USE OF THE PCA ROAD METER IN THE WASHINGTON PAVEMENT CONDITION SURVEY SYSTEM

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In 1965 Washington State developed a new system for evaluating the condition of pavements for use in programming future reconstruction or rehabilitation. Basically, the method involves the cataloging of the extent and severity of pavement distresses and an evaluation of the ridability of the pavement. Each of the 4 statewide surveys that have been performed to date have been by teams that were trained in the elements of the system and then were "calibrated" to achieve a uniformity of ratings.

Although this method has served to provide comparative rankings of pavements that were generally accepted by all concerned, it was believed that more accurate ratings would result if the subjective "seat-of-the-pants" ride rating could be supported by a more objective method of pavement smoothness evaluation. A possible answer to this problem was presented by the introduction of the PCA road meter (1).

The PCA road meter, developed by Brokaw, is basically an electrical-mechanical instrument for measuring a vehicle's reaction to the roadway while traversing the pavement at speeds up to 65 mph. The element of measurement is the vertical deviation of the rear axle from the body of the vehicle as the rear wheel and axle assembly is activated by pavement roughness. In the development of this apparatus, it was calibrated against the CHLOE profilometer, which was used in determining the present serviceability of pavement test sections in the AASHO Road Test. This calibration provided a means for converting the road meter results to a present serviceability index (PSI) for any pavement tested.

In 1968 a road meter was lent to the Materials Laboratory for familiarization and evaluation. The instrument was installed in a 1968 Ford Custom sedan. As experience was gained with the characteristics of the instrument, its potential in our pavement condition rating system was recognized, and the decision was made to purchase a PCA road meter for inventory use. However, the original manufacturer of the instrument had ceased production, but it was soon learned that a California manufacturer was working on a modified version of the PCA road meter.

THE MODIFIED PCA ROAD METER

In our use of the original road meter, we recognized several shortcomings in the instrument's performance with regard to inventory work. To overcome these deficiencies, we discussed several improvements with the California manufacturer, which were included in the specifications for the instrument that was ordered. The modifications by which more efficient use of the road meter would be obtained included the following:

1. Dual sets of counters—In the Washington Pavement Condition Rating System (WPCRS), pavement segments that range in length from 0.1 to 1 mile are rated. With one bank of counters, it would be necessary to stop at the end of each segment, record the results from the counters, reset them, and either back up sufficiently to reach the next rating section at test speed or rate alternate test sections and make duplicate

passes over the pavement. Dual sets of counters eliminated the need for this duplication.

2. Accurate odometers coupled to the counters—Because the derived readings from the road meter are counts per mile, the accuracy of the results are improved by the use of electrical odometers reading to 0.01 mile, which are connected through one switch to each bank of counters.

3. Automatic remote zeroing—The original version of the PCA road meter required that the test vehicle be stopped on the level and out of gear when the meter was zeroed. The zero point shifts on the contact plate with any change in the load distribution in the test vehicle. One consistent cause of shifting during testing is the amount of gas in the gas tank. With automatic remote zeroing through a small servomotor, it is possible to zero the instrument while the vehicle is in motion by observing the indicator lights on the counter console.

4. Multiple readout capability—With the dual banks of counters, switching arrangements were provided to permit counting on either bank alone, both banks simultaneously, or the accumulation of all counts to one side of zero on one bank and all counts to the opposite side of zero on the other bank. This last capability was included to see if different causes of pavement roughness could be distinguished by the type of reaction imparted to the test vehicle.

The manufacturer of the instrument also had made several modifications to the original PCA road meter, which he had been including in instruments made for other purchasers. The most significant of these were in the translator contact assembly and the linkage between the axle housing and the translator.

The translator assembly was moved into the trunk of the test vehicle and mounted vertically. The contact plates were made for easy replacement when the contact ribbons become worn enough to cause a significant change in contact spacing.

The connecting linkage was made from a solid rod as compared to the chain used on the original model. This resulted in a much more positive response by the instrument to any roadway roughness; i.e., reaction time of the chain-spring arrangement on the original meter permitted a certain amount of relaxation on any sudden axle movement, which the solid connection does not allow.

CALIBRATION OF MODIFIED ROAD METER

The modified PCA road meter was received from the manufacturer in August 1970 and installed in the same 1968 Ford Custom sedan as used for the original road meter.

