THE USE OF ROAD PROFILE STATISTICS FOR MAYSMETER CALIBRATION

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SUMMARY REPORT 251-1(S)

PREFACE

Research Report 251-1 is the first report presenting results from Research Project 3-10-79-251, "Deployment of a Digital Road Profilometer." The study has two primary objectives: (1) to provide continuing support to the Texas State Department of Highways and Public Transportation (SDHPT) in all projects requiring profilometer data and (2) to assist SDHPT in the purchase and adaptation of a new digital profilometer system while ensuring that Maysmeter calibration and other projects are not adversely affected by the transition to the new hardware.

The Surface Dynamics Profilometer (SDP) was originally developed under Research Studies 3-8-63-73, "Development of a System for High-Speed Measurement of Pavement Roughness," and 3-8-71-156, "Surface Dynamics Road Profilometer Applications."

A significant result of these studies was the development of a set of equations which can be used to predict a serviceability index that is based on road profile statistics. Present Serviceability Ratings (PSR) had been obtained from a 1968 sujective rating experiment on Texas roads; then the profile-based Serviceability Indices (SI) made it possible to interpret profilometer data in quantitative terms that relate more directly to ride quality or roughness. One of those indices, SI2, has served for a number of years as a relatively stable reference statistic for calibrating the SDHPT Maysmeters.

Report 251-1 describes work by The University of Texas at Austin Center for Transportation Research (CTR) to upgrade the existing Maysmeter calibration program by developing an improved profile statistic for use as a calibration standard. SI2 was not an optimal reference, primarily because of the presence of long wavelength roughness components that are not measurable by the Maysmeter. The new statistic, which results from a Maysmeter simulation that is based on Root-Mean-Square Vertical Acceleration (RMSVA), allows more accurate calibrations and will be more easily adapted to on-board computation with the new digital profilometer.

ABSTRACT

The use of profile statistics from designated road sections has proved to be an effective method of Maysmeter calibration. For best results, the statistic used must be tailored so that it quantifies what Maysmeters, as a class, actually measure regardless of the intended use of the measurements.

For this purpose, a family of profile summary statistics based on the concept of Root-Mean-Square Vertical Acceleration (RMSVA) was developed. Some of these statistics have been found to correlate strongly with Maysmeter response. Moreover, the relationships are linear, much as the relationships between different Maysmeter units are linear. When selected RMSVA indices are combined to form a serviceability index representing "Maysmeter roughness," an effective calibration standard results. This RMSVA-based

reference, termed SIV, exhibits distinct advantages over the profile statistic (SI2) used previously for calibration.

First, because of its higher correlation with Maysmeter readings, SIV allows more accurate calibrations; that is, two Maysmeters calibrated at different times are more likely to agree when measuring the same road. Second, because of its relative simplicity, SIV is a more consistent and precise measurement of roughness when considered as a profilometer measurement. The repeatability of measurements, as shown by pairs of successive profilometer runs and also by consistency on sections that change very slowly, is much improved. Since it is less sensitive to the characteristics of profilometer hardware and is simple to compute, RMSVA is well suited for transition to the new digital profilometer.

INTRODUCTION

One of the more important applications of the Surface Dynamics Profilometer (SDP) is to provide a stable calibration reference for response-type roughness measuring instruments. The latter devices, of which the Mays Ride Meter (Maysmeter) is typical, are relatively inexpensive and are used by many agencies for routine pavement monitoring. In Texas, a Maysmeter is calibrated by running the unit on approximately 30 designated flexible pavement road sections near Austin and then using statistical means to correlate its measurements with appropriate data obtained on those same sections with the profilometer.

The use of the profilometer as a reference vehicle has eliminated the difficulty of trying to maintain a "stable" Maysmeter for this purpose; however, the problem of relating profile data to Maysmeter measurements must be solved if accurate calibrations are to result.

Two approaches are possible for developing profile statistics suitable for both roughness measuring device calibration and general roughness evaluation. The first is dynamic modelling of a hypothetical device with certain physical constants pre-defined and with sequences of profile evaluations taken as system input. For example, the Quarter Car Index (QI), which has been used successfully for Maysmeter calibration in Brazil, was so developed. Such indices are useful, however, not as simulations of particular instruments but simply as profile summary statistics whose required high correlation with the target class of devices must be shown experimentally.

The alternative statistical approach which is described in this report is to obtain data from response-type roughness measuring instruments on representative road sections and then use regression techniques to select a profile statistic which the instruments are capable of measuring reliably.

In early 1978 a profile statistic which in principal relates to root-mean-square vertical acceleration (RMSVA) was investigated for use as a road roughness measure. It was able to describe quite well the behavior of eight Maysmeter (mounted on five trailers and three cars) all run on the Austin test section in late 1977. A Maysmeter simulation statistic was thereby derived. The corresponding serviceability index, SIV, has since provided to be a definite improvement over the calibration standard, SI2, that was used previously. The latter statistic is based in part on certain power spectral estimates to which the Maysmeters are not sensitive.

