The Pavement Serviceability-Performance Concept

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A system is described wherein the serviceability of pavements is rated subjectively by a panel made up of men selected to represent many important groups of highway users. Through multiple regression analysis a mathematical index is derived and validated through which pavement ratings can be satisfactorily estimated from objective measurements taken on the pavements. These serviceability indices (or the direct ratings) always refer to the conditions existing at the time the measurements (or ratings) are made. Performance of a pavement may then be determined by summarizing the serviceability record over a period of time.

The system, developed at the AASHO Road Test, has potential for wide application in the highway field, particularly in sufficiency rating, evaluation of design systems, and evaluation of paving materials and construction techniques through the provision of an objective means for evaluation of performance.

● THE RELATIVE PERFORMANCE of various pavements is their relative ability to serve traffic over a period of time. There have been no widely accepted definitions of performance that could be used in the evaluation of various pavements or that could be considered in the design of pavements. In fact, design systems in general use in highway departments do not include consideration of the level of performance desired. Design engineers vary widely in their concepts of desirable performance. By way of example, suppose that two designers were given the task of designing a pavement of certain materials for certain traffic and environment for 20 years. The first might consider his job to be properly done if not a single crack occurred in 20 years, whereas the second might be satisfied if the last truck that was able to get over the pavement made its trip 20 years from the date of construction. There is nothing in existing design manuals to suggest that either man was wrong. This is simply to demonstrate that any design system should include consideration of the level of serviceability to traffic that must be maintained over the life of the road. How long must it remain smooth and how smooth?

One popular design system involves determination of the thickness of slab required to hold certain computed stresses below a certain level. It is clear that cracks will occur if a pavement is overstressed, but nowhere can be found any reference to the effect of such cracks on the serviceability of the pavement. Engineers will agree that cracks are undesirable, and that they require maintenance, but the degree of undesirability seems to have been left dimensionless. It may be apparent that one pavement has performed its function of serving traffic better than another, but a rational answer to the question, "How much better?" has not been available.

To provide dimensions for the term "performance" a system has been devised that is rational and free from the likelihood of bias due to the strong personal opinions of groups or individuals. It is easily conceivable that such a system could be adopted by all departments, thus providing for the first time a national standard system for rating highways and pavements.

Before discussing the derivation and a particular application of the pavement serviceability-performance system, it is necessary to set down some fundamental assumptions upon which the system is based.

1. There is a statement attributed to D.C. Greer, State Highway Engineer of Texas, that "highways are for the comfort and convenience of the traveling public." A reasonable inference from this simple statement is that the only valid reason for any road or highway is to serve the highway users. Another definitive opinion is that "a good highway is one that is safe and smooth."
2. The opinion of a user as to how he is being served by a highway is by-and-large subjective. There is no instrument that can be plugged into a highway to tell in objective units how well it is serving the users. The measurement of damage to goods attributed to rough roads may provide an exception to this rule (but one of minor importance), as a road rough enough to damage properly packed and properly suspended goods would be classed subjectively so low by all users that little could be gained by an objective measure.
3. There are, however, characteristics of highways that can be measured objectively which, when properly weighted and combined, are in fact related to the users subjective evaluation of the ability of the highway to serve him.
4. The serviceability of a given highway may be expressed by the mean evaluation given it by all highway users. There are honest differences of opinion, even among experts making subjective evaluations of almost anything. Thus, there are differences of opinion as to which automobile in a given price range is best; differences among judges of a beauty contest; differences as to which bank, broker, grocery store, or bar to patronize; etc. Opinion as to the serviceability of highways is no exception. Economic considerations alone cannot explain these differences.

Thus, in order for normal differences of opinion to be allowed with the smallest average error for each individual highway user, serviceability, as previously stated, may be expressed in terms of the mean evaluation of all users.

5. Performance is assumed to be an over-all appraisal of the serviceability history of a pavement. Thus it is assumed that the performance of a pavement can be described if one can observe its serviceability from the time it was built up to the time its performance evaluation is desired.

AN EXAMPLE OF THE USE OF THE SERVICEABILITY-PERFORMANCE SYSTEM

In this section is described a typical example of the system which has been in actual field use at the AASHO Road Test. Definitions and detailed steps in the development and use of a Performance Index for evaluation of the Road Test pavements are included. It is emphasized that the case herein described is only one of many possible applications of the principles involved. It happened to relate to the performance of the pavements only, yet it would have been easy to extend the system to provide a measure of the sufficiency of the entire highway, including grade, alignment, access, condition of shoulders, drainage, etc., as well as characteristics of the pavement itself.

Purpose

The principle objective for the AASHO Road Test calls for significant relationships between performance under specified traffic and the design of the structure of certain pavements. To fulfill this objective, an adequate and unambiguous definition of pavement performance was required. For reasons previously mentioned none was available.

Special Considerations

In addition to the primary assumptions listed in the early paragraphs of this report, certain special considerations relating to the specific requirements of the Road Test were included.

Inasmuch as the project was designed to provide information relating to the pavement structure only, certain aspects of normal pavement serviceability were excluded from consideration, including surface friction, condition of shoulders, etc.

Test sections at the Road Test were as short as 100 ft, too short for a satisfactory

subjective evaluation of their ability to serve traffic (most highway users consider a high-speed ride over a pavement necessary before they will rate it). Thus, objective measurements that could be made on the short sections had to be selected and used in such a way that pavements only 100 ft long could be evaluated as though they were much longer.

Definitions

To fulfill the requirements of the Road Test, rather ordinary terms were given specific definitions as follows:

Present Serviceability—the ability of a specific section of pavement to serve high-speed, high-volume, mixed (truck and automobile) traffic in its existing condition. (Note that the definition applies to the existing condition—that is, on the date of rating—not to the assumed condition the next day or at any future or past date.) Although this definition applies to the Road Test and may apply to any primary highway system, the system could easily be modified for use with city streets, farm roads, etc. Obviously, serviceability must be defined relative to the intended use of the road.

Individual Present Serviceability Rating—an independent rating by an individual of the present serviceability of a specific section of roadway made by marking the appropriate point on a scale on a special form (Fig. 1). This form also includes provision for the rater to indicate whether or not the pavement is acceptable as a primary highway. For the Road Test application, when rating highways other than those in the primary system, the rater was instructed to exclude from consideration all features not related to the pavement itself, such as right-of-way width, grade, alignment, shoulder and ditch condition, etc.

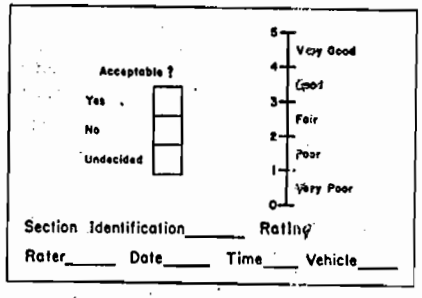

Figure 1. Individual present serviceability rating form.

Present Serviceability Rating (hereafter PSR)—the mean of the individual ratings made by the members of a specific panel of men selected for the purpose by the Highway Research Board. This panel was intended to represent all highway users. It included experienced men, long associated with highways, representing a wide variety of interests, such as highway administration, highway maintenance, a federal highway agency, highway materials supply (cement and asphalt), trucking, highway education, automotive manufacture, highway design, and highway research.

Present Serviceability Index (hereafter PSI)—a mathematical combination of values obtained from certain physical measurements of a large number of pavements so formulated as to predict the PSR for those pavements within prescribed limits.

Performance Index (hereafter PI)—a summary of PSI values over a period of time. There are many possible ways in which the summary value can be computed. Perhaps the simplest summary consists of the mean ordinate of the curve of PSI against time.

Steps in Formulation of a Present Serviceability Index

The following represents a minimum program for the establishment, derivation and validation of a PSI (or any similar index that may be considered for another purpose).

1. Establishment of Definitions—There must be clear understanding and agreement among all those involved in rating and in formulation and use of the index as to the precise meanings of the terms used (see preceding definitions for Road Test case). Exactly what is to be rated, what should be included, and what excluded from consideration?

2. Establishment of Rating Group or Panel—Because the system depends primarily on the subjective ratings of individuals, great care should be taken in the selection of the persons who will make up the rating group. Inasmuch as serviceability is here defined to be the mean opinion of this group, it is important that the raters represent highway users. They should be selected from various segments of the users with divergent views and attitudes.

3. Orientation and Training the Rating Panel—An important step is that in which the members of the Panel are instructed in the part they are to play. They must clearly understand the pertinent definitions and the rules of the game. It has been found worthwhile to conduct practice rating sessions where the raters can discuss their ratings among themselves. Note that when they make their official ratings they must work independently, with no opportunity for discussion of the ratings until the entire session has been completed.

