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Subjective and Mechanical Estimations of Pavement Serviceability for Rural-Urban Road Networks

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To manage paved road networks efficiently, highway agencies require comprehensive, periodic inventory or pavement evaluation data. These data should be reliable, quickly and easily acquired, and manageable. The results of a study that involved subjective and mechanical measurements of both the roughness and structural adequacy of a combined rural-urban road network are presented. A new high-speed, computerized unit was used to make the mechanical measurements of roughness, and panel ratings were used for the subjective measurements. Structural adequacy was both rated by a panel and mechanically measured with a Dynaflect. Very good correlations were obtained between panel ratings and measured roughness for both urban and rural sections. The relations obtained and the resource and time requirements involved demonstrate that, by using such methods, highway agencies can quickly and efficiently inventory the serviceability of paved road networks. Ratings of structural adequacy did not correlate with measured deflection. The results suggest that, whereas surface distress or condition can be measured by panel ratings, structural adequacy can only be measured by mechanical means.

All highway agencies conduct inventory measurements and needs studies of some sort on their road networks based on various measures of functional, structural, and serviceability adequacy. Candidate projects are identified from these studies, and priorities are determined for investments in both new construction and rehabilitation to the limit of the available budget. Figure 1 shows the major elements of such a system of inventory needs priority within the framework of an overall system of road management.

Periodic inventory or evaluation measurements provide the basis for the identification of needs and all subsequent management activities. In other words, this is the basic management information.

Much of the inventory information currently collected by highway agencies is a combination of subjective and objective measurements. Ideally, such information would be subject to the following criteria:

1. It would be capable of being collected quickly, easily, and efficiently; be as objectively based as possible; be reliable and repeatable; and relate directly to the structural, functional, and serviceability indicators;
2. It would cover or represent the entire network and include sufficient frequency on the more deteriorated sections so that needs could be identified soon enough in advance to allow for proper programming; and
3. The information would itself be manageable.

In the light of these considerations, the Waterloo region of Ontario initiated a pavement evaluation study in 1978 as a part of their 1979 needs study update (1, 2). This regional municipality is about half urban and half rural and has about 1935 km of arterial roads and streets. A key requirement for the needs study update was the correlation of certain subjective pavement ratings with actual physical field measurements. The purpose of this paper is to describe the following specific results of the study:

1. The use of a new high-speed unit for obtaining roughness and other road data on an automated, mass-inventory basis;
2. The correlation of measured roughness with

Figure 1. General structure of road management system.

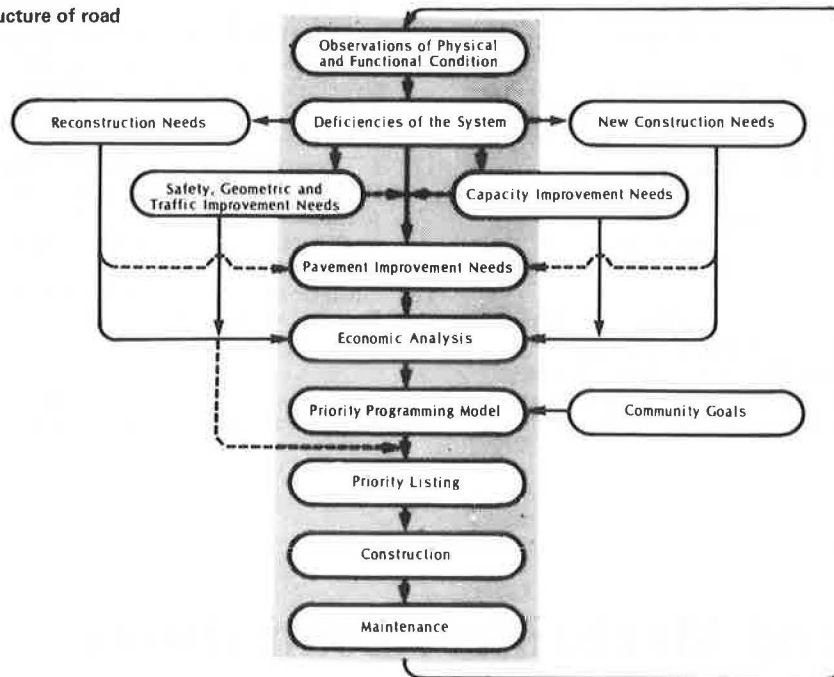


Figure 2. Automatic Road Analyzer unit.



