedure should also provide an indication of the performance of a pavement throughout its life if evaluated periodically, be applicable to all roads, and be usable as a tool in developing final highway improvement programs.

Many studies have been devoted to the problem of the evalution 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 three general types: 1) evalution by sufficiency rating systems, 2) evaluation by surface riding quality indicators, and 3) evaluation by subjective serviceability ratings. The latter two types of procedures were the subjects of this research.

PURPOSE AND SCOPE

This study was first of all concerned with the evalution by the traveling public of the present serviceability of highway pavements and its desirable level and with the ability of highway and other personnel to estimate such ratings of present serviceability. It was also concerned with road roughness, as measured by the Standard Bureau of Public Roads roughometer, as a method for the objective determination of the present serviceability of pavements.

The purposes of this study were: 1) to determine the correlation of present serviceability ratings made by experts in the field of highway engineering with similar ratings made by typical road users, 2) to determine the correlation of roughometer measurements with present serviceability ratings, and 3) to attempt the development of a simple, economical evaluation procedure which would accurately rate the serviceability of highway pavements.

Sixty pavement sections located within a 40-mile radius of Lafayette, Indiana, were studied. The pavement sections varied in length from 0.5 to 12.75 miles, averaged five miles, and totaled approximately 300 miles. Nineteen of the sections were rigid pavements; 22 were rigid with bituminous overlay; and 19 were flexible pavements. All types of pavement condition—from excellent to very poor—were included in each surface type.

The test sections were basically state highway designated maintenance sections and their location is shown in Figure 1. They were

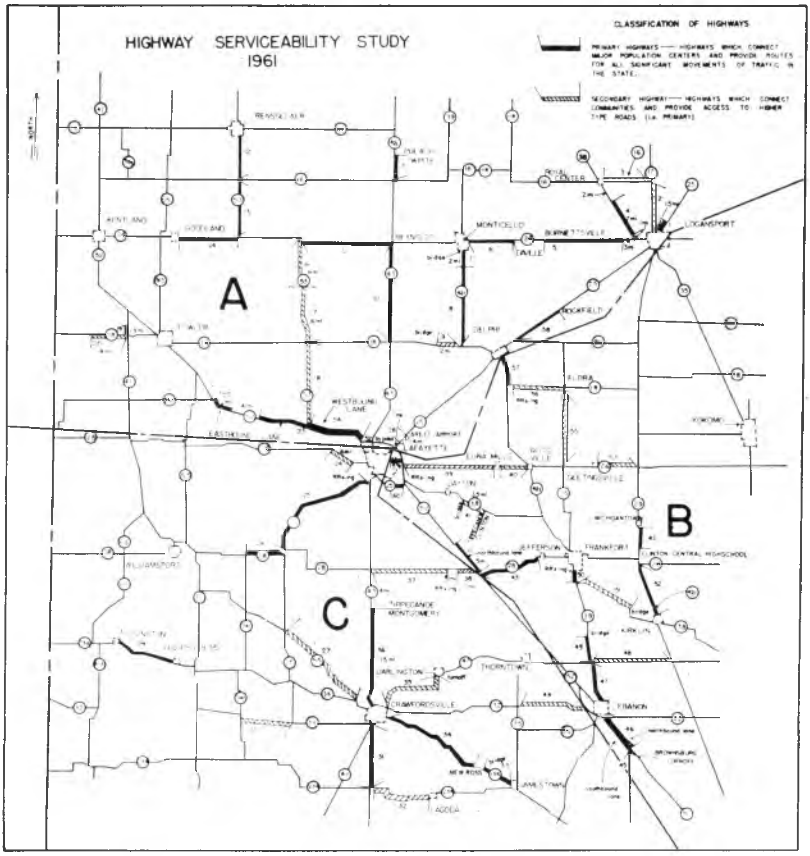

Fig. 1. Location of the pavement sections.

identified to the members of the rating panels only as primary highways or secondary highways. The information as to whether the pavement was rigid, rigid with overlay surface, or flexible was not provided the raters, although many of them were capable of noting this information while rating.

