EVALUATION OF THE PCA ROAD METER

Patrick C. Hughes

Present serviceability rating (PSR) as employed by the Minnesota Department of Highways is an adaptation of the system developed and used at the AASHO Road Test (1).

Present serviceability is defined as "the ability of a specific section of pavement to serve high-speed, high-volume, mixed (trucks and automobiles) traffic in its existing condition" (2). In general, present serviceability is a function of transverse and longitudinal profile. However, patching, cracking, faulting, and spalling no doubt contribute to some extent.

In evaluating a roadway on the basis of PSR, a numerical rating between 0 and 5 is given each section surveyed with respect to its present serviceability as previously defined. The numerical scale and range of general pavement conditions that the ratings represent are as follows: 4.0 to 5.0, very good; 3.0 to 4.0, good; 2.0 to 3.0, fair; 1.0 to 2.0, poor; and 0.0 to 1.0, very poor.

The individual rater must disregard grade, alignment, right-of-way width, shoulder, ditch condition, and all other factors not directly related to the ridability of the highway. He, in effect, asks himself: "How well would I like to drive over roads just like this section all day long?" He decides what the existing pavement condition is and then refines the corresponding numerical range by rating to one-tenth of a point. As an example, a roadway considered to be "good" and approaching "very good" might be given a rating of 3.8 or 3.9

The true PSR for a section of pavement would be the average of the ratings of all the individual users of that pavement. Obviously, obtaining a true PSR is not practical. The number of raters must be quite small to make the determination of the ridability factor by this method a practical matter. Because 3 raters were needed to conduct the structural rating portion of the surveys to determine a pavement condition rating and because the ridability determinations (PSR) and structural ratings could be made in one general operation, it was decided that the average of 3 raters would have to suffice for PSR determinations.

Investigators at Purdue University (3) determined the number of raters required to rate pavements within various permissible errors of the true rating at the 90 and 95 percent probability levels. Table 1 gives these results at both the 90 and 95 percent probability levels.

With 3 raters, we can expect that 10 percent of the average ratings will be at least 0.8 from the true rating. A deviation from the true rating of this magnitude is definitely unacceptable.

RIDABILITY AS DETERMINED BY RATING PANELS

The determination of PSR, then, in the early stage of this study was accomplished by 3 raters (driver, front-seat passenger, and rear-seat passenger) riding in a car traveling at the posted speed limit of the section of highway in question. Each rater recorded his PSR on a scratch pad for every ½ mile driven for the length of the project. The driver announced "half mile" each time the odometer indicated that ½ mile had been driven since the start of a project or since the last announcement. Each ½ mile

Table 1. Number of raters required to estimate the true rating.

Permissible Error	Number of Raters Required: 95 Percent Probability	90 Percent Probability
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

Table 2. Comparison of district and research ratings.

Rating Number	Type of Pavement	District PSR	Research PSR	Deviation
1	Bituminous	2.3	2.8	-0.5
2	Bituminous	2.9	2.8	+0.1
3	Concrete	3.2	3.4	-0.2
4	Concrete	2.5	1.6	+0.9
5	Bituminous	1.3	2.6	-1.3
6	Bituminous	2.2	3.0	-0.8
7	Concrete	1.7	2.0	-0.3
8	Concrete	2.9	2.7	+0.2
9	Bituminous	2.5	2.8	-0.3
10	Bituminous	1.7	2.4	-0.7
11	Bituminous	2.1	2.3	-0.2
12	Bituminous	2.0	2.7	-0.7
13	Bituminous	2.1	2.5	-0.4
14	Bituminous	1.9	1.9	0.0
15	Bituminous	2.2	2.4	-0.2
16	Bituminous	1.4	2.0	-0.6
17	Bituminous	3.0	2.9	+0.1
18	Bituminous	1.6	2.5	-0.9
19	Bituminous	2.3	2.6	-0.3
20	Bituminous	2.9	2.3	+0.6
21	Bituminous	2.4	2.6	-0.2
22	Concrete	1.5	2.0	-0.5
23	Concrete	2.4	2.5	-0.1
24	Concrete	1.6	2.4	-0.8
25	Bituminous	2.3	2.5	-0.2
26	Bituminous	2.7	3.0	-0.3
27	Concrete	2.5	2.1	+0.4
28	Concrete	2.8	2.4	+0.4
29	Bituminous	2.2	2.5	-0.3
30	Bituminous	3.0	3.1	-0.1
31	Bituminous	2.4	2.6	-0.2
32	Concrete	2.4	2.3	+0.1
33	Bituminous	3.4	3.1	+0.3
34	Bituminous	2.9	2.3	+0.6
35	Concrete	2.7	2.2	+0.5
36	Concrete	2.5	2.2	+0.3
37	Bituminous	2.5	2.9	-0.4
38	Concrete	2.1	2.3	-0.2
39	Concrete	2.4	2.5	-0.1
40	Bituminous	2.1	2.6	-0.5
41	Concrete	2.7	2.6	+0.1
42	Concrete	1.7	2.2	-0.5
43	Bituminous	2.8	3.0	-0.2
44	Bituminous	2.8	2.7	+0.1
45	Concrete	2.7	2.3	+0.4
46	Concrete	2.9	2.3	+0.6

Figure 1. Pavement rating form.

Trunk Highway________ Control Section________ Lane Surveyed________ Date________

Begin Survey ________ End Survey ________ Total Length ________ Weather ________

Raters 1________, 2________, 3________ Unit Type________ Unit Number________

MILE	P.S.R.				JOINTS					CRACKS					PATCHED				SCALE		DISTORTION				NOTES
	Rater 1	Rater 2	Rater 3	AVG.	Total Visible	Spalled	%	Faulted	%	Panels Visible	Number Cracked	%	Faulted	%	100 % Overlay	%	5 Ft Square	%	5 Ft. Square	%	Rater 1	Rater 2	Rater 3	AVG.	
	(1a)	(1b)	(1c)	(1d)	(2)	(3)	(3a)	(4)	(4a)	(5)	(6)	(6a)	(7)	(7a)	(8)	(8a)	(9)	(9a)	(10)	(10a)	(11a)	(11b)	(11c)	(11d)	
							$(\frac{3}{2} \times 100)$		$(\frac{4}{2} \times 100)$			$(\frac{6}{5} \times 100)$		$(\frac{7}{5} \times 100)$		$(\frac{8}{5 \cdot 8} \times 100)$		$(\frac{9}{5} \times 100)$		$(\frac{10}{5} \times 100)$					

was rated as a separate section of highway, and there was no discussion among the raters until the entire project was completed. Each rater recorded his PSR value on a rating form (Fig. 1, columns 1a, 1b, and 1c), and an average value was derived.

During 1966, 3-man rating teams from each of the 9 construction districts applied this rating system to more than 6,000 miles of inferior and old Minnesota highways. The results of the first year's efforts were used in a resurfacing program.