panel ratings of riding comfort in a designed experiment that recognizes the requirements and resources of the agency involved and rural versus urban conditions; and

3. The correlation of measured surface deflection with subjectively based ratings of structural adequacy.

SELECTION OF STUDY SITES

Both urban and rural road sections were considered to be needed because of differences in such factors as speed, operating condition, and environment. It has been shown that the opinions of road users about the quality of a road vary depending on the condition (i.e., urban or rural) in which they are traveling (3).

In selecting the location of the sections, which consisted of 28 rural and 27 urban, an attempt was made to obtain as many sections as possible for each range of riding comfort index (RCI) values. [RCI is the Canadian measure of present serviceability, on a scale of 0 to 10, adopted by the Roads and Transportation Association of Canada (4).] RCI was measured in 10 groups: 0.0-0.9, 1.0-1.9, and so on to 9.0-10.0. Although the majority of values would naturally fall in the middle range, sections with very low and very high

RCIs were also needed to establish a complete range of conditions for regression analysis.

All rural sections selected were on two-lane paved regional roads. Half of the urban sections selected were on four-lane regional streets, and the rest were on two-lane streets.

An attempt was made to select the rural sections so that they were well spread out across the region. Urban sections were selected from all three of the major cities in the region—Kitchener, Waterloo, and Cambridge.

All rural sections were approximately 1200 m long. Urban sections, however, were relatively shorter (300 m long) because of traffic lights, stop signs, and other such constraints.

FIELD MEASUREMENTS

Roughness

Longitudinal roughness on the study sections was measured by a recently developed unit, the Automatic Road Analyzer (ARAN), which is housed in a Ford van and measures roughness by use of an accelerometer. The data are recorded in digital form on magnetic tape. Other parameters that can be measured and similarly recorded in digital form include crossfall and grade angle, right and left rut depths (a process that is still being developed), skid resistance, and 12 coded categories of pavement distress that are entered on a keyboard. The ARAN unit, shown in Figure 2, has an on-board "intelligent" computer terminal with keyboard plus an acoustic coupler transmission system. It also has hard-copy recording and on-board editing capabilities for which specially developed software is used. Extensive repeatability measurements at various speeds and roughness levels have been made on the ARAN unit in cooperation with the Ontario Ministry of Transportation and Communications (MTC) (5). These measurements indicate that the unit provides a high degree of repeatability and can be used over a wide speed range (i.e., "float" in traffic).

Table 1. Field data for rural and urban sections.

Section	Average RCI		Average Roughness Value		Structural Index		Deflection (mm)	
	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
1	4.1	5.3	645.99	496.58	2	15	0.028	0.028
2	7.9	5.0	113.13	553.29	20	14	0.026	0.029
3	1.4	5.1	1168.94	406.26	-	5	0.029	0.021
4	4.5	3.3	361.00	660.02	6	-	0.018	0.028
5	8.2	8.2	115.58	199.14	20	20	0.025	0.022
6	4.8	4.6	252.88	387.80	3	15	0.035	0.024
7	4.5	5.8	235.77	200.41	3	16	0.026	
8	7.9	6.4	82.97	210.09	20	9	0.022	0.02
9	6.1	7.3	182.03	150.27	5	20	0.029	0.028
10	8.3	5.1	77.00	470.14	20	-	0.028	0.028
11	5.6	4.5	227.57	588.39	0	-	0.042	0.04
12	2.6	7.7	417.82	170.23	0	19	0.042	0.015
13	8.0	8.3	87.29	198.67	19	20	0.019	0.019
14	4.3	4.8	363.00	431.61	6	16	0.035	0.027
15	7.8	7.7	96.20	208.91	17	19	0.016	0.029
16	8.0	5.0	86.89	398.12	20	-	0.020	0.039
17	9.0	3.4	67.28	687.27	20	1	0.025	0.033
18	7.5	3.7	101.41	568.68	19	5	0.020	0.04
19	6.6	7.3	378.76	174.64	8	18	0.019	0.03
20	6.7	7.3	157.73	191.01	10	20	0.029	0.023
21	2.8	6.1	658.25	374.01	15	17	0.018	0.033
22	7.0	4.6	169.60	519.97	19	5	0.026	0.03
23	6.4	7.0	123.04	217.10	-	19	0.023	
24	3.4	5.7	613.69	286.72	18	12	0.029	0.022
25	4.5	7.7	326.08	186.08	12	20	0.032	
26	6.7	4.8	133.89	408.55	15	17	0.028	
27	4.9	4.0	224.68	571.01	3		0.022	
28	7.8		71.15		20		0.018	