The first study with the new meter was an attempt to correlate test results between the old and new meters by testing a number of miles of roadway that had been tested with the old meter. This soon revealed that the characteristics of the 2 instruments were sufficiently different that direct correlation was not practical. Efforts were then concentrated on familiarization and evaluation of the new meter.

The road meter is affected by many variables, of which only 3 have significant influence on test results for discussion in this report. They are wind velocity, vehicle speed, and vehicle suspension changes.

Initial calibration experiments with the new road meter pointed out the need for alterations to the vehicle's suspension to eliminate excessive vibration and sidesway. The situation was remedied by the installation of new heavy-duty shock absorbers on all 4 wheels and a complete front-end alignment that included wheel balancing. Steel-belted radial tires were also installed for improved uniformity. A number of measurements were repeated on sections that had previously been measured prior to suspension modifications. The results are shown in Figure 1. The scatter of results and correspondingly low coefficient of correlation are indicative of the influence of the running gear on the vehicle. The measurements were made on both asphalt concrete (AC) and portland cement concrete (PCC) pavements having a range of roughness characteristics.

The next variable investigated was the effect of wind. A number of sections of roadway were repeatedly measured with the road meter under different wind conditions and the results compared. Three sections of road were chosen as test sites: 2 on Interstate 5 and 1 on a county road in the Olympia area. The Interstate sections were essentially north-south routes having less than average roughness, and the county road section was essentially an east-west route having more than average roughness. Wind measurements were made prior to each run with a hand-held floating-ball-type wind gauge. Wind conditions varied from zero wind to a steady 10- to 12-mph wind with gusts to 25 mph. It was concluded from the results that a steady wind has little effect on the count rate, but that a gusty wind increases the count rate in proportion to the number and magnitude of the gusts. Isolation of the exact count-rate increase with wind speed was not attempted because of the time and variables involved in such a study, but it may be sufficient to recommend that road meter measurements be ceased when the test vehicle is perceptively rocked back and forth by the wind during testing.

The remaining variable examined was vehicle speed. A series of readings was taken at 30, 40, and 50 mph on the same mile sections of road, and the average count rates for each mile at each speed were compared. The route included various pavement types and varied roughness. The results indicate a general decrease in counts as the speed of the test decreased. A greater count decrease was noted in going from 50 mph to 40 mph than from 40 mph to 30 mph. The equation for the relation between counts per mile at 50 mph and counts per mile at 40 mph is $C_{50} = 1.15\ C_{40} + 36$, where C_{50} is the count at 50 mph and C_{40} is the count at 40 mph. A similar equation written for 30 mph is $C_{50} = 1.17\ C_{30} + 75$, where C_{30} is the count at 30 mph and C_{50} is the count at 50 mph. These equations appear to be valid regardless of pavement type or roughness.

In summary, the following conclusions can be stated based on our research:

1. A change in the suspension of the test vehicle can have a large effect on the count rate of the road meter;
2. The counts per mile of any particular section of roadway decrease in a linear function as the speed of the test vehicle decreases; and
3. The counts per mile of a particular section of roadway will be influenced by wind gusts that strike the vehicle during the test, and testing should not be attempted under conditions of gusty or strong winds.

COMPARISON OF ROAD METER AND SUBJECTIVE RIDE RATINGS

In the development of the original PCA road meter, the instrument was calibrated against the CHLOE profilometer (6, 10, 14), and therefrom a relation between count and present serviceability was developed. To go back a little further, the CHLOE-present serviceability relation was developed by comparing the subjective evaluations by a panel of raters with the results obtained with the CHLOE profilometer on the same sections of pavement.

As stated previously, an integral part of the WPCRS is the subjective ride rating. During the 1971 WPCRS survey, all pavement smoothness evaluations were made both by subjective ride ratings and with the modified road meter. These dual ratings furnished an excellent sample for comparison and analysis and, in effect, provided a basis for standardization quite similar to that used to calibrate the original PCA road meter.

In our analysis, 10,082 individual ratings were reviewed; from these it was decided that, with the large number of observations, good representation could be obtained for the AC pavements by including only the rated segments of 1 mile in length. Because of the fewer number of observations available, the rated segments of PCC pavements of ½ mile or more in length were included. As any rated section is shortened, the accuracy of rating is subject to a higher percentage error, both in the subjective ride rating and the road meter count.