After the district rating teams were well into their schedule of rating, a team from the research office rated a sample of the roads that had been rated by the district teams. The purpose of this was to check the accuracy and repeatability of the rating system.

From the experience of the research team and information accumulated from district rating teams, it appeared that the system, when applied uniformly, was an accurate indicator of the relative condition of pavements. It was not difficult for one team to rate consistently. Also, it appeared that teams that fully understood the system rated consistently and uniformly. Of the 9 district teams, 4 rated pavements very similarly to the research team. In 2 districts where a member of the research team accompanied the district team for 1 day, the subsequent check rating by the research team disclosed good agreement between ratings. In 4 of the 5 districts where the ratings did not agree well, the discrepancies were, in general, explainable.

Table 2 gives the data collected as a result of the check ratings. It was assumed that the research team's ratings were uniform throughout the state. Therefore, those ratings were subtracted from the districts' ratings to show the difference.

Figure 2 shows a frequency distribution of the deviations in PSR's for the projects. As can be seen, the deviations were distributed in an approximately normal curve. The mean of all the deviations was -0.14. A mean of -0.14 indicates that the district teams tended to rate lower than did the research team. However, this was unduly influenced by one district, which was consistently lower and in which several checks were made. Excluding the values from that district, the mean is -0.04, which would be highly acceptable.

The discouraging aspect of the investigation of the PSR was the range of deviations that occurred. The values ranged from a +0.9 to -1.3 or a total of 2.2. At the outset it was hoped that the system for determining PSR would be accurate to ±0.3. However, it is apparent from the investigation that this was not realized.

There are explanations for some of the discrepancies that occurred, but not all can be explained. One source of deviation was the difference in cars used by the various teams. The car used by the research team was a 1962 2-door Plymouth. Cars used by the districts were a 1966 Ford, three 1965 Plymouths, three 1964 Fords, and two 1962 Plymouths. There was one obvious discrepancy when concrete pavements had faulted joints: This type of roughness was smoothed out by the new cars better than by the old cars.

Another problem that may have affected the PSR was the tendency of some rating teams to "zero in" on one member or on each other. If this was the case, then the PSR lost its validity as an unbiased sample of opinions. Raters probably were not aware of its happening since it can occur almost subconsciously. Practices that encouraged this were rating many projects consecutively without a break, having the driver call out his rating to be recorded by a passenger, or discussion of the project while rating.

Projects that were too long were difficult to rate accurately. There seems to be an "attention span" or maximum length of time during which a raters' attention is directed toward the business of rating. After the attention span is passed, a rater typically reaches the end of a ½-mile section and discovers that he does not remember what the first three-fourths of the ½ mile was like. He then either rates the last 500 ft or gives the section a rating that reflects the ride of the previous ½ mile. Also, in projects that are too long, there may be a definite change in the condition of the road. Projects should have been split up in these situations.

A problem occurred when a rater allowed himself to be affected by the visual condition of the road. As an example, a patch is associated with a bump or rutting with sidesway. A good patch, however, is smooth, and sometimes even severe rutting does not cause sidesway. Seeing a patch and associating it with a bump, a rater may "feel" a bump that in reality is not there.

It would seem that, if the rating system is to be an effective means of determining pavement condition, differences between any 2 rating teams on a given section of pavement should, in general, be within 0.3. To obtain this accuracy using a panel rating system would require more than 20 raters per district (Table 1). This of course is not practical.

It is felt that a considerably higher degree of uniformity of rating on a statewide basis could be attained if only one team rated the entire state. The values obtained could be significantly different from those obtained from the true PSR (Table 1), but the uniformity would be improved to the point that an acceptable relative measure of pavement condition would result. It would, of course, be almost impossible for one team to rate the 6,000 miles of pavement that were surveyed in the first year.

Because it was considered essential that a ridability factor remain a part of the condition rating, a more objective means of determining this factor, such as an electromechanical apparatus, was researched. It was felt that such an alternative method would give a reasonable estimate of true PSR, provide acceptable uniformity throughout the state, be economical, and not require an excessive amount of manpower.

RIDABILITY AS DETERMINED BY THE ROUGHOMETER

One device that was available for measuring ridability was the Minnesota roughometer. This device continuously records on tape the roughness of the pavement. Its operating speed, however, is only 20 mph, and there was only one such device available in the highway department. It would, therefore, be almost impossible to use this device for a program as extensive as that envisioned for the condition rating surveys. To purchase just one additional roughometer would cost in excess of $10,000. The need was for a rapid, inexpensive means for accurately and uniformly measuring pavement ridability.

RIDABILITY AS DETERMINED BY THE ROAD METER

The PCA road meter was evaluated on the basis of its ability to correlate with PSR. In an effort to better approximate true PSR, 6 raters were used in the correlation study. It was recognized that a significant error in PSR might occur when using 6 raters. However, this was all the manpower available at the time, and it was felt that a good indication of the road meter's ability to correlate with PSR would result. The road meter was installed in a 1966, 2-door, full-sized Ford (coil springs) for the evaluation.

A total of 26 sections of bituminous pavement having an estimated PSR range of 1.7 to 4.2 and 17 sections of concrete pavement having an estimated PSR range of 1.4 to 4.0 were rated by using both methods. The length of section varied from 0.5 to 5.0 miles. In most cases, both lanes of the roadway were rated, and each lane was considered to be one section.

The PSR determinations were, in all cases, made prior to use of the road meter to ensure that the road meter results would not influence the raters.

It was previously concluded that any acceptable means for determining riding quality must (a) be capable of giving a reasonable estimate of PSR, (b) provide satisfactory uniformity of rating on a statewide basis, (c) be reproducible, (d) not require excessive manpower, and (e) be economical.

The Road Meter Must Give a Reasonable Estimate of PSR

Figure 3 shows the relation between PSR and road meter summation of counts (Σ-counts) for all 43 projects rated. The curve was drawn by the freehand method. The standard deviation of 0.205 PSR indicates that the road meter is capable of making a reasonable estimate of PSR. It must be realized that PSR as shown in Figure 3 was determined by a 6-man rating team and that 10 percent of these values could be more than 0.5 from the true PSR. It is felt that increasing the number of members on the

Figure 2. Frequency distribution of PSR deviations between district and research raters.

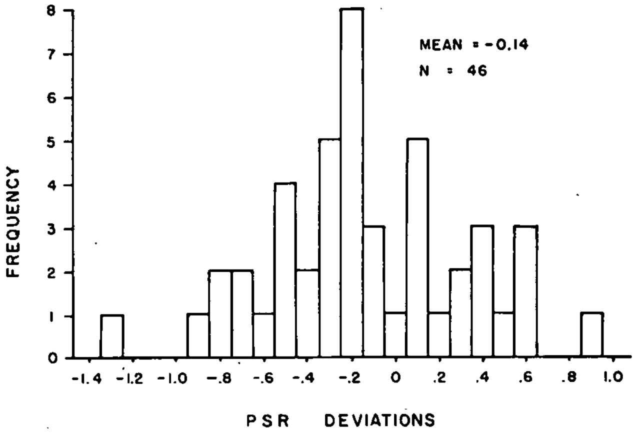


Figure 3. Correlation of PSR and road meter data (concrete and bituminous pavements).