4. Selection of Pavements for Rating—Ratings are to be made of the serviceability of pavements; therefore, a wide range of serviceability should be represented among the pavements that are selected for rating. Moreover, represented among the sections selected should be pavements containing all of the various types and degrees of pavement distress that are likely to influence the serviceability of highways. Prior to a field rating session, engineers study the highway network in the area under consideration (say 200 mi or less in diameter) and pick sections of roadway such that a reasonable balance is obtained among sections, of which some are obviously in very good condition, some are good, some fair, some poor and some obviously very poor. The Road Test system was based on four rating sessions in three different states in which 138 sections of pavement were studied. About one-half were flexible pavement and one-half rigid. The Road Test Panel members agreed among themselves that the minimum desirable length of a pavement to be rated was 1,200 ft; however, in a few cases shorter sections were included. This length was sufficient so that the raters could ride over the section at high speed and not be influenced by the condition of pavement at either end of the section.

5. Field Rating—The members of the Panel are taken in small groups to the sections to be rated. They are permitted to ride over each section in a vehicle of their choice (usually one with which they are familiar), to walk the pavement and to examine it as they wish. Each rater works independently—there is no discussion among the raters. When each is satisfied as to his rating, he marks his rating card and turns it in to a staff representative. The group then moves on to the next section. Each group takes a different route in order to reduce the possibility of bias over the day (raters may rate differently in the afternoon than in the morning; therefore, the groups are scheduled so that some sections are rated by one or two groups in the morning and the same sections by the other groups in the afternoon). It has been found that, near metropolitan areas, sections with satisfactorily different characteristics can be found near enough together so that the raters can travel routes containing about 20 sections per day. When rating present serviceability of a pavement, raters have found it helpful to ask themselves: "How well would this road serve me if I were to drive my own car over roads just like it all day long today?" Here again, of course, serviceability is related to the intended use of the road (primary highway, city street, farm road, etc.).

6. Replication—It is necessary to determine the ability of the Panel to be consistent in its ratings. The Road Test Panel rated many sections twice, first on one day and again on another day near enough to the first so that the section did not change physically, yet remote enough so that all extraneous influences on the raters would be in effect. In general it might be expected that replicate ratings would differ more when separated by several months than when separated by only one day. For this reason it may be supposed that the replication differences observed in the Road Test Rating sessions are to some degree an underestimate of replication differences in a larger time reference frame. The difference between repeated ratings on the same section is a criterion for the adequacy of a present serviceability index derived from measurements.

7. Validation of Rating Panel—Because the Panel is intended to represent all highway users, it is necessary to test its ability to do so. To a limited extent such validation was obtained for the Road Test Panel by selecting other groups of users and having them rate some of the same sections that had been rated by the Panel. One such group consisted of two professional commercial truck drivers who made their ratings

based on the rides they obtained when driving their own fully-loaded tractor-semitrailer vehicles. Another group was made up of ordinary automobile drivers not professionally associated with highways. For the sections involved these studies indicated that the ratings given pavements by the Road Test Panel were quite similar to those that were given by the other user groups. Of course, 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.

8. Physical Measurements—If it is practicable for the Panel to rate all roads in the area of interest often enough, no measurements need be taken. Analyses may be based on the PSR itself. Since it was not possible for the Panel to rate the Road Test sections (ratings were desired every two weeks), it was necessary to establish a PSI or index that would predict the Panel's ratings. To accomplish this, measurements of certain physical characteristics of the pavements were necessary. In order to determine which measurements might be most useful, the members of the Panel were asked to indicate on their rating cards which measureable features of the roadway influenced their ratings. This study made it apparent that present serviceability was a function primarily of longitudinal and transverse profile, with some likelihood that cracking, patching, and faulting would contribute. Thus, all of these characteristics were measured at each of the 138 sections in three states that were rated by the Panel. It should be noted that several other objective measurements could have been added to the list if other phenomena were permitted consideration by the established rules of the game. In this category might be skid resistance, noise under tires, shoulder and ditch conditions, etc.

Measurements fall rather naturally into two categories: those that describe surface deformation and those that describe surface deterioration. Of course, phenomena in the second category may or may not influence measurements in the first category. Measures of surface deformation will reflect the nature of longitudinal and transverse profiles—or may represent the response of a vehicle to the profile, as does the BPR roughometer. Supplemental profile characteristics, such as faulting, will ordinarily be measured. Present and past surface deterioration will be reflected through measures of cracking, spalling, potholing, patching, etc., and may include phenomena whose influence on present serviceability ratings range from negligible to appreciable.

9. Summaries of Measurements—There are many different ways to summarize longitudinal and transverse profiles. For example, longitudinal profile may be expressed as total deviation of the record from some baseline in inches per mile, number of bumps greater than some minimum, some combination of both of these, or by any number of other summary statistics involving variance of the record, power spectral density analysis, etc. Transverse profile may be summarized by mean rut depth, variance of transverse profile, etc. The variance of rut depth along the wheel paths is also a useful statistic. Cracking occurs in different classes of severity, as do other measures of surface deterioration, and measurements in any of these classes may be expressed in one unit or another.

10. Derivation of a Present Serviceability Index—After having obtained PSR's and measurement summaries for a selection of pavements, the final step is to combine the measurement variables into a formula that "gives back" or predicts the PSR's to a satisfactory approximation. Part of this procedure should consist in determining which of the measurement summaries have the most predictive value and which are negligible after the critical measurements are taken into account. The technique of multiple linear regression analysis may be used to arrive at the formula, or index, as well as to decide which measurements may be neglected. For example, it can turn out that a longitudinal profile summary will be sensitive to faulting so that faulting measurements need not appear in the index formula whenever this profile measure is included.

The decisions as to which terms should be in the serviceability formula and which terms should be neglected may be made by comparing the lack of success with which the formula "gives back" the ratings with a preselected criterion for closeness of fit—such as the Panel's replication error (see previous discussion, item 5). That is, there is no justification for a formula that can predict a particular set of ratings with greater precision than the demonstrated ability of the Panel to give the same ratings to the same pavements twice. Thus the multiple linear regression analysis will yield a formula that

will combine certain objective measurements to produce estimates of the Panel's ratings to an average accuracy no greater than the Panels's average ability to repeat itself.

Performance

In the preceding section the steps in the formulation of a present serviceability index were delineated. The index is computed from a formula containing terms related to objective measurements that may be made on any section of highway at any time. At the AASHO Road Test these measurements are made and the index computed for each test section every two weeks. Thus a serviceability-time history is available for each test section beginning with the time test traffic operation was started. As can be seen from Figure 1, the present serviceability values range in numerical value from zero to five.

In order to fulfill the first Road Test objective, to find relationships between performance and pavement structure design, some summarization of the serviceability-time history is implied. Performance may be said to be related to the ability of the pavement to serve traffic over a period of time. A pavement with a low serviceability during much of its life would not have performed its function of serving traffic as well as one that had high serviceability during most of its life, even if both ultimately reached the same state of repair.

The Road Test staff studied many alternate techniques for summarizing the serviceability-time history into an index of performance. The performance index chosen consisted of the mean ordinate of the serviceability-time history record. The choice of mean ordinate of serviceability-time record was largely due to its simplicity and the ease with which it can be understood by those interested in the Road Test findings.

ROAD TEST INDEXES

The techniques previously described were used in the derivation of present serviceability indexes for the AASHO Road Test. This section of the report includes tabulations of the actual data obtained in the field rating sessions by the Road Test Rating Panel and data obtained from the objective measurements of the pavements rated. Relationships among the ratings and various measurements are shown graphically and the results of the regression analyses in which the serviceability indexes were derived are given.

The matter of precision required of an index and precision attained in the Road Test indexes is discussed. Alternate measurement systems are mentioned for the benefit of agencies not able to equip themselves with elaborate instruments.

Ratings for Selected Pavements

After the establishment of concepts, ground rules, and rating forms for present serviceability ratings, the AASHO Road Test Performance Rating Panel rated 19 pavement sections near Ottawa, Ill., on April 15-18, 1958; 40 sections near St. Paul-Minneapolis on August 14-16, 1958; 40 sections near Indianapolis on May 21-23, 1959; and 39 sections on and near the Road Test in Illinois on January 20-22, 1960. Ten Illinois sections, 20 Minnesota sections, 20 Indiana sections and 24 sections on and near the Road Test were flexible pavements, whereas all remaining sections were rigid pavements. Each section was 1,200 ft long except those on the Road Test, which averaged 215 ft. With the generous cooperation of the respective state highway departments, sections at each location were selected to represent a wide range of pavement conditions.

Coincident with the rating session, Road Test crews and instruments were used to obtain condition surveys and profile measurements for each section. Summaries for all evaluations of the 74 flexible pavement sections are shown in Table 1; corresponding evaluations for the first 49 rigid pavements are given in Table 2.