After evaluating the road meter for effects from wind, speed, and vehicle suspension system, we repeatedly traversed a number of sections of pavement to determine the variations within the instrument. Typical results are given in Table 1. These were run over a period of time after the test vehicle characteristics were stabilized with new heavy-duty shock absorbers, radial tires, wheel balancing, and so forth.

Figure 1. Comparison of old and new shock absorbers.

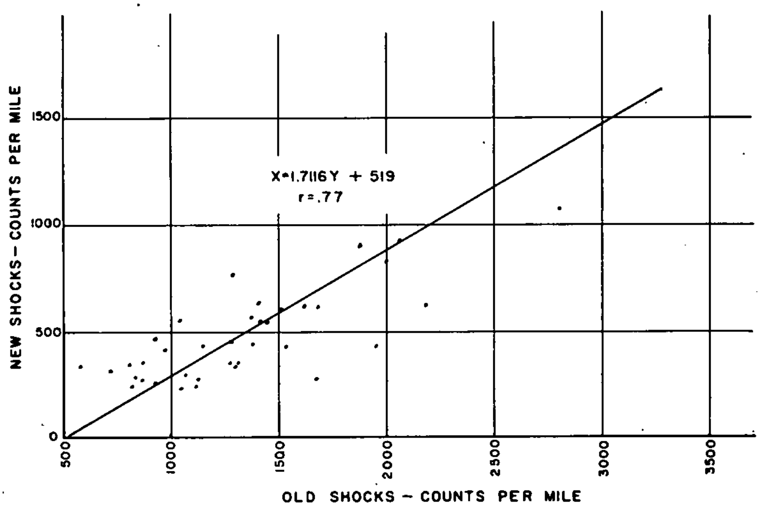

Table 1. Road meter evaluation.

Test Location	Number of Observations	Road Meter Count (average)	Standard Deviation	Coefficient of Variation (percent)
1	10	219	60	27
2	10	272	90	33
3	10	320	93	29
4	10	333	88	26
5	5	1,630	161	10
6	5	815	129	16
7	5	1,207	156	13
8	4	721	48	7
9	16	2,612	275	10
10	16	2,909	283	10
11	16	2,710	298	11
12	16	2,632	257	10
13	16	275	69	25
14	16	294	101	34
15	15	270	72	27
16	16	224	50	22

Table 2. Analysis of bituminous pavements.

Ride Rating	Number of Observations	Road Meter Count			Standard Deviation	Coefficient of Variation (percent)
		Average	Low	High		
1	0	–	–	–	–	–
2	132	427	115	1,133	181	42
3	241	574	179	1,508	235	42
4	663	760	165	2,194	332	44
5	1,081	1,299	253	4,262	590	45
6	410	1,850	361	5,087	918	50
7	208	2,576	544	5,518	1,140	44
8	19	4,187	2,739	6,601	1,158	28
9	0	–	–	–	–	–

A direct comparison of ride ratings with road meter counts was used to develop a well-defined logarithmic curve from the overall averages, but rather wide ranges of values were noted with resultant high standard deviations. The results of these comparisons are given in Table 2 for the AC pavements and Table 3 for the PCC pavements.

In comparing the results given in Tables 1, 2, and 3, it is necessary to establish the road meter as the standard for measuring the ridability of a pavement. The analysis shows this to be reasonable in that the standard deviations for the road meter itself are much lower than the standard deviations developed from the comparisons of subjective ride ratings with road meter counts during the 1971 WPCRS. This is shown in Figure 2.

Another factor that supports this approach is revealed when subjective ride ratings are evaluated on a day-to-day basis and when long stretches of apparently equal roadway are rated. This appears to be related to what might be labeled the psychology of the rater's task in that a level of rating is established in his mind for a particular section of roadway, and little or no change in ride rating is made until triggered by a very obvious change such as pavement type. Repetitious testing by the road meter on some of these sections has shown that there is often a measurable difference in the mile-by-mile smoothness of the section that is sufficiently significant to have an effect on the ride score.