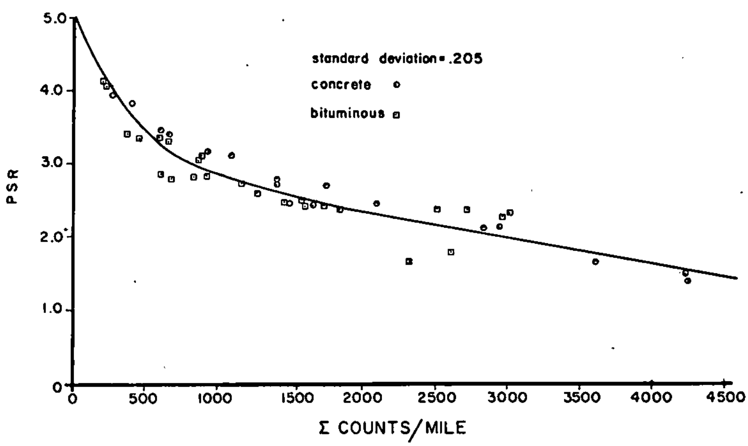


Figure 4. Correlation of PSR and road meter data (bituminous pavements).

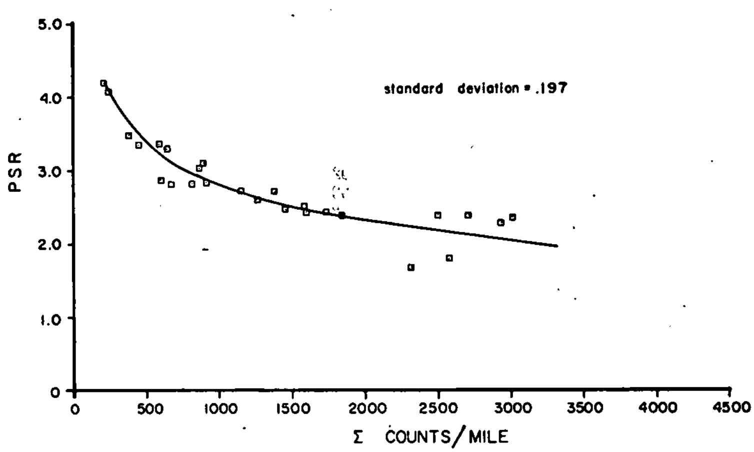


Figure 5. Correlation of PSR and road meter data (concrete pavements).

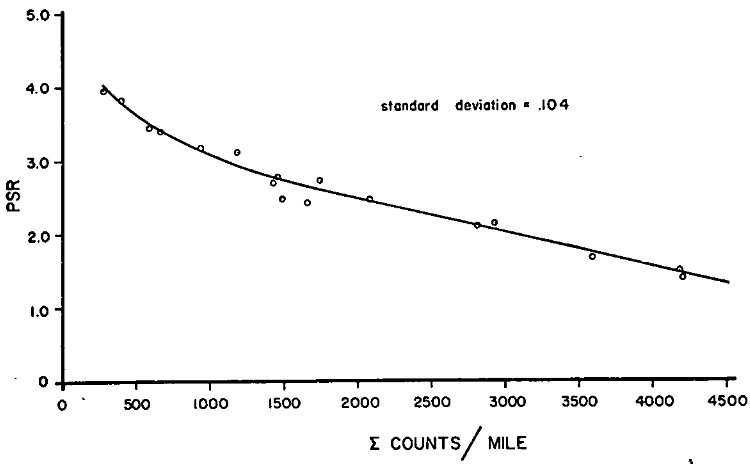


Table 3. Repeatability check of road meter.

Test Section	PSR Maximum	Average	Minimum	Range	Standard Deviation
1	1.50	1.33	1.21	0.29	0.09
2	1.64	1.58	1.54	0.10	0.03
3	3.28	3.20	3.10	0.18	0.04
4	3.38	3.26	3.20	0.18	0.05
5	2.52	2.50	2.48	0.04	0.01
6	2.52	2.50	2.46	0.06	0.02
7	2.79	2.71	2.65	0.14	0.05

Note: Tests made with 1966, 2-door, full-sized Ford (coil springs).

Table 4. Effect of type of tire on PSR as determined by road meter.

Test Section	PSR Standard Tires	Snow Tires	Difference
1	2.95	3.12	+0.17
2	3.15	3.20	+0.05
3	2.20	2.25	+0.05
4	2.40	2.30	-0.10
5	1.14	1.26	+0.12
6	1.40	1.58	+0.18

Note: Tests made with 1968, 4-door, full-sized Plymouth (leaf springs).

Table 5. Effect of vehicle speed on PSR as determined by road meter.

Test Section	Type of Pavement	PSR at 30 mph	Difference[a]	PSR at 45 mph	Difference[b]	PSR at 60 mph
1	Concrete	4.15	+0.05	4.20	-0.19	4.01
2	Concrete	2.55	-0.18	2.37	-0.21	2.16
3	Bituminous	4.22	-0.22	4.00	-0.30	3.70
4	Bituminous	4.05	-0.25	3.80	-0.44	3.36
5	Bituminous	4.50	-0.36	4.14	-0.29	3.85
6	Concrete	3.33	-0.33	3.00	-0.20	2.80
7	Concrete	3.75	-0.64	3.11	-0.58	2.53
8	Bituminous	4.15	-0.45	3.70	-0.23	3.47
9	Bituminous	3.08	-0.67	2.41	-0.27	2.14
10	Bituminous	4.62	-0.38	4.24	-0.34	3.90
11	Concrete	4.70	-0.50	4.20	-0.40	3.80
12	Concrete	3.50	-0.08	3.42	+0.05	3.47
13	Concrete	3.58	-0.26	3.32	-0.14	3.18
14	Bituminous	3.48	-0.16	3.32	-0.30	3.02
15	Bituminous	3.51	-0.16	3.35	-0.32	3.03
16	Bituminous	3.49	-0.28	3.21	-0.23	2.98
17	Concrete	2.31	-0.17	2.14	-0.27	1.87
18	Concrete	2.95	-0.35	2.60	-0.17	2.43
19	Concrete	2.10	-0.12	1.98	-0.17	1.81

Note: Tests made with 1966, 2-door, full-sized Ford (coil springs).

[a]Average difference is -0.30. [b]Average difference is -0.28.

rating team would, in general, tend to decrease the deviation between the road meter and PSR.