For a period of two years, both SIV and SI2 were recorded during the quarterly profilometer runs of the test sections. Although the overall mean and variability of the sections were about the same for both indices, the SIV differences between repeated profilometer runs were only one-fourth to one-third as great as the SI2 differences. Furthermore, SIV is a more reliable measurement of roughness, as shown by consistency on sections having no major maintenance and experiencing little or no overall change in roughness during the period of study. The serviceability of 19 essentially unaltered sections declined an average of only 0.2 unit per year.

Although SIV was finally adopted as the calibration standard during January 1980, it was adopted in a provisional way that did not require modification of MRMCAL, the program that processes the calibration session data and produces a chart relating raw profilometer readings to serviceability estimates. The original version of MRMCAL employs a nonlinear regression algorithm. The recommended method is to use a revised program, MRMCAL2, to perform a simple linear fitting of the Maysmeter readings to an RMSVA-derived Maysmeter simulation.

Although the Maysmeter calibration problem motivated the development of RMSVA roughness indices, careful monitoring of the Austin test sections and other pavements has revealed surface properties that could never be detected by Maysmeters or by devices which reduce roughness evaluations to a single number. The RMSVA indices computed from a road profile can provide a "signature" that reflects roughness over a broad range of profile wavelengths. Distinctive signatures corresponding to certain pavement classes or types of deteioration have been tentatively identified and their interpretation remains as a promising subject for future research.

SUMMARY OF RESULTS FOR THE AUSTIN TEST SECTIONS

Beginning in January 1978, both SI2 and SIV were recorded for the quarterly profilometer runs on the Austin test sections. The results are listed in Tables 4.1 and 4.2 (Ref 16). Each measurement is acutally the mean of two separate runs, with differences between repeats being at least three times larger for SI2 than for SIV. The SI2 results were also more erratic over the time period. Seventy percent of the variation of SIV about the means of 19 relatively unaltered sections could be explained by linear declines whereas only 42 percent of SI2 variation could be so explained. These facts suggest that the simpler statistic SIV, while correlating much better with Maysmeters, is also less sensitive to the measuring system and factors not related to the actual profile. Interestingly, the mean decline for these 19 sections over one year was only 0.22 serviceability units, which is comparable to the discrepancy between repeated SI2 measurements with the profilometer.

BENEFITS OF THE RECOMMENDED METHOD

In summary, the advantages of adopting the procedures described in Research Report 251-1 (Ref 16), which employ statistic MO instead of SI as the Maysmeter calibration standard, are as follows:

(1) More accurate calibrations. This means that it will be safer to assume that the pavement is rougher than another when the determination is based on Maysmeter measurements made at different times or with different units. This is a benefit of the high correlation between Maysmeters and the profile statistic developed to simulate them.

(2) Simplicity. The calibration curves are much easier to deal with if they are linear. In this case the unit's calibration parameters, α_i and β_i , are the easily comprehended slope and intercept. Furthermore, the linear calibration model is by far the most widely used and studied; techniques for obtaining confidence intervals for parameters and estimates, etc., are well established.

(3) Adaptability to further requirements and conditions. The quality of SIV as an estimate of PSR (the mean of a subjective panel rating) might be expected to be less than that of SI2 because of the elimination of components not measureable by the Maysmeter; however, there are reasons to believe that the Maysmeter-derived SIV is not significantly worse than SI2 in predicting PSR and certainly much better for comparing the roughness of roads. Because the SI prediction equation (4.3) (Ref 16) is just a recaling of the calibrated unit's adjusted output, MO, and is free of the calibration process itself (i.e., parameters α_i and β_i), it is easily replaced when better PSR data are obtained. Important to the development of new and better relationships is the preservation of information provided by accurately calibrated Maysmeters.

CONCLUSIONS

It is importat not to confuse the problem of calibrating a group of instruments with the problem of interpreting their measurements. When the Texas Maysmeter calibration method was first devised, the Serviceability Index (SI) was the best available estimate of Present Serviceability Rating (PSR), a measure of roughness which is meaningful. Since serviceability estimates were sought from the Maysmeters, SI was chosen as the best standard against which all units were to be calibrated. This would have been a godd approach, however, only if Maysmeters were capable of measuring SI with as much accuracy as their precision would seem to indicate. Unfortunately, this is not the case. At best, Maysmeters ca be assigned scalings so that different units give comparable "Maysmeter roughness" ratings. How the ratings should be used to predict other things, such as ride quality, is a problem to be considered apart from the calibration process itself.