Note: 1 mm = 0.039 in.

A software package has also been developed to calculate and enter into a data bank any summary statistics, such as mean roughness for a section or mean plus standard deviation, desired by direct computer analysis of the magnetic tapes. This means that mass-inventory, raw data can be efficiently used and "managed," with no manual recording, keypunching, etc.

In this study, roughness was measured on each rural section at 50-m intervals and at 80-km/h operating speed. Urban sections were measured at 50 km/h because of speed-limit restrictions. An average roughness for each section was then calculated from the raw data. Table 1 gives the average roughness values for each rural and urban section used in the study.

Deflection

In the next step, surface deflection was measured on the same sections. An average of four Dynaflect tests were taken on rural sections. The average maximum deflection on each section was calculated and converted to maximum spring deflections by using a spring-fall ratio of 1.2. Two tests were taken on each urban section, and average spring maximum deflections were calculated for purposes of correlation. Table 1 gives the average spring deflections for rural and urban sections, respectively.

Riding Comfort

In the second part of the field study, panel ratings were used to determine the RCIs of the previously selected rural and urban sections. A panel was formed for rating purposes under guidelines described by Nakamura and Michael (6). Nakamura and Michael have shown that a panel consisting of highway engineers does not rate pavements any more consistently than a similar panel consisting of members from various professions. They have also developed a table for selecting a panel size to achieve a certain degree of accuracy.

A panel of eight was used in the study with the assumption that the average of their ratings would be 0.6

units away from the true rating 19 out of 20 times, as suggested by Nakamura and Michael (6). The panel included five men and three women; their occupations were secretary (one), housewife (one), teacher (one), technician (two), farmer (one), and engineer (two).

Panel members were "trained" before the rating sessions. The purpose of the study was explained, and the pavement serviceability concept (RCI) and its use to the pavement engineer were discussed. The rules of the rating sessions and factors to be considered in the rating process were explained. After the instruction session, the panel members were taken to the field and asked to rate four urban and four rural sections. Their ratings were then discussed with them to make sure that they had understood the rules.

The instructions to be followed by each rater during the rating sessions were prepared under the guidelines of a Texas study (7). Raters were located in the test vehicle (a 1978 Chrysler Lebaron) in a random order. There were four raters in each vehicle; all, including the driver, rated each of the 28 rural and 27 urban sections. Ratings were completed in four days.

Six rural and six urban sections were rated again by each rater. Because of time limitations, these replications were done one day before the actual rating sessions. The sections selected for replication were chosen at random.

Structural Adequacy

In the second phase of the rating sessions, a panel of three was used to rate the structural adequacy of the 28 rural and 27 urban sections used in the study. This panel was composed of professionals in the field: the director of roads and traffic for the region, a representative from MTC, and an experienced engineer from a consulting firm.

Ratings were performed according to the procedures set by MTC, which are described in detail elsewhere (1). Ratings were completed in one day. Table 1 gives the results in terms of a "structural index" for all sections used in the study.

ANALYSIS OF DATA

Riding Comfort

The panel ratings were first analyzed to see if any systematic error occurred in the rating procedures. The leniency error (8), which can be defined as the deviation of each rater's average rating for all sections from the overall mean rating, was calculated for each rater. The analysis indicated that the magnitude of leniency error in the data was insignificant.

Similarly, further analyses showed halo and central tendency effects (8) to be insignificant. It was therefore decided that the raters' performance was reasonable and no correction in the raw data was necessary.