PROCEDURES

Selection of the Panels of Raters

The 60 pavement sections were rated by three panels of raters, with ten raters in each panel. Two of the panels were composed of professionals in the field of highway engineering. One of these was composed of engineers from the Indiana State Highway Commission; the second was composed of staff members of the Purdue University School of Civil Engineering; and a third panel was composed of laymen who were randomly selected as typical road users.

The members of the state highway panel were selected by officials of the State Highway Commission from their engineering personnel. All such personnel were from the central office in Indianapolis or from the Crawfordsville district (the district serving the Lafayette area). They represented such highway interests as planning, road design, road construction, bituminous construction, maintenance, and traffic engineering. 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 and they averaged 30,700 miles annually.

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 related to transportation. Members 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 layman panel was selected in a random manner from the Lafayette and Purdue University telephone directories and 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 student, graduate student-staff member, plant supervisor, professor of electrical engineering, welder, tavern manager, truck driver, housewife, housewife-former school teacher, and school nurse. The ages of these 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; annual driving mileage ranged from 2,000 to 20,000 miles with a mean of 7,800 miles.

Rating Instructions

Each rater in this study was individually instructed. This was done to keep each rater from being influenced by the other raters, and it was felt 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 likely to ask questions, and it was very important that the raters clearly understood the "rules of the game." All raters were given identical instructions including a discussion of the general purpose and scope of the study.

Each rater was also instructed to always keep the following question in mind when rating each pavement section: If I were to ride over this pavement section regularly for the appropriate purposes, how well would it serve me? The raters were told that for secondary highway pavements the use would be primarily short trips, with purposes such as to work or to town, while for primary highway pavements some longer trips would be included with such purposes as business and vacation.

It was also 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. The raters were also instructed to rate only the *existing* condition of the pavement section.

Each rater was requested to drive over the pavement sections in a vehicle similar to one that he normally drove. He could ride over the pavement sections at any speed he desired, but 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.

Each rater was instructed to rate the serviceability of each pave-

HIGHWAY ____________________

SECTION ____________________

DATE ____________________

TIME ____________________

WEATHER ____________________

RATER ____________________

5
Very Good
4
Good
3
Fair
2
Poor
1
Very Poor
0

Is this a primary or secondary road? ____________________

Is this pavement acceptable for this classification? ______

Fig. 2. Rating card.

ment section on a 0 to 5 point rating scale (see Figure 2) by marking on the vertical scale a horizontal line at the value he felt was the serviceability rating of that pavement. One card was used for each pavement section by each rater. He was also instructed to state the acceptability (Yes or No) of each pavement section, after noting its highway classification. The rater was also required to observe the sixty pavement sections in a specified order. The rating of the 300 miles was done by each rater over three days, not necessarily consecutive, and for statistical randomizing purposes, different travel routes were followed by each rater within each panel but with one rater in each panel being assigned the same route.

DISCUSSION OF RESULTS

Panel Rating Values

A summary of the rating data obtained by the three panels for each pavement section is given in Tables 1, 2, and 3 for rigid, rigid-overlay,

TABLE 1
SUMMARY OF PRESENT SERVICEABILITY RATINGS
RIGID PAVEMENT SECTIONS

Pavement Section & Classification	Length	Mean Serviceability Ratings			PSR	Roughness Index (in./mi)
		ISHC	Purdue	Laymen		
1 P	1.25	2.7	2.8	2.5	2.7	128
4 P	6.50	2.6	2.6	2.3	2.5	129
7 P	1.75	2.6	2.4	2.2	2.4	116
17 S	4.75	2.4	2.2	2.2	2.3	128
18 S	8.75	2.6	2.6	2.4	2.6	124
19 P	1.25	1.3	1.3	1.5	1.4	175
21 P	4.50	3.1	3.1	3.0	3.1	115
22 P	1.75	3.8	4.1	4.0	4.0	89
23 P	11.00	3.3	3.6	3.3	3.4	99
28 S	1.00	4.1	4.0	3.7	3.9	87
45 P	3.25	4.4	4.7	4.2	4.4	85
46 P	3.25	4.6	4.6	4.4	4.5	91
47 P	3.75	4.4	4.3	3.9	4.2	90
49 P	2.25	4.2	4.1	4.0	4.1	91
50 P	2.25	4.3	4.3	3.9	4.2	75
54 P	5.50	3.4	3.2	3.1	3.2	107
57 P	2.00	3.0	2.9	2.7	2.9	112
59 P	0.50	1.4	0.9	1.0	1.1	237
60 P	0.75	2.4	2.3	2.5	2.4	132
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