Figures 4 and 5 show the correlation between PSR and road meter results for bituminous and concrete pavements respectively. Plotting the results from the 2 types of pavement on separate curves improves the correlation as evidenced by the reduction in standard deviation (σ = 0.197 for bituminous pavements and σ = 0.104 for concrete pavements). Although correlation is improved only slightly for bituminous pavements, a significant improvement is noted for concrete pavements. It would seem, then, that use of 2 separate curves for the 2 types of pavements is advantageous.

The Road Meter Must Give Reproducible Results

Several factors were studied to see which would affect the reproducibility of the road meter output. Such things as tire type and pressure, automobile speed, automobile load, air temperature, wind velocity and direction, automobile type (make and suspension system), and changes in the condition of the automobile due to use were considered.

To check the repeatability of the road meter under the same conditions, we ran the device 5 times on 7 sections of pavement (bituminous and concrete) ranging from 1 to 4 miles in length. Table 3 gives the results of the repeatability check. As indicated, the road meter showed excellent repeatability under the same operating conditions. In fact, the maximum standard deviation found for any of the sections rerun was less than 0.10.

Once it was determined that the road meter results were reproducible under the same operating conditions, it was necessary to find what changes in operating conditions would affect the PSR as determined by the road meter. These were made as follows.

Type of Tire and Tire Pressure—Initial tests on 6 sections of roadway (bituminous and concrete) were made with standard 2-ply tires and winter 4-ply snow tires (all tires inflated to a pressure of 30 psi). The winter tires were only placed on the rear. Table 4 gives the results of the tire check. The data gathered indicate that there is no significant difference between the PSR's obtained with snow tires and those obtained with standard tires.

As for the effect of change in tire pressure, Brokaw (4, p. 8) stated that, for standard tires, tire pressure within the range of 24 to 26 psi had no significant effect on present serviceability index.

Based on the preceding information it was decided that standard tires should be used on the test vehicle. It was decided also that the tires and tire pressure should be kept the same as when the vehicle and road meter were calibrated. The tire pressure should be checked each test day when the tire is cold.

Speed of Automobile—To check the effect of vehicle speed on PSR as determined by the road meter, we ran tests on 19 sections of roadway (10 concrete and 9 bituminous) at 30, 45, and 60 mph. Table 5 gives the PSR's obtained at the different test speeds. Also given are the average differences in PSR's obtained between 30 and 45 mph and between 45 and 60 mph. The results indicate that vehicle speed does significantly affect PSR. The PSR dropped an average of 0.29 per 15-mph increment increase in speed. The variation was not uniform, however, because variation per individual section ranged from +0.05 to -0.67 per 15-mph increment increase in speed. The effect of vehicle speed on Σ-counts was studied by Brokaw (4), who found it to be significant also.

Ideally, the operating speed of the test vehicle should be the same as the posted speed limit because that is the speed that most vehicles travel and is the speed at which ridability is usually judged. However, having an operating speed equal to the posted speed limit is impractical because slow-moving traffic frequently causes a large reduction in speed (over 5 mph). It was decided that an operating speed equal to the posted speed limit minus 5 mph would be used. The allowable variation in operating speed, using the preceding information, was set at ±5 mph.

Load in the Automobile—Because of the short length of time available for evaluating the road meter, only a limited number of tests were made to determine what effect different vehicle loadings (amount of gas in tank, weight of equipment in trunk, and number of occupants in car) would have on PSR as determined by the road meter. Table 6 gives the results of the testing. Although only a limited number of tests were run, it appears that, except for the case of a passenger in the back seat, none of the other types of car loadings had any effect on the PSR. The variation found in test sections 1 through 4 appeared to be within acceptable limits.

Based on the limited information gathered from the vehicle loading tests it was decided that, when testing, no passenger would sit in the back seat, the gas tank would be at least one-quarter full, and there would be no more than 100 lb in the trunk (excluding spare tire and jack). Additional tests should be run to determine the effect of large weights in the back seat or trunk on PSR.

Air Temperature—Tests by Brokaw (4, p. 10) evaluate temperature effects. Low temperatures appear to significantly affect road meter results. This is probably due to changes in the operating characteristics of the shock absorbers and other vehicle components including tires.

After due consideration of this variable, it was decided that the road meter should only be operated at temperatures above 15 F. Also, before beginning the actual testing, the road meter should be turned on and the test vehicle driven several miles to allow all components to warm up and to check out the counters.

Wind Velocity and Direction—Effects of wind were also researched by Brokaw (4, p. 10). He found that the wind did not significantly affect the road meter PSR until it reached a velocity of 15 mph. He found that crosswinds of more than 15 mph were of the most concern because they can result in a change in the static reference position of the rolling contact of the road meter. He also indicated that head winds and tail winds are of less concern than crosswinds, but that no limits have been established. Although no actual data were accumulated on this variable, the results of Brokaw's tests were verified during the evaluation of the other test variables.

Based on Brokaw's findings, it was determined that the road meter should only be operated when the wind velocity is less than 15 mph regardless of the direction.

Type of Automobile—Automobile variability has gained most attention since the road meter came into use in Minnesota. In 1967, tests were run to correlate Σ-counts obtained using the road meter in a 1967 Plymouth with PSR as determined using the road meter in the 1966 Ford. The Plymouth was a full-sized, 2-door vehicle with leaf springs and heavy-duty suspension. Figure 6 shows the relation of Σ-counts and PSR for the 1967 Plymouth for both bituminous and concrete pavements. Based on this limited amount of test data, it was determined that the 1967 Plymouth could not be used as the test vehicle. As indicated in Figure 6, between a PSR of 4.0 and 3.0 there is a difference of less than 300 in the Σ-counts. The road meter probably cannot discriminate between a 4.0 road and a 3.0 road with any accuracy. Likewise, toward the other end of the curve, there is an extremely large range in Σ-counts for a corresponding small range in PSR. Such a relation between PSR and Σ-counts was determined to be unacceptable.

Also in 1967, 10 road meters were built and installed in 1966 Fords (all were 2-door, full-sized vehicles with coil springs). This allowed an evaluation of the variability between identical vehicles. One meter (laboratory) was calibrated with panel ratings. The other 9 meters were then calibrated to a PSR determined using the laboratory meter, and correlation curves were drawn for each of the 10 road meters. Table 7 gives a comparison of the correlation curves at 7 different Σ-counts. Although the car-to-car standard deviations at the various Σ-counts do not show great variation (although the differences might be significant), it is obvious that there is a need for individual calibration of meters even though they are installed in identical automobiles.

During 1968, because it was anticipated that the road meter vehicle (1966 Ford) would be exchanged for a 1968 vehicle (Chevrolet or Plymouth), tests were run to correlate PSR obtained by using the road meter in the 1966 Ford with Σ-counts using the 2 other vehicles. The Chevrolet was a full-sized, 2-door vehicle with coil springs.

Table 6. Effect of various car loadings on PSR.