The principal objective of the fourth rating session was to rate flexible pavement sections that included rather severe degrees of rutting—a phenomenon not included in the previous sets of flexible pavement. A second objective of the fourth session was to rate a small number of rigid pavements only for the purpose of checking present serv-

TABLE 1

DATA FOR 74 SELECTED FLEXIBLE PAVEMENTS

Pvt. Loc.	Sect. Code	Present Serviceability Ratings: AASHO Panel 1st PSR	AASHO Panel Regr. diff in PSR	AASHO Panel Std. dev. of PSR among raters	Truck Drivrs PSR	Canad. Raters PSR	Acceptability Opinions: AASHO Panel Yes	Acceptability Opinions: AASHO Panel No	Longitudinal and Transverse Roughness: $\overline{SV}$ Mean Slope Variance in Wheelpths ($\times 10^6$)	$\overline{AR}$ Mean AASHO Rough. in Wheelpths in./mi. @ 10 mph	$\overline{RD}$ Mean Rut Depth, (in.)	$\overline{RDV}$ Mean Rut Depth Variance $in^2 \times 100$	Major Cracking: Class 2 + Cracks, ft^2/1000 ft^2	Major Cracking: Long. & Trans. Cracks, ft/1000 ft^2	Patching Ft^2 per 1000 ft^2	Transformations: Log $(1+\overline{SV})$	Transformations: $\overline{RD}^2$	Transformations: Sq. rt. C+P	PSI 121: Pres. Serv. Index	Resid. Diff. Betw'n PSR & PSI
	F 3	4.3		.1	4.5	4.3	1.0	.0	2.8		.10	.7	0	0	0	.57	.01	.0	3.9	.4
	F 4	2.4		.4		2.0	.0	.6	20.5		.22	9.2	343	0	0	1.33	.05	18.5	2.3	.1
	F 5	3.3		.7	3.5	2.6	.6	.2	9.2		.08	3.6	8	0	0	1.01	.01	2.8	3.1	.2
	F 6	4.4	.1	.2	3.5		1.0	.0	3.5		.08	.7	0	0	0	.65	.01	.0	3.8	.6
Ill.	F 7	3.8	.1	.6	2.5	3.6	.9	.0	15.5		.06	.4	0	0	0	1.22	.00	.0	2.7	1.1
	F 8	2.6	.2	.7	2.0	2.7	.3	.6	9.5		.08	5.7	64	0	0	1.02	.01	8.0	3.0	.4
	F 9	3.2	.2	.6	3.0	3.0	.6	.2	14.0		.15	3.4	2	0	3	1.18	.02	2.2	2.7	.5
	F10	2.4	.0	.5	3.0	2.2	.1	.6	16.8		.16	3.4	17	0	14	1.25	.03	5.6	2.6	.2
	F11	1.3	.3	.5	1.5		.0	1.0	42.8		.26	10.3	292	0	11	1.64	.07	17.4	1.6	.3
	F12	1.1	.3	.2	1.0	1.7	.0	1.0	56.0		.19	10.9	21	0	2	1.76	.04	4.8	1.6	.5
	101	3.8	.3	.4			1.0	.0	1.9		.04	.4	0	29	0	.46	.00	5.4	4.1	.3
	102	3.8		.6			1.0	.0	1.5		.09	.3	0	34	0	.40	.00	5.8	4.2	.4
	103	3.8		.4			1.0	.0	1.7		.05	.2	0	14	0	.43	.00	3.7	4.2	.4
	104	3.8	.0	.4			1.0	.0	2.1		.04	.4	0	9	0	.49	.00	3.0	4.1	.3
	105	3.2		.4			.6	.1	7.0		.14	.5	0	0	10	.90	.02	3.2	3.3	.1
	106	1.3		.4			.0	1.0	58.5		.07	6.6	145	22	35	1.77	.00	12.2	1.5	.2
	107	1.3	.2	.4			.0	1.0	58.4		.08	2.9	75	12	55	1.77	.01	11.9	1.5	.2
	108	2.1		.6			.0	.9	17.6		.13	3.2	15	0	5	1.27	.03	4.5	2.5	.4
	109	1.5	.2	.2			.0	1.0	36.2		.37	5.6	30	2	76	1.57	.13	10.4	1.7	.2
Minn.	110	2.4	.0	.9			.0	.8	11.4		.07	3.2	2	0	3	1.09	.00	2.2	2.9	.5
	111	4.2		.2			1.0	.0	1.7		.11	.2	0	0	0	.42	.01	.0	4.2	.0
	112	3.9		.4			1.0	.0	1.4		.09	.2	0	0	0	.38	.01	.0	4.3	.4
	113	3.1	.1	.6			.4	.4	7.8		.08	1.3	1	68	66	.94	.01	11.6	3.1	.0
	114	2.2		.7			.0	.9	27.8		.13	5.2	0	1	4	1.46	.02	2.2	2.2	.0
	115	1.5		.6			.0	1.0	33.4		.08	5.4	0	7	6	1.54	.01	3.6	3.0	.5
	116	2.9	.5	.5			.6	.1	6.0		.02	.7	0	180	0	.85	.00	13.4	3.3	.4
	117	1.6	.0	.6			.0	1.0	39.4		.12	4.6	0	0	0	1.61	.01	.0	1.9	.3
	118	4.0	.2	.3			1.0	.0	1.6		.04	.2	0	0	0	.41	.00	.0	4.2	.2
	119	4.2		.5			1.0	.0	1.3		.03	.2	0	0	0	.36	.00	.0	4.3	.1
	120	2.9	.1	.5			.3	.2	5.8		.01	1.4	0	74	0	.84	.00	8.6	3.3	.4
	301	4.1		.6			1.0	.0	4.6	101	.24	.4	44	43	0	.75	.06	9.3	3.4	.7
	302	4.0		.5			1.0	.0	5.4	123	.34	.5	204	75	0	.81	.12	16.7	3.2	.8
	303	3.2		.5			.6	.1	20.1	146	.02	.4	12	1	0	1.32	.00	3.6	2.5	.7
	304	2.4	.0	.4			.2	.5	29.2	134	.17	1.8	455	0	17	1.28	.03	21.7	2.0	.4
	305	2.9	.1	.3			.4	.3	9.1	129	.10	1.2	292	0	32	1.00	.01	18.0	2.9	.0
	306	2.4	.2	.5			.3	.5	20.5	161	.12	2.4	816	0	0	1.33	.01	28.6	2.2	.2
	307	1.7	.3	.6			.1	.9	95.9	383	.02	1.9	719	0	111	1.99	.00	28.8	1.0	.7
	308	1.0		.4			.0	1.0	51.8	296	.03	5.1	691	0	161	1.72	.00	29.2	1.5	.5
	309	1.3		.4			.0	1.0	41.2	233	.14	7.0	613	0	159	1.62	.02	27.8	1.6	.3
Ind.	310	3.2		.6			.7	.1	11.5	144	.18	2.0	17	0	0	1.10	.03	4.1	2.8	.4
	311	2.7		.4			.4	.4	15.0	162	.14	.8	45	0	0	1.20	.02	6.7	2.6	.1
	312	1.6		.4			.0	1.0	49.8	217	.23	2.3	502	0	31	1.71	.05	23.1	1.5	.1
	313	1.4		.4			.0	1.0	42.0	182	.27	2.9	437	0	72	1.63	.07	22.6	1.7	.3
	314	2.6		.5			.3	.4	19.0	127	.24	1.2	10	64	2	1.30	.06	8.7	2.4	.2
	315	3.4		.7			.9	.0	6.9	107	.22	.2	183	46	0	.90	.05	15.1	3.1	.3
	316	2.9		.5			.5	.4	11.3	140	.09	.8	177	0	4	1.09	.01	13.4	2.8	.1
	317	4.3		.2			1.0	.0	2.9	95	.01	.1	0	0	0	.59	.00	.0	3.9	.4
	318	4.3		.3			1.0	.0	3.3	92	.00	.0	1	0	0	.63	.00	1.0	3.8	.5
	319	4.2	.0	.3			1.0	.0	3.8	92	.12	.2	0	1	0	.68	.01	1.0	3.7	.5
	320	3.9	.3	.4			.9	.0	3.8	105	.16	.4	0	2	0	.68	.03	1.4	3.7	.2
	501	3.8		.3			1.0	.0	5.8	132	.08	.3	0	0	0	.83	.01	.0	3.4	.4
	502	3.4		.6			.8	.1	10.3	168	.20	2.2	51	0	0	1.05	.04	7.2	2.9	.5
	503	3.1	.0	.3			.7	.0	7.6	129	.11	.8	17	0	7	.93	.01	4.9	3.2	.1
	504	4.1		.2			1.0	.0	2.6	109	.03	.2	0	0	0	.56	.00	.0	4.0	.1
	505	3.4		.2			1.0	.0	3.8	89	.33	.9	14	0	0	.68	.11	3.7	3.5	.1
	506	3.4		.4			.9	.0	4.8	89	.24	.9	0	0	0	.76	.06	.0	3.5	.1
	507	2.8		.4			.6	.3	7.6	103	.43	1.4	5	0	25	.93	.18	5.4	2.9	.1
	508	3.5		.5			.9	.0	4.0	75	.26	.5	0	0	0	.70	.21	.0	3.4	.1
	509	3.3		.5			.8	.0	2.9	84	.39	.4	9	0	0	.59	.15	3.0	3.7	.4
	510	3.3		.4			.9	.0	5.0	90	.44	1.0	2	0	0	.78	.19	1.3	3.3	.0
	511	3.6		.5			1.0	.0	3.5	90	.47	.6	0	0	0	.65	.22	.0	3.5	.1
	512	3.2		.7			.8	.0	5.1	87	.53	1.3	0	0	0	.79	.28	.0	3.1	.1
Test Road Sect.	513	3.4		.5			.8	.0	2.6	75	.56	.5	0	0	0	.56	.31	.0	3.5	.1
	514	1.8		.5			.0	.9	11.1	122	.73	5.1	80	0	16	1.08	.53	9.8	2.1	.3
	515	3.3		.7			.9	.0	2.5	79	.38	.5	0	0	0	.54	.14	.0	3.3	.5
	516	2.6		.6			.4	.3	5.4	86	.55	.6	15	0	0	.81	.30	3.9	3.0	.4
	517	3.2		.6			.5	.1	5.4	83	.54	.7	1	0	0	.81	.29	1.2	3.1	.1
	518	1.7		.4			.0	.8	21.0	149	.92	2.8	222	0	0	1.34	.85	14.9	1.2	.5
	519	2.4		.5			.1	.4	6.5	99	.53	1.5	21	0	0	.88	.28	4.6	2.9	.5
	520	3.0	.2	.6			.6	.1	6.8	89	.46	1.0	0	0	0	.89	.21	.0	3.0	.0
Off Site Sect.	521	3.3		.5			.7	.1	4.3	118	.09	.4	0	0	0	.72	.01	.0	3.6	.3
	522	2.7		.4			.6	.1	13.7	185	.11	3.8	300	0	1	1.17	.01	17.4	2.6	.1
	523	2.4		.4			.2	.2	10.8	137	.22	1.3	496	0	52	1.07	.05	23.4	2.7	.3
	524	0.9		.5			.0	1.0	88.1	281	.25	6.2	392	0	60	1.95	.06	21.2	1.0	.1
Sum		215.4	3.9	34.2												75.19	5.59	565.7	215.4*	22.3
Mean		2.91	.16	.46												1.02	.076	7.64	2.91	.30
Sum of Squares		66.85														13.27	1.34	5255	56.42*	10.42*
Sum of Products with PSR																-26.69	-1.51	-369.3		
Sum of Products with $\log(1+\overline{SV})$																	-.166	171.63		
Sum of Products with $\overline{RD}^2$																		-3.90		