To help clarify this point with an analogy, suppose that the reading of several homemade thermometers inserted in lakes of a given region correlated fairly well with the number of fish caught during the day. It would be desirable to know that one lake is a better fishing prospect than another, even though they were measured with different theomometers. A decidedly inferior approach to calibrating the thermometers would be to derive for each one of them, separately, a prediction equation by comparing its readings to the number of fish actually caught in a representative sample of lakes. Since the number if fish caught is only partially dependent on lake temperature we must expect that the individual equations derived from such a claibration procedure would be highly variable, depending on our sample lakes, the time of year, etc. Obviously, a much better approach would be to use a standard thermometer to correlate each homemade device with demperature, i.e., with something it is capable of measuring precisely. Then, with the benefit of results from all of the calibrated instruments, one could seek a relationship between temperature and number of fish caught, number of fishermen, or whatever.

The analogy between Maysmeters and thermometers is not perfect, for it is not at all obvious what the equivalent of temperature in pavements should be. Our study of the Texas Maysmeter suggests, however, that a simple profile statistic based on RMSVA can serve effectively as a calibration standard. When the statistic is rescaled by regression techniques to approximate a serviceability rating, we find that different Maysmeters that are calibrated against it can measure roads and agree to within one or two tenths of a serviceability unit (2-5 percent). This precision, of course, says nothing about the accuracy of such measurements as predictors of subjective serviceability ratings since the Maysmeter, like the thermometer, is necessarily limited in its response. However, quite apart from provideing imperfect estimates of serviceability, it is evident that the Maysmeter is capable of measuring a certain kind of roughness with good precision. The obvious benefit of this is in making comparisons--for example, revealing differences in separate pavements and showing trends in deterioration or the effects of rehabilitation on roughness. It is for this purpose, especially, that a good calibration method based on a stable and valid reference is necessary.

REFERENCES

1. Walker, Roger S., and W. Ronald Hudson, "Analog-To-Digital System," Research Report 73-4, Center for Highway Research, The University of Texas at Austin, April 1970.

2. Walker, Roger S., and W. Ronald Hudson, "The Use of Spectral Estimates for Pavement Characterization," Research Report 156-2, Center for Highway Research, The University of Texas at Austin, August 1973.

3. Bergland, G. D., "A Guided Tour of the Fast Fourier Transform," IEEE Spectrum, July 1969.

4. Blackman, R. B., and J. W. Tukey, "The Measurement of Power Spectra," Turkey, Dover Publications, Inc., New York, 1958.

5. Williamson, Hugh J., W. Ronald Hudson, and C. Dale Zinn, "A Study of the Relationships Between Various Classes of Road-Surface Roughness and Human Ratings of Riding Quality," Research Report 156-5F, Center for Highway Research, The University of Texas at Austin, August 1975.

6. Al-Rashid, Nasser I., Clyde E. Lee, and William P. Dawkins, "A Theoretical and Experimental Study of Dynamic Highway Loading," Research Report 108-1F, Center for Highway Research, The University of Texas at Austin, May 1972.

7. "Quarter Car Simulater Instruction Manual," K. J. Law Engineers, Inc., (unpublished).

8. Hudson, W. Ronald, David McKenzie, and Grover Cunningham, "A Generalized Roughness Index for the Compatible Evaluation of Roads," Texas Research and Development Foundation, December 1980.

9. McKenzie, David, and Maitree Srinarawat, "Root Mean Square Vertical Acceleration (RMSVA) as a Basis for Mays Meter Calibration," Technical Memorandum BR-23 (unpublished), Center for Highway Research, The University of Texas at Austin, February 1978.

10. Roberts, Freddy L., and W. Ronald Hudson, "Pavement Serviceability Equations Using the Surface Dynamics Profilometer," Research Report 73-3, Center for Highway Research, The University of Texas at Austin, April 1970.

11. Walker, Robert S., and W. Ronald Hudson, "A Correlation Study of the Mays Road Meter with the Surface Dynamics Profilometer," Research Report 156-1, Center for Highway Research, The University of Texas at Austin, February 1973.

12. Hu, Yi Chin, Hugh J. Williamson, and B. Frank McCullough, "A Study of the Mays Ride Meter," Research Report 177-3, Center for Highway Research, The University of Texas at Austin, January 1977.

13. Walker, Roger S., and W. Ronald Hudson, "The Use of Spectral Estimates for Pavement Characterization," Research Report 156-2, Center for Highway Research, The University of Texas at Austin, August 1973.

14. Williamson, Hugh J., and W. Ronald Hudson, "A Study of the Relationships Between Various Classes of Road-Surface Roughness and Human Ratings of Riding Quality," Research Report 156-5F, Center for Highway Research, The University of Texas at Austin, August 1975.

15. Scheffe, "A Statistical Theory of Calibration," The Annals of Statistics, 1973, Vol 1, pp 1-47.

16. McKenzie, David W., W. Ronald Hudson, and C. E. Lee, "The Use of Road Profile Statistics for Maysmeter Calibration," Research Report 251-1, Center for Transportation Research, Bureau of Engineering Research, The University of Texas at Austin, August 1982.

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The full text of Research Report 251-1 can be obtained from Mr. Phillip L. Wilson, State Planning Engineer, Transportation; Transportation Planning Division, File D-10R; State Department of Highways and Public Transportation; P. O. Box 5051; Austin, Texas 78763.