TABLE 2
SUMMARY OF PRESENT SERVICEABILITY RATINGS
OVERLAY PAVEMENT SECTIONS

Pavement Section & Classification	Length	Mean Serviceability Ratings ISHC	Purdue	Laymen	PSR	Roughness Index (in./mi)
2 S	6.00	2.0	2.6	2.4	2.3	167
5 P	7.75	2.7	2.2	2.3	2.4	93
6 P	4.25	2.6	2.2	1.9	2.2	98
8 P	7.50	3.0	3.1	3.3	3.1	89
10 P	9.25	3.1	2.7	3.1	3.0	105
11 P	3.00	4.1	4.0	4.2	4.1	75
12 P	3.75	3.6	3.6	3.9	3.7	80
13 P	6.50	3.6	3.6	3.6	3.6	87
14 P	6.50	2.9	2.9	2.8	2.8	85
15 P	8.25	2.7	2.5	2.8	2.7	98
16 S	4.50	2.4	2.4	2.4	2.4	154
25 P	12.75	3.8	3.5	3.3	3.5	91
26 P	3.50	3.9	3.8	3.9	3.9	76
29 P	5.75	3.9	3.9	3.5	3.8	79
31 P	2.50	4.0	4.0	3.4	3.8	73
34 P	9.00	3.1	3.0	3.0	3.0	91
36 P	10.75	3.9	3.9	3.6	3.8	88
38 S	0.50	2.7	3.0	3.2	3.0	114
42 P	1.50	2.6	2.6	2.6	2.6	92
43 P	2.50	2.5	2.5	2.6	2.6	106
52 P	5.25	3.7	4.0	3.8	3.8	85
58 P	4.25	4.0	4.2	4.1	4.1	82
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

and flexible pavement sections, respectively. Pavement section numbers may be found adjacent to the sections in Figure 1. The mean of all 30 ratings for each section was assumed to be the Present Serviceability Rating (PSR) for that section. It can be seen from these three tables that there were no marked differences between the ratings of each panel or between the PSR's and the mean ratings of each panel.

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 high-

TABLE 3
SUMMARY OF PRESENT SERVICEABILITY RATINGS
FLEXIBLE PAVEMENT SECTIONS

Pavement Section & Classification	Length	Mean Serviceability Ratings				Roughness Index
		ISHC	Purdue	Laymen	PSR	(in./mi)
3 S	5.75	2.1	2.3	2.1	2.2	116
9 S	1.75	2.5	2.3	2.6	2.5	134
20 S	3.75	2.7	2.9	3.1	2.9	139
24 S	3.75	2.8	3.1	3.0	2.9	110
27 S	10.50	1.3	1.8	1.5	1.5	144
30 S	5.00	2.7	2.5	2.8	2.7	155
32 S	5.50	3.5	3.6	4.0	3.7	87
33 P	3.25	4.1	4.2	3.9	4.1	62
35 S	7.00	2.7	3.1	3.0	2.9	103
37 S	8.50	2.1	2.3	2.4	2.2	152
39 S	9.50	3.2	3.3	3.1	3.2	92
40 S	3.00	2.3	2.7	2.9	2.6	110
41 S	3.25	1.6	2.1	2.3	2.0	144
44 S	6.75	3.7	3.7	3.7	3.7	64
48 S	7.75	2.1	2.6	1.7	2.1	94
51 S	6.25	2.9	2.9	3.2	3.0	108
53 S	3.50	1.8	2.0	2.2	2.0	137
55 S	8.25	2.2	2.4	2.4	2.3	133
56 S	5.25	2.8	2.9	3.1	2.9	131
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

way 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.

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 one of the desired analyses 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.

Table 4 shows the results of the ANOV. The model used was:

TABLE 4
SUMMARY OF ANALYSIS OF VARIANCE-SERVICEABILITY RATINGS

Source	Degrees of Freedom	Sum of Squares	Mean Squares	Variance Ratio	F_a	Level of a	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

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

where,

$Y_{(i)j(k)l}$ = the rating of the (k)lth rater on the (i)jth 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
SR = section within pavement type-rater within rating panel type interaction
e = the residual error

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.