Test Section	Gas Tank Level	Number of Passengers[a]	Location of Passengers	Weight in Trunk (lb)	PSR
1	Full	1	Front seat	100	1.80
1	Full	1	Front seat	0	1.84
1	¾	1	Front seat	0	1.84
2	Full	1	Front seat	100	2.40
2	Full	1	Front seat	0	2.43
2	¾	1	Front seat	0	2.45
3	Full	1	Front seat	100	2.30
3	Full	1	Front seat	0	2.33
3	¾	1	Front Seat	0	2.42
4	Full	1	Front seat	100	1.82
4	Full	1	Front seat	0	1.82
4	¾	1	Front seat	0	1.85
5	Full	1	Front seat	0	3.55
5	Full	1	Back seat	0	3.65
6	Full	1	Front seat	0	3.00
6	Full	1	Back seat	0	3.15

Note: Tests made with 1966, 2-door, full-sized Ford (coil springs).
[a]Does not include driver.

Figure 6. Correlation of PSR and road meter data using 1967 Plymouth.

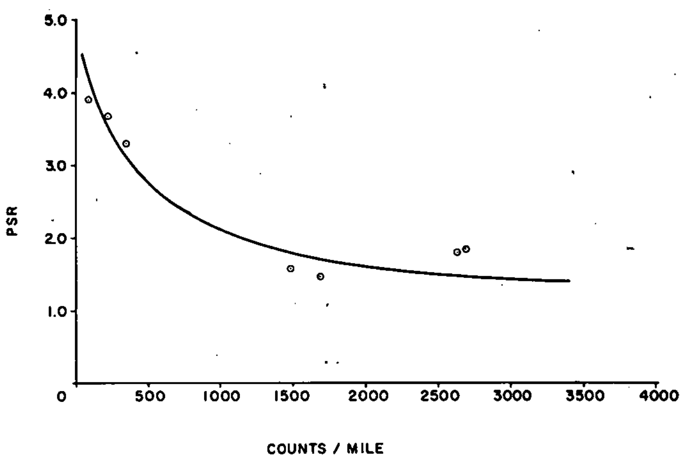


Table 7. Comparison of PSR's (concrete pavements).

Σ-counts[a]	PSR Value by Vehicle[b] Laboratory	1	2	3	4	5	6	7	8	9	Average	Standard Deviation	Range
500	4.30	4.29	4.05	4.47	4.45	4.33	4.48	4.43	4.35	4.25	4.34	0.13	0.43
1,000	3.65	3.65	3.45	3.95	3.90	3.66	3.96	3.92	3.70	3.54	3.74	0.18	0.51
2,000	2.77	2.67	2.61	2.90	2.83	2.65	3.00	3.03	2.70	2.60	2.78	0.16	0.43
3,000	2.20	2.00	1.96	1.98	2.17	2.15	2.21	2.39	2.10	2.07	2.12	0.13	0.43
4,000	1.82	1.54	1.51	1.50	1.75	1.76	1.62	1.90	1.68	1.67	1.68	0.14	0.40
5,000	1.54	1.18	1.17	1.29	1.42	1.45	1.25	1.54	1.36	1.36	1.36	0.13	0.37
6,000	1.26	0.90	0.89	1.08	1.16	1.20	0.95	1.22	1.11	1.11	1.09	0.13	0.37

[a]Same type of counter was used in all vehicles. [b]All vehicles were 1966 Fords with standard suspension and standard shock absorbers.

The Plymouth was a full-sized, 4-door vehicle with leaf springs. Figures 7 and 8 show the relation of PSR and Σ-counts determined by using the road meter in the 1968 Chevrolet. Both figures show an acceptable relation. Figure 9 shows a curve relating PSR and Σ-counts on bituminous roads determined by using the road meter in the 1968 Plymouth. The reason that the 1968 Plymouth was an acceptable test vehicle and not the 1967 Plymouth is not known, but it was probably due to the fact that the 1967 car had heavy-duty suspension.

In 1969, road meters were installed in six 1969 Fords of identical model and suspension system. This again allowed a comparison of PSR's at the same road meter outputs for identical automobiles. The results are given in Table 8. The results again show that there is a need for individual calibration of road meters even though they are installed in identical cars.

Some work has been done to evaluate the effect of standard versus heavy-duty suspension systems on road meter PSR. As mentioned earlier in this report an attempt was made in 1967 to correlate PSR with Σ-counts obtained by using a road meter installed in a 1967 Plymouth having heavy-duty suspension. The test results (Fig. 6) indicated that the Plymouth could not be used as the test vehicle because the slope of the curve in the figure was too steep at the top and too flat at the bottom. The slope of the curve made it difficult to differentiate between roads with PSR's ranging between 4.5 and 3.0 and between 2.0 and 1.0. Additional testing of this type was done in 1970. A comparison was made between a 1969 Ford with heavy-duty suspension and a 1970 Ford with standard suspension. The PSR's obtained with the same Σ-counts for both vehicles are given in Table 9. There is a noticeable difference between the PSR's with the same Σ-counts for both automobiles. However, curves were drawn relating PSR to Σ-counts for both vehicles, and both were determined to be acceptable. The heavy-duty suspension in the 1969 Ford reduced the movement between the rear-axle housing and the vehicle body, especially on smooth roads. As the roads became rougher, the road meter outputs also got closer and in fact equaled each other at a PSR of about 1.5 on bituminous roads and 1.0 on concrete roads.

As a result of all of the testing, it was determined that, to ensure that an acceptable correlation exists between PSR and Σ-counts for any combination of road meter and test vehicle, the combination must be calibrated individually with the laboratory road meter. The laboratory road meter is calibrated to panel PSR each spring. Although heavy-duty suspension apparently can be used in a test vehicle (correlation check must be made), it is recommended that standard suspension be used because it is more responsive to pavement roughness.

Condition of Test Vehicle—Although no testing was done to evaluate the effect of the deterioration in vehicle condition on road meter output, it is reasonable to assume that there is some significant effect.

To avoid any change in road meter output due to deterioration in vehicle condition, the suspension system, shock absorbers, and tires must be maintained in excellent condition. Each spring the shock absorbers should be replaced, the tires should be balanced dynamically and checked for roundness, the front end should be in good alignment, and any vibrations that may interfere with obtaining accurate PSR's must be corrected. New vehicles, the same model for each district and the central laboratory, should be obtained every 3 years.

If repairs are to be made on the test vehicle, the following procedures should be used:

1. Select 2 sections of pavement, one having a high PSR and one having a low PSR.
2. Run the road meter on both sections before and after repairs. The Σ-counts obtained on each section should be an average of a minimum of 2 runs. The values of the runs should be within 0.1 PSR of each other.
3. If the difference in PSR of either pavement is more than 0.2 PSR, return the vehicle and road meter to the central office for recalibration.