The comparisons between ride rating and road meter values were reviewed to determine the possible effect of functional class of highway on the level of ratings. It should be mentioned that, within the parameters for length of rating sections included in this analysis, there were no ride ratings at the 0, 1, or 9 levels. There were very few ratings of 2 and 8, which would tend to make these results somewhat suspect, but the ratings were not out of line with the other data and therefore were included. In effect, then, the potential scale of 10 was reduced to 7. In ratings 2 through 7, the ride ratings with the lowest average road meter count were on the Interstate System. There were no ratings of 8 on the Interstate System. Conversely, the ride ratings with the highest average road meter counts were found on the lowest functional class system. This could indicate that the rating teams are influenced by the functional class of highway being rated, i.e., being more critical in their ride ratings of the higher class highways.

A similar analysis was made to see if a variation pattern could be developed among rating teams. There were basically four 2-man teams involved in the 1971 survey with very little shift of personnel. In comparing the 4 teams, it was possible to develop 25 relations, with all 4 teams involved in 15, 3 teams involved in 4, and 2 teams involved in 6. Of the 25 relations, the ride ratings of team 1 had the lowest average road meter count in all 15 relations, and the remaining comparisons of lowest count with ride ratings were distributed among teams 2, 3, and 4 in the ratio of 3, 5, and 2 respectively. The highest road meter count per ride rating was noted 12 times for team 4, 8 times for team 2, 3 times for team 3, and twice for team 1. These relations do indicate a pattern of variation among rating teams. Although in most instances the variations are within the standard deviation for the rating being compared, such variation does indicate that the subjective ride rating should be replaced by the road meter.

DEVELOPMENT OF FORMULAS

From these background data were developed the means of incorporating the road meter results into the WPCRS with 2 principal objectives in mind. First, the transfer should be done with the highest degree of continuity possible; i.e., the new overall pavement ratings resulting from the use of the road meter should be capable of comparison with previous readings with minimum departure in the normal point drop from the past biennial ratings of the individual pavements. Second, the scale or formula developed should result in an expanded rating scale using the full range of the relative ride rating from 0 through 9.

As can be seen, these 2 objectives are somewhat opposed and can only be resolved by compromise. In reviewing the overall rating results, such a compromise can be

Table 3. Analysis of PCC pavements.

Ride Rating	Number of Observations	Road Meter Count Average	Low	High	Standard Deviation	Coefficient of Variation (percent)
1	0	–	–	–	–	–
2	0	–	–	–	–	–
3	31	618	315	1,083	224	36
4	129	693	209	1,615	287	41
5	143	1,025	350	3,924	552	54
6	43	1,549	538	2,678	627	41
7	18	3,532	1,432	8,090	1,738	49
8	1	3,692	–	–	–	–
9	0	–	–	–	–	–

Figure 2. Standard deviation versus road meter count.

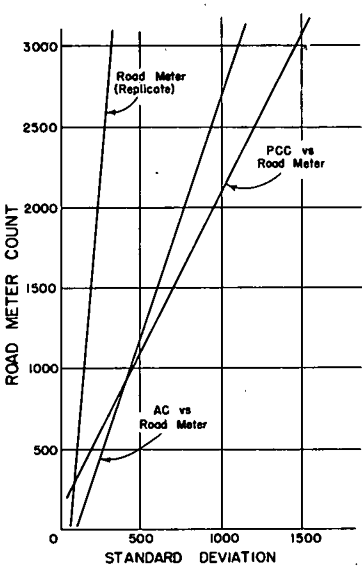

Figure 3. Relation of ride rating scores and road meter counts.

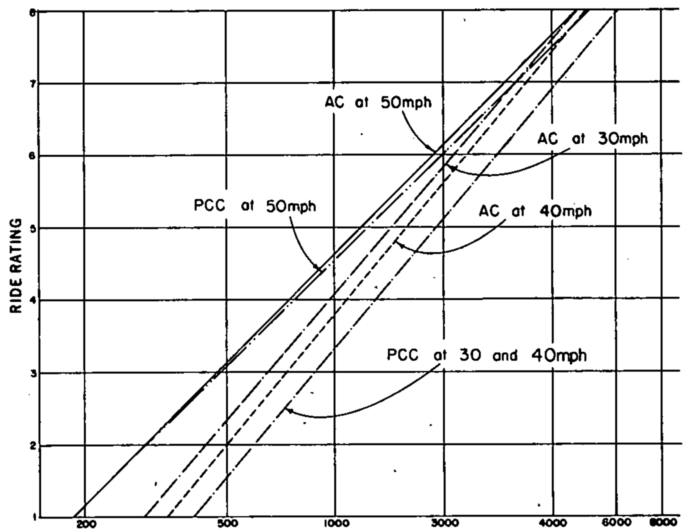

Table 4. Conversion of road meter counts to ride rating scores.