*Obtained from Unrounded Calculations

PSI 121 = $5.03 - 1.91 \log(1+\overline{SV}) - 1.38\overline{RD}^2 - .01\sqrt{C+P}$

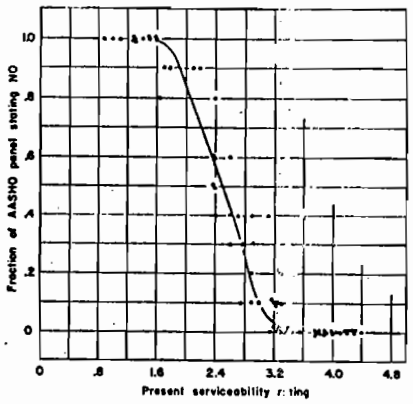

Figure 4. Unacceptability vs present serviceability rating; 74 flexible pavements.

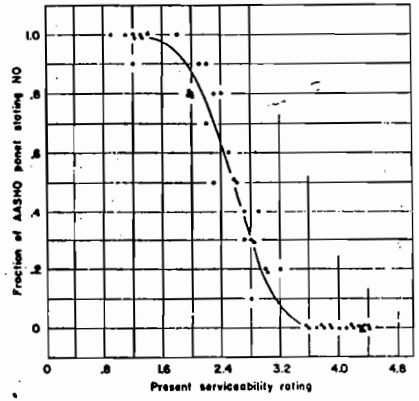

Figure 5. Unacceptability vs present serviceability rating; 49 rigid pavements.

The symbol $\overline{SV}$ is used for the summary statistic of wheelpath roughness as measured by the Road Test longitudinal profilometer. For each wheelpath the profilometer produces a continuous record of the pavement slope between points 9 in. apart. For a particular wheelpath, the slopes are sampled, generally at 1-ft intervals, over the length of the record. A variance[1] is calculated for the sample slopes in each wheelpath, then the two wheelpath slope variances are averaged to give $\overline{SV}$.

A Bureau of Public Roads road roughness indicator, or roughometer, has been adapted for use at the AASHO Road Test, but this development was not made until just prior to the Indiana rating session and still more developmental work has been done on the AASHO roughometer since the Indiana session. The AASHO roughometer has a modified output and is run at 10 mph, so roughometer values shown in Tables 1 and 2 are not those that would be obtained with the BPR roughometer at 20 mph. Nevertheless, roughometer values in inches per mile are given in the tables so that it may be noted that the roughometer values averaged for both wheelpaths, $\overline{AR}$, are correlated with the corresponding mean slope variances. Figures 6 and 7 show the extent of this correlation for the last two rating sessions.

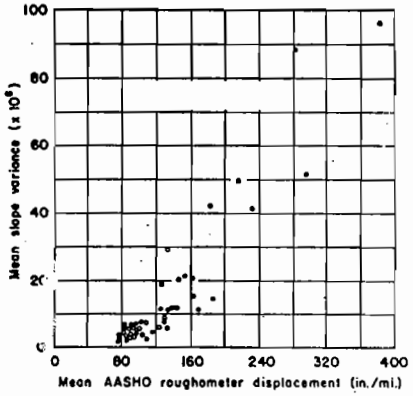

Figure 6. Slope variance vs AASHO roughometer displacement; 44 flexible pavements.

One other instrument, a rut depth gage, was used to obtain profile characteristics of the flexible pavement sections. This gage is used to determine the differential elevation between the wheelpath and a line connecting two points each 2 ft away (transversely) from the center of the wheelpath. Rut depth measurements were obtained at 20-ft intervals in both wheelpaths. Average rut depth values, $\overline{RD}$, for the flexible sections are given in Table 1, where it may be noted that the values range from 0 to nearly 1 in. Variances were calculated for the rut depths in each wheelpath, then the two wheelpath variances were averaged to give the $\overline{RDV}$ values given in Table 1. Figure 8 indicates the correlation between $\overline{SV}$ and $\overline{RDV}$ for the 74 flexible sections.

Profile information for rigid pavements included a measure of faulting in the wheelpaths. These measurements are given in Table 2, expressed in total inches of faulting (in wheelpaths only) per 1,000 ft of wheelpath.

The remaining measurements for flexible pavement sections are given in Table 1 under the headings of area affected by class 2 and class 3 cracking, length of transverse and longitudinal cracks, and patched area, where areas and lengths are expressed per 1,000 sq ft of pavement area. Corresponding measurements for rigid pavements are shown in Table 2 in terms of length of class 2 and sealed cracks, spalled area, and patched area. Lengths for rigid pavement cracks were determined by projecting the cracks both transversely and longitudinally, choosing the larger projection, then expressing the accumulated result in feet per 1,000 sq ft of pavement area. Only spalled areas having diameters greater than 3 in. were considered, and both spalling and patching are expressed in square feet per 1,000 sq ft of pavement area. Virtually any pair of measurements are intercorrelated to some degree, some more highly than others. Figures 9 and 10 indicate the degree to which $\overline{SV}$ is correlated with the sum of cracking and patching values. It is obvious that a stronger correlation exists in Figure 10 than in Figure 9. If either correlation were perfect, one or the other of the plotted variables would be redundant in an index of present serviceability.

The remaining columns in Tables 1 and 2 are connected with the development of present serviceability indices and will be discussed in succeeding paragraphs.

[1]The variance of a set of N sample values, $Y_1, Y_2, \ldots, Y_N$ is defined to be the sum of all N squared deviations from the mean divided by N-1. Thus the variance of Y is $\sum (Y-\bar{Y})^2/(N-1)$, where $\bar{Y} = \sum Y/N$ is the sample mean.