The raw data were then analyzed to see if the ratings were affected by (a) location in the automobile and (b) differences between drivers and passengers. Analysis of variance (ANOVA) techniques were used for this purpose. None of the effects was found to be significant. It was possible, therefore, to use the average panel rating on each section as a reasonable approximation of its true rating.

The replicated ratings were also analyzed to check raters' ability to repeat an observation of the same pavement section. The results of the ANOVA indicated that there is a significant variation between raters and sections. In other words, ratings vary significantly from one section to another. This, of course, is quite normal since the same response cannot be expected from all raters on all sections.

The replication factor was not found to be significant for rural sections, but it was significant for urban sections. From a statistical point of view, this means that raters are capable of repeating their ratings on rural but not on urban sections. This cannot be generalized, however, because the urban replication session was done immediately after the rater training sessions and before the actual rating sessions. The main reason for the significant replication effect on urban sections was probably the raters' lack of sufficient experience. The extremely good results obtained from the subsequent rating sessions clearly support this argument.

In summary, the riding comfort data were first analyzed to see if any systematic error occurred in the rating process. It was found that the magnitude of the systematic errors in the data was negligible and did not affect the overall outcome of the process. The data were then analyzed to see if the ratings were affected by location in the automobile and differences between drivers and passengers. None of these effects was found to be significant. Analysis of the replication data produced reasonable results. It was therefore concluded that the average of eight raters on each section could be used to represent the true ratings of the sections. These average values are given in Table 1.

Approximating Riding Comfort Data

The average RCI data on each section were then related to the roughness of the pavement as measured by the ARAN unit. Several regression models were tested to approximate RCI by roughness. The following regression equations were selected as best representing these relations. For rural sections,

$$RCI = 18.8744 - 5.6398 \log_{10} X \quad (1)$$

For urban sections,

$$RCI = 22.8457 - 6.7686 \log_{10} X \quad (2)$$

where X = pavement roughness divided by 10, as measured by the ARAN unit.

Figures 3 and 4 show the data used in the analysis and the resulting regression equations for rural and urban sections, respectively. Statistical characteristics of the relations, as shown in Figures 3 and 4, are quite acceptable.

Rural sections 12 and 19 were excluded from the analysis because of the nonuniform nature of their roughness. Section 12, for example, was generally rough but contained a very smooth subsection that affected the ratings. Urban section 7 was excluded because, as a result of a mix-up in the rating process, raters did not rate the same section that was measured by the ARAN unit.

Equations 1 and 2 are generally similar. This, of course, is quite acceptable because the RCI concept is basically the same for both rural roads and urban streets. The minor changes in the slopes of the curves are attributable to changes in speed, driving conditions, and environment.

In the practical use of Equations 1 and 2, therefore, one can measure the roughness of a pavement section and then estimate the road user's subjective opinion (i.e., the RCI) from the equations. Once they are developed, such equations should be fairly "stable" for an area or region for several years and require no new or check panel ratings.

The rural and urban data were also analyzed together because of the similarity of Equations 1 and 2 and the fact that speed appeared to be the only major difference in the relations of Figures 3 and 4. The following equation was derived:

$$RCI = 22.8147 - 5.9607 (\log_{10} X) - 0.0402 (S) \quad (3)$$

where S = speed in kilometers per hour. The statistics for this equation are $S_0 = 0.54$, $R^2 = 0.91$, $t_1 = 22.51$, $t_2 = 7.38$, and $F_{2,49} = 255.59$. These statistics indicate that Equation 3 could be used with sufficient accuracy for both rural and urban sections instead of Equations 1 and 2.

It also appears that the curves of Figures 3 and 4 would merge at the extremes; in other words, the effect of speed is more significant in the medium roughness range. This is quite logical because a very smooth pavement should give a good ride no matter what the speed and a very rough pavement is rough at all speeds.

Approximating Structural Adequacy Ratings

Correlating a subjectively based structural adequacy rating with surface deflection was one of the objectives of the study. But, as Figure 5 shows, it was not possible to develop an acceptable relation between these two factors. Figure 5 clearly indicates that there is no relation between ratings of structural adequacy and surface deflection. This, of course, supports the argument that the structural adequacy of a road or street cannot be accurately rated by visual means. It also indicates that the raters do not actually rate the load-supporting ability of the pavement but other factors such as appearance, distress, or ride quality.