Type of Pavement	Test Speed (mph)	Common Logarithm A	Common Logarithm B	Natural Logarithm A	Natural Logarithm B
Bituminous	50	2.0833	0.1983	4.7970	0.4567
Bituminous	40	2.3717	0.1663	5.4609	0.3830
Bituminous	30	2.3008	0.1714	5.2978	0.3947
PCC	50	2.0648	0.2061	4.7543	0.4746
PCC	30 and 40	2.4373	0.1689	5.6120	0.3889

Note: $R_s = \frac{\log(RM) - A}{B}$, where R_s = ride score, RM = road meter counts per mile, and A and B = constants related to pavement type and test speed.

effected that will have little influence on a large percentage of the state's highway mileage and that will accommodate the variations inherent in the present method.

The ride-rating-versus-road-meter-count relation is of a logarithmic nature. By regression analysis, a series of formulas was developed for both bituminous and PCC pavements at the 3 test speeds used in the road meter inventory. Curves were plotted from these formulas, and, by applying the full range of road meter counts obtained in the survey, the formulas were modified such that the potential for using the full range of ride scores was introduced.

This procedure produced rational curves for all combinations of pavement types and test speeds except for PCC pavements tested at 30 mph. There were only 43 observations for this combination, and they were centralized in only 4 ride ratings, 4 through 7. These data are insufficient for a meaningful analysis, and, because such a small percentage of pavements is involved, it is recommended that the curve developed from PCC pavements tested at 40 mph also be used for 30 mph.

The formulas for the various combinations are given in Table 4. Expressions are given in both common and natural logarithms. The curves that were developed are shown in Figure 3. The ride score (R_a) as determined by these equations is comparable to the ride as scored by the rating teams and enters into the formula for calculating the final rating in the same manner; i.e., $R_R = \sqrt{G_R \times G_D}$, R_R = final rating, G_R = ride rating = 100 - 10 × R_a, and G_D = defect rating.

CONCLUSIONS AND RECOMMENDATIONS

Experience with the PCA road meter, both the original model and the modified version, has confirmed the value of this instrument in providing an objective measure of the smoothness, or ridability, of a pavement. Comparisons of results of subjective evaluations with road meter testing show the coefficients of variation with the road meter to be significantly lower.

From attempts at comparing results obtained by the original version with those by the modified model of the PCA road meter, it is concluded that there are response characteristics for each instrument that make straight-line correlation questionable at best. Rather than attempting a correlation of the modified version with a CHLOE profilometer to provide a relation between meter count and present serviceability index on a scale from 1 to 5, we correlated the results of a statewide survey using the road meter with subjective ride ratings by teams of trained raters as determined during the course of a normal condition survey. The results thus obtained were used to develop formulas that could be used for integrating road meter results into the pavement condition rating system. These formulas will also expand the ride rating portion of the system to include a wider range of values than previously obtained by the subjective ride ratings.

It is recommended that the subjective ride ratings in the present method for evaluating pavements be replaced by the use of the modified PCA road meter. It is recognized that our experience to date is based on one instrument in one vehicle and that, undoubtedly, when it becomes necessary to change vehicles, a correlation study will be required. This may result in a modification of formulas, but the improved accuracy of ratings more than compensates for this possibility.

In the operation of road meters, testing should not be done during periods of strong or gusty wind. Careful attention must be given to wheel balance, tire pressure, and suspension system. Whenever a change is made in one or more of these areas, the instrument should be recalibrated against established standards. When more than one road meter becomes available, one instrument can be established as standard. Also, selected sections of roadway can be established as temporary standards, but it must be remembered that roughness in roadway sections will increase with time and, in some cases, will change daily, or even hourly, with varying weather conditions.

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