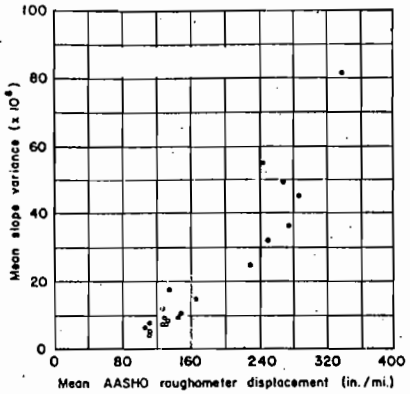

Figure 7. Slope variance vs AASHO roughometer displacement; 20 rigid pavements.

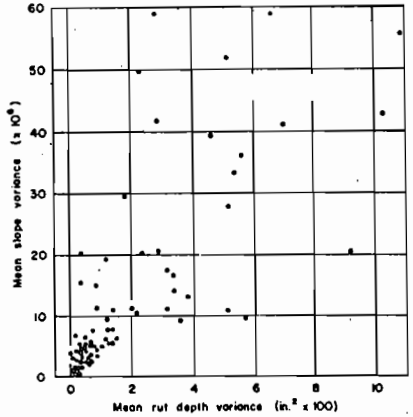

Figure 8. Rut depth variance vs slope variance; 74 flexible pavements.

Hypothesis and Assumptions for Present Serviceability Index

It has been stated that one requirement for an index of present serviceability is that when pavement measurements are substituted into the index formula, the resulting values should be satisfactorily close to the corresponding present serviceability ratings. There are also advantages if the index formula can be relatively simple in form and if it depends on relatively few pavement characteristics that are readily measured.

Guided by the discussion of the AASHO Rating Panel as well as by results from early rating sessions, the general mathematical form of the present serviceability index was assumed to be

$$PSI = C + (A_1R_1 + A_2R_2 + \ldots) + (B_1D_1 + B_2D_2 + \ldots) \quad (1)$$

in which R_1, R_2, ... are functions of profile roughness and D_1, D_2, ... are functions of surface deterioration. The coefficients C, A_1, A_2, ..., B_1, B_2, ... may then be determined by a least squares regression analysis. It is expected, of course, that A_1, A_2, ..., B_1, B_2, ... will have negative signs. To perform the analysis, the PSR for the jth of a set of sections is represented by

$$PSR_j = PSI_j + E_j \quad (2)$$

where E_j is a residual not explained by the functions used in the index. Minimizing the sum of squared residuals for all sections in the analysis leads to a set of simultaneous equations whose solutions are the required coefficients. The respective effect of adding or deleting terms in Eq. 1 will be to decrease or increase the sum of squared residuals. The change in residual sum of squares can be used to deduce the significance of adding or dropping terms from the index formula.

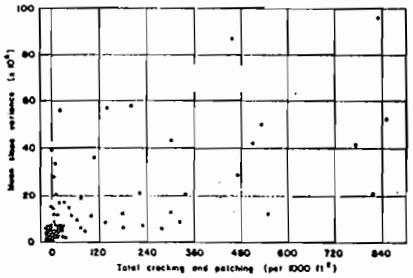

Figure 9. Mean slope variance vs cracking and patching; 74 flexible pavements.

The model for PSI is linear in that if all functions save one are given a numerical value, then PSI versus the remaining function represents a straight line relationship. for this reason it is desirable to choose functions R_1, R_2, ..., D_1, D_2, ..., that have linear graphs when plotted with PSR values. For example, logarithms, powers, etc., of the original measurements may be used as linearizing transformations.

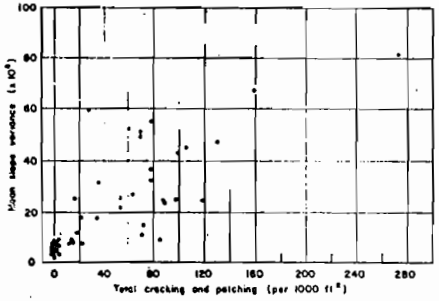

Figure 10. Mean slope variance vs cracking and patching; 49 rigid pavements.

It is important to note that a present serviceability index developed from observed ratings and measurements can only reflect the characteristics that were actually present in the observed pavements. And that for any particular characteristic, the index can only reflect the observed range of values for the characteristic. For example, if the selected pavements had no potholes, there is no objective way to infer how potholing would affect the present serviceability ratings, and the index cannot contain a function of potholing. As another example, if faulting in the selected pavements ranged from 0 to 10, there would be no way to infer the effect on PSR of pavements whose faulting was in the range 50 to 100. This same argument applies to the present serviceability ratings themselves. If PSR's for the selected pavements range only from 2.0 to 4.0, there is no way to infer

what pavement characteristics must be like in order to produce a value of 1.0 or 5.0, say, except to extrapolate the index on the assumption that linearity holds over the full range of pavement characteristics.

For these reasons it has been stated that selected pavements should show all phenomena of interest, the complete range of interest for each phenomenon, and should be associated with PSR values that span the full range of interest.

Thus pavement selection amounts to the assumption that all interesting phenomena and ranges have been encompassed by the selections. Extrapolations of the index to measured values outside the range of those found in the selected pavements amounts to the assumption that the index formula remains linear in the region of extrapolation.

Choice of Functions for the Present Serviceability Index

Measurements from the Illinois and Minnesota sections were plotted in succession against corresponding PSR values to determine which measurements were essentially uncorrelated with PSR and to deduce the need for linearizing transformations. It was indicated that the mean wheelpath slope variance, $\overline{SV}$, was highly correlated with PSR, though curvilinearly. Figures 11 and 12 show the nature of this correlation for all selected pavements. From several alternatives, the transformation

$$R_1 = \log (1 + \overline{SV})$$

was selected as the first function of profile roughness to appear in the PSI model for both flexible and rigid pavements. The result of this transformation is shown in Figures 13 and 14, where PSR values are plotted against R_1 for flexible and rigid pavements, respectively.

For the flexible pavements, mean wheelpath rut depth, $\overline{RD}$, was included as a second profile measurement to appear in the PSI equation. The selected function of rut depth was

$$R_2 = \overline{RD}^2$$

The scatter diagram of PSR vs RD^2 is shown in Figure 15.

Although preliminary analyses considered the possibility of several functions of surface deterioration (say one function for each of the measured manifestations), it was

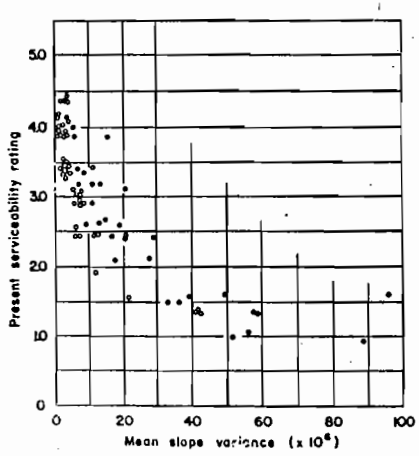

Figure 11. Present serviceability rating vs slope variance; 74 flexible pavements.

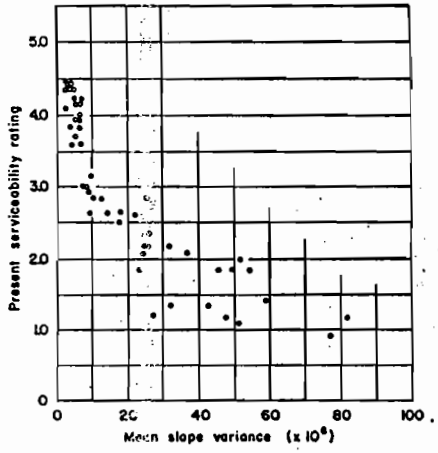

Figure 12. Present serviceability rating vs slope variance; 49 rigid pavements.

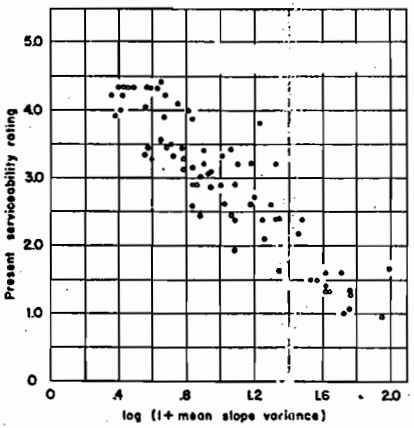

Figure 13. Present serviceability rating vs log (1 + mean slope variance); 74 flexible pavements.