Future rating sessions and measurements of condition in terms of percentage of damaged area are

Figure 3. RCI versus roughness for rural roads.

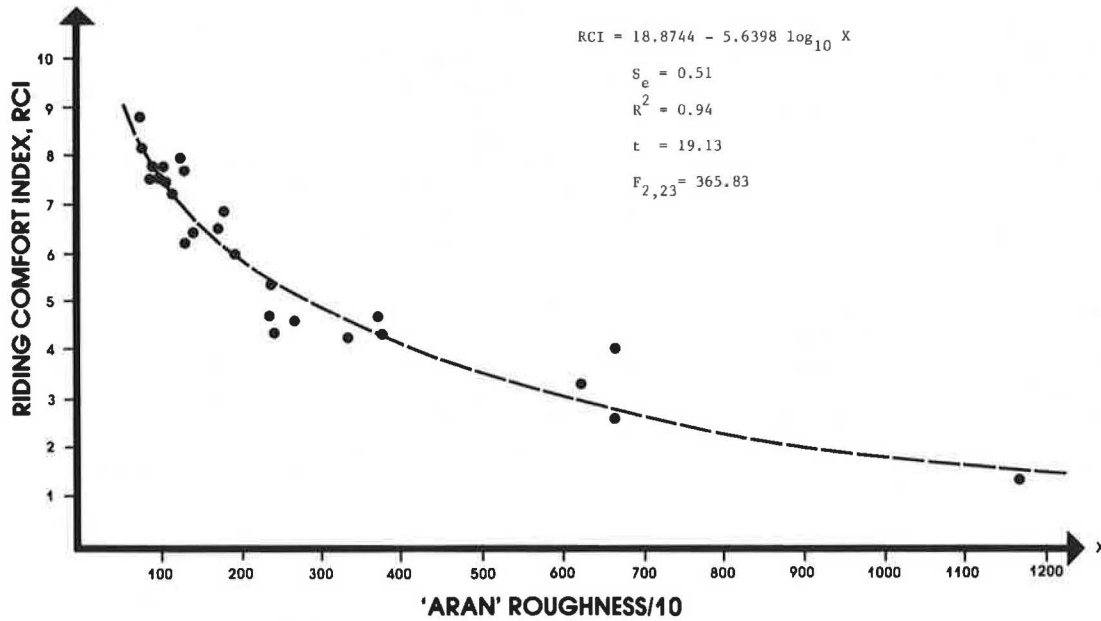


Figure 4. RCI versus roughness for urban roads.