The finding that raters within a panel type differed significantly supports the common belief 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 have tended to rate the rigid pavement sections "higher" than the other raters while he might also have tended to rate the overlay and flexible sections "lower" than the others. Whereas, another rater might have rated the rigid sections "lower" than the other raters while rating the flexible and overlay sections "higher."

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 PSR's of the rigid pavement sections ranged from 1.1 to 4.5; the PSR's of the overlay pavement sections ranged from 2.2 to 4.1; and the PSR's of the flexible pavement sections ranged from 1.5 to 4.1. There was a nonsignificant difference between the pavement types; that is, the overall means of the three pavement types did not differ significantly. Tables 1, 2, and 3 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 nonsignificant difference between the rating panels. This is compatible with the statement that the mean highway serviceability ratings of highway authorities were similar to the mean serviceability ratings of the traveling public. The nonsignificant 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 widely varying ratings of serviceability by individuals is evidenced when one compares individual serviceability ratings and the resulting priority rankings. Raters 1, 2, and 9 of the state highway panel were selected at random as an example of this variability. They were not the most variable persons in the panels, and neither were they the least variable. Raters 1 and 9 were maintenance engineers; rater 2 was a planning engineer. Some of the individual serviceability ratings and priority rankings of these three persons are presented in Table 5.

TABLE 5
COMPARISON OF INDIVIDUAL PRIORITY RANKINGS AND SERVICEABILITY RATINGS OF THREE RATERS—FLEXIBLE PAVEMENT SECTIONS

Pavement	Rater #1		Rater #2		Rater #9	
Section	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

The priority rankings are based on the individual serviceability ratings; i.e., the lower the serviceability rating, the higher the maintenance or reconstruction priority ranking.

Therefore, if rater 1 were to determine the maintenance program from the 19 flexible pavement sections included in this study, pavement sections 48, 41, 27, and 37 would be the first four sections to be improved and in that order of priority. However, if rater 9 were to determine the maintenance program, pavement sections 27, 41, 55, and 3 or 48 would be the first four sections to be improved. Section 37, which was ranked number 4 by rater 1, would be number 10 on the priority list of rater 9. Rater 2 on the other hand would also rank it number 10 and ranks sections 48, 55, 40 and 53 as the first four to be improved.

The individual rating values also vary widely. Section 48, which is ranked number 1 by rater 1, is given a 2.1 serviceability rating by him and a 0.9 serviceability rating by rater 2. Rater 9 gives it a 1.5 serviceability rating. It is apparent that altogether different priorities and resulting maintenance and reconstruction programs would result if they were determined by different individuals.

The panel evaluation method, however, minimizes the individual variability in serviceability ratings and priority rankings of pavement sections and if a sufficient number of raters are used the resulting ratings and priority rankings by several panels of the same size will be virtually the same. The numbers of raters required for a panel which would rate pavements within 0.3 to 1.0 point of the "true" rating at 95 per cent and 90 per cent probability levels are shown in Table 6.

TABLE 6

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 rating study would use one panel. The number of raters in the panel would depend on the accuracy and level of probability desired. That is, if it were desired that the serviceability rating of the pavement sections be within 0.5 of the "true" ratings of the sections 95 per cent of the time, 11 raters would be required for the panel. If the pavement ratings needed to be within 0.8 of the true rating 90 per cent of the time, only three raters would be required.

As noted previously, there was a difference between the ratings and resulting rankings of raters 1, 2, and 9 of the state highway panel. If the ratings of these three men were averaged, Table 6 indicates that the chances are 19 out of 20 that the mean serviceability ratings of the three men would be within 0.9 point of the "true" ratings, and 9 out of 10 that the mean serviceability ratings would be within 0.8 point of the "true" ratings. Moreover, if mean serviceability ratings of all ten state highway panel raters were utilized, this table states that the chances are about 19 out of 20 that the mean serviceability ratings would be within 0.5 point of the "true" ratings.

The mean ratings of raters 1, 2 and 9, the state highway panel ratings, and the "true" ratings are presented in Table 7 for the flexible pavement sections. The resulting priority rankings are also presented for these three groups of persons and for each of the three raters. The individual ratings for raters 1, 2, and 9 may be found for these same pavements in Table 5. The mean of the 30 individual serviceability ratings (all 30 members of the three panels) was assumed to be the "true" rating of a section.