In order to make a calibration check of the road meter and test vehicle, a calibration check course consisting of at least 5 sections of pavement should be established within each district. These pavements should be constructed such that little change

Figure 7. Correlation of PSR and Σ-counts using 1968 Chevrolet (concrete pavements).

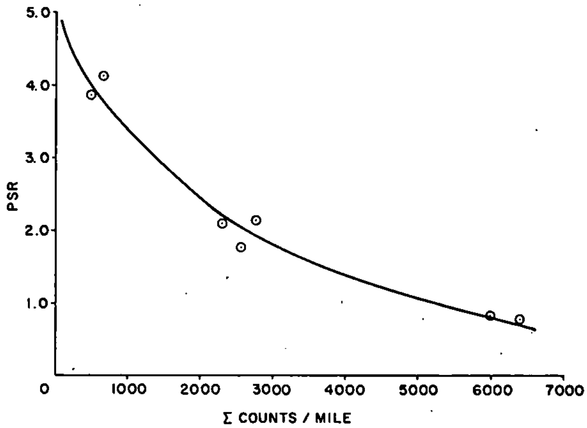


Figure 8. Correlation of PSR and Σ-counts using 1968 Chevrolet (bituminous pavements).

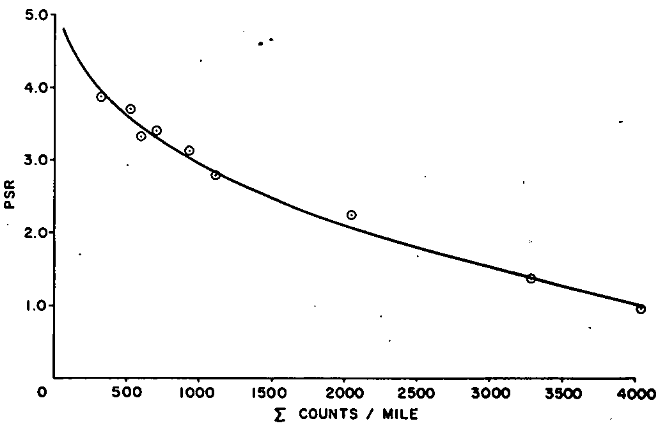
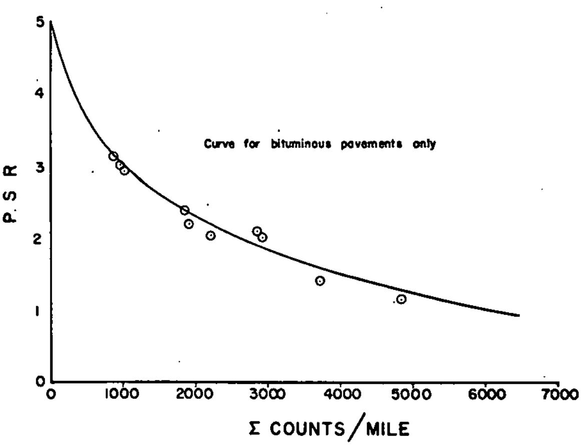


Figure 9. Correlation of PSR and Σ-counts using 1968 Plymouth (bituminous pavements).



in roughness is expected. The course should be run immediately after initial calibration and periodically thereafter to ensure that initial calibration is maintained. The initial calibration should be established from an average of a minimum of 2 runs on each section, provided that the PSR values are within 0.1 unit of each other. If the calibration check rating on at least 2 of the sections is within 0.2 PSR of the initial rating, calibration is acceptable. If the difference in rating of 4 of the sections is more than 0.2 PSR, a check for road meter malfunctions as well as deterioration in test vehicle condition should be made. Both the road meter and the test vehicle should be taken to the central office for recalibration.

The methods previously outlined to keep the road meter within calibration and to ensure reproducible results have worked satisfactorily so far. To cite an example, during the fall of 1968 one construction district ran its road meter over newly completed construction projects that were to be considered for the merit award program. The resulting PSR's were very low, considering the age of the projects. Because the district claimed that its road meter checked closely with its calibration check course, it was felt that there was an error in the testing procedure or something was wrong with the car.

The central office road meter vehicle was sent to the district to drive over the district calibration check course. The results were that the laboratory car indicated PSR's as much as 0.8 higher than the district's car.

In November 1968 a check was made in the metropolitan area with the district equipment. First, the laboratory meter was used in the laboratory vehicle, which was driven on 2 sections of bituminous road that had a significant difference in PSR. The district road meter was then placed in the laboratory car, which was driven over the same 2 sections. The results showed no significant difference (PSR of 0.1) in road meters. Next, the district's car and road meter were run on the same 2 sections of road. This combination showed a significantly lower PSR.

During testing it was observed that the district's car developed a shimmy in the front end at speeds of more than 55 mph. A check of the car repair records showed that this problem had been occurring regularly without any permanent repair having been made. This problem probably explains the reason for a greater difference in PSR at higher speeds. Therefore, a list of suggested repairs was submitted to the district in the hope that they would make the needed corrections for future ratings. The repairs were made before the 1969 rating season, and, although there were no checks made, the problem appeared to have been corrected.

In addition to all of the preceding factors, which were evaluated to determine their effect on road meter output reproducibility, several other variables were at least taken into consideration. These included effects of digital counter sensitivity, spring tension, and pretest adjustments. Although no formal evaluation was made of these variables, they were checked and are covered, as well as all of the other factors, in the operating instructions for the PCA road meter in the Appendix.

The Road Meter Must Provide Satisfactory Uniformity of Rating on a Statewide Basis

It was obvious that, if the mileage rated in 1966 by the panels from each district (6,379 miles) was typical of the mileage to be rated in future years, more than one road meter would be required. Therefore, a total of 10 devices were employed. One was located in each of the 9 construction districts for rating pavements in that district. The remaining road meter was controlled by the office of materials, and, as a master, was used for calibration of the other devices.

In 1967 the master road meter was correlated with PSR on both bituminous and concrete pavements. Twelve raters were used for the PSR determinations to ensure that true PSR would be approached (Table 1). A total of 28 sections of bituminous pavement and 15 sections of concrete pavement were used for this correlation.

A calibration course, consisting of 8 concrete and 7 bituminous pavements, was laid out, and each district road meter was calibrated against the master road meter. It was felt that in this way a high degree of uniformity in PSR would result among districts.

Probably the best indication of the actual uniformity of the rating system is a comparison of the standard errors between the laboratory vehicle and each of the district vehicles. Table 10 gives such a comparison for bituminous and concrete pavements using the data collected in the 1969 calibration of district road meters.

In 1969 the "pooled" standard error and standard deviation of the standard error were 0.17 and 0.07 for bituminous pavements and 0.16 and 0.05 for concrete pavements. This means that there is a 95 percent probability that a single test of PSR determination on a bituminous pavement, using any 1 of the district road meters chosen at random, will be within 0.31 of the PSR determined using the laboratory road meter. Similarly, there is a 95 percent probability that a PSR determination on a concrete pavement will be within 0.26 of the PSR determined using the laboratory road meter.