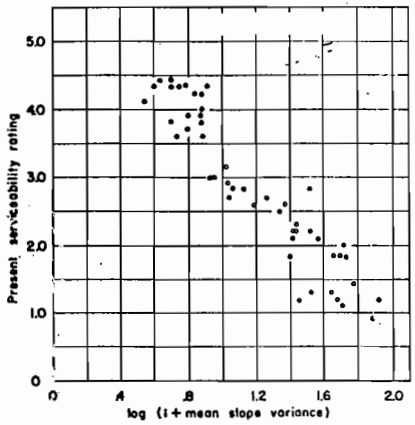

Figure 14. Present serviceability rating vs log (1 + mean slope variance); 49 rigid pavements.

apparent that no loss would be incurred by lumping all major cracking and patching into a single number to represent surface deteriorations. Values for this sum, C + P, are not shown in Tables 1 and 2, but may be obtained from cracking and patching measurements given in the tables.

Scatter diagrams for PSR versus C + P are shown in Figures 16 and 17. For whatever reasons, it is apparent that there is little correlation between PSR and C + P for the flexible pavements, but that a fair degree of correlation exists between these variables for the rigid pavements. For both flexible and rigid pavements the transformation

$$D_1 = \sqrt{C + P}$$

was selected as a linearizing transformation for C + P.

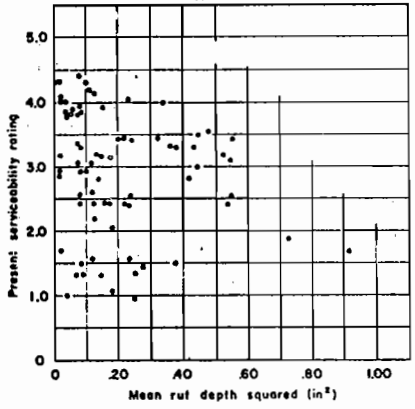

Figure 15. Present serviceability rating vs mean rut depth squared; 74 flexible pavements.

Thus the present serviceability index models to be used are

$$PSI = A_0 + A_1R_1 + A_2R_2 + B_1D_1 = A_0 + A_1 \log (1 + \overline{SV}) + A_2\overline{RD}^2 + B_1 \sqrt{C + P} \qquad (3)$$

for flexible pavements, and

$$PSI = A_0 + A_1R_1 + B_1D_1 = A_0 + A_1 \log (1 + \overline{SV}) + B_1 \sqrt{C + P} \qquad (4)$$

for the rigid pavements. It is not expected that the coefficients A_0, A_1, and B_1 have the same values for both Eqs. 3 and 4.

There are many other possibilities for Eqs. 3 and 4. Not only might other instruments be used to detect deformation and deterioration, but other summary values than $\overline{SV}$, C+P and $\overline{RD}$ might be used. Moreover, one may choose different functions of $\overline{SV}$, C+P and $\overline{RD}$ than appear in Eqs. 3 and 4, or perhaps include still more functions of pavement measurements.

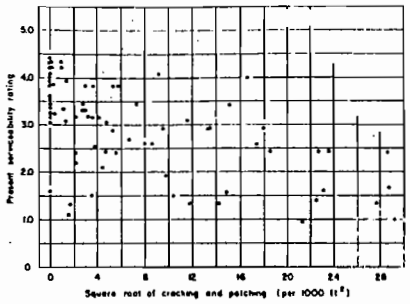

Figure 16. Present serviceability rating vs square root cracking and patching; 74 flexible pavements.

It is clear that one of the most important elements of pavement serviceability is its longitudinal profile in the wheelpaths. The profile of the road coupled with the appropriate characteristics of the vehicle (mass, tires, springs, shock absorbers, speed, etc.) produce the "ride" attained in that vehicle over that road. The actual profile of the wheel path as though taken with rod and level at very close spacing may be called the displacement profile, p. The first derivative of the displacement profile is the profile of the slope, p'. A plot of the slope profile would have the same abscissa as the displacement profile, distance along the road, and its ordinate would represent the rate of change of displacement, or slope of the road at any point. The second derivative of the displacement profile is the "acceleration" profile, p'', and represents the rate of change of slope, and the third derivative has been called the "jerk" profile, p''', the rate of change of acceleration. It has been suggested that jerk may be more highly correlated with a rider's opinion of his ride than any of the other representations. Perhaps this is true when one is seeking to define "ride" but the efforts at the Road Test were directed toward a definition of the "smoothness of a road" independent of the vehicle that might use it. No small amount of effort was spent in studying correlations of the variances of various profile derivatives with the present serviceability ratings, but there was no evidence that elevation variance, acceleration variance, or jerk variance has higher correlation with PSR than the slope variance. On the other hand, when a number of the slope profiles were subjected to generalized harmonic analysis to determine how variance was associated with the wavelength spectrum, there was some indication that slope variance in certain regions of the wavelength spectrum is more highly correlated with PSR than is the total slope variance. More study of this question is still under way at the Road Test.

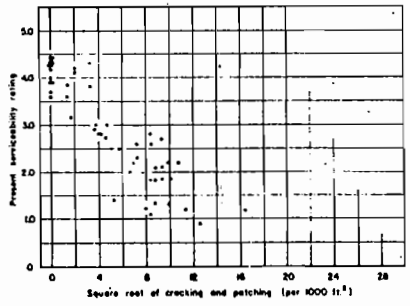

Figure 17. Present serviceability rating vs square root cracking and patching; 49 rigid pavements.

Coefficients for the Present Serviceability Index

Substitution of Eq. 3 in Eq. 2 gives

$$PSR_j = A_0 + A_1R_{1_j} + A_2R_{2_j} + B_1D_{1_j} + E_j$$

in which $R_{1_j} = \log (1 + \overline{SV}_j)$, $R_{2_j} = \overline{RD}_j^2$ and $D_{1_j} = \sqrt{C_j + P_j}$ for the jth pavement.

Least squares estimates for A_0, A_1, A_2 and B_1 are found by minimizing the sum of squared residuals, E_j, through solving the following four simultaneous equations for A_0, A_1, A_2 and B_1.

$$A_1 \sum(R_1-\overline{R_1})^2 + A_2 \sum(R_1-\overline{R_1})(R_2-\overline{R_2}) + B_1 \sum(R_1-\overline{R_1})(D_1-\overline{D_1}) = \sum(R_1-\overline{R_1})(PSR-\overline{PSR}) \quad (5a)$$

$$A_1 \sum(R_2-\overline{R_2})(R_1-\overline{R_1}) + A_2 \sum(R_2-\overline{R_2}) + B_1 \sum(R_2-\overline{R_2})(D_1-\overline{D_1}) = \sum(R_2-\overline{R_2})(PSR-\overline{PSR}) \quad (5b)$$

$$A_1 \sum(D_1-\overline{D_1})(R_1-\overline{R_1}) + A_2 \sum(D_1-\overline{D_1})(R_2-\overline{R_2}) + B_1 \sum(D_1-\overline{D_1})^2 = \sum(D_1-\overline{D_1})(PSR-\overline{PSR}) \quad (5c)$$

$$\overline{PSR} = A_0 + A_1\overline{R_1} + A_2\overline{R_2} + B_1\overline{D_1} \quad (5d)$$

Summations in Eqs. 5 are over all pavements in the analysis, and bars over symbols denote arithmetic means. Sums like $\sum(R_1-\overline{R_1})^2$ are called sums of squares, while sums like $\sum(R_1-\overline{R_1})(D_1-\overline{D_1})$ are called sums of products. Eqs. 5 may be expanded to more terms and more equations if the index model contains more than three functions.

Since the model (Eq. 4) for rigid pavements has only three undetermined coefficients, only three simultaneous equations need be solved.
These equations are

$$A_1 \sum(R_1-\overline{R_1})^2 + B_1 \sum(R_1-\overline{R_1})(D_1-\overline{D_1}) = \sum(R_1-\overline{R_1})(PSR-\overline{PSR}) \quad (6a)$$

$$A_1 \sum(R_1-\overline{R_1})(D_1-\overline{D_1}) + B_1 \sum(D_1-\overline{D_1})^2 = \sum(D_1-\overline{D_1})(PSR-\overline{PSR}) \quad (6b)$$

$$\overline{PSR} = A_0 + A_1R_1 + B_1D_1 \quad (6c)$$

All means, sums of squares, and sums of products for Eqs. 5 and 6 are given in Tables 1 and 2, respectively.