Of the 60 state highway panel serviceability ratings not one deviated as much as 0.5 from the "true" rating and only two deviated as much as 0.4 point from the "true" rating. Of the 60 mean ratings obtained from the ratings made by the three subject raters, only one deviated 0.8 from the "true" and one deviated 0.9 from the "true." On the other hand, of 60 ratings made by rater 1, 23 deviated 1.0 point or greater from the "true," while 17 of those made by rater 2 and 16 of the ones made by rater 9 deviated 1.0 or greater from the "true."

The highway panel priority ranking of all pavement sections is quite similar to the priority ranking as determined by all 30 raters

TABLE 7
COMPARISON OF SERVICEABILITY RATINGS AND PRIORITY RANKINGS OF THIRTY, TEN, AND THREE MEMBER RATING PANELS AND INDIVIDUALS FLEXIBLE PAVEMENT SECTIONS

Pavement	Serviceability Ratings			Priority Rankings					
Section	30 Raters	10 Raters	3 Raters	30 Raters	10 Raters	3 Raters	#1	#2	#9
27	1.5	1.3	1.5	1	1	1	3	5	1
41	2.0	1.6	1.7	2	2	3	1	7	2
53	2.0	1.8	2.2	2	3	5	6	4	9
48	2.1	2.1	1.5	4	4	1	1	1	4
37	2.2	2.1	2.4	5	4	7	4	10	10
3	2.2	2.1	2.4	5	4	7	5	8	4
55	2.3	2.2	2.1	7	7	4	11	2	2
9	2.5	2.5	2.6	8	9	9	13	5	6
40	2.6	2.3	2.2	9	8	5	7	3	7
30	2.7	2.7	3.4	10	10	13	12	13	12
20	2.9	2.7	3.3	11	10	11	10	11	14
56	2.9	2.8	3.5	11	13	14	14	12	14
24	2.9	2.8	3.8	11	13	16	7	15	17
35	2.9	2.7	2.9	11	10	10	7	14	7
51	3.0	2.9	3.3	15	15	11	14	8	12
39	3.2	3.2	3.5	16	16	14	16	15	11
32	3.7	3.5	4.3	17	17	17	18	18	14
44	3.7	3.7	4.3	17	18	17	17	17	17
33	4.1	4.1	4.7	19	19	19	18	18	19

(Table 7 indicates this for the 19 flexible sections). The three-rater panel (raters 1, 2, and 9) priority ranking was in fair agreement, but individual priority rankings were generally in poor agreement.

It is evident that the panel method of rating, even small panels of three or more persons, is superior to a method which utilizes individual ratings, as the "accuracy" of rating and priority ranking is appreciably improved.

Although there was agreement by the panels of highway authorities and laymen on the serviceability rating of a pavement, there was some variation of opinion as to the acceptable level of pavement condition. The state highway panel had the highest standards for acceptability of pavement sections and the layman panel had the lowest standards; in other words, the lay persons as a group did not feel a pavement had to be in as good a condition to be acceptable as did the highway authorities.

It was therefore arbitrarily assumed for this study that if 70 per cent of the 30 raters accepted a section, the section would be considered "acceptable" (i.e., the section was satisfactory as it was, and no reconstruction was required to bring it to higher standards at that time). If 50 per cent of the 30 raters did not accept the condition of a section, the section was declared "unacceptable" (i.e., improvement was required at an early date). Pavement sections between these 50 and 70 per cent limits were classified as "doubtful" relative to acceptability, but at least the condition of these pavement sections was not as poor as those classified as "unacceptable."

Using the above discussed criteria, a present serviceability rating of 2.5 or higher was found to be acceptable for primary highways and a rating of 2.0 or less unacceptable. For secondary highways, a rating of 2.0 or greater was acceptable and a rating less than 1.5 was unacceptable. Ratings between those listed were in a zone of doubt as to acceptability.

Rater Characteristics

Various rater characteristics as evidenced by the ratings such as range difference, sum difference, standard deviation, and respective ranking orders were also summarized and analyzed.