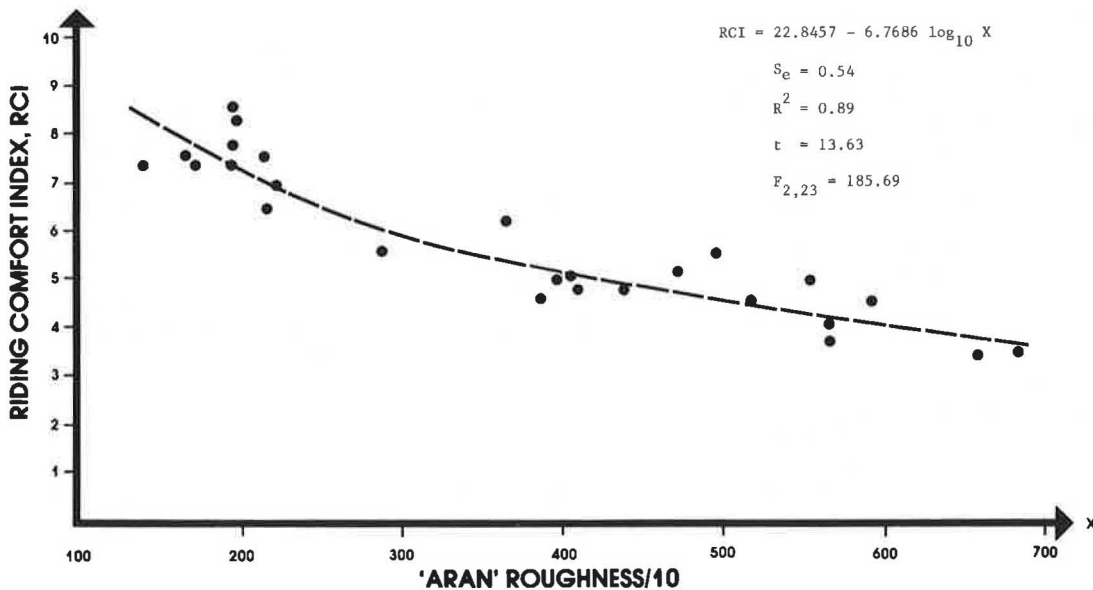
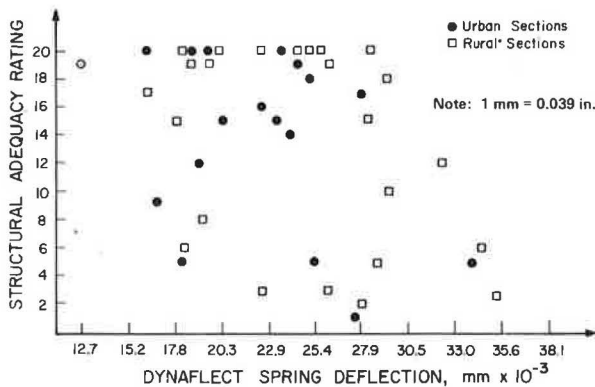


Figure 5. Structural adequacy versus deflection.



planned, and it is hoped that they will assist in solving this problem [Karan (3) has shown in a previous study that panel ratings of pavement condition or surface distress can be well correlated with condition survey measurements].

It is quite obvious, however, that ratings of structural adequacy do not give any indication of the structural strength of a pavement. The probable reason for this is that surface distress, which has actually been rated in this process, does not always correlate with the structural capacity of the overall pavement system. For example, a relatively thick pavement with extensive surface distress may have a better structural support than a thinner, new pavement with very little or no surface distress. In addition, the time delay between loss of structural adequacy and surface distress has an effect. A crack, for example,

may reduce the rating because it increases the amount of the distressed area, but it usually takes some time to affect the structural capacity of the road surface.

It is, of course, difficult (if not impossible) to take these factors into account in the visual rating process. Thus, it seems more logical to use mechanical techniques to determine the structural capacity of a pavement and condition survey techniques to measure the degree of surface distress.

OPERATING SPEED VERSUS ROUGHNESS

Karan and others (9) have shown that vehicle speeds are significantly affected by pavement roughness. Tests performed on two-lane highways in southern Ontario have clearly indicated this effect. The following equation has been presented for estimating average highway speed:

$$Y = 30.7368 + 1.0375 X_1 - 11.2421 X_2 + 0.0062 X_3^2 \quad (4)$$

where

- Y = average highway speed (km/h),
- X₁ = RCI,
- X₂ = volume/capacity (V/C) ratio, and
- X₃ = speed limit (km/h).

It should be emphasized that this equation is only for rural highways. Apparently, there are no data or studies available on the effects of pavement roughness on vehicle speeds on urban streets. However, at lower speeds this effect should be quite insignificant, and on an urban street vehicles can always maintain the speed limit regardless of roughness. Speed limit can therefore be used as the average street speed in the urban situation.

For rural roads, the relation given by Equation 4 can be used for estimating average highway speed.

CONCLUSIONS

Panel ratings of riding comfort and pavement structural adequacy, deflection measurements, and mechanical roughness measurements with a new high-speed, automated unit were made on 28 rural and 27 urban road sections in Ontario. The major conclusions of the study can be summarized as follows:

1. Very good correlations were obtained between panel ratings of riding comfort and mechanically measured roughness for both urban and rural sections.
2. Panel ratings of structural adequacy did not correlate with measured deflection, probably because the panel was actually rating surface distress.
3. The results demonstrate the practicability and usefulness to highway agencies of quickly and efficiently inventorying the serviceability of their paved road networks by developing relations between mechanically measured roughness and panel ratings of riding comfort.

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