The standard error between laboratory vehicle and panel PSR was 0.26 and 0.19 for bituminous and concrete pavements respectively. However, if we were to assume that the PSR determined using the laboratory road meter is the true PSR, we can, using the results of Nakamura and Michael (3), determine the number of raters required to get the same uniformity that we expect to get with district road meters. At the 95 percent probability level, we can expect to be within 0.31 and 0.26 of the true PSR on bituminous and concrete pavements respectively (PSR determined using the laboratory road meter). The results of the Purdue study (Table 1) indicate that, at the 95 percent probability level, it would take about 31 raters to be within 0.3 of the true rating. In other words, using a district road meter in 1969 was as good as using a rating panel consisting of 31 people. This degree of uniformity is quite high and results in a much better rating system than the one (3-man panels) used at the outset of this study.

The Road Meter Must Not Require Excessive Manpower

The road meter can be effectively operated by 1 man. It requires no manipulation during operation, and, except for an occasional glance at the counters to see that the device is functioning properly, the operator can devote full time to driving.

The Road Meter Must Be Economical

The cost of building the 10 road meters now in service (one for each construction district and one for the central laboratory) was about \$3,760 or \$376 per road meter. Materials accounted for approximately \$214 per device with labor costing the remaining \$162.

Because only 1 man is required to determine PSR with the road meter, the time of 2 men can be saved over the normally used 3-man rating team. In 1966 approximately 6,379 miles of pavement were rated. This averages out to about 700 miles per district. If we assume that each district rating team rated 700 miles of road at an average rating speed of 50 mph and also that each team drove an additional 1,000 miles going to and from the roads to be rated at an average speed of 50 mph, than the man-hours saved per district would be as follows: 1,700 miles/50 mph x 2 men = 68 man-hours. If we use \$6 per hour as the average salary (rater's were H.T. III's, CE II's, CE III's, or CE IV's), the savings per district per year would be at least \$6 per hour x 68 man-hours = \$408. The maintenance costs of the road meter are quite low. If we assume a maintenance cost of \$25 per year, the road meter would pay for itself in about 1 year: construction and maintenance costs = \$401; annual road meter saving = \$408.

CONCLUSION

Based on the results of the evaluation of the PCA road meter, it can be concluded that the road meter is superior to the normal 3-man rating team as a method of determining riding quality. The road meter provides a uniformly accurate determination of PSR at a cost that compares favorably with the rating team method.

Table 8. Comparison of PSR's using 1969 Fords (bituminous pavements).

	PSR Value by Vehicle[a]								
Σ-counts	Laboratory	1	2	3	4	5	Average	Standard Deviation	Range
150	3.75	3.80	3.68	3.78	4.01	3.91	3.82	0.12	0.33
500	3.11	3.13	3.03	3.13	3.30	3.22	3.15	0.09	0.27
1,500	2.52	2.53	2.45	2.55	2.67	2.60	2.55	0.08	0.22
2,500	2.25	2.25	2.18	2.30	2.36	2.31	2.28	0.06	0.18
3,500	2.07	2.07	2.00	2.11	2.17	2.13	2.09	0.06	0.17

[a]All vehicles were 1969 Fords with heavy-duty suspension and heavy-duty shock absorbers.

Table 9. Comparison of PSR's, 1969 and 1970 Fords.

	PSR Value by Vehicle			
Σ-counts	1[a]	2[b]	3[c]	4[d]
150	4.46	5.0	3.75	5.0
500	3.51	4.49	3.11	4.0
1,500	2.65	3.22	2.52	3.05
2,500	2.25	2.63	2.25	2.63
3,000	1.99	2.24	2.07	2.34

[a]1969 Ford with heavy-duty suspension on concrete pavement.
[b]1970 Ford with standard suspension on concrete pavement.
[c]1969 Ford with heavy-duty suspension on bituminous pavement.
[d]1970 Ford with standard suspension on bituminous pavement.

Table 10. Comparison of standard errors between laboratory vehicle and each district vehicle.

	PSR Standard Error by District Vehicle[a]											
Type of Pavement	1	2	3	4	5	6	7	8	9	Average	Standard Deviation	Range
Bituminous	0.18	0.10	0.25	0.13	0.16	0.27	0.22	0.11	0.09	0.17	0.07	0.18
Concrete	0.25	0.12	0.20	0.11	0.11	0.12	0.22	0.19	0.13	0.16	0.05	0.12

[a]District vehicles were 1966 Fords with standard suspension except for district 8 vehicle, which was a 1969 Ford with heavy-duty suspension.

Figure 10. Present serviceability rating form.

Trunk Highway ________ Control Section ____________ Lane Surveyed ________ Date ____________

Begin Survey ____________________________ End Survey ______________________ Driver ____________

Tire Pressure ________ Temperature ________ Ave. Speed ______ Length __________

Counter No.	Counts	Factor	Product	Notes
1		1		
2		2		
3		3		
4		4		
5		5		
6		6		
7		7		
8		8		
9		9		
10		10		
11		11		
		Σ =		

Σ/Length = PSR =

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APPENDIX

GUIDELINES FOR USE OF PCA ROAD METER

These instructions have been prepared to ensure uniform and proper use of the PCA road meter for determining pavement ridability by the pavement rating teams in the construction districts. Contained herein is a list of the requirements of the vehicle in which the road meter is mounted, an outline or check list of the procedures for operation, and sections on preventing, recognizing, locating, and correcting malfunctions.

To ensure uniformity of rating by the 9 separate road meters that will be used throughout the state, it is imperative that each operator be completely familiar with and rigidly follow the instructions herein.

Vehicle Requirements

1. The vehicle in which the road meter is mounted must be in excellent condition with standard suspension, shock absorbers, and tires. Each spring the shock absorbers should be replaced (check part numbers to ensure shocks are not heavy-duty type), the tires should be balanced dynamically and checked for roundness, the front end should be in good alignment, and any vibrations that may interfere with obtaining accurate PSR's must be corrected. New vehicles, the same for each district and the office of materials, should be obtained every 3 years. This can be coordinated through the equipment section and the materials section.

2. If so desired, the road meter may be removed from the vehicle when the vehicle is to be used for purposes other than pavement rating.

3. If it is necessary to use the road meter in a vehicle other than the one in which it was calibrated, the road meter and new vehicle must be brought into the central office for calibration. The office of materials will provide a calibration and troubleshooting service.

4. If any repairs are to be made on the vehicle or road meter which may affect results, the procedure listed below should be followed:

   a. Select 2 sections of pavement—one having a relatively high PSR and the other a relatively low PSR.

   b. Use the road meter on both sections both before and after repairs. The number of counts obtained on each section should be an average of a minimum of 2 runs. The values of these runs should be within 0.1 PSR of each other.

   c. Compare the road meter results before and after repairs for each pavement. If the difference in PSR of either pavement is more than 0.2 PSR, the vehicle and road meter should be brought back into the central office for recalibration.