The range difference indicates the amount of the rating scale utilized by a rater. It is interesting to note that only one rater out of the 30 utilized the entire rating scale.

The sum difference is the difference of the sum of a rater's ratings from the sum of the sixty "true" ratings (PSR's). A positive sum difference indicates a higher than "true" sum of ratings and 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 30 raters were ranked from high to low according to the sum difference; thus, the rater ranked number one by this measure was the "highest" rater and the rater ranked number 30 was the "lowest" rater. Table 8 lists these values for the

TABLE 8
SUMMARY OF RATER CHARACTERISTICS

Rater	Range Difference	Mean of Ratings	Sum Difference	Sum Dif. Rank	Standard Deviation	St. Dev. Rank
1	2.8	3.85	+50.1	1	0.438	21
2	4.6	2.78	—13.8	20	0.437	20
3	3.5	3.44	+25.7	6	0.445	23
4	2.9	2.60	—24.6	29	0.358	11
5	3.5	2.83	—10.5	18	0.365	12
6	3.9	3.04	+ 1.8	12	0.336	9
7	3.3	2.85	— 9.8	17	0.479	26
8	4.8	3.63	+ 3.71	2	0.520	28
9	4.6	2.66	—21.0	26	0.464	24
10	3.7	2.28	—44.2	30	0.412	17
Panel Mean	3.76	2.996			0.4254	
11	3.8	3.16	+ 9.0	11	0.319	8
12	4.7	2.75	—15.3	22	0.440	22
13	3.6	2.66	—21.4	27	0.348	10
14	3.6	2.73	—17.1	25	0.297	5
15	3.6	2.90	— 6.8	15	0.245	1
16	4.0	3.24	+13.9	9	0.272	4
17	4.0	3.28	+16.3	8	0.265	3
18	4.1	2.82	—11.7	19	0.302	7
19	4.1	3.41	+24.2	7	0.475	25
20	3.6	3.56	+32.6	3	0.395	16
Panel Mean	3.91	3.051			0.3358	
21	3.8	2.62	—23.3	23	0.376	13
22	4.6	3.23	+13.1	10	0.298	6
23	4.0	3.55	+32.3	4	0.504	27
24	4.0	2.76	—15.3	22	0.389	15
25	3.2	2.92	— 5.7	14	0.428	19
26	4.8	3.47	+27.7	5	0.558	29
27	5.0	2.73	—17.0	24	0.609	30
28	3.5	2.85	— 9.7	16	0.379	14
29	4.5	2.77	—14.7	21	0.427	18
30	3.8	2.96	— 3.2	13	0.255	2
Panel Mean	4.12	2.986			0.4223	
Grand Mean	3.93	3.01			0.3945	

30 raters of this study with the raters in the state highway panel listed as numbers 1-10, the Purdue panel 11-20, and the layman panel 21-30. No concentration of "high' or "low" raters occurred in any one of the panels.

The standard deviation of the ratings is a measure of the variability of an individual's ratings and it is an indication of the rater's consistency. Thus, the rater with the lowest standard deviation was the most consistent rater. Each of the 30 raters was ranked as to his consistency to the "true" ratings, and this information is also shown in Table 8.

It is interesting to note that seven of the Purdue panel members ranked in the top ten according to consistency but that this concentration of consistency did not result in significantly different panel ratings for the pavement sections. The consistency of these seven raters was offset by the three remaining raters who ranked 16th, 22nd, and 25th in this characteristic.

Two of the laymen were in the top ten for consistency with the three woman raters ranked 19th, 29th, and 30th. The state highway panel had only one of its members in the top ten for consistency.

Correlation of Serviceability Ratings and Roughness Indices

Roughness measurements were made on each section of pavement in the study using the Standard BPR roughometer owned by the Indiana State Highway Commission. The average values of these readings in inches per mile for each entire pavement section are shown in Tables 1, 2, and 3 and were correlated by regression analysis with the present serviceability ratings as determined by all 30 raters.

Scatter-diagrams of roughness values and serviceability ratings were plotted for each pavement type. These are shown in the following figures—first for rigid pavements in Figure 3. The line shown is the linear regression line which best fits the data and the equation of the line is given. Here y (the present serviceability index) equals 5.90-.0241 x (the roughness index). Note that for rigid pavements an excellent correlation exists.

Figure 4 shows the plot and resulting linear regression line for overlay pavements and Figure 5 shows similar data for flexible pavements. The correlation is not as good for either the overlay or flexible pavements as it is for rigid pavements.

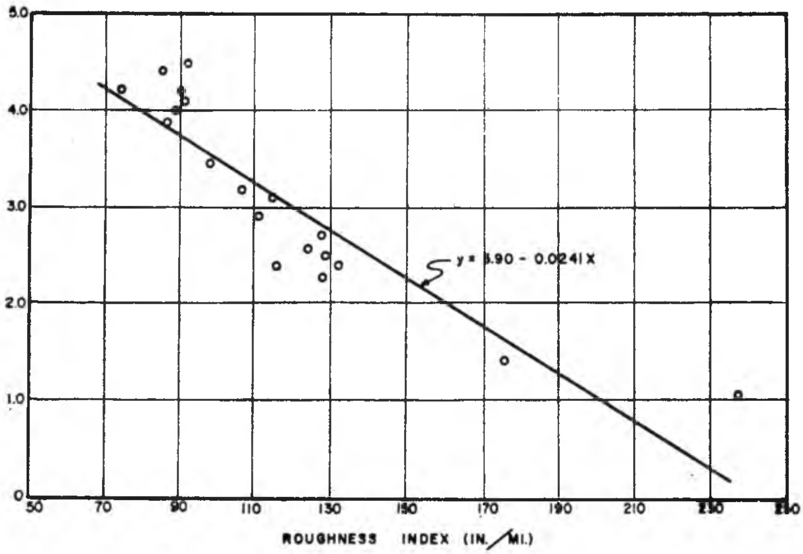

Fig. 3. Present serviceability rating vs. roughness index; rigid pavement sections.

The scatter-diagrams (Figures 3, 4, and 5) indicated that an exponential curve might be a better fitting curve than a straight line. The exponential curve $Y = aX^b$ was therefore fitted to the data of

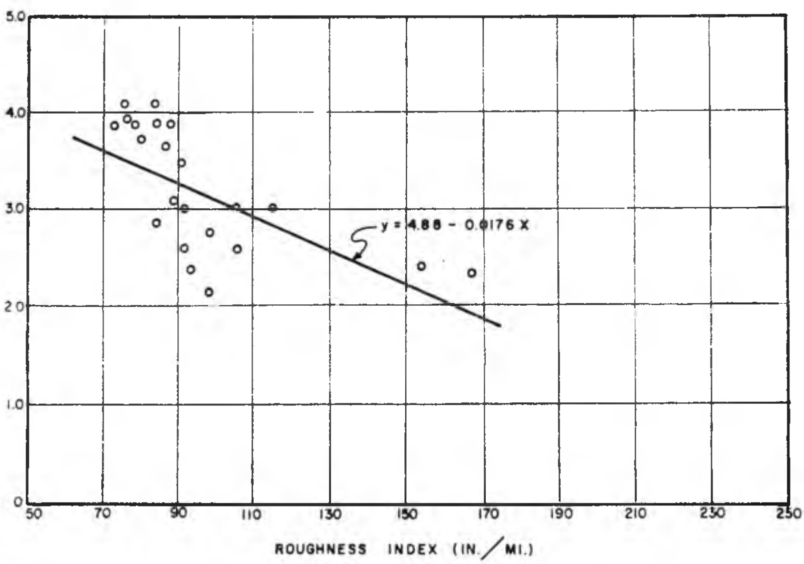

Fig. 4. Present serviceability rating vs. roughness index; overlay pavement sections.

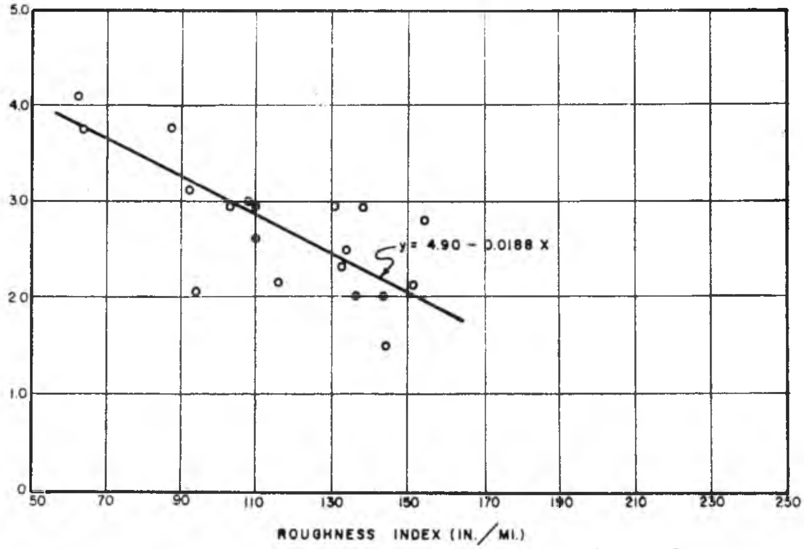

Fig. 5. Present serviceability rating vs. roughness index; flexible pavement sections.

each pavement type. The least squares method of regression was used and the following equations resulted:

For the rigid pavement sections:

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

For the overlay pavement sections:

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

For the flexible pavement sections:

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

where Y was the PSI (Present Serviceability Index which is an estimate of the Present Serviceability Rating) and X was the roughness index.

The resulting equations provided a slightly better fitting curve for the rigid and overlay sections but a poorer fitting curve for the flexible sections. Correlation coefficients (r) and squared correlation coefficients (r^2) were calculated for the three pavement types for the linear and exponential cases. The results are summarized in Table 9.

TABLE 9

CORRELATION COEFFICIENTS AND SQUARED CORRELATION COEFFICIENTS OF PRESENT SERVICEABILITY RATINGS WITH ROUGHNESS INDICES

	r		r^2	
Pavement Type	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 (r) indicates the amount of relationship between the serviceability ratings and roughness values. The squared correlation coefficient (r^2) is the amount of the variation of the serviceability ratings that may be explained by the roughness values. The negative correlation coefficients indicate a negative association of the variables; that is, as the roughness values increased, the serviceability rating values decreased.

The results clearly indicate the presence of a high correlation between the serviceability ratings and the roughometer values for the rigid sections. Most (82 per cent and 96 per cent) of the variation in the ratings may be explained for rigid pavements as dependent on the roughness value. There is, however, only a fair degree of correlation between the ratings and the roughometer values for the overlay and the flexible sections. Roughometer values account for only about 50 per cent of the variation in the serviceability ratings of these two pavement types. The other half of the variation in the ratings for these sections, therefore, must be due to other factors which are not evaluated by the roughometer.

SUMMARY 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 present 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 made use of a rating panel—the number of raters required in the rating panel being dependent on the "accuracy" required for the serviceability ratings. Since there was found to be nonsignificant panel differences, it was concluded that the amount of rater experience and knowledge in the highway field is not of importance in the selection of raters.

The second method utilized measurements obtained by a roughometer as the independent variable in regression equations to obtain present serviceability indexes (estimates of the present serviceability ratings). When compared to serviceability ratings obtained by a large rating panel, the indexes 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.

Since both the roughometer and the panel rating methods provided excellent serviceability ratings for rigid pavement sections, a cost comparison of the two methods was made using the 19 rigid pavement sections in this study as the pavements to be rated. The resulting analysis indicated that a seven-member rating panel would cost only slightly more than the roughometer method. Such a seven-member rating panel would predict mean serviceability ratings that would be within 0.6 point of the "true" ratings 19 out of 20 times. If the accuracy required in the ratings had been such that only six persons or less were necessary, the more economical method in this case would have been the rating panel method.

The decision of which method to use in any case 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 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 the roughometer method is not good), then it would be efficient to also use it for the rigid pavements.

CONCLUSIONS

The conclusions made from the results of this study 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 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 index (PSI—an estimate of the present serviceability rating, PSR) of a rigid pavement section can be quite

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 index (PSI)

A slightly less accurate index 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 least expensive.

8) Primary highway pavements with PSR's of 2.5 or higher and secondary highway pavements with PSR's of 2.0 or higher are "acceptable" to the traveling public.

9) Primary highway pavements with PSR's of 2.0 or lower and secondary highway pavements with PSR's of 1.5 or lower are "unacceptable" to the traveling public.

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