For the flexible pavements, Eqs. 5 are:

$$13.27\ A_1 - 0.166\ A_2 + 171.63\ B_1 = -26.69 \quad (7a)$$

$$-0.166\ A_1 + 1.34\ A_2 - 3.90\ B_1 = -1.51 \quad (7b)$$

$$171.638\ A_1 - 3.90\ A_2 + 5255\ B_1 = -369.3 \quad (7c)$$

$$2.91 = A_0 + 1.02\ A_1 + 0.076\ A_2 + 7.64\ B_1 \quad (7d)$$

and the solution turns out to give

$$PSI = 5.03 - 1.91 \log(1 + \overline{SV}) - 1.38\ \overline{RD}^2 - 0.01\sqrt{C + P} \quad (8)$$

For the 49 rigid pavements the least squares equations are:

$$7.55\ A_1 + 71.71\ B_1 = -19.70 \quad (9a)$$

$$71.71\ A_1 + 905.7\ B_1 = -206.5 \quad (9b)$$

$$2.83 = A_0 + 1.19\ A_1 - 0.087\ B_1 \quad (9c)$$

whose solution leads to the index

$$PSI = 5.41 - 1.78 \log(1 + \overline{SV}) - 0.09\ \sqrt{C + P} \quad (10)$$

It is noted in Tables 1 and 2 that the total variation in PSR is given by the sums of squares

$$\sum(PSR-\overline{PSR})^2 = 66.85 \text{ for the 74 flexible pavements, and} \quad (11a)$$

$$\sum(PSR-\overline{PSR})^2 = 57.92 \text{ for the 49 rigid pavements.} \quad (11b)$$

The variation in PSR as shown by Eqs. 11 may be separated into two parts, a sum of squares attributable to the measured variables and a sum of squares for residuals. Thus,

$$\sum(PSI-\overline{PSR})^2 = \sum(PSI-\overline{PSR})^2 + \sum(PSR-PSI)^2 \quad (12)$$

when the first term on the right side of Eq. 12 is generally called the sum of squares for regression, or the explained sum of squares. To obtain the sum of squares for regression for the flexible pavements,

$$\sum(PSI-\overline{PSR})^2 = A_1 \sum(R_1-\overline{R_1})(PSR-\overline{PSR}) + A_2 \sum(R_2-\overline{R_2})(PSR-\overline{PSR}) + B_1 (D_1-\overline{D_1})(PSR-\overline{PSR}) \quad (13)$$

is calculated, then the residual sum of squares is found by subtraction. For the rigid pavements, the term containing A_2 is omitted from Eq. 13. Sums of squares for regression are

$$(-1.91)(-26.69) + (-1.38)(-1.51) + (-0.01)(-369.3) = 56.42 \text{ for}$$

the flexible pavements, and

$$(-1.78)(-19.70) + (-0.037)(-206.5) = 53.08 \text{ for the}$$

rigid pavements.

Dividing regression sums of squares by the total variation given in Eq. 11 gives

$$\frac{56.42}{66.85} = 0.844 \text{ for the flexible pavements, and}$$

$$\frac{53.08}{57.92} = 0.916 \text{ for the rigid pavements.}$$

Thus, the PSI formulas account for 84.4 percent and 91.6 percent of the variation in PSR for flexible and rigid pavements, respectively. By subtractions, the respective sums of squared residuals are 10.43 and 4.84, so that the root mean square residuals are about 0.38 and 0.32, respectively.

The last columns of Tables 1 and 2 show calculated values for the present serviceability indexes, as well as for residuals. At the bottom of the last column of the tables it may be noted that the mean residual was 0.30 for flexible pavements and 0.26 for rigid pavements. In both cases, the mean residual is about twice the mean difference between replicate ratings given by the AASHO Rating Panel.

It may be noted from the residual columns of Tables 1 and 2 that six flexible and three rigid pavement residuals exceeded 0.5, the largest replication difference given by the Panel. However, the index formulas span ratings made more than a year apart, whereas all replicate ratings were made on successive days. As previously stated, it is quite possible that replicate PSR's would be more different when made over larger intervals of time.

When the fifteen rigid pavement PSR values from the fourth rating session were compared with PSI values given by Eq. 10, the sum of the algebraic deviations was practically zero while the mean discrepancy was 0.3. Inasmuch as only two of the deviations exceeded 0.5, it was inferred that Eq. 10 served to fit the new PSR values to about the same degree as it predicted those from which it was derived.

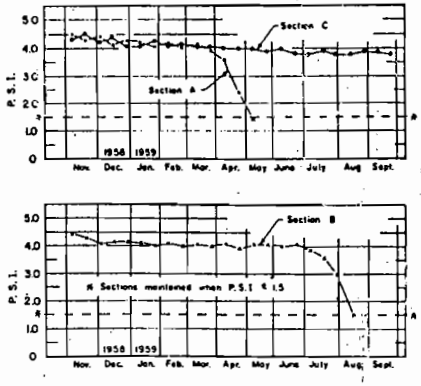

Figure 18. Present serviceability history of three selected test sections on the AASHO road test.

Case Histories of Present Serviceability Index

Figure 18 shows the present serviceability index history of three selected test sections at the AASHO Road Test. Sections A and B have been replaced since the beginning of the test; Section C was still in the test in October 1959. Abscissa values represent two-week intervals for which index values are computed by PSI 111 and PSI 211, respectively.

The performance indexes computed for four dates from these serviceability-time history curves are given in Table 3.

SUMMARY

The fundamental purpose of this paper has been to introduce concepts of present serviceability and performance that can be

TABLE 2

DATA FOR 49 SELECTED RIGID PAVEMENTS

Pvt. Loc.	Sect. Code	Present Serviceability Ratings: AASHO Panel 1st PSR	AASHO Panel Replic. diff. in PSR	AASHO Panel std. dev of PSR among raters	Truck Drivrs PSR	Canad. Raters PSR	Acceptability Opinions: AASHO Panel Fraction Yes	Fraction No	Longitudinal Roughness: $\overline{SV}$ Mean Slope Var'nce in wh'pth (x10⁶)	$\overline{AR}$ Mean AASHO Rdmtr. @ 10 mi/hr (in./mi)	F Faulting in wh'pth in /1000'	Cracking C Class 2 and Sealed Cracks ft/1000 ft²	Spalling ft²/1000ft² for areas > 3" Dia.	Patching P Patch'd Area ft²/1000ft²	Transformations: Log (1+$\overline{SV}$)	Log $\overline{AR}$	Sq root C+P	PSI 211 Pres. Serv. Index	Resid. Diff. Betw'n PSR & PSI
Ill.	R1	2.0	.2	.6	1.5		.0	.8	52.0		2	53	4	6	1.72		7.8	1.7	.3
	R2	4.2		.3	4.5		1.0	.0	6.5		0	4	0	0	.68		2.0	3.7	.5
	R3	2.6	.3	.6	2.5		.2	.5	22.2		0	42	0	11	1.37		7.3	2.3	.3
	R4	2.3	.2	.3	2.5		.0	.5	26.2		0	66	0	7	1.44		7.3	2.2	.1
	R5	1.2		.4	1.5		.0	1.0	47.8		1	122	0	28	1.69		11.4	1.4	.2
	R6	2.8	.1	.6	2.5	3.0	.2	.1	25.5		2	25	2	1	1.42		4.0	2.5	.3
	R7	4.4	.0	.3	4.5	4.4	1.0	.0	3.2		0	0	0	0	.63		0	4.3	.1
	R8	1.1	.2	.4			.0	1.0	50.8		3	65	11	5	1.71		8.4	1.6	.5
	R9	0.9	.0	.3			.0	1.0	76.8		1	74	19	85	1.89		12.6	0.9	.0
Minn.	201	1.3	.1	.6			.0	1.0	43.3		1	40	60	59	1.65		10.0	1.6	.3
	202	1.8		.5			.0	1.0	24.2		0	23	4	66	1.40		9.4	2.1	.3
	203	2.1	.3	.6			.1	.9	24.7		0	47	1	41	1.41		9.4	2.1	.0
	204	4.1		.3			1.0	.0	2.4		0	4	0	0	.54		2.0	4.3	.2
	205	3.8	.3	.4			1.0	.0	4.0		0	2	0	0	.70		1.4	4.0	.2
	206	3.0	.0	.5			.6	.2	7.8		1	14	0	1	.95		3.9	3.4	.4
	207	3.0		.6			.4	.2	7.5		1	22	0	0	.93		4.7	3.3	.3
	208	2.9	.1	.6			.3	.4	9.7		0	14	0	0	1.03		3.7	3.2	.3
	209	2.5		.4			.4	.2	17.6		0	34	0	0	1.27		5.8	2.6	.1
	210	1.4		.5			.0	1.0	59.2		0	16	500	12	1.78		5.3	1.8	.4
	211	4.3		.2			1.0	0	3.0		0	0	0	0	.60		0	4.3	.0
	212	4.3	.0	.4			1.0	0	4.0		0	0	0	0	.70		0	4.1	.2
	213	3.7		.4			1.0	0	5.3		0	0	0	0	.80		0	4.0	.3
	214	3.6	.3	.5			1.0	0	4.4		0	0	0	0	.73		0	4.1	.5
	215	3.9		.4			1.0	0	5.3		0	0	0	0	.80		0	4.0	.1
	216	3.9	.0	.6			1.0	0	6.3		0	0	0	0	.87		0	3.8	.1
	217	1.3	.0	.4			.0	1.0	32.3		0	76	2	1	1.52		8.8	1.9	.6
	218	1.2		.4			.0	1.0	27.8		10	64	0	0	1.46		8.0	2.1	.9
	219	2.2		.6			.0	.9	25.6		4	97	0	1	1.42		9.9	2.0	.2
	220	4.4	.0	.3			1.0	.0	4.0		0	0	0	0	.70		0	4.1	.3
Ind.	£01	4.0		.3			1.0	0	6.6	134	2	0	1	0	.88	2.13	0	3.8	.2
	£02	3.8		.4			1.0	0	6.6	126	4	11	1	0	.88	2.10	3.3	3.5	.3
	£03	3.6		.6			.9	0	6.8	133	1	2	4	0	.89	2.06	1.4	3.7	.1
	£04	3.2		.6			.6	.2	9.8	131	4	1	1	2	1.03	2.12	1.7	3.4	.2
	£05	2.6		.6			.3	.3	14.6	167	5	72	13	0	1.19	2.22	8.5	2.5	.1
	£06	2.8		.6			.4	.3	10.4	151	5	70	10	1	1.06	2.18	8.4	2.8	.0
	£07	1.8	.5	.6			.1	.8	49.4	268	1	11	4	29	1.70	2.43	8.4	1.6	.2
	£08	1.8		.6			.1	.8	54.5	245	2	42	8	37	1.74	2.39	8.9	1.5	.3
	£09	2.1		.6			.2	.8	36.6	276	1	50	7	29	1.58	2.44	8.9	1.8	.3
	£10	2.2		.5			.2	.8	25.1	230	2	66	5	33	1.42	2.36	10.9	1.9	.3
	£11	1.8		.5			.1	.8	45.4	286	0	20	6	65	1.67	2.46	10.2	1.5	.3
	£12	2.7		.6			.4	.4	9.9	147	5	81	3	5	1.44	2.17	9.3	2.7	.0
	£13	4.2		.4			1.0	.0	6.1	106	1	0	1	0	.85	2.03	0	3.9	.3
	£14	4.3		.4			1.0	.0	5.2	112	1	0	0	0	.79	2.05	0	4.0	.3
	£15	4.3		.4			1.0	.0	7.1	132	1	0	0	0	.91	2.12	0	3.8	.5
	£16	1.2	.3	.6			.0	.9	81.9	338	8	54	1	219	1.92	2.53	16.5	0.5	.7
	£17	2.2	.0	.6			.1	.9	32.2	253	16	36	1	0	1.52	2.40	6.0	2.2	.0
	£18	4.3	.1	.3			1.0	.0	4.6	113	1	0	0	0	.75	2.06	0	4.1	.2
	£19	2.8	.0	.7			.5	.3	12.6	126	2	5	2	13	1.13	2.10	4.2	3.0	.2
	£20	2.7	.1	.4			.1	.3	17.8	137	2	5	7	16	1.27	2.14	4.6	2.7	.0
Sum		136.6	3.1												58.23		254.3	138.6*	12.5
Mean		2.83	.13												1.19		5.19	2.83*	.26
Sum of Squares		57.92													7.55		905.70	53.08*	4.84*
Sum of Products with PSR															-19.70		-206.53		
Sum of Products with Log (1+$\overline{SV}$)																	71.77		