5. The road meter should be used only when the vehicle gas tank is at least one-quarter full.

6. The vehicle should have no more than 100 lb (excluding spare tire and jack) in the back seat or trunk when the road meter is being used.

7. Tire pressure shall be checked and maintained at the same pressure as when the vehicle and road meter were calibrated. Readings shall be made when the tire is cold.

Road Meter Operation

1. Insert the locking pin to hold rolling contact plate to aluminum track. Pull cable chain to attaching bolt on contact plate, taking care that all slack in the cable is removed, and note the "normal fit." Proper hookup is normal fit minus one link. The locking pin must be removed before making proper hookup. Connect the tension spring to the eyebolt.

2. Insert the single plug of the electrical cable into the receptacle on the counter box. Insert the 2 plugs on the other end of the cable into the appropriate receptacles of the switch assembly.

3. Turn on the road meter and drive for several miles to allow all components to warm up and to check counters 1 through 10 with number 11 counter.

4. Prior to rating, stop the car and make sure it is on a relatively level surface that is similar in crown to the pavement to be rated. Put car in parking gear. With the driver and passenger (if there is one) seated where they will be during rating, make use of the vernier dial and the indicator light to move the switch plate until the center segment is directly under the rolling contact. Turn meter off and make sure counters are zeroed. The road meter is now ready for use.

5. Select starting point of section of highway to be rated. Get up to operating speed (5 mph less than posted speed limit) ahead of starting point. At starting point switch road meter on and accurately note odometer reading. Drive the project at 5 mph less (±5 mph) than the posted speed limit. At the end of section being rated, switch road meter off and at the same time accurately note odometer reading. Determine length by taking the difference between beginning and ending odometer readings and record on the rating form.

6. The road meter should be turned off just before railroad crossings and bridge decks and turned on again after passing over the crossing or deck.

7. If at any time the speed of the automobile varies more than 5 mph from the speed limit minus 5 mph, the road meter will be turned off, the odometer reading recorded, and a landmark at the point of termination will be noted. Without zeroing the counters, rating can be resumed when the proper speed can be attained at the point of termination.

8. After the project is rated, stop the car on a relatively level surface that is similar in crown to the pavement just rated. Turn on the road meter. If the rolling contact is not on the center segment (indicator light off), the entire project must be run again. If the meter is still zeroed (indicator light on), proceed to the next step.

9. Record the readings on each counter in the appropriate column on the rating form.

10. Determine Σ-counts by adding the products of the readings on each counter and the appropriate counter number (Fig. 10).

11. Determine and record the PSR using the appropriate curve.

12. If the operator feels there is a large discrepancy between PSR determined from the appropriate curve and what he actually noted while performing the test, the project should be run again. (Example: a new project that should have a PSR of about 4 recording a PSR of 2.5 or 2.9.) If the discrepancy continues after a recheck, the road meter should be checked for a malfunction. If no malfunction is found, call the office of materials.

13. If more than 20 miles is to be driven before rating again, disconnect tension spring, disconnect cable, and insert hold-down pin.

Malfunctions

1. Preventing malfunctions: The following procedures should be observed to ensure a minimum number of malfunctions and erroneous readings.

a. Prior to each rating the road meter should be "warmed up" by operating for several miles.

b. Each day the effective unstressed length of the tension spring should be determined. The spring should be replaced once the unstressed length is more than $4^3/_4$ in. and must be replaced before the unstressed length reaches 5 in.

c. When connecting the cable to the plate, one must be sure to remove the hold-down pin before connection is made. Any substantial movement of the car body with respect to the axle, while the pin is still in place, may cause the cable to break.

d. The road meter shall not be used if the wind velocity is more than 15 mph or the air temperature is below 15 F.

e. A calibration check course consisting of at least 5 sections of pavement should be established within each district. These pavements should be such that little change in roughness is expected. The course should be run immediately after initial calibration and periodically thereafter to ensure that initial calibration is maintained. The initial calibration should be established from an average of a minimum of 2 runs on each section, provided that the PSR values are within 0.1 of each other. If the calibration check rating on at least 2 of the sections is within 0.2 PSR of the initial rating, calibration is acceptable. If the difference in rating of 4 of the sections is more than 0.2 PSR, the road meter and vehicle should be taken to the central office for recalibration.

2. Recognizing malfunctions: To ensure that results obtained with the road meter are representative of the pavements' ridability, the operator must be able to recognize erroneous readings when and if they occur. In general, the most successful method of determining if a malfunction has occurred is to observe the readings on the counters after a project has been run. The relative number of counts on the various counters should be such that the following conditions are met. Failure to do so indicates a possible malfunction and will result in an erroneous reading.

a. If at least 50 counts have been accumulated on a counter, the total count on that counter should be less than the count on every lower numbered counter.

b. If at least 100 counts have been accumulated on a counter, the count on that counter should be no more than 80 percent of the count on the next lower numbered counter.

c. Regardless of count, no counter should have over 3 counts more than any lower numbered counter.

3. Locating and correcting malfunctions: Once it is recognized that a malfunction exists, it is then necessary to locate the problem so that corrective action can be taken. The following procedure, if followed, will result in locating and correcting most malfunctions. After the operator is satisfied that all connections between the road meter and counters are secure, the electrical power is turned on; while the car is in a static position, the switch plate is moved so that the rolling contact makes contact with each segment. As contact is made, observe if the appropriate counter is activated.

a. If all counters record properly, the meter should be rezeroed and the projects rerun.

b. If one or more counters record properly only when the rolling contact is on one side of the center segment, then the malfunction is in the wiring encapsulated within the sealer alongside the switch plate.

c. If one or more counters fail to function properly, regardless of which side of center the rolling contact is located, then use the rotary switch to switch the number 11 counter to the counter number in question. If the counter numbered 11 does not function when the rolling contact is on the proper segment, the malfunction is in the electrical wiring and can be located by using an electrical continuity tester. If the counter numbered 11 functions properly when switched to the counter number in question, then the counter number in question is defective, and the following procedure should be carried out:

(1) Remove cover of counter box by removing 4 screws on side;

(2) Check to see that electrical connection of counter in question is intact;

(3) If the connection is good, remove the red wire from the terminal, and cut the black wire as far away from the counter as possible;

(4) Send the defective counter to the office of materials for repair; and

(5) Use the number 11 counter as a substitute for the defective counter by using the rotary switch. It is then necessary to operate without a number 11 counter. The counts for the number 11 counter will be estimated to be one-half of the counts on the number 10 counter and will be recorded as such.

d. If 5 or more counters indicate a consistent "skipping" tendency (e.g., 2 or 3 counters each having the same total number of counts), then examine the road meter to be sure that the grid plate contact strips and the switch plate rolling contact are clean. Steel wool or emery cloth can be used for cleaning.