*Obtained from Unrounded Calculations

PSI 211 = 5.41 − 1.80 log(1+$\overline{SV}$) − .09 $\sqrt{C+P}$

iceability indexes derived from the first 49 sections. For these reasons, flexible pavements from all four sessions appear in Table 1, but Table 2 includes only rigid pavement sections from the first three sessions.

Present serviceability ratings given in Col. 3, Tables 1 and 2, are mean values for individual ratings given by the Road Test Panel. In general, each mean represents about ten individual ratings. It may be noted that for both pavement types the PSR values range from about 1.0 to 4.5, with nearly the same number of sections in the poor, fair, good, and very good categories. The grand mean PSR for all rated pavements was slightly less than 3.0 for both pavement types.

More than 40 of the sections were revisited by the Panel during the same rating session, and differences between first and second mean ratings are given in Col. 4, Tables 1 and 2. The replication differences ranged from 0 to 0.5, the mean difference being less than 0.2 for both flexible and rigid pavements. Col. 5, Tables 1 and 2, gives the standard deviation of individual PSR values for each section. These standard deviations are of the order 0.5, an indication that only about two or three individual ratings (out of ten) were farther than 0.5 rating points from the Panel mean PSR.

As mentioned earlier, certain of the Illinois sections were rated by two truck drivers, whose mean ratings are given in Col. 6. Col. 7 gives mean ratings given to selected Illinois sections by a group of about 20 Canadian raters. It can be seen that there is general agreement among the various rating groups.

The next two columns of Tables 1 and 2 represent summaries of the AASHO Panel response to the acceptability question. For a particular section the tables show what fraction of the Panel decided the present state of the pavement to be acceptable and what fraction decided the pavement to be unacceptable. By implication the remaining fraction of the Panel gave the undecided response.

Figures 2, 3, 4 and 5 show the connection between corresponding PSR values and acceptability opinions for the two types of pavement. Freehand curves indicate in Figures 2 and 3 that the 50th percentile for acceptability occurs when the PSR is in the neighborhood of 2.9, whereas the 50th percentile for unacceptability corresponds roughly to a PSR of 2.5, as shown in Figures 4 and 5.

Measurements for Selected Pavements

Following the acceptability opinion, Tables 1 and 2 give summary values for measurements made on the selected pavements. Measurements are shown in three categories—those that describe longitudinal and transverse roughness, those that summarize surface cracking and, finally, a measurement of the patched area found in the section.

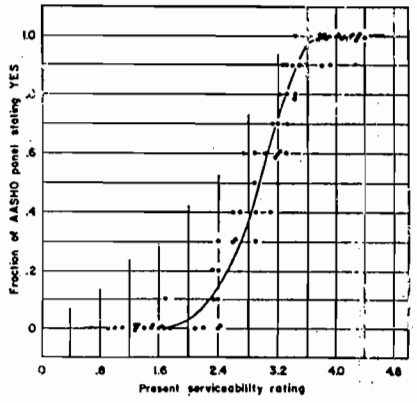

Figure 2. Acceptability vs present serviceability rating; 74 flexible pavements.

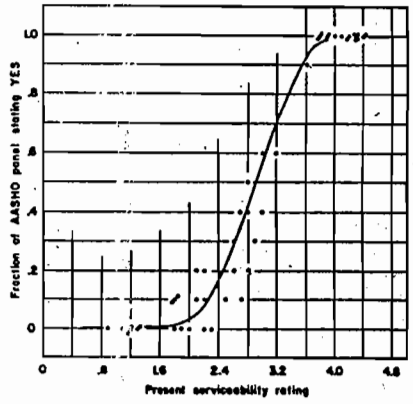

Figure 3. Acceptability vs present serviceability rating; 49 rigid pavements.

TABLE 3

Date	Sect. A	Sect. B	Sect. C	For Service of Approximately
Dec. 1958	4.4	4.3	4.4	2 months
Mar. 1959	4.2	4.2	4.2	5 months
June 1959	3.4	4.1	4.1	8 months
Oct. 1959	2.3	3.4	4.3	1 year

clearly defined. Although the examples and illustrations are specific instances of the concepts, it has not been supposed that the procedures and indexes discussed herein represent any final goal. In fact, the details have been given only to illustrate the concepts.

If any highway department were interested in applying these principles to its own highway system with evaluation of pavement serviceability and/or performance in mind, the following steps should be taken:

1. Establish a rating panel or committee.
2. Decide which features of the roadway are to be considered.
3. Rate a large number of roadway sections that include among them a wide range of each of the selected features (that is, very rough to very smooth, deep ruts to no ruts, etc.)
4. Make objective measurements of the features considered.
5. Derive a serviceability index.

When the index has been derived, any section of highway in the state may be measured and the results of the measurements entered into the index, to obtain an estimate of the rating for that section without the need for the Panel to visit it. All highways in the state could be classified in this manner to provide an objective sufficiency rating system and an objective means to determine priorities for maintenance and reconstruction.

If the measurements were made and present serviceability indexes computed at several times during the lives of any particular set of pavements, their performance could be evaluated and compared to help the highway department check its design methods and compare various materials and construction techniques.

In this system, then, may be found the "dimension" for serviceability and performance that has been missing in design equations. The designer can be told to design for a specified performance level for a specified number of years and the means is provided to